Master thesis (45 ECTS)

Potential for wetland restoration in Odense River catchment and nitrogen removal

A GIS-based analysis of Odense River catchment

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Author would like to thank the EU and the Innovation Fund Denmark (Denmark), the Federal Ministry of Food and Agriculture (Germany), the National Centre for Research and Development (Poland) for funding, in the frame of the collaborative international consortium CLEARANCE financed under the ERA-NET Cofund WaterWorks2015 Call. This ERA-NET is an integral part of the 2016 Joint Activities developed by the Water Challenges for a Changing World Joint Programme Initiative (Water JPI).

1. Summary

Wetlands have the capacity to remove nitrogen from surface waters in the process of denitrification. Odense River catchment has been a subject of intensive wetland restoration to mitigate N loss and restored wetland area has been reported to reduce the N load to Odense river with 124 tons N per year. The objective of this thesis was that further wetland restoration in Odense River catchment would result in further reductions in N load to coastal waters. The potential wetland area was found by creating an index model that showed suitable areas. Direct upland area to each wetland was calculated in ArcGIS, N loss from each upland was calculated and removal from the direct upland was estimated based on soil type and drainage probability. N removal by flood inundation was based on a flood estimate accounting for 10% of the time, which was calculated based on measured data of stream water level increase from monitoring stations and the upstream river length (Upstream Length Model, UPM). The flood based on the UPM provided a very good flood estimate, that evenly distributed flood upstream as well as downstream and required minimum data inputs. Compared to flood based on MIKE11 calculations of water level increase, the UPM performed better, as MIKE11 resulted in a very unlikely overestimation in one of the streams, which shouldn't be the case considering the amount of input data used to calculate water level elevations in MIKE11. The UPM can be further improved during stream simplification, which is a necessary step to provide a satisfying interpolation of elevation raster used in flood calculation in ArcGIS.

The N load and removal in already restored wetlands was also calculated and amounted to 75,094 kg N. The comparison between calculated N removal against measured data from to restored wetlands showed the calculated values to be underestimated. That is due to the flood calculation accounting for only 36 days, while many restored wetlands are designed to be flooded for longer time periods. Another issue is that N removal in shallow lakes couldn't be calculated due to lack of data on lake residency time.

The restoration of an additional 5543.9 ha of wetlands was calculated to remove 405,392 kg N. That calculation didn't include N removal in shallow lakes, so the potential N removal could be higher. The highest N removal per ha was found in wetlands irrigated with drainage water and was caused by a higher percentage of agricultural cropping in the direct upland area compared to non-drained upland area. Several irrigated wetlands had very high calculated N loads, where an expected removal rate of 50% is questionable, as according to measured data high N loads are associated with decreased removal rates. The actual N

removal in wetlands with non-drained upland area could be higher than calculated, as many of them could be groundwater fed. The calculated flood N removal could be more accurate in potential wetlands than restored wetlands, as many streams overflood for approximately a month yearly. As N loss varies between the direct upland areas, the potential wetland area can be modified to yield higher N removal per wetland area.

2. Introduction

In the years 1989-2002 N load to aquatic environments from point sources such as sewage treatment plants has been reduced and nowadays land based diffuse sources are the main responsible for the nutrient pollution (Kronvang et al., 2005). Denmark has a high agricultural production, which covers over half of its total area, and it has been found to be the main nonpoint pollutant of the water environments due to nutrient loss (DEPA, 2009). Nitrogen is an essential nutrient for plant growth and is applied in large amounts on agricultural fields (Hatch et al., 2001). A proportion of the N is leached through the soil as NO_3^- and enters the streams (Jensen et al., 2019). From there, it is further transported to lakes, coastal waters and estuaries (Follett, 2008). The quality of water bodies has been deteriorating due to the process of eutrophication, where due to increased nutrient input the primary production increases. The consequences of algal blooms are decreased secchi depth, oxygen depletion and death of fish (Kronvang, 2001).

To protect water quality, many initiatives have been put in place to reduce the nutrient load to coastal waters, one of them being Water Framework Directive, which demands the aquatic environments is to reach a good ecological status (EU, 2000). It acknowledges wetland nutrient removal as a tool to improve water quality, and encourages wetland restoration (EU, 2000). The wetland area in many European countries has been vastly reduced during the past century, as wetland soils were seen as undesirable and were drained for the expansion of agricultural land or urban expansion (Hollis, 1991, Jones, 1993).

2.1. N removal in wetlands

Wetlands remove N in the process of denitrification, where NO_3^- and other oxidized forms of nitrogen are reduced to gaseous forms, mainly N_2. It is favored by permanently wet conditions, which are present in wetland soils – in fact, O_2 content in soil directly controls the denitrification rate (Burgin and Groffman, 2012, Groffman, 1994). Additionally, presence of low amounts of O_2 in wetland soils leads to a production of N_2O rather than N_2, which is a very potent greenhouse gas (Burgin and Groffman, 2012) (EPA). At a pH of over 7, N_2O production has been found to decrease, leaving N_2 as the main result of denitrification (Šimek et al., 2002). Generally, neutral soil pH has been found to be more favorable for denitrification than acidic soil conditions (ŠImek and Cooper, 2002). Other factors impacting denitrification rates is availability of nitrate and carbon to be decomposed and provide electrons. For optimal denitrification, the water should be stagnant or moving slowly – fast moving water supplies O_2 (Vepraskas et al., 2016). The denitrification rates increase with increasing temperatures, reaching optimum at approximately 25˚C (temperatures higher than 25˚C lead to reductions in denitrification rates) (Canion et al., 2014).

Riparian wetlands receive their water and N load directly from the upland area due to rainfall causing surface runoff. Some of the water will infiltrate the soil and enter the wetland through the soil as diffuse water flow or directly as groundwater. In certain areas drainage delivers the water into the streams (Dahl et al., 2007). Wetlands are also often flood inundated, which in Northern Europe typically occurs during the winter months due to high rainfall, soil saturation and therefore lack of ability to efficiently lead the water away. The high amount of water causes the rivers to overflow their banks (Şen, 2018).

2.2. Other services provided by wetlands

2.2.1. Carbon sequestration

As anoxic conditions are present in wetland soils, the decomposition of organic material is slow, resulting in peat deposition (Mitsch and Gosselink, 2000). Hence, wetlands are carbon sinks (Xiaoyan et al., 2019). It is estimated that worldwide, one-third to half of the carbon sequestered in soils is stored in wetlands (Mitsch and Gosselink, 2000).

The drainage of wetland soils has resulted in mineralization of the stored organic matter, and release of carbon to the atmosphere (Byun et al., 2018, Holden, 2005).

2.2.2. Biodiversity

Wetland habitats are very important for many bird species as places for breeding or as shelter for migrating birds in spring and autumn. For example, the restored wetland of Egå Engsø near Aarhus attracts up to 10,000 birds a day, and 169 bird species have been registered since restoration in 2006. The Egå Engsø area has attracted several red listed species such as *Anas querquedula*, *Crex crex*, *Podiceps nigricollis* and *Charadrius dubius* (Aarhus_Kommune).

Wetlands also offer a habitat for various aquatic invertebrate phyla. Rotifera, Turbellaria, Nematoda, Annelida, Mollusca and Arthropoda thrive in wetland environments (Batzer and Boix, 2016). In Egå Engsø, 94 species of aquatic invertebrates have been recorded, many of them being uncommon in Denmark (Aarhus_Kommune). Of course, wetlands provide shelter to terrestrial species as well. They are crucial for maintaining arthropod diversity in agricultural landscapes, as wetlands provide heterogeneity necessary in homogenized agricultural land (Hendrickx et al., 2007). Amphibians, such as frogs, use wetlands mainly for reproductive purposes – the eggs and larva occupy the wetlands, until they lead a terrestrial life as adults (Valk, 2006).

2.2.1. Phosphorus retention

Wetlands receive surface waters containing soil with phosphorus bound to clay particles and minerals (Reddy and DeLaune, 2008). The P retention occurs by sedimentation (Kronvang et al., 2009). There is a finite capacity of P accumulation, as P cannot be removed from the system in a gaseous form. If the storage capacity of a soil is reached, P will be released to the water. In wetlands, a P-gradient is observed, where the highest P-concentrations are observed near the inlet, as that is where most of the sediment is deposited (Reddy and DeLaune, 2008). The P retention varies a lot in wetlands: in Karlmosen, a 53% retention of P load, or 8.14 kg P per ha was found. In the restored wetland of Egebjerg, a retention of 0.13 kg P per ha, or 6% of input P was found (Hoffmann et al., 2011).

2.3. Phosphorus release

Phosphorus is bound to iron and aluminum ions in soil (Mitsch and Gosselink, 2000). Under reducing conditions, which are present in wetlands soils, the bound phosphorus is released to surface waters (Kinsman-Costello et al., 2014, Nair et al., 2015). Additionally, agricultural soils have been fertilized with a surplus of P, resulting in a storage of P in soil (Jensen et al., 2019). Therefore, there is a risk of P release, when previously drained soils are rewetted (Kinsman-Costello et al., 2014). The phosphorus can be then transported further downstream, and can be especially problematic in lakes, as they are P-limited and P inputs result in eutrophication (Kinsman-Costello et al., 2014).

2.4. Wetland restoration

In Denmark, the Second Action Plan on the Aquatic Environment to fulfill the Water Framework Directive aimed to restore 8,000-12.500 ha of wetlands during the years of 1998-2003. In 2002, 515 ha of wetlands were restored and additional 2,900 ha of wetlands were expected to be restored in 2003 (Grant and Waagepetersen, 2003). The third Action Plan on the Aquatic Environment to fulfill the Water Framework Directive aimed to further restore wetlands with a total area of 4000 ha during the years 2004-2005 (Schmidt et al., 2004). By the year 2007, the total established wetland area was 5343 ha and additional area of 3396 ha was granted for restoration, amounting to a total of 8739 ha (Børgesen et al., 2009).

Since the implementation of wetland restoration as a measure to mitigate N-transport to the sea in The Second Action Plan on the Aquatic Environment, VMPII in 1998, over 800 ha of wetlands had been restored in Odense River catchment alone, amounting to almost 9% of the total area in Denmark (Windolf et al., 2016).

In restoration projects, four main N removal types are distinguished: irrigation with drainage water, groundwater discharge, flood inundation and shallow lakes (Naturstyrelsen, 2014).

If a wetland is to be restored on drained land, the drains must be disconnected to allow the water to infiltrate the soil. If the direct upland area to the wetland is drained, the restoration would include disconnecting the drains at the wetland boundary, allowing the drainage water to flow on the wetland surface and allowing for infiltration to occur. If the wetland area is limited around the stream, distribution channels can be established to allow for the water to be more evenly distributed across the wetland area. In case of irrigation of drainage water, the upland/wetland ratio is important, because a too high hydraulic load in relation to the wetland area will result in water quickly flowing directly to the stream, reducing the N removal efficiency and also risk of water erosion (Hoffmann et al., 2005).

Under restoration, river channels that have been straightened out are re-meandered to allow flood inundation. That results in decrease water transfer capacity, slowing the water flow in the stream channel and reducing the stream slope (Hoffmann et al., 2005). In the upstream area of River Brede, the restoration of the river channel was found to result in 33 days' worth of flood inundation in contrast to 0 days before the restoration (Kronvang et al., 1998). The flooding events can also be encouraged by methods as simple as stopping or reducing stream maintenance – stream vegetation is often harvested, resulting in increased water transfer. Allowing vegetation to grow uninhibited will result in increased resistance against the water flow, leading to increased sediment deposition and raised bed level (Hoffmann et al., 2005).

Shallow lakes have been turned into agricultural land by drainage or water pumping, and very often the restoration requires as little as stopping the drainage or pumping activities. In certain cases the lake outlet has been modified to increase water outflow from the lake, and in this case the restoration will include a modification of the outlet (Hoffmann et al., 2005).

2.1. N removal in restored wetlands in Denmark

The monitoring data of actual N removal is sparse, as only a limited number of project areas are monitored, and the monitoring usually only occurs within a year after restoration (Hoffmann et al., 2006). There are two restored wetlands in Odense River catchment, with available monitoring data: Karlmosen and Gedebækken. The N removal in Karlmosen has been estimated as 270 kg N per ha, but the measured removal in 2005 was 337 kg N per ha (Hoffmann et al., 2006). In 2003, the measured removal was only 93 kg N per ha, due to low water discharge in the streams – N removal efficiency in Karlmosen is dependent on sufficient water supply (Hoffmann et al., 2003). In Gedebækken the total N retention per ha is 5%, or 24 kg TN per ha in 2015 (Hoffmann et al., 2018a). In fact, the actual N removal in restored wetlands is highly variable, as it depends on climatic conditions (Audet et al., 2019) (Land et al., 2016).

Nonetheless, the wetland restoration in Odense River catchment is seen as a huge success story. It has been found that the N load in Odense River between years 2000-2014 has been reduced by 39%, or 377 tons N per year by implementing various measures, of which 124 tons per year are being attributed to the extensive wetland restoration (Windolf et al., 2016).

2.2. Legislation

Wetland restoration projects area conducted in upland areas to coastal waters or lakes. There are three types of wetland restoration projects: N-removing wetlands, P-removing wetlands and peat-wetlands (Miljøstyrelsen, 2018).

In a N-removing wetland, the minimum N-removal must be at least 90 kg N per ha. The hydrology should be re-established as close to the natural state as possible. The project must not result in an increased P-release from the project area (Miljøstyrelsen, 2018).

Wetlands projects aiming to remove P are to be restored in upland areas to lakes, where there is a need for reduction in P-inputs to improve ecological conditions in the lakes. The upland area of the stream flowing into a P-wetland should be at least 2 km^2 and the project area must remove at least 5 kg P per ha per year (Miljøstyrelsen, 2018).

The peat wetlands are restored on low lying soils, with at carbon content of at least 12%. The project should lead to a reduction of greenhouse gas emissions equivalent to 13 tons CO_2 per year. The project should also contribute with a N-removal of at least 30 kg N per ha per year. Wetland restoration of peat-soils aims to restore the natural hydrology as much as possible.

The project should not lead to a P-release from the restored area (Miljøstyrelsen, 2018).

For all projects economic efficiency is estimated expressed as DKK per kg N per ha per year, per kg P per ha per year or per ton CO_2 equivalents per year (Miljøstyrelsen, 2018).

Wetland restoration is often conducted on privately owned soil, mainly agricultural land, and hence results in loss of economically viable land for the land owner. Therefore, farmers are offered either a monetary compensation or land consolidation. The wetland restoration on agricultural land is dependent on whether a farmer wishes to participate, as the participation is voluntary (Naturstyrelsen).

The funds for wetland restoration projects are limited, hence the financing of the projects are prioritized according to the highest economic efficiency in case of nutrient removal. Regarding restoration of peat-soils, prioritizing criteria include economic efficiency, total yearly CO_2 equivalent reduction, highest N removal per ha per year as well as close approximation to Natura2000 habitats (Miljøstyrelsen, 2018).

2.3. Calculation of N load and removal

The direct upland to a wetland is defined as the upland area, from which the N is transported from during rain events (Hoffmann et al., 2018b). The N loss from the direct upland is calculated using the following formula (Naturstyrelsen, 2014):

$N_{loss\ per\ ha} = 1.124 * \exp\left(-3.08 + 0.758 * \mathrm{LN(A)} - 0.003 * \mathrm{S} + 0.0249 * \mathrm{D}\right)$, where

A = yearly runoff in mm

S = % sandy soil

D = % agricultural area

The total N loss from a direct upland is calculated by following way:

$$N_{loss,\ total} = N_{loss\ per\ ha} * direct\ upland\ area\ (ha)$$

In groundwater fed wetlands, a removal rate of 90% is assumed (Naturstyrelsen, 2014).

In wetlands irrigated by drainage water, a 50% removal rate is assumed. If the irrigated wetland area has a high infiltration capacity, the removal rate is increased to 75% (Naturstyrelsen, 2014).

In inundated flood plains, the N removal is estimated to be 1.0 kg per ha per day, if the N concentrations are below 5 mg N per L, but above 2 – 2.5 mg N L and 1.5 kg N per ha per day, if the N concentrations are above 5 mg N per L. The removal is dependent on continuous supply of nitrogen, meaning a continuous water exchange in the flooded area. Nitrogen removal rates are set to zero at distances exceeding 100m due to lack of continuous water exchange, and thereby N removal (Naturstyrelsen, 2014).

The estimation of N removal in a shallow lake according to following formula:

$$N_{retention\ (\%)} = 42{,}1 + 17{,}8 * log_{10}(T_w)$$

The time retention in years (T_w) is calculated as $T_w = \frac{V}{Q_{til}}$, where Q_{til} is the water inflow to the lake and V is water volume of the lake. The water retention time must be at least 1 week in order to calculate the N retention (Naturstyrelsen, 2014).

2.4. Problem Statement

This thesis is conducted as a part of the Clearance research project, which emphasizes the need for further improvements in nutrient reduction in aquatic ecosystems and suggests wetland restoration as one of the main ways to reach that goal (CLEARANCE, 2018).

Objective:

A further restoration of riparian wetlands in Odense River catchment will reduce the transport of nitrogen to coastal waters.

1. An index model will be created to find areas for potential wetlands restoration.
2. Direct upland areas to each wetland will be calculated by using GIS-based tools.
3. The N loss from each upland will be calculated by using the N_{loss} formula presented in section 1.3.
4. Based on soil type and drainage information, the N-removal will be estimated.
5. The potential wetlands will by classified by removal type.
6. The same calculations will be performed on already restored wetlands and the calculated N removal will be compared to available measured data.

7. The implications for further wetland restoration in Odense River catchment will be discussed as well.

3. Methods

The input data for the index model will be following:

- Høje Målebordsblade
- Agrosinks Extended Wetlands
- Flood calculation
- Slope of the terrain
- Stream slope

Høje Målebordsblade show the wetland areas in 1842-1899. Already at that time many wetland areas have been modified, so the wetland signature visible in Høje Målebordsblade does not accurately depict all past wetland area (see Figure 3.1).

Figure 3.1. A close up in one of the areas with wetland signature in Høje Målebordsblade. The wetland signature is not continuous and appears to have been modified by ditches.

Agrosinks Extended wetlands is layer showing estimated peat distribution in 1900. It is based on maps from the beginning of 1900's showing low-laying soils as well soil classification from 1970's, ochre maps from 1980's and low-laying soils from GEUS (Greve et al., 2008). Flooding will be modelled for Odense River catchment to identify the areas prone to flood. Areas with potential for flooding can be further identified by calculating the stream slope, as flat areas tend to overflood with increased water inputs.

Also slope of the terrain (based on the DEM – Digital Elevation Model) will be used, as it shows the flat areas in the landscape and can be used to set the wetland boundary in an area, where other data indicates potential for wetland restoration.

3.1. Datasets used

- GeoDanmark-vandløb 1:10.000, downloaded from https://download.kortforsyningen.dk/, a very detailed stream shapefile, which is updated every year.
- GeoDanmark-søer 1:10.000, downloaded from https://download.kortforsyningen.dk/, a very detailed polygon shapefile containing lakes, updated every year.
- DHM/Rain 0,4x0,4m downloaded from https://download.kortforsyningen.dk/, a hydrologically correct digital elevation model. Cells have been altered where streams are crossed by bridges, so the stream is continuous.
- Odense catchment, extracted from the Danish Catchment Database 1:50.000, DCE, the catchment boundary of Odense River.
- Jordbundskort 2014 1:20.000, DCA, downloaded from http://miljoegis.mim.dk/cbkort?profile=jordbrugsanalyse. A polygon shapefile converted from raster, which contains the JB1-11 soil classification (Adhikari et al., 2013). o IMK-markkort 2018, downloaded from https://kortdata.fvm.dk/download/, a polygon dataset containing agricultural fields and the current crops.
- Agrosinks Extended Wetlands (AEW) (Greve et al., 2008), a polygon shapefile containing possible peat distribution in 1900. The layer is based on maps from the beginning of 1900's showing low-laying soils as well soil classification from 1970's, ochre maps from 1980's and low-laying soils from GEUS.
- Agro Sinks Peat 2010 (Gyldenkærne and Greve, 2015), shows mineral and organic low-laying soils, is based on soil drillings conducted in 2009-2010.
- Høje målebordsblade as WMS service https://kortforsyningen.dk/indhold/webserviceliste-0, scanned maps from 1842-1899 containing wetland signature from that time period.
- Digitalized Høje Målebordsblade (HM) approx 1:20.000, Aarhus Univrsity, a polygon dataset with digitalized wetland polygons based on Høje Målebordsblade within a 100m buffer of Kort10-vandløb 2016.

- Restored wetlands downloaded from https://kortdata.fvm.dk/download/Tilsagn, and updated by Aarhus university. A shapefile showing the restored wetlands in Denmark.
- Probable drainage (Olesen, 2009), DCA, shows probability of drainage on both wet and dry soils based on soil type and geological properties.

3.2. Flooding events

Streams naturally overflood, and an area that prone to flooding is a good choice for a wetland restoration project.

The first step in flood calculation is creating an elevation raster in “Topo to Raster”, where elevation points are included. The tool interpolates the elevation of the single points onto the whole stream network. This solution is preferred over using a fixed water elevation level all over the stream network, as the effect would be unrealistic. Measurements of water level from stations in Odense catchment are downloaded from www.odaforalle.dk . The time period is from 2007 to 2017. Some of the station only have a year’s worth of data. An interpolation was conducted directly based on the difference between max and mean elevation values from the stations. Due to the tool not being able to distinguish between upstream and downstream or stream size, all streams in a close proximity of an elevation point are affected by it. As result, many small streams got high stream elevation values, which was deemed unrealistic (see Figure 3.3.2).

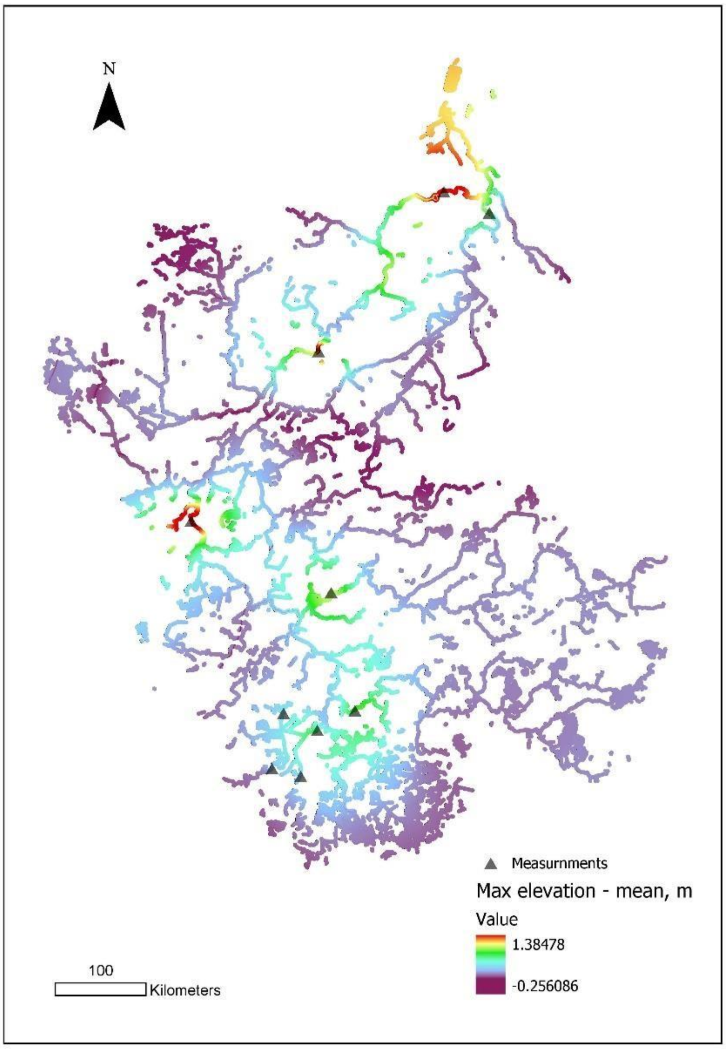

Figure 3.2.2. "Topo to Raster" interpolation using elevation points. The point values are max-mean of stream water level in meters based on measurements from 10 monitoring stations. The highest water elevation increase values are seen downstream. The interpolation is uneven and if it was used in further flood calculations many small streams would overflood, while many areas would not be flooded at all.

To achieve a more fitting interpolation, more elevation points were needed. It was visible that the highest water elevation values occurred downstream. It was assumed that the water elevation increase in a location is dependent on the upstream stream length and can be used to estimate stream water elevation. To have more reference points, stations with measurements from before 2007 were included, but only the last available year was used.

More points are added to the stream network, and upstream length to each point is traced. This is done by first creating a Geometric Network using ArcMap, as this function is not available in ArcGIS Pro. Points are randomly placed across the stream network. The streams need to be split, where the lines and points intersect. Flow direction is set on the river network. A model is built, where the upstream sections for each point are traced.

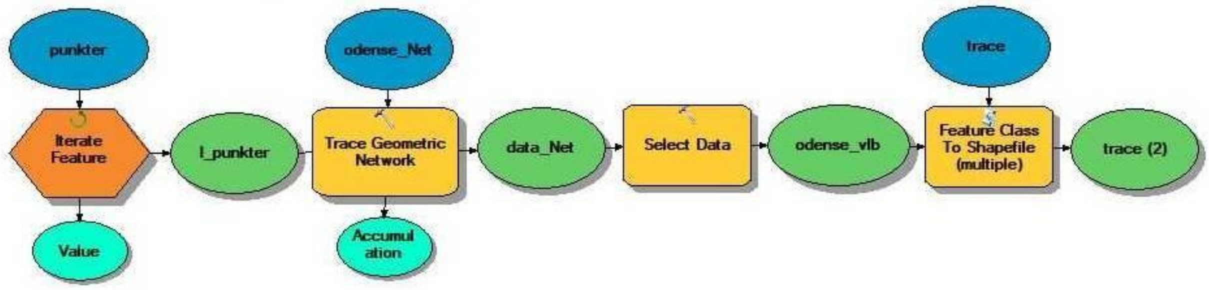

Figure 3.2.3. Tracing upstream length to random points in ArcMap. "Trace Geometric Network" traces the upstream river length to each point located in the stream network selected via the iterator. The upstream river sections for each point are then saved in a shapefile. As result, the upstream river length for each point can be calculated.

First, the max-mean elevation increase is analyzed using R.

The stream level elevation increase values nor upstream length were found to be normally distributed (Wilk-Shapiro test p-values 0.04 and 0.001, respectively). Therefore, the data was transformed by using a Log10 transformation. A following linear model was built:

Stream water elevation (max-mean) ~ Upstream length

The model was shown to be significant with a p-value=0.00 and adjusted R^2=0.81.

Additionally, it was checked whether stream channel width measured from the pattern visible in the flow direction raster would strengthen the model. The stream width was also Log10 transformed, as it wasn't normally distributed (Wilk-Shapiro test p-value of 0.007).

*Stream water elevation (max-mean) ~ Upstream length * Stream width* was found to have a p-value of 0.00 and adjusted R^2=0.81. However, a p-value of 0.45 in an ANOVA analysis of variance showed that the interaction model can be reduced to the original model dependent on upstream length only.

It was found that for the interpolation in "Topo to Raster" to be consistent, the distance in between points needed to be 100m. Additionally, the interpolation was uneven in areas, where stream branches were clustered, such as in forests or in merging points between a small and a large stream. Therefore, the stream needed to be simplified by removing the clustered stream groups and various stream branches.

Instead of estimating Max-mean, following percentiles minus the mean were calculated: 0.9^{th}, 0.95^{th}, 0.99^{th}, 0.999^{th}, 0.9995^{th}.

The values used to elevate the stream surface must be in meters over sea level rather than in relation to the mean. Therefore, the estimated stream elevation levels must be added to the

DEM. The DEM values were extracted to each station measurement as well as each trace point.

Table 3.2.1. The station number, upstream length, height in meters over sea level and the calculated percentiles of measured stream water levels. The elevations of the highlighted were found to be inconsistent with the measured water elevation values.

Station ID	Upstream length, m	DEM	0.9	0.95	0.99	0.999	0.9995
45000001	314485.8	1.60	2.06	2.26	2.66	2.88	2.93
45000003	292116.3	11.23	11.79	11.99	12.40	12.71	12.78
45000004	186579.8	17.00	17.82	18.02	18.38	18.61	18.63
45000033	2371.4	36.20	34.99	35.02	35.08	35.12	35.12
45000043	34011.9	3.37	3.42	3.46	3.56	3.63	3.64
45000045	6678.9	30.40	30.53	30.58	30.69	30.75	30.76
45000047	41469.2	27.75	28.05	28.15	28.57	28.61	28.62
45000080	26390.7	16.69	17.06	17.11	17.36	17.41	17.41
45000088	175910.8	19.95	1.77	1.96	2.42	2.81	2.87
45000090	2423.0	35.69	43.89	43.91	43.98	43.99	43.99
45000117	51206.0	31.17	31.70	31.78	32.10	32.17	32.18
45000174	289308.4	12.54	1.29	1.56	2.00	2.22	2.25
45000804	226584.9	14.75	15.31	15.50	15.79	15.86	15.87

A variety of percentiles of the measured stream elevations were calculated: 0.01, 0.05, 0.1, …, 0.95, 0.99. Then, a correlation between each percentile and the DEM values were calculated. The stations highlighted in Table 3.2.1 were excluded in the correlation calculation, as the water level elevation over sea level did not fit with the extracted DEM values. That could be due to the numbers only expressing water elevation in the stream rather than water elevation level over the sea level (stations 45000088 and 45000174) or the points being moved during snapping to the stream (stations 45000033 and 45000090), causing the point to be in a different location. All percentiles were highly correlated with the DEM values, but the highest correlation was found with the 0.5 percentile. Therefore, the water elevation to be added to the DEM values in each point was modelled as a difference between 0.5th and 0.9th,

0.95th, 0.99th, 0.999th, 0.9995th percentiles.

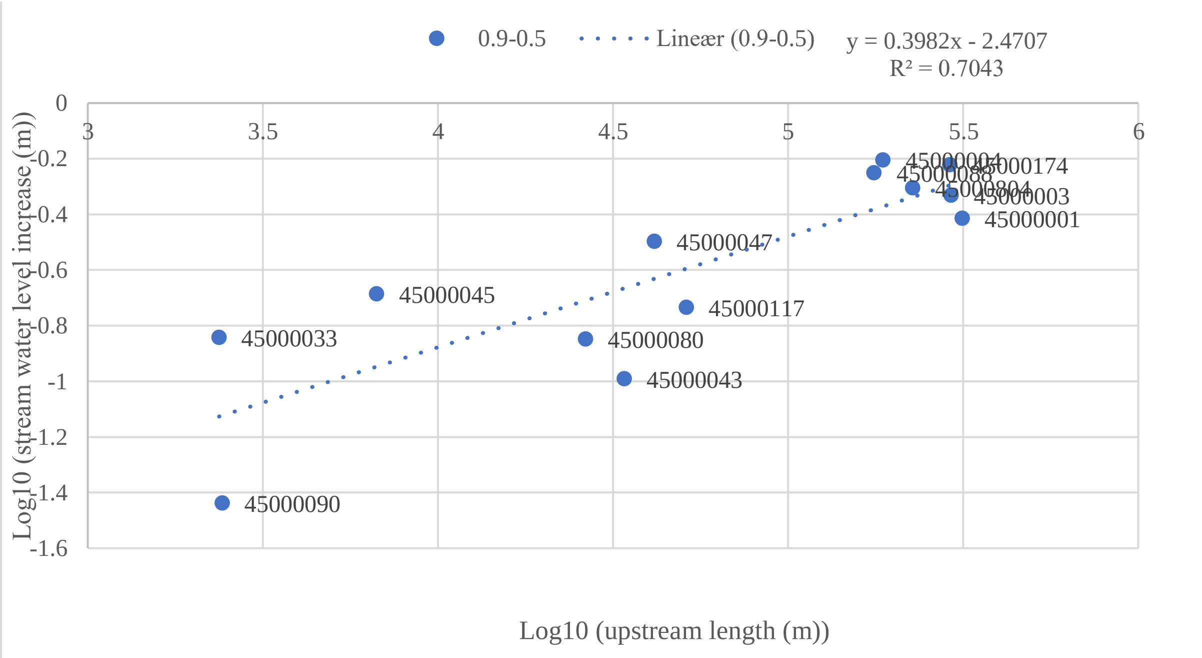

Figure 3.2.4. The linear relationship between the log10 transformed upstream length and log10 transformed stream water level increase between the 0.5th and 0.9th percentiles. The R^2 of 0.7 suggest a good explanation of the dependent variable (log10 transformed stream water level increase) by the explanatory variable (log10 transformed upstream length).

The linear equation is used to calculate log10(stream water level increase). The resulting values area transformed by using antilog (10^y). As can be seen in Figure 3.2.5, the estimated stream water level increase follows the shape of a power function. This is done for all five percentiles, and graphs showing the linear relationships between log10(upstream length (m)) and log10(stream water level increase (m)) for the 0.95th, 0.99th, 0.999th and 0.9995th percentiles can be seen in Figures 8.1-8.4 in the Appendix.

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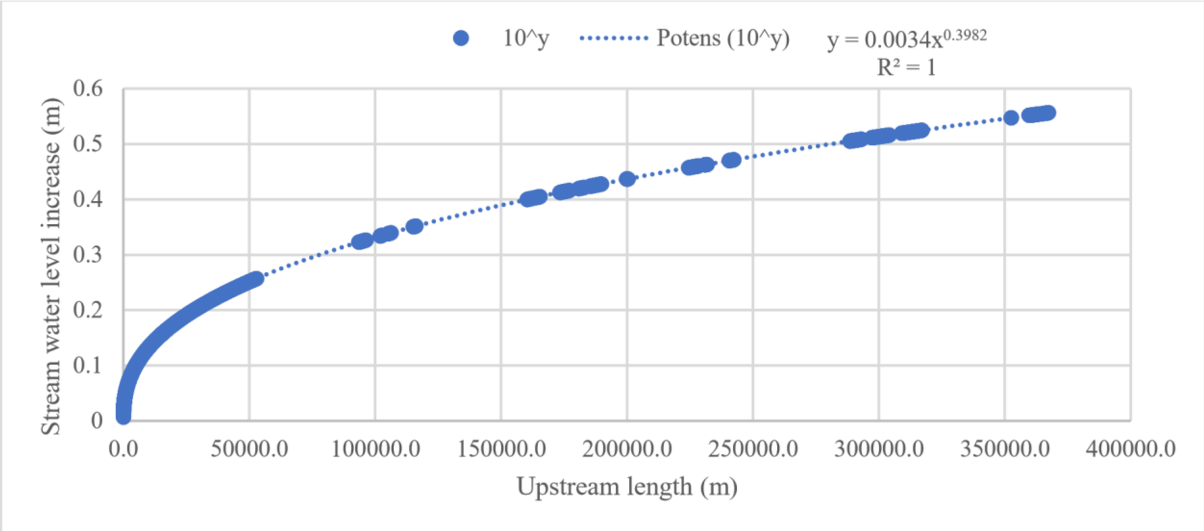


Figure 3.2.5. The estimated stream water level increase as function of upstream length for the 0.9th percentile. The estimated values follow the shape of a power function.

The stream water level values transformed with antilog are finally added to the DEM value in each traced point and are used in "Topo to Raster" interpolation using point elevation values.

Flooding can be calculated by using GIS methods shown in Figure 3.3.1:

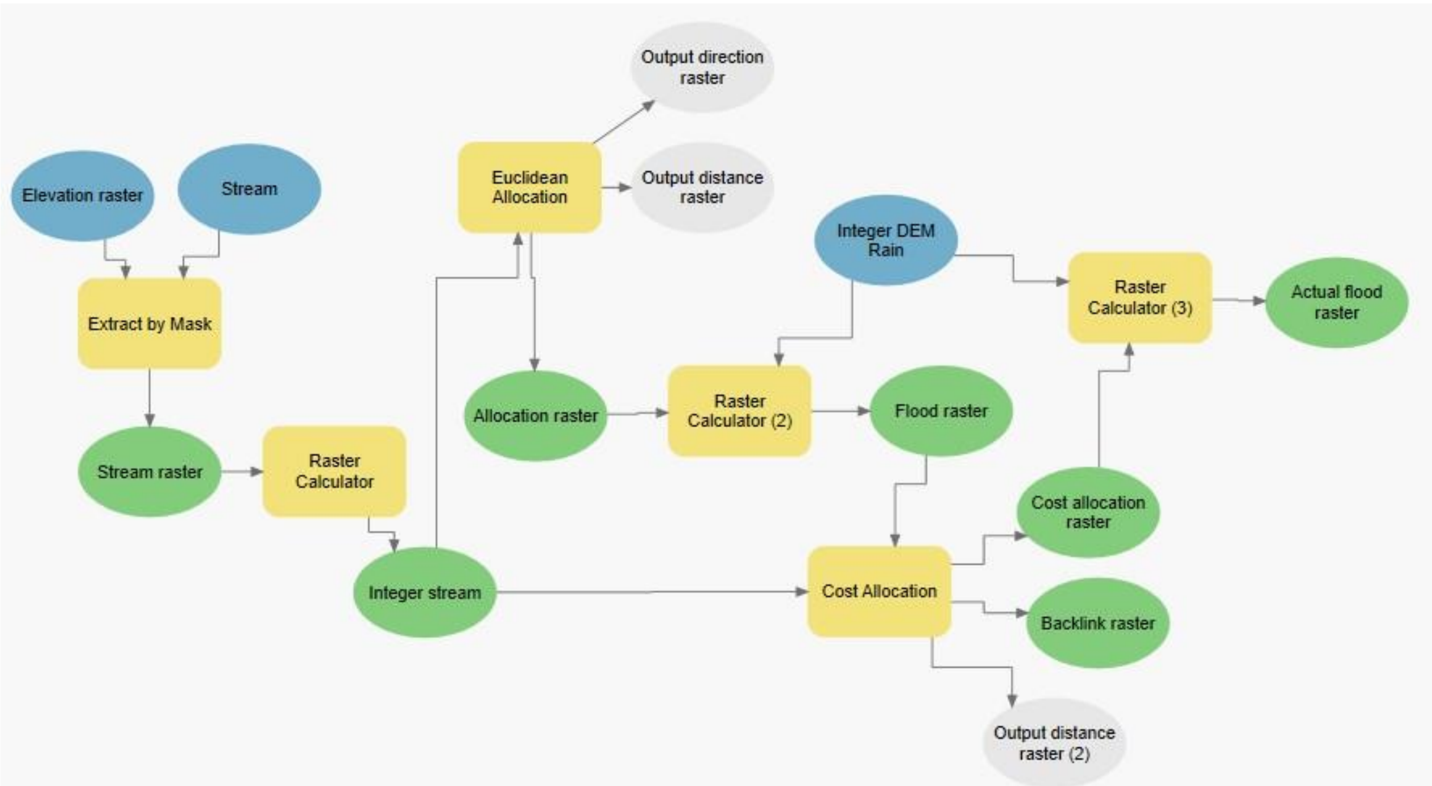


Figure 3.2.1. Flood calculation in ArcGIS. The details are described in the paragraph below.

The first step to the flood calculation is an elevation raster, which contain the values, by which the stream surface is to be elevated. The raster values are extracted by mask using a stream shapefile, resulting in a raster layer containing the stream with interpolated elevation values. The stream raster is then converted to integer. “Euclidean Allocation” calculates the shortest distance to each cell and the distance limit is set to a 1000m. In the next step, the cells of DEM Rain (converted to integer) that lie no higher than 100cm over the stream raster are extracted, including areas that are not connected to the stream. Then, the “Cost Allocation” tool discards cells of the flood raster, according to the least accumulative cost. In this step, cells that aren’t connected to the stream are discarded. Finally, all the potentially flooded areas are reclassified to have the same value using “Raster Calculator”.

To figure out which percentile should be used in the index model, the different flood layers are compared to both digitalized Høje Målebordsblade (HM) and Agrosinks Extended Wetlands (AEW). This is done by counting the raster cells within the Høje Målebordsblade and Agrosinks extended wetlands that overlap with the various percentiles, as a method to express the level of compliance between the layers. The 0.9995th percentile had the highest cell count, but there was only a marginal difference between 0.999th and 0.9995th percentiles.

3.3. DEM Slope

The slope is calculated using the “Slope” tool on a DEM resampled to the cell size of 1.6 m.

The slope is reclassified, so layers of 1%, 2%, 3%, 4% and 5% slope are achieved. The slope layers are generalized using the “Boundary Clean” tool and “Majority” (8 cells) filter. Then, all five slope layers are added to the AEW and HM layers, the attributes where the layers overlap are extracted to a table, and the tables are merged together, just like regarding the flood calculation. The slope of 5 % had the highest cell count and was chosen to be used in the index model.

3.4. MIKE 11

The MIKE11 calculation of river Odense is a set of modelled water elevation values in various streams. The data does not contain coordinates, as the collection occurred in 1990-2006 and GPS was not used at the time. The mapping of points, for which the stream level has been modelled is done with help of fixing points (bridges), which are easily identified using a map. The digitalization of points is done manually in ArcGIS by measuring the distance from the mentioned fixed points.

The data points digitalized are located in following streams: Holmehave Bæk, Hågerup Å, Sallinge Å, Silke å, Odense Å and Lindved Å. Percentiles 0.9, 0.95, 0.99, 0.999 and 0.9995 were calculated.

It was noticed that in a number of points, located mainly in Holmehave Bæk, the estimated stream elevation values were over 5 m higher than the actual terrain model and were deleted. The flood calculation is done the same method described in section 3.3.

3.5 Stream slope

One way to find the areas that potentially can be flooded is to find the stream sections with a 0‰ slope. In a flat section an additional amount of water will cause the stream to overflow, as the water is not led away efficiently. However, this calculation failed and was not used, but the method is described below.

The slope is calculated as ‰ in the following way:

$$\frac{Max\ stream\ elevation - \min stream\ elevation}{Stream\ length} * 1000 = ‰\ slope$$

Zonal statistics can be used to calculate the range in the height over sea level within a stream section. Then, the stream sections with a 0‰ can be found to pin point areas that are likely to overflood.

A “Topo to Raster” tool is used to smooth out the stream channel to compute a hydrologically correct stream network. The digitalized stream network does not lie accurately in the stream channel of the terrain model. Therefore, if the height measurements are transferred directly to a stream section, the stream will go up and down, rather than steadily downhill (see Figure 3.5.1).

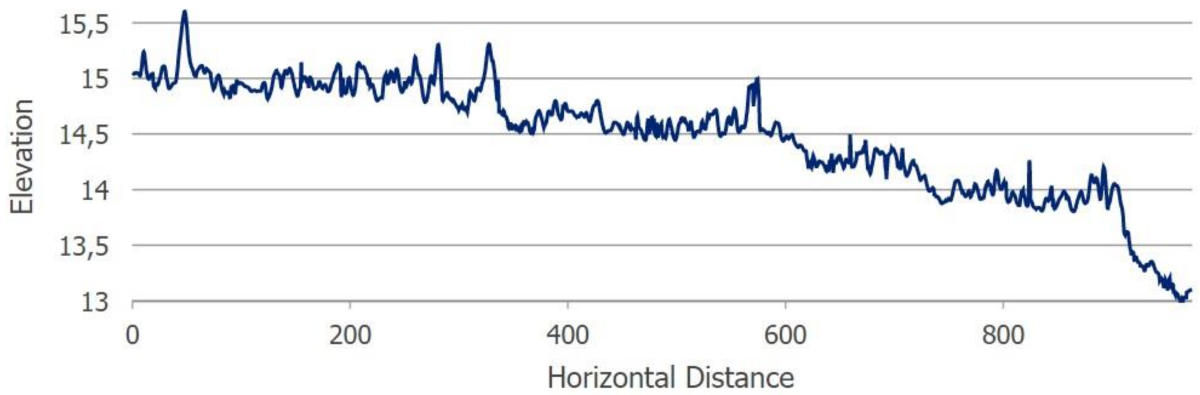


Figure 3.5.1. The elevation of a stream section interpolated from the original DEM. Horizontal distance is depicted in meters, and elevation is depicted in meters over the sea level. The stream elevation clearly jumps up and down, which is not hydrologically correct.

The “Topo to Raster” tool smooths out the channel to ensure that the stream network doesn’t lie outside of the stream channel.

The “Topo to Raster” uses the stream network shapefile, a contour based on the DEM and a boundary buffer as input. The boundary buffer is a zone around the stream, within which the tool operates, as we are only interested in a smoothing out only in a limited distance from the stream. The DEM contour provides height information to be interpolated and the stream is used to pinpoint the area to be smoothed out.

The tool cannot operate on the whole stream network at once and it is necessary to limit the extent in which the tool operates. Therefore, buffers are split into individual shapefiles, as shown in Figure 3.5.2.

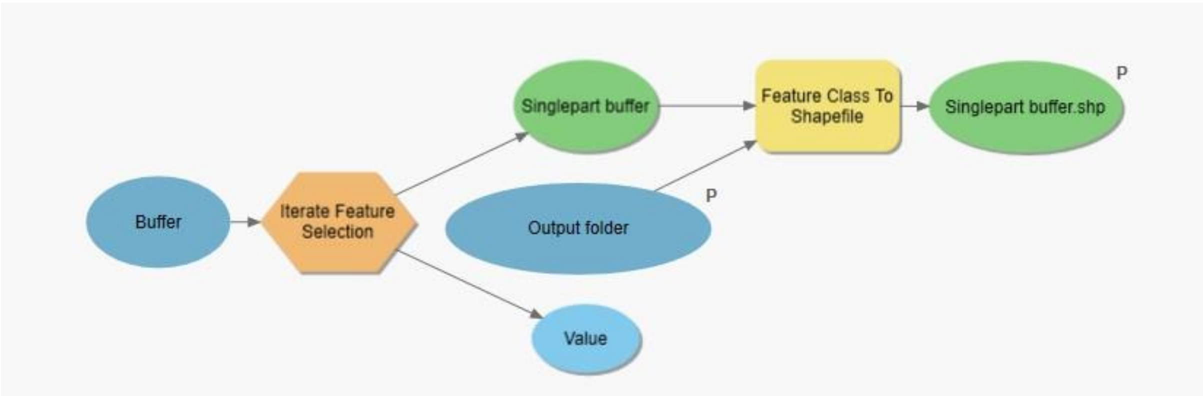


Figure 3.5.2. An overview over the iterating model, where the features of a multipart buffer shapefile are converted to single shapefiles in order to be later used in “Topo to raster” to produce smoothed out stream channels to ensure hydrologically correct surface elevation values.

Then, the individual buffers are used in “Topo to Raster”, as shown in Figure 3.5.3.

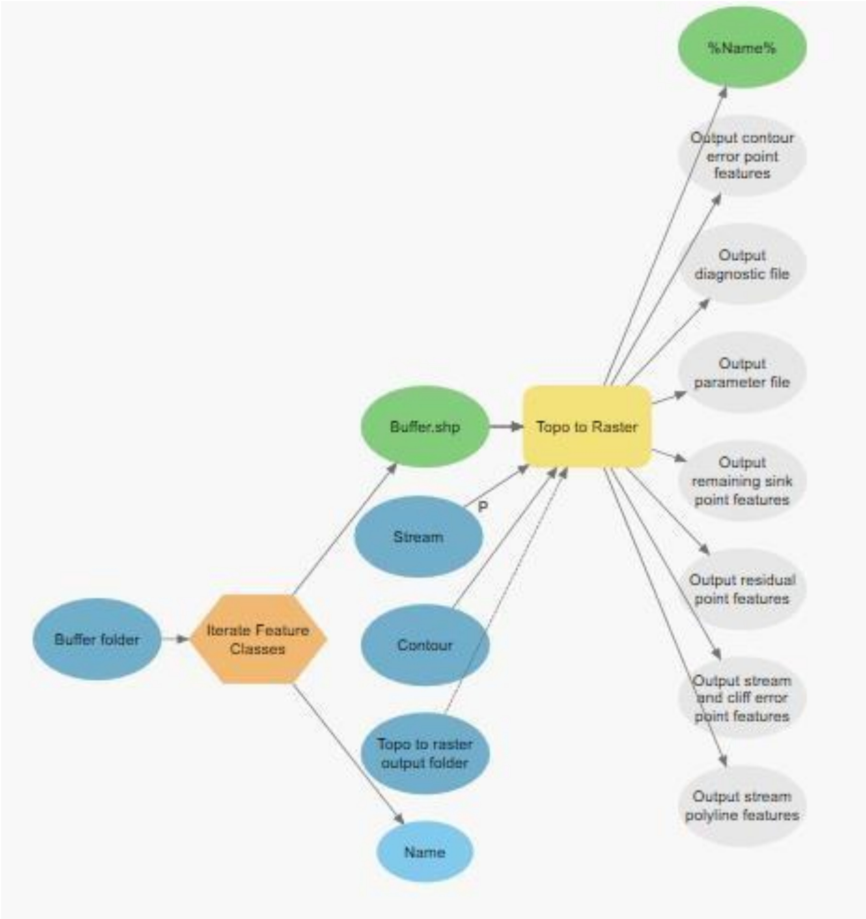


Figure 3.5.3. An iterating model, where the individual buffers are selected and used in "Topo to Raster" to interpolate the elevation values depicted by the contour of the stream channel, to finally ensure hydrologically correct surface elevation values.

The resulting raster files are than merged together in a mosaic dataset. The rasters do overlap, and to get the smoothest result a cubic resampling technique is used, as it uses 16 input cells to generate the most continuous output. Otherwise, no smoothing would occur between the neighboring raster datasets, and a value for a cell could vary between the overlapping raster. There is therefore a risk of a sudden increase in the slope of the stream, which goes against the purpose of executing Topo to Raster. As can be seen in Figure 3.5.4, the range in stream elevation is reduced.

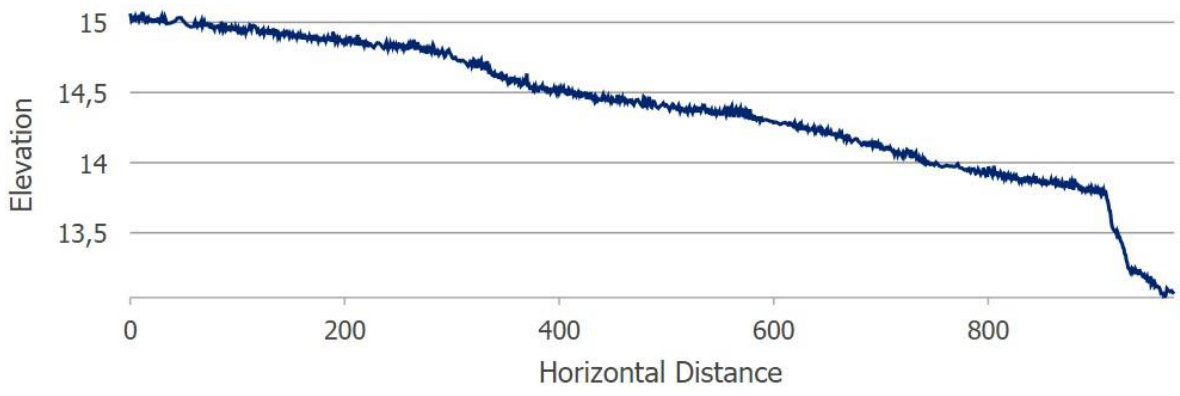


Figure 3.5.4. Elevation of a stream section interpolated from a smoothed-out raster. Horizontal distance is depicted in meters, and elevation is depicted in meters over the sea level. The stream elevation is more even compared to Figure 3.5.1 and more hydrologically correct.

At first, 100m buffer zones were used. It was found that if an edge of a raster overlapped the stream channel of another raster, the final value in the stream channel would be corrupted. That is due to the tool concentrating on the stream channel in the center of a boundary buffer and no smoothing is done on the edges. This was resolved by conducting "Topo to Raster" with a 20m buffer instead of a 100m.

It was found that multiple stream sections had differed from DEM by values as high as 2-3 meters and it appeared that the tool had pushed lower downstream values upstream. It is unknown why this error occurred, and how to correct it. The calculations were eventually dropped.

3.6 Index model for potential wetlands

An index model is computed in Raster Calculator by adding the rasters together. The input layers are the calculated Flood9995, the calculated Slope 5%, Digitilized Høje Målebordsblade and Agrosinks Extended Wetlands. The rasters are reclassified and get following values:

- Flood, 0.9995th percentile (F): 1
- Slope 5% (S): 10
- Agrosinks Extended Wetlands (AEW): 100
- Digitilized Høje Målebordsblade (HM): 1000

This way, it can be known which layers overlap in a certain area (see Figure 3.6.1). For example, a value of 1111 will mean that all layers overlap and a value of 11 will mean that flood and slope overlap. Additionally, an index model, where all values are equal to 1 is computed for an easier overview (Figure 3.6.2).

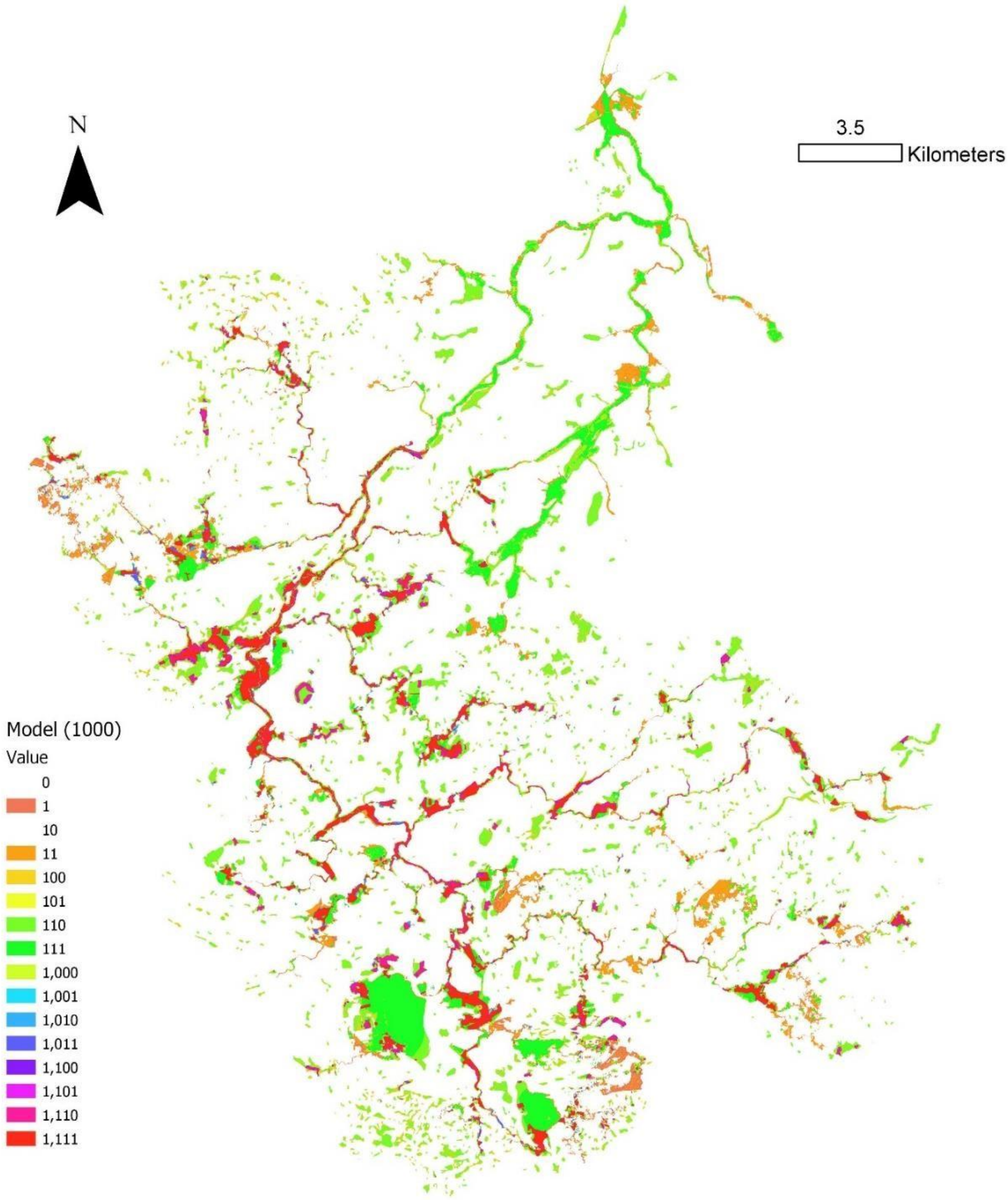


Figure 3.6.1. Index model, where each layer combination is unique. The value of 1 as the first digit shows the presence of flood, the value of 1 as the second digit shows the presence of slope, the value of 1 as the third digit shows the presence of Agrosinks Extended Wetlands and the value of 1 as the fourth digit shows the presence of the digitalized Høje Målebordsblade.

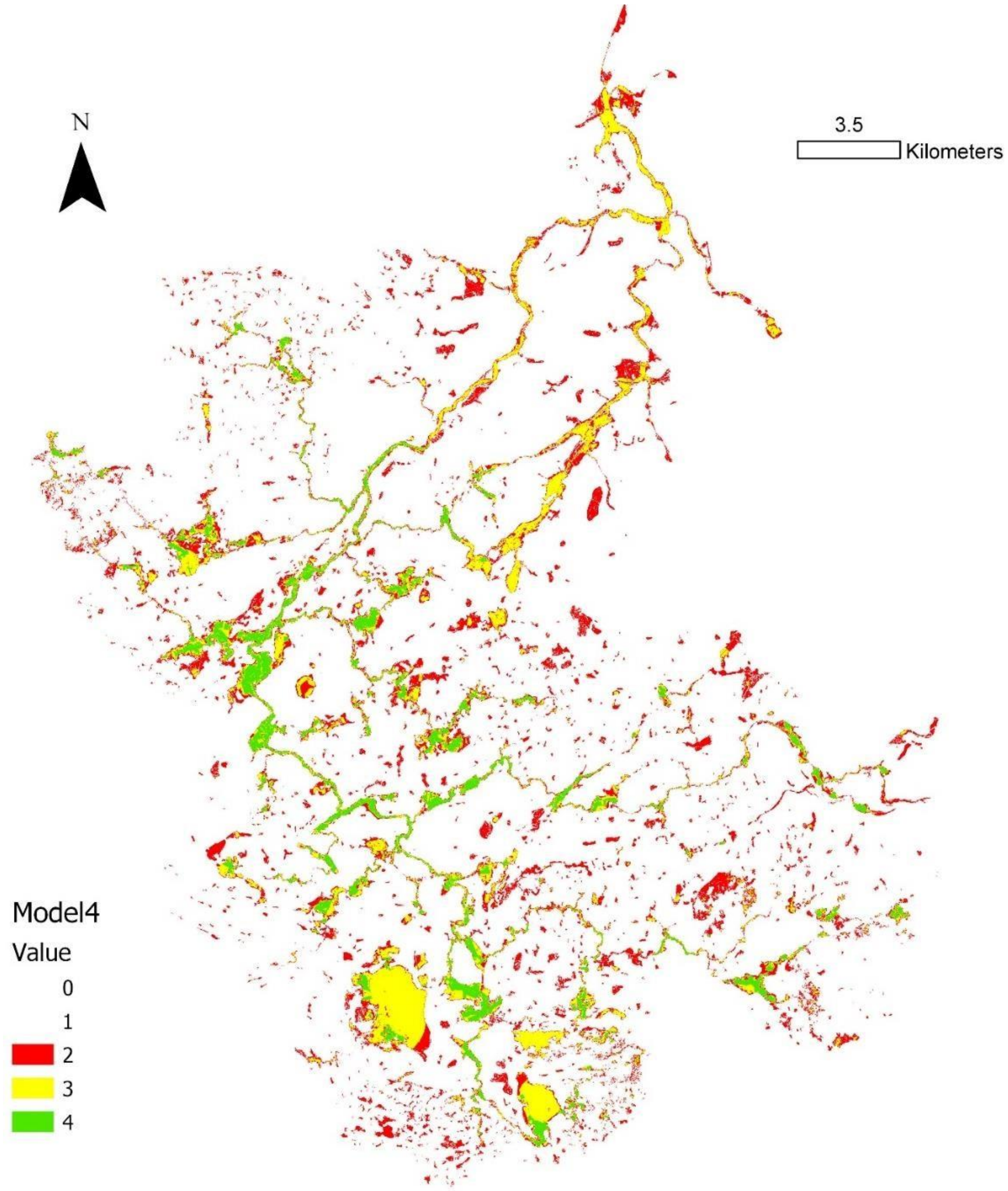


Figure 3.6.2. Index model, where the all the input layers have the value of 1. The value of 4 shows that all four layers overlap, the value of 3 shows that only three layers overlap and so on.

It was decided that the results of the index model will be converted from raster to polygon, rather than manually digitalized.

Initially, it was intended that only areas where all rasters overlap will be deemed a potential wetland. However, the Høje Målebordsblade were only digitalized within a 100m buffer of a stream network from 2016. Therefore, the layer is showing a limited amount of the potential wetland area. Additionally, Høje Målebordsblade is not an accurate indicator of past wetland areas, as many wetlands already had been modified with ditches at that time. Also, the flood calculation does not cover the whole stream network. Therefore, using the flood as a criterion for wetland restoration would exclude all the streams, where flood wasn't modelled.

Additionally, due to the flood calculation predicting flood in areas, where its occurrence seemed questionable, the flooded area alone cannot be used as an indicator of wetland area.

Therefore, as little as only AEW and slope can be used to define the wetland boundary. However, after conversion, many wetland areas were not continuous but consisted of small areas in a close proximity of each other. This type of area would have to be manually edited and reshaped, while the AEW layer provided the same desired boundary, and therefore AEW on its own was deemed a sufficient criterion for a potential wetland. The slope layer covers the whole catchment area and can be useful to manually set the wetland boundary, but it cannot be used as an indicator of wetland soil on its own.

Finally, all attributes from the index model with a value over 11 were converted to polygons. An overview of the model values and whether they were used in the raster to polygon conversion process can be seen in Table 3.6.1. The vast majority (84.5%) of the area converted to polygon consisted of an overlap of at least 2 layers, and almost half (45.3%) of the converted area consisted of at least 3 layers overlapping.

Table 3.6.1. An overview over the resulting values from the index model and whether they were used to finalize the potential wetlands.

F=Flood, S=Slope, AEW = Agrosinks Extended Wetlands, HM=Digitilized Høje Målebårdsblade

Value	Layers	Included/excluded	Total area, ha	% of potential wetland area
0		-		
1	F	-	496.9	
10	S	-	35169.5	
11	S + F	-	1112.5	
100	AEW	+	1297.5	14.8
101	AEW + F	+	310.0	3.5
110	AEW + S	+	2687.7	30.7
111	AEW + S + F	+	2061.0	23.5
1000	HM	+	60.2	0.7
1001	HM + F	+	26.9	0.3
1010	HM + S	+	71.9	0.8
1011	HM + S + F	+	82.1	0.9
1100	HM + AEW	+	151.6	1.7
1101	HM + AEW + F	+	182.3	2.1

1110	HM + AEW + S	+	429.9	4.9
1111	HM + AEW + S + F	+	1404.8	16.0

After the conversion to polygon, the features not intersecting the continuous stream network are excluded. To put further restrictions on the number of potential wetlands, polygons with a size of under 1 ha are excluded.

3.7 Calculation of direct upland

To calculate upland to a wetland the "Watershed" tool in ArcGIS is used. It requires a flow direction raster, which is calculated based on DEM Rain, where sinks in terrain have been filled. Besides the flow direction, the tool needs a point of reference to which it should calculate the upland to. Therefore, lines are created across the stream sections at wetland boundary. An overview of these processes can be seen in Figure 3.7.1.

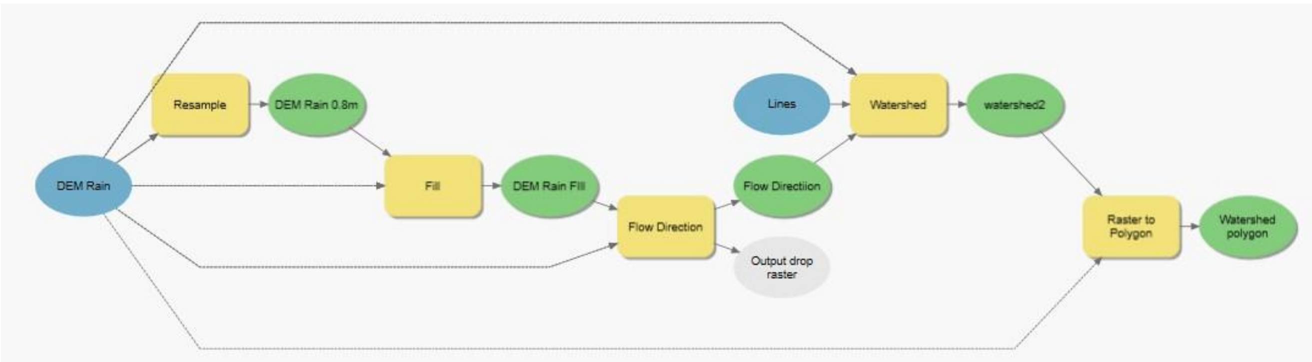


Figure 3.7.1. Overview of the tools and processes in the watershed calculation. The Digital Elevation Model (DEM) is resampled to increase the cell size. The depressions in the landscape are filled to enable the water to flow away, so each cell can have a designated flow direction. The flow direction raster is used in the "Watershed" tool, which calculates the upland area to boundary lines, which have been set to cross the stream on the edge of the wetland area. Lastly, the raster containing upland areas is converted to polygon.

The uplands are then split along the stream network, so there is a separate upland area on each side of a stream.

3.8 Calculation of N loss

3.8.1 The formula

The N loss in kg N per ha from the upland area is calculated using the following formula:

$N_{loss\ per\ ha} = 1.124 * \exp(-3.08 + 0.758 * \mathrm{LN(A)} - 0.003 * \mathrm{S} + 0.0249 * \mathrm{D})$, where:

A = yearly runoff in mm

S = % sandy soil

D = % agricultural area

3.8.2 Data preparation

3.8.2.1 Agricultural area:

The IMK-markkort 2018 is used, which is a polygon file containing information on what crop is grown on each agricultural field. It is simplified by using a table called afgrode_simp.dbf, which has classified the different crops into following groups:

- In agricultural rotation
- Forest and natural areas
- Grass
- Unknown crop
- Energy forest
- Vegetables and horticulture
- Environmental scheme

Agricultural rotation and Vegetables are counted as agricultural area. The decision whether a crop is seen as in agricultural rotation is made based on whether it is fertilized, with the help of the report from The Danish Agricultural Agency (Naturstyrelsen, 2017). Permanent grass is not counted as agricultural area due to its low nitrogen leaching (Olesen, 2016).

3.8.2.2 Sandy soil

A shapefile containing the information on the JB soil classification is used. JB1, JB2, JB3 and JB4 are classified as sandy soils and used in the formula (Adhikari et al., 2013).

3.8.2.3 Precipitation

The data used is a text file containing daily precipitation measured by DMI within a grid, where quadrants have the size of 10x10km. The text file is converted to csv table and imported to ArcGIS, and measurements from 2008-2018 are selected. Using the “Frequency” tool, the precipitation in mm is calculated. “Summary statistics” is used to calculate the mean yearly precipitation for each quadrant.

The “Identity” tool is used to on the upland polygons, to transfer the information regarding agricultural use, sandy soil and precipitation. Finally, the “Frequency” tool is used to summarize the shape area. It is then calculated as the percentage of the original upland area.

The N loss is calculated using the formula mentioned earlier. The N loss per ha is multiplied with the total upland area

3.9 Estimation of N removal

3.9.1 Irrigation with drainage water

The raster layer "Prob_DK_drain" shows the probability of drainage as a value between 0.1 and 0.9, corresponding to 10% and 90% probability. "Zonal statistics" is used to obtain the mean drainage probability. It is assumed that an upland with at mean of at least 50% drainage probability is drained, and hence these direct uplands are classified as irrigated with drainage water and the N load from these upland areas is expected to be removed by 50% (Naturstyrelsen, 2014). If there is infiltration, the N removal is estimated to be 75%. To find areas with infiltration, soil permeability is roughly estimated in the upland areas within wetland boundary. During the watershed calculation multiple uplands per wetland were created, so the wetland soil permeability calculation was done according to each upland. JB soil types 1-3 are assumed to have a high to very high permeability, JB 4 to have a moderate permeability and JB 5-11 have a low permeability (Hoffmann et al., 2018b). Organic matter varies in permeability according to its degree of decomposition, highly decomposed matter having low permeability (Hoffmann et al., 2018b). JB11 is classified as Humus and is therefore assumed to be highly decomposed with a low permeability. The drainage water that flows into wetland areas with a mean permeability of over 0.5 are assumed to have enhanced N removal due to infiltration, and hence are estimated to remove 75%.

In several uplands there is a lack of information on drainage potential or the drainage probability was under 50%. Therefore, mean permeability was also calculated for the whole upland area. If the mean permeability is under 0.5 it is assumed that the water travels as overflow and is assumed to have a 50% N removal rate. On the other hand, if the permeability is 0.5 or higher, it is assumed that the water infiltrates the soil, and hence has a 75% removal rate. Assuming overflow is a simplification, as overland flow only occurs in periods of high rainfall (Mitsch and Gosselink, 2000). The classification into overflow merely suggests limited infiltration capacity and lower removal compared to soil types with higher permeability.

3.9.2 Groundwater fed wetlands

Many streams are more or less groundwater fed. The Base Flow Index (BFI) is an indicator of how much of the stream discharge is attributed to groundwater flow (the index varying from

0 to 1, 1 indicating the stream being 100% groundwater fed) (Singh et al., 2019). There is not systematic knowledge of BFI for Danish streams. Therefore, it cannot be known whether a stream section receives groundwater discharge or not. Therefore, lack of drainage and soil types with high permeability in the direct upland area could seep into groundwater.

Certain wetlands apparent in Høje Målebordsblade are said to be Fens, suggesting the area is groundwater fed. These areas are could be assigned 90% N removal, if the upland area is estimated to have a diffuse water transport pathway.

3.9.3 Inundation of floodplains and riparian areas

The 90th percentile of the flood calculation is used, as it shows the estimated flood level 10% of the time, meaning 36 days per year. The flood is converted to polygon and cut with a 100m buffer. "Identity" and "Frequency" are used to calculate the flooded area with potential for N removal within the potential wetlands.

3.9.4 Shallow lakes

No lakes are suggested in this project due to difficulties with estimation of the lake location, volume and water inflow. The potential wetlands based on the index model do include large, well established lakes (Arreskov Sø, Søbo Sø, etc.) and these are erased, so the final N removal per ha wetland does not include the lake area. They are erased from the uplands as well.

3.9.5 Wetland classification

Finally, the wetlands were classified into types by whether they are flood inundated, receive drainage water or not. If the transport pathway from the direct upland was classified as "Overland flow" or "Diffuse flow", the wetland would be classified as "Natural flow". If the transport pathway was through irrigation, the wetland would be classified as "Irrigation". To simplify the results, "Irrigation" also includes irrigated areas with infiltration. As during flood inundation, the water is still at distances exceeding 100m from the stream, a wetland is assumed to be both flood inundated and irrigated with drainage water, if there is a substantial area between the actively flooded area and the wetland boundary.

3.10 Restored wetlands

The uplands, N load and N removal is calculated with the methods described earlier. A summary over the project area and ID is shown in Table 3.10.1.

Table 3.10.1. An overview over the restored wetlands, their area and their ID.

Wet ID	Project name	Area, ha
1	Maebaekken	10.9
2	Sandholt Moellebaek - VMPII	54.7
3	Silke River - VMPII/SVNI	146.9
4	Odense River ved Brobyvaerk - VMPII	104.4
5	Odense River Etape 1 - VMPII/SVNI	68.8
6	Odense River Etape 2 - VMPII/SVNI	295.7
7	Brahetrolleborg Gods - VMPII	45.6
8	Geddebaekken - VMPII	44.1
9	Karlsmosen - VMPII	62.5
10	Hammerdam - VMPII	9.8
11	Posens Mose	26.1
12	Sallinge River sydvest	2.8
13	Sallinge River nordvest	3.1
14	Sallinge River ost	8.5
15	Sallinge River rest	36.8
16	Sallinge River rest	1.8
17	Sallinge River rest	2.8
18	Sallinge River rest	23.0
19	Sallinge River rest	36.4
20	Sallinge River rest	16.3

An overview of the location of the restored wetlands can be seen in Figure 3.10.1.

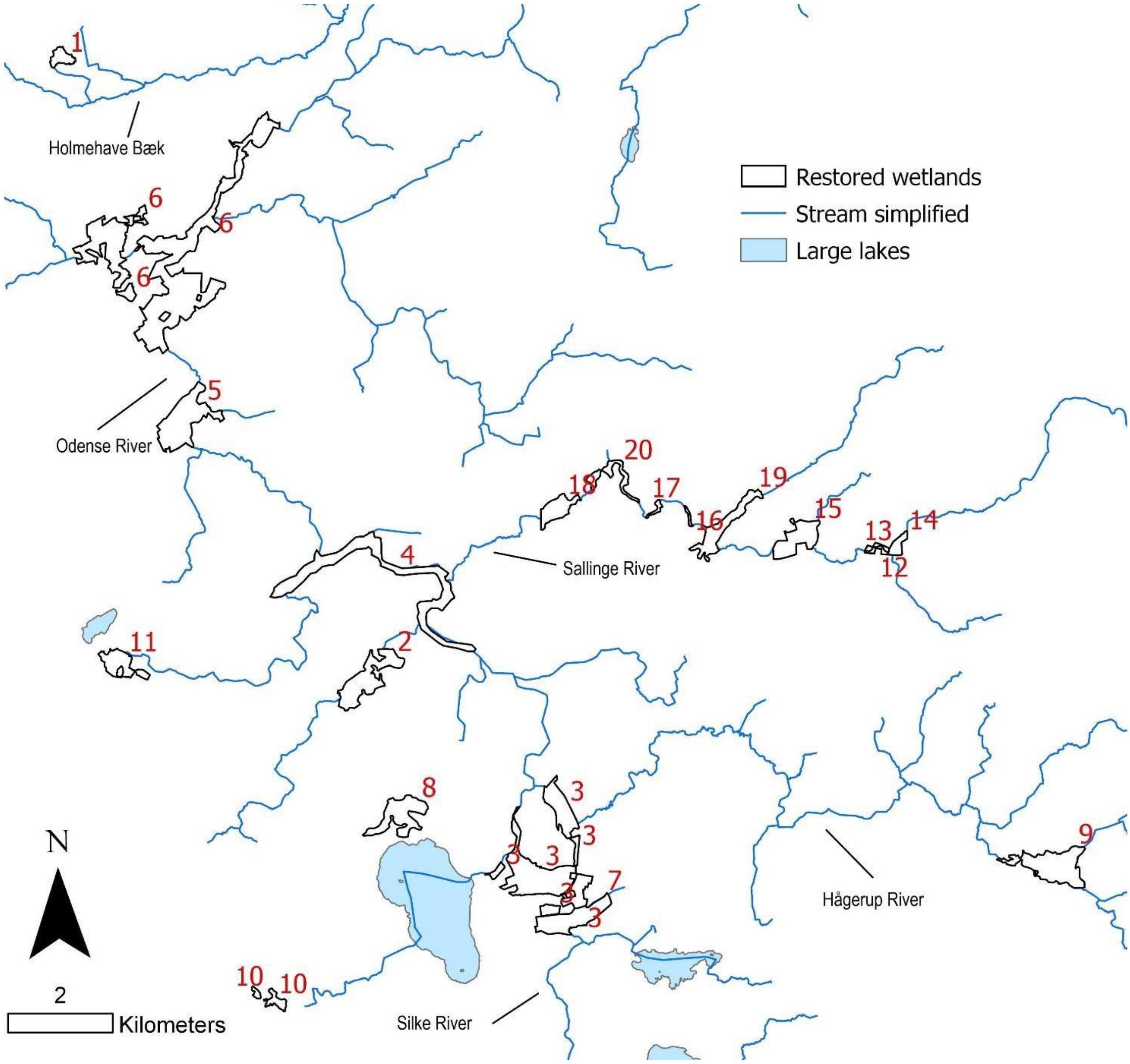


Figure 3.10.1. The location of the restored wetlands and their ID.

1= Maebaekken, 2= Sandholt Moellebaek – VMPII, 3= Silke River - VMPII/SVNI, 4= Odense River ved Brobyvaerk – VMPII, 5= Odense River Etape 1 - VMPII/SVNI, 6= Odense River Etape 2 - VMPII/SVNI, 7= Brahetrolleborg Gods – VMPII, 8= Geddebaekken – VMPII, 9= Karlsmosen – VMPII, 10= Hammerdam – VMPII, 11= Posens Mose, 12= Sallinge River sydvest, 13= Sallinge River nordvest, 14= Sallinge River ost, 15= Sallinge River rest, 16= Sallinge River rest, 17= Sallinge River rest, 18= Sallinge River rest, 19= Sallinge River rest, 20= Sallinge River rest

4. Results

4.1. Flooding events

4.1.1. The upstream length model (UPM)

The flood calculated based on the upstream river length can be seen in Figure 4.1.1.1. The upstream river length model will be further addressed as UPM.

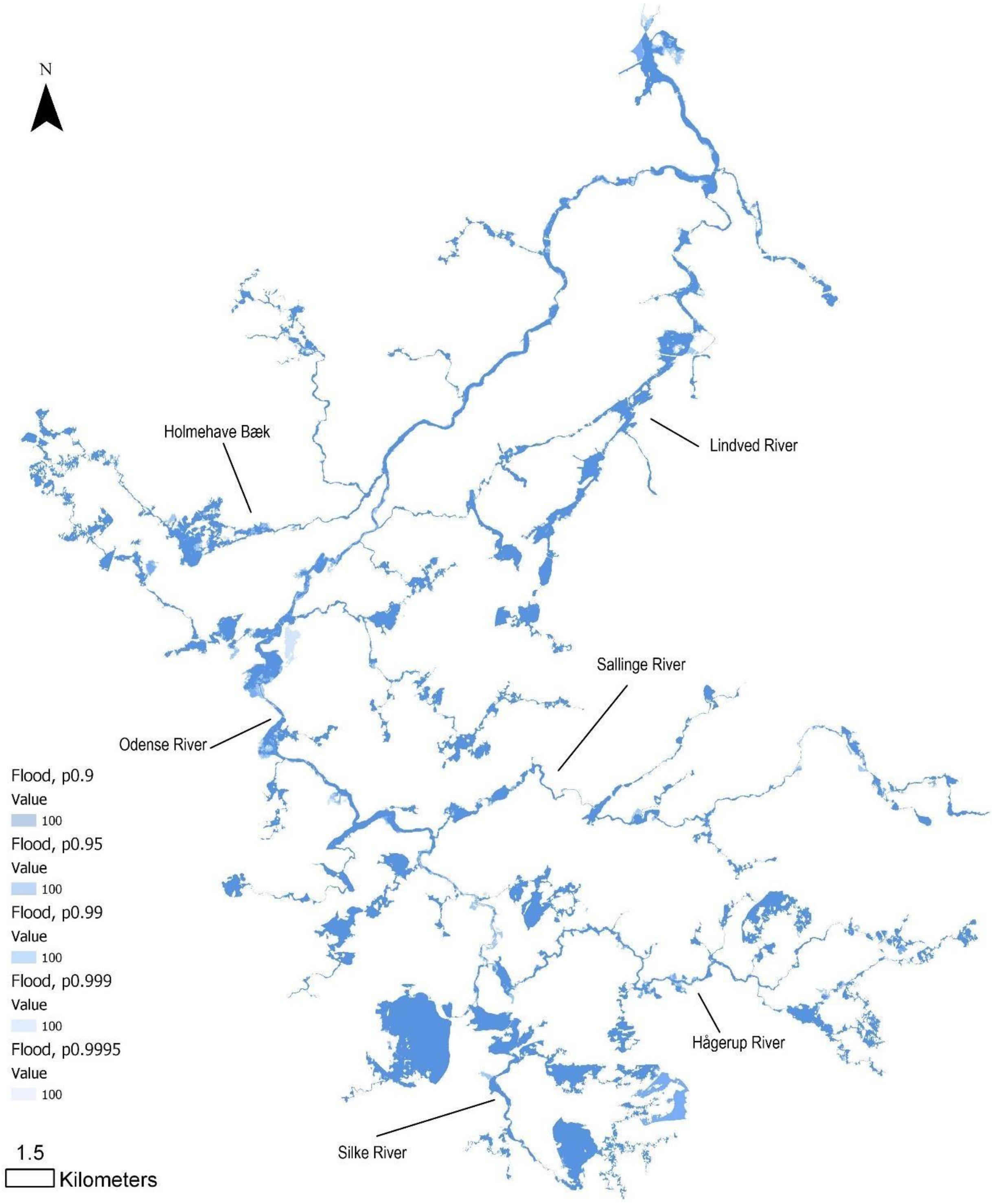
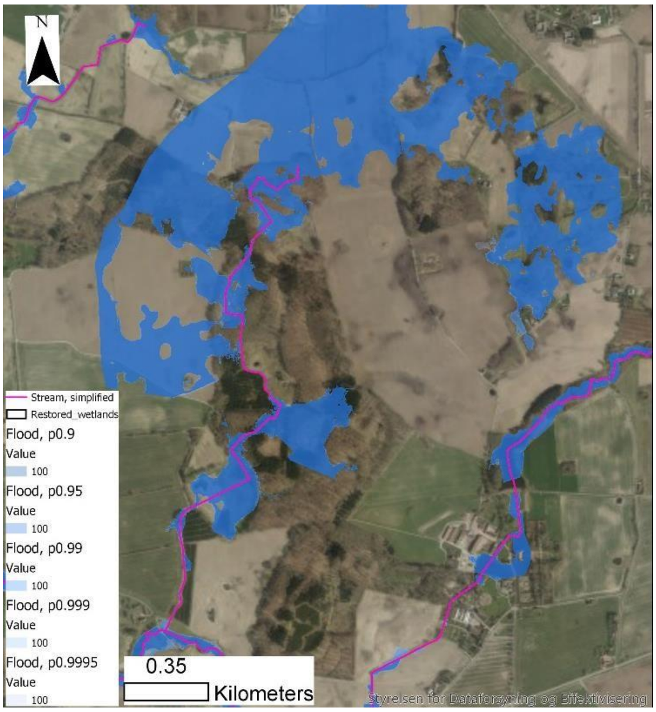
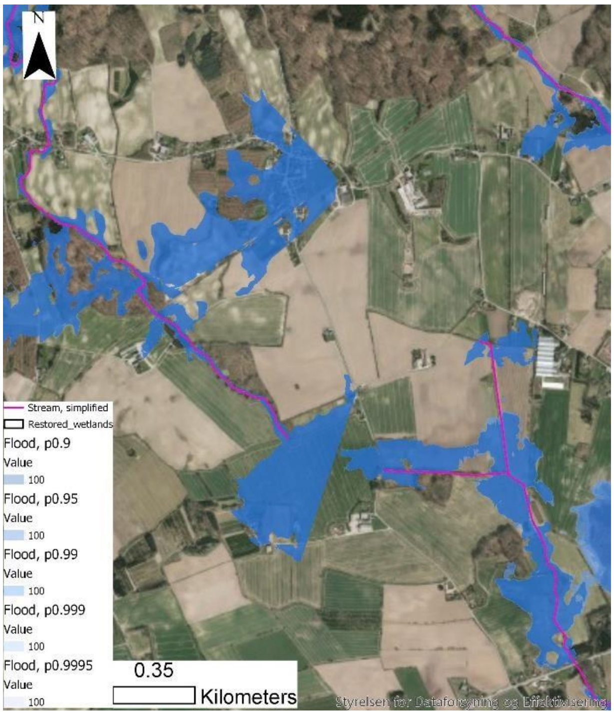


Figure 4.1.1.1. The flood calculated based on the stream water levels as function of the upstream length (UPM). The 0.9th, 0.95th, 0.99th, 0.999th and 0.9995th percentiles are shown. The darker blue areas show an overlap between multiple percentiles, while the light blue areas indicate only being flooded by the highest percentiles. The 0.9th percentile shows flooding 10% of the time, the 0.95th percentile shows flooding 5% of the time, the 0.99th percentile shows flood 1% of the time, the 0.999th percentile shows flooding 0.001% of the time and the 0.9995th percentile shows flooding 0.0005% of the time.

In general, the modelled flood fits well both upstream and downstream – the flood seems to be evenly distributed across the whole catchment. In some areas the modelled flood has been cut off at the distance of 1000m from the stream due to the analysis being conducted within a 1000m distance from the stream. In some areas the model seems to be overestimating the flood, which can be seen below in Figures 4.1.1.2 and 4.1.1.3.





Figures 4.1.1.2 (left) and 4.1.1.3 (right). A closer overview of some of the overestimated areas with a spring orthophoto as background. The areas are located on upstream ends of small streams surrounded by agriculture. Due to the upstream location of the areas, that level of overflooding seems unrealistic.

Here, overflooded areas are located at the upstream end of streams sections. Based on the spring orthophoto, the streams are small, and the digitalized stream line does not seem to overlay the stream channel properly.

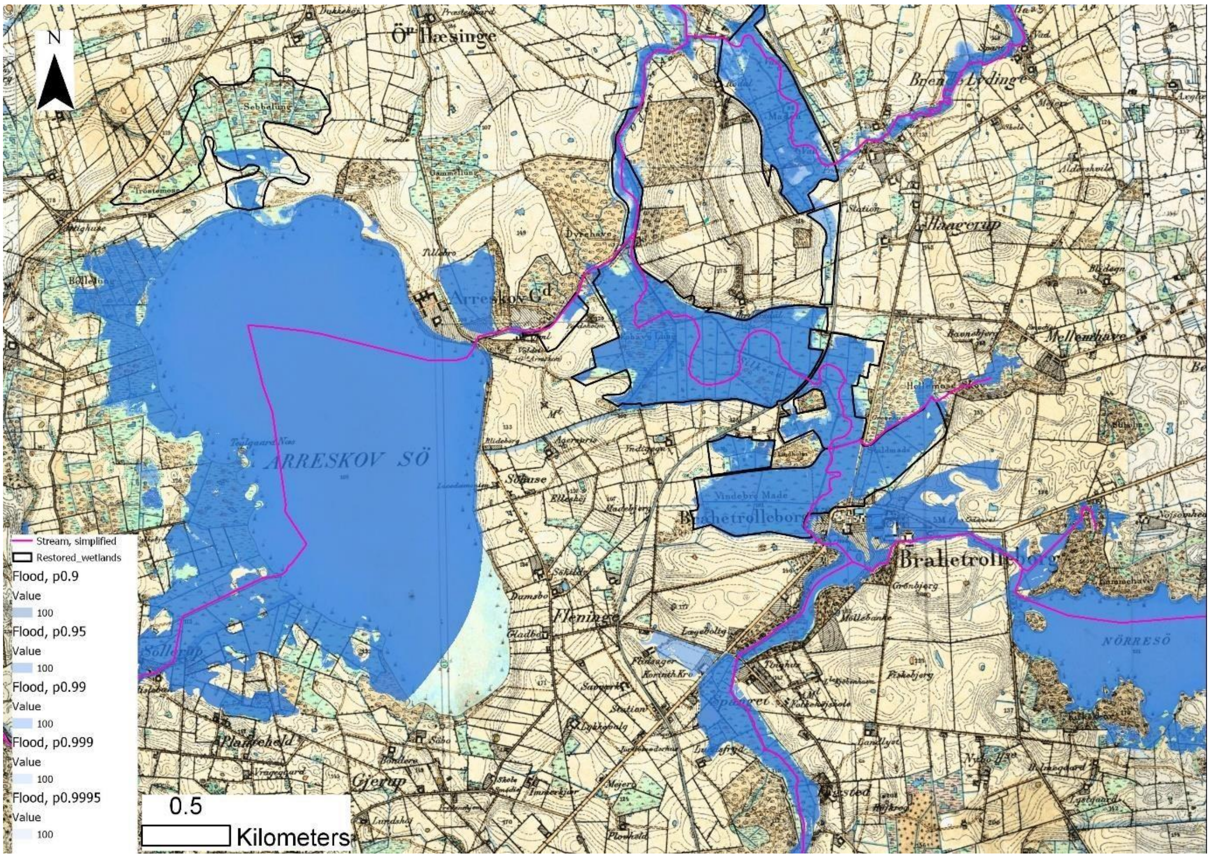


Figure 4.1.1.4. A closeup of the modelled flood based on the stream water levels as function of the upstream length near Arreskov Sø and the restored wetlands of Silke River - VMPII/SVNI (WetID=3) and Brahetrolleborg Gods – VMPII (WetID=7) with Høje Målebordsblade as background.

As Figure 4.1.1.4 shows, the modelled flood seems to fit very well with the wetland araes noted in Høje Målebordsblade, where the restored wetlands Silke River - VMPII/SVNI (WetID=3) and Brahetrolleborg Gods – VMPII (WetID=7) are shown. Also, the calculated flood follows the wetland pattern from Høje Målebordsblade around Arreskov Sø, but it is limited to 1000m from the simplified stream due to the analysis setup. The flood also follows the pattern of the riparian wetland under the Brahetrolleborg Gods restored wetland.

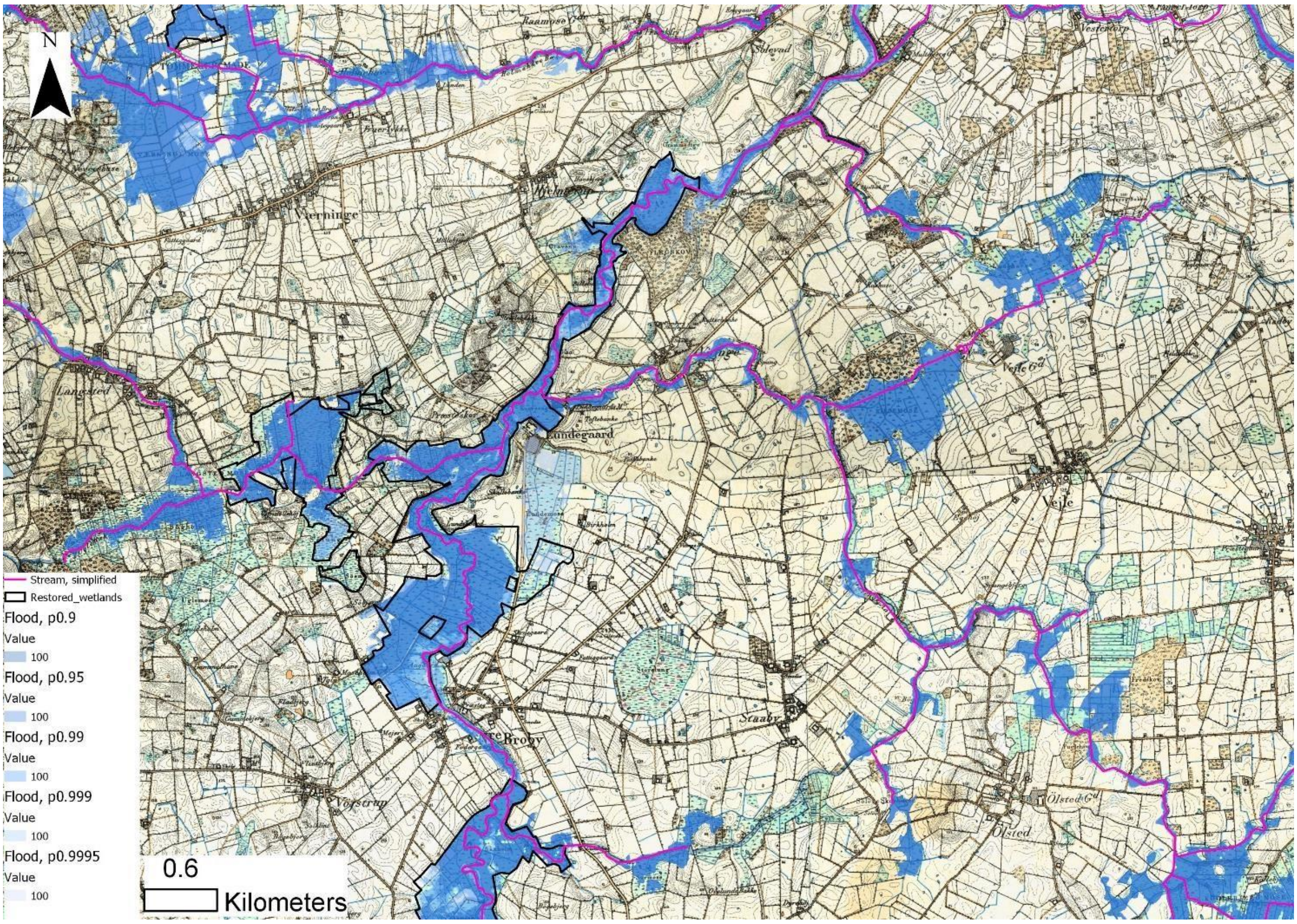


Figure 4.1.1.5. A closeup of the modelled flood based on the stream water levels as function of the upstream length near Odense River Etape 2 - VMPII/SVNI (WetID=6) with Høje Målebordsblade as background. This restored wetland is further downstream compared to Figure 4.1.1.4.

As can be seen in Figure 4.1.1.5, the flood also fits well higher downstream. Also here, the simulated flood follows the shape of wetlands in Høje Målebordsblade. In many areas, there is little differences between the 0.9th and 0.9995th percentiles in terms of flooded area. For example within the boundary of Brahetrolleborg Gods restored wetland, the 0.9995th percentile yielded only an additional 1.12 ha of flooded area compared to the 0.9th percentile, resulting in a 2.7 % increase in flooded area. In the Odense River Etape 2 - VMPII/SVNI (WetID=6), and additional area of 58.47 ha was flooded with the 0.9995th percentile, resulting in an area increase of 31%. On the right side of mentioned wetland an area called Lundemose is flooded as well (see Figure 4.1.1.5).

4.1.2. Comparison of MIKE11 and UPM

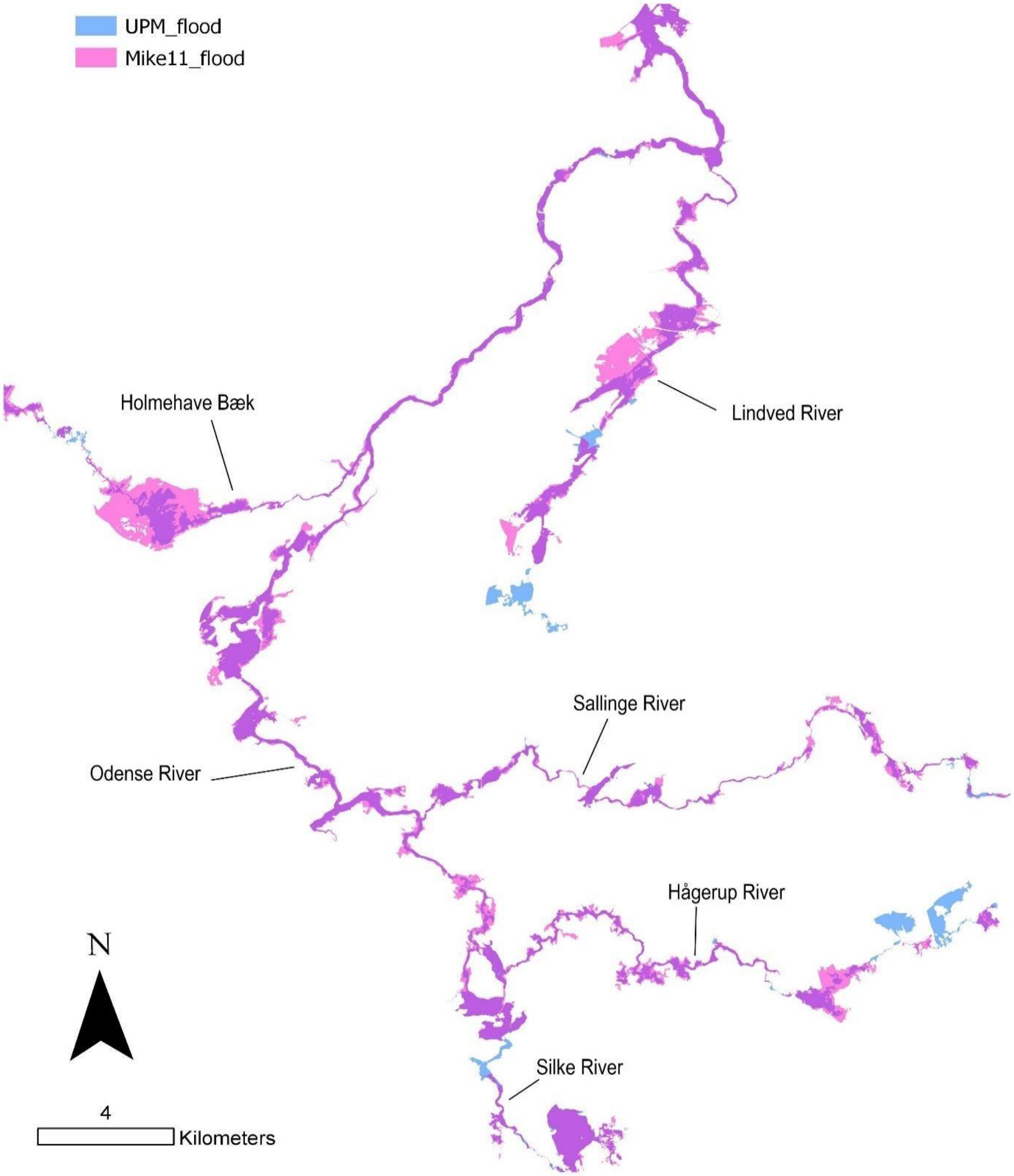
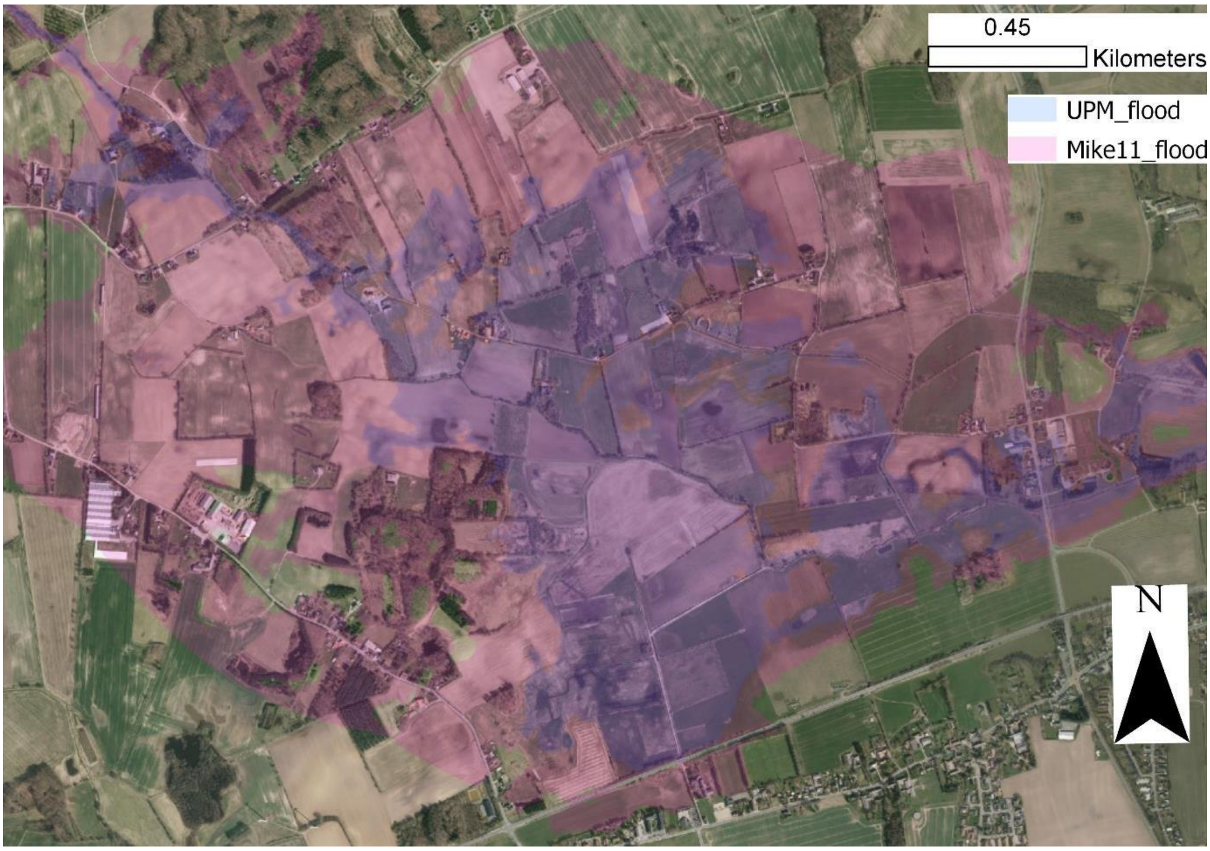


Figure 4.1.2.1. Comparison of modelled flood based on stream water level elevations from MIKE11 and the Upstream river length model (UPM) in Odense River, Lindved River, Silke River, Hågerup River, Holmehave Bæk and Sallinge River.

As can be seen in Figure 4.1.2.1, the MIKE11 and the Upstream length model (UPM) do mostly overlap. In comparison to MIKE11, the UPM underestimates the flooded area. In fact, if the cell counts of AEW and HM are compared, MIKE11 yields has a 12.4% higher area of overlap with HM and a 16.8% higher overlap with AEW. Additionally, as can be seen in Figure 4.1.2.1, the UPM predicts flood where, according to MIKE11, no flood is expected.



4.1.2.2. The flooding based on MIKE11 and UPM water elevation values with the spring orthophoto as background. The overflooding stream is Holmehave Bæk.

The high estimation of MIKE11 is especially visible in Figure 4.1.2.2. The area of Holmehave Bæk is highly flooded according to the MIKE11 model. In this stream section several stream elevation values were over 5 meters higher than the DEM, and even though they have been removed, due to the interpolation in "Topo to Raster" this stream section did receive high elevation values. As result, a very large area that contains buildings is estimated to be flooded, which seems unlikely. Furthermore, the flooded area is cut off at the down facing left corner, as the upper limit for calculation was set to 1000m from the stream. On the other hand, the UPM in this area follows the shape of the wetlands shown in Høje Målebordsblade (visible in Figure 4.1.1.5 in the preceding paragraph). In general, there is very high overlap between the two models.

4.2. Restored wetlands

4.2.1. Direct uplands

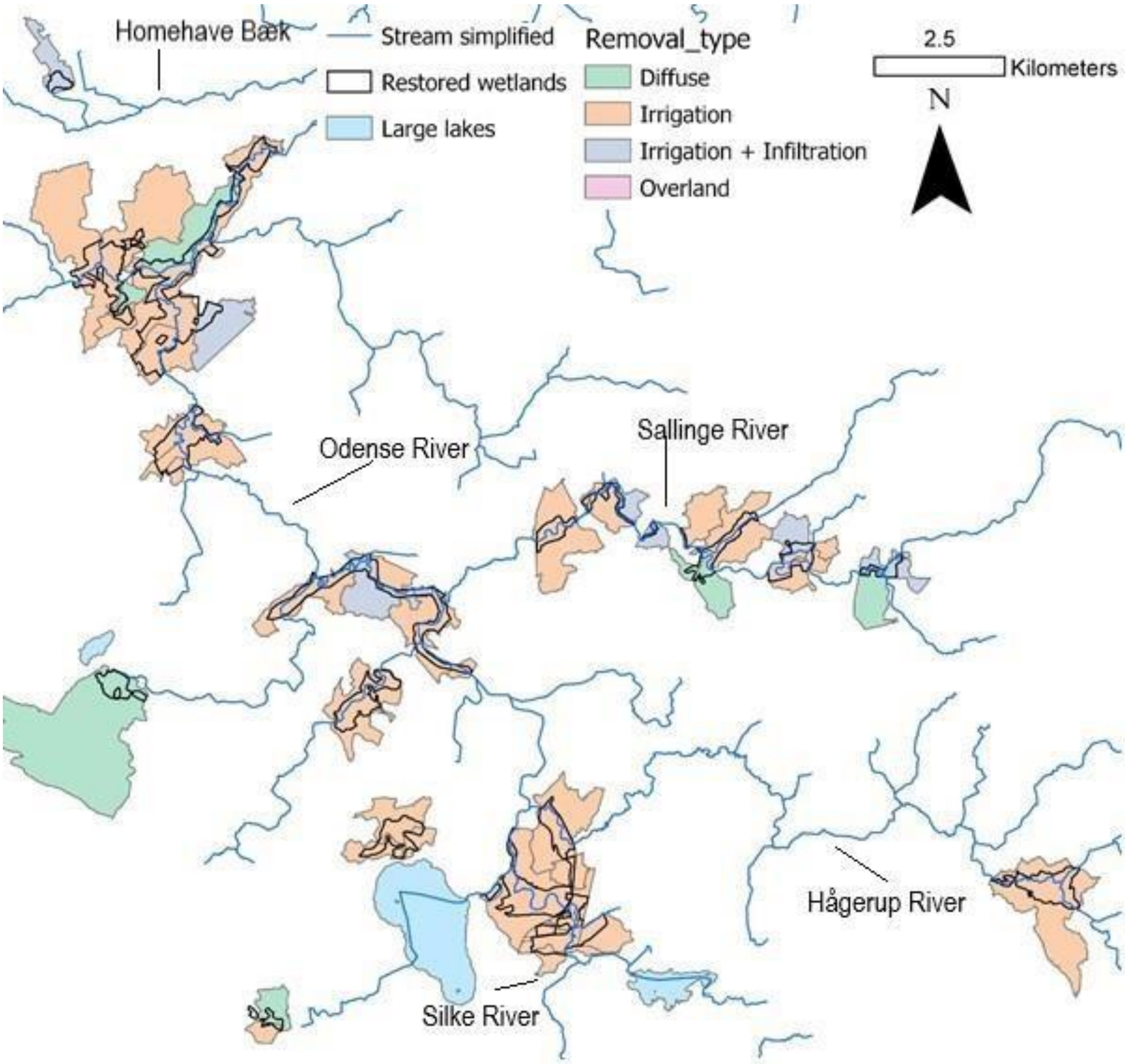


Figure 4.2.1.1. The restored wetlands and their estimated direct uplands classified according to removal type based on drainage probability and soil type.

Figure 4.2.1.1 shows the restored wetlands, their uplands and estimated removal type suggested for each upland. Irrigation with drainage water is suggested for the majority of wetlands. A total number of 58 uplands can be irrigated with drainage water, with a total upland area of 2689.3 ha. Additionally, 18 uplands are assumed to be drained with infiltration occurring on the wetland site, corresponding to 382.2 ha. 17 uplands have been classified as overland flow with a total area of 1.5 ha. Lastly, N loss from 11 uplands are expected to arrive to the wetlands via a diffuse pathway, with a total upland area of 791.8 ha. The upland/wetland ratio varies from 2.3 to 33.2, the mean ratio being 7.1 (see Figure 4.2.1.2). 15 out of 20 project areas have a ratio under 6.2.

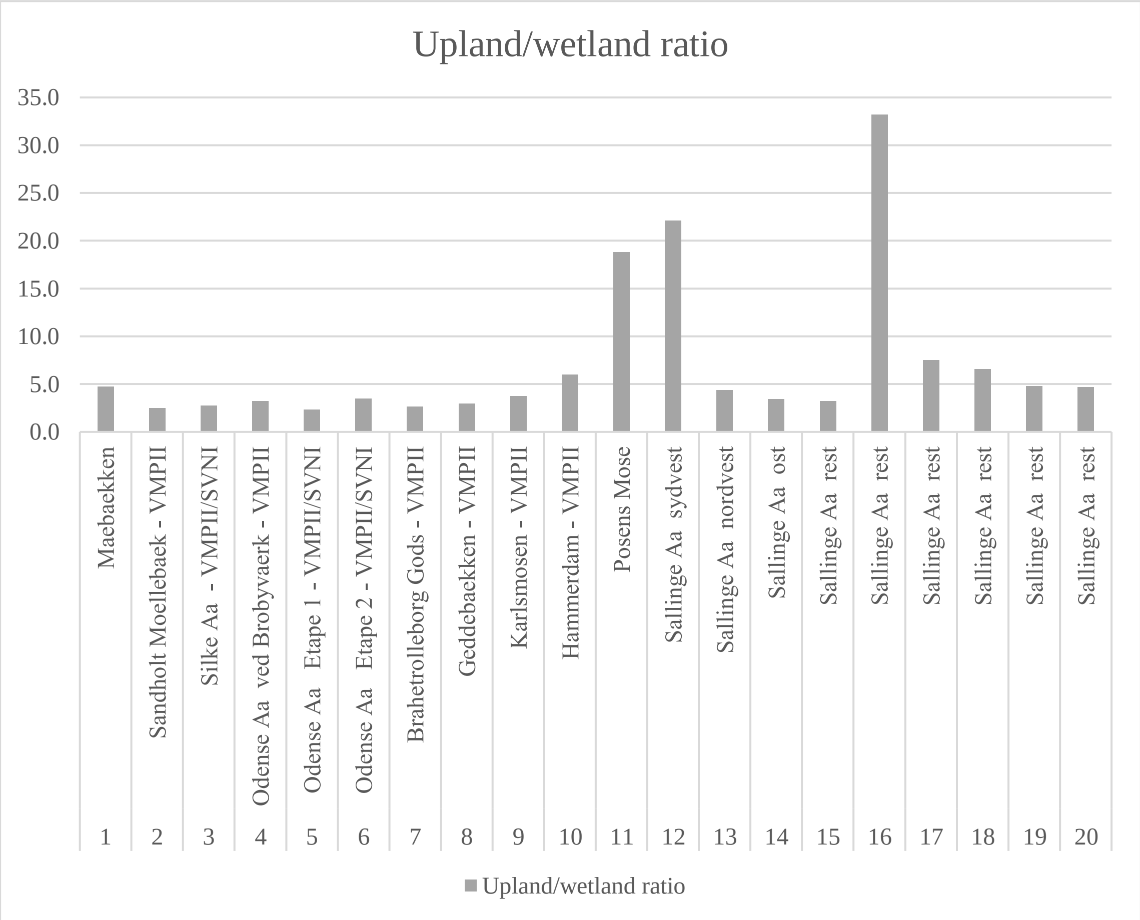


Figure 4.2.1.2. The upland/wetland ratios in the restored wetlands.

4.2.2. N load from direct uplands and removal

A removal estimate per ha of wetland area can be seen in Figure 4.2.2.1, as well as the total loss from each upland.

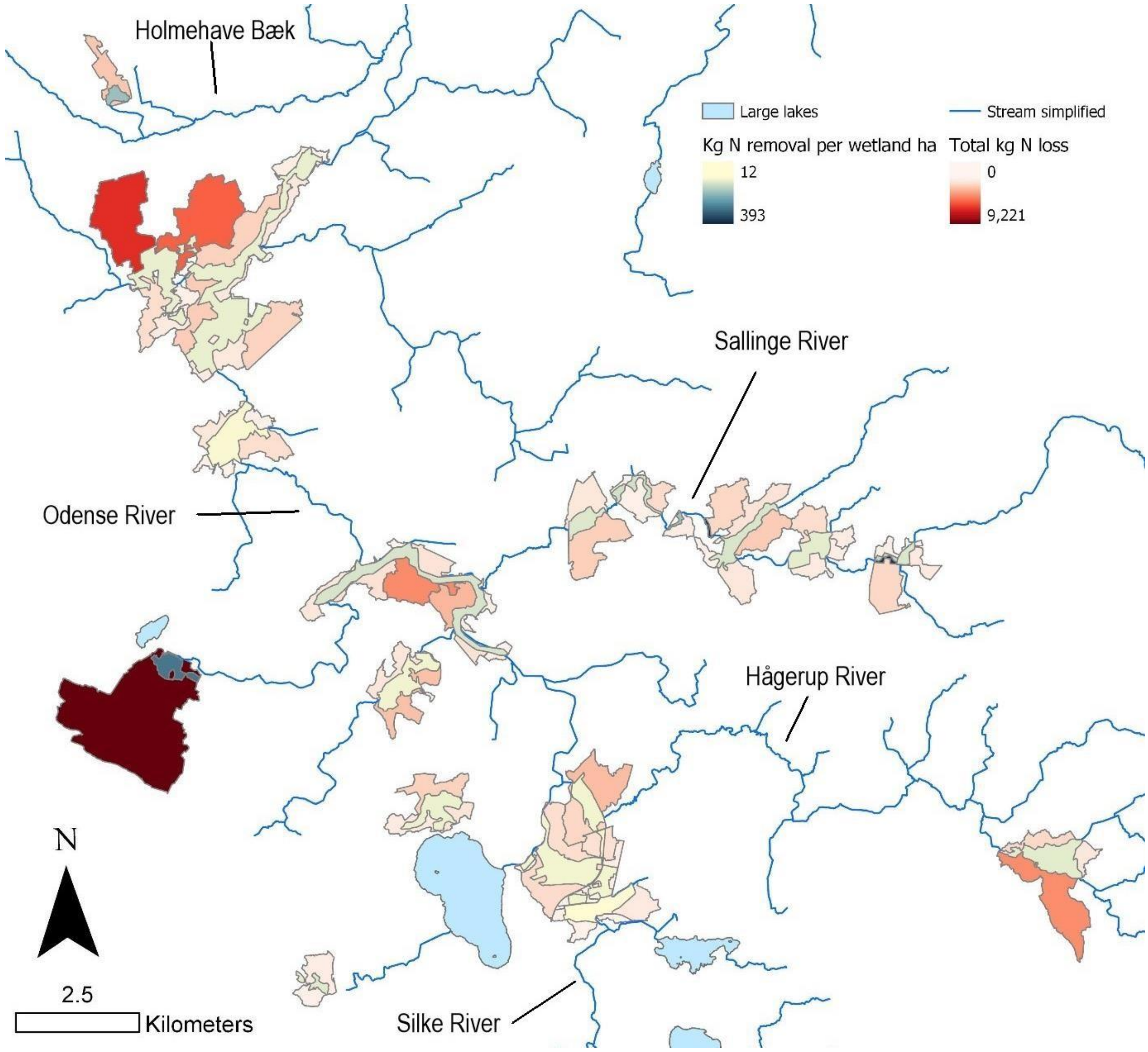


Figure 4.2.2.1. The calculated total N loss from each direct upland and estimated N removal of the load from direct uplands expressed as kg N per ha of wetland area.

It is seen that the N loss varies between uplands, the high loads generally coming from large uplands. Estimated N removal varies from 12 to 393 kg N per wetland ha. The highest N load per wetland ha as well as N removal was found in the project area Sallinge River Vest (WetID = 16), with a wetland area of only 1.8 ha. It is also here, that the highest upland/wetland ratio of 33.2 is found. The lowest N removal per ha was found Brahetrolleborg Gods (WetID = 7) with only 12 kg N – this area has an upland/wetland ratio of 2.7.

4.2.3. N flood removal

The estimated N removal expressed per wetland ha is shown in Figure 4.2.3.1. The results count for 36 days.

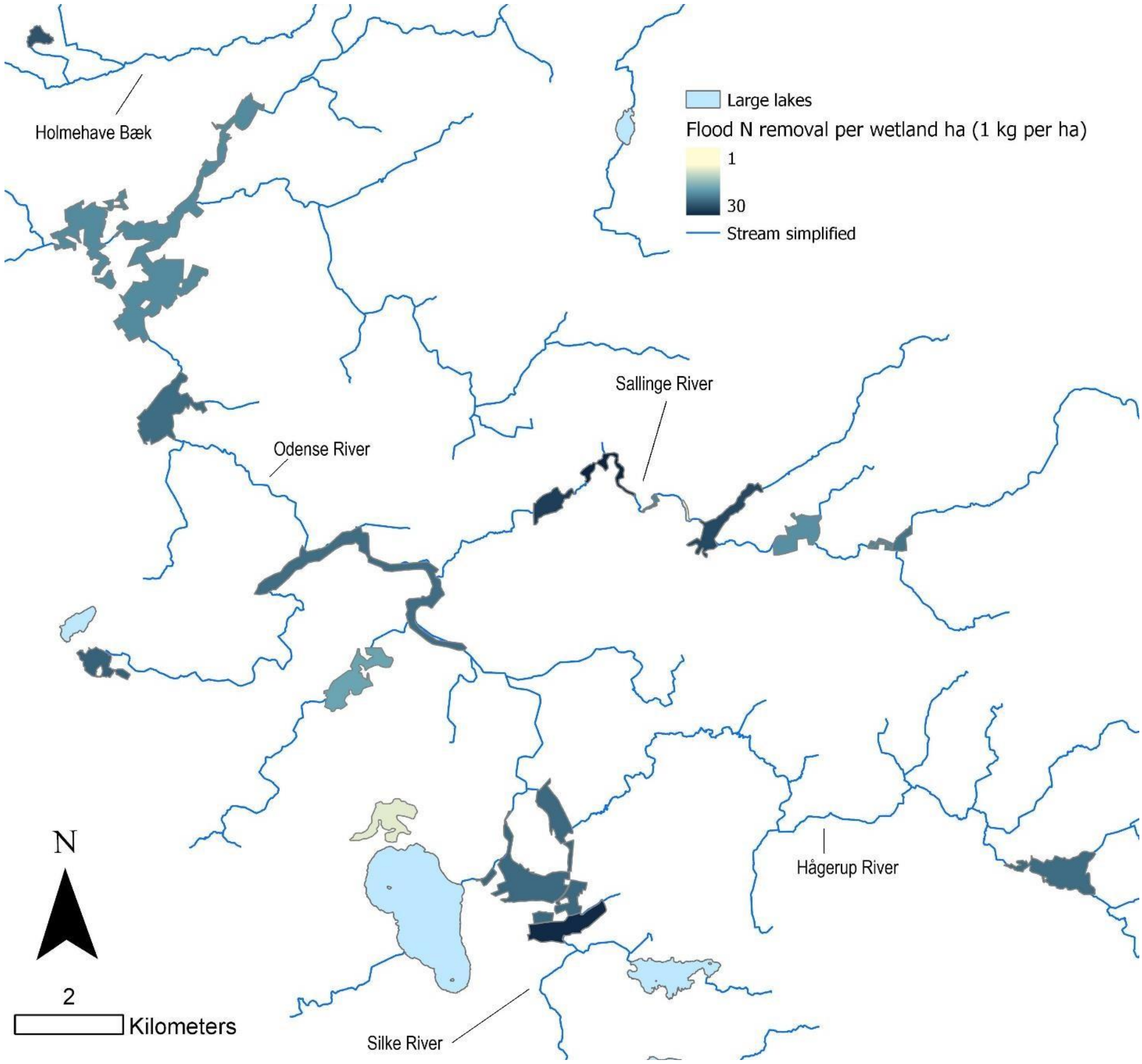


Figure 4.2.3.1. The estimated N removal per ha wetland area by flood inundation, assuming the low N removal of 1 kg N per ha flooded area within a 100m distance from the stream.

The N removal shown is the low estimate, assuming a removal of 1 kg N per flooded ha within a 100m distance from the stream. The removal varies from 1 kg per ha to 30 kg N per wetland ha. The low value of 1 kg per wetland ha was found in the project area with WetID of 16 (Sallinge River rest). In this wetland only 0.05 ha has been flooded according to the Upstream length model.

Another low value of 3.6 kg N removed per wetland ha was found in Gedebækken (WetID=8), an area where the stream section was removed during the simplification of the stream, and hence the modelled flood only covered a small area of that wetland.

Other than that, the mean flood removal was 19.5 across the restored wetlands.

The estimated maximum flood removal of 1.5 kg N per ha flooded area within a 100 m distance from the stream ranged from 1.4 kg N to 44.5 kg N, with a mean of 29 kg N.

A summary of the results can be seen in Table 4.2.3.1.

Table 4.2.3.1. The restored wetlands and their area, direct upland area, upland/wetland ratio, total N load from direct uplands, suggested removal type and the total estimated removal in kg N as well as estimated kg N removal per ha. The estimated removal values are calculated assuming the maximum flood removal of 1.5 kg N per ha flooded area within a 100m distance from the stream.

FI = Flood Inundation, Ir = Irrigation with drainage water, NF = Natural flow

WetID	**Name**	**Wetland area, ha**	**Direct upland area, ha**	**Upland/ wetland ratio**	**N load, total kg N**	Removal type	**Estimated removal (max)**	**Esimated removal per ha (max)**
1	Maebaekken	10.9	51.2	4.7	1927.1	FI + Ir	1837.9	168.9
2	Sandholt Moellebaek - VMPII	54.7	137.6	2.5	3036.6	FI + Ir	2718.0	49.7
3	Silke Aa - VMPII/SVNI	146.9	407.8	2.8	8036.4	FI + Ir	8807.2	59.9
4	Odense Aa ved Brobyvaerk - VMPII	104.4	338.6	3.2	10764.7	FI + Ir	9615.2	92.1
5	Odense Aa Etape 1 - VMPII/SVNI	68.8	160.3	2.3	2663.1	FI + Ir	3525.3	51.2
6	Odense Aa Etape 2 - VMPII/SVNI	295.7	1029.2	3.5	20641.1	FI + Ir	18977.4	64.2
7	Brahetrolleborg Gods - VMPII	45.6	121.3	2.7	1117.4	FI + Ir	2556.8	56.0
8	Geddebaekken - VMPII	44.1	129.6	2.9	3023.5	FI + Ir	1747.9	39.6
9	Karlsmosen - VMPII	62.5	233.2	3.7	5720.0	FI + Ir	4846.5	77.5
10	Hammerdam - VMPII	9.8	58.6	6.0	686.6	Ir	450.7	45.9
11	Posens Mose	26.1	491.4	18.8	9221.0	FI + NF	7793.1	298.1
12	Sallinge Aa sydvest	2.8	62.6	22.1	1405.3	FI + NF	1131.3	399.2
13	Sallinge Aa nordvest	3.1	13.4	4.4	360.5	FI + Ir	354.1	116.0
14	Sallinge Aa ost	8.5	29.1	3.4	620.4	FI + Ir	720.5	85.2
15	Sallinge Aa rest	36.8	117.7	3.2	2627.0	FI + Ir	2557.8	69.4
16	Sallinge Aa rest	1.8	59.6	33.2	1414.0	Ir	707.0	393.2
17	Sallinge Aa rest	2.8	21.2	7.5	478.0	FI + Ir	436.1	154.3
18	Sallinge Aa rest	23.0	150.7	6.5	2439.9	FI + Ir	2139.9	93.0
19	Sallinge Aa rest	36.4	175.5	4.8	3655.8	FI + Ir	3445.9	94.6
20	Sallinge Aa rest	16.3	76.2	4.7	1569.0	FI	725.3	44.5
	Total	**1001.3**	**3864.7**		**81407.4**		**75093.9**	

As can be seen in Table 4.2.3.1, the majority of the restored wetlands are classified as Flood Inundation + Irrigation. The total N removal has been estimated to 75,094 kg N.

4.3. Potential wetlands

4.3.1. An overview

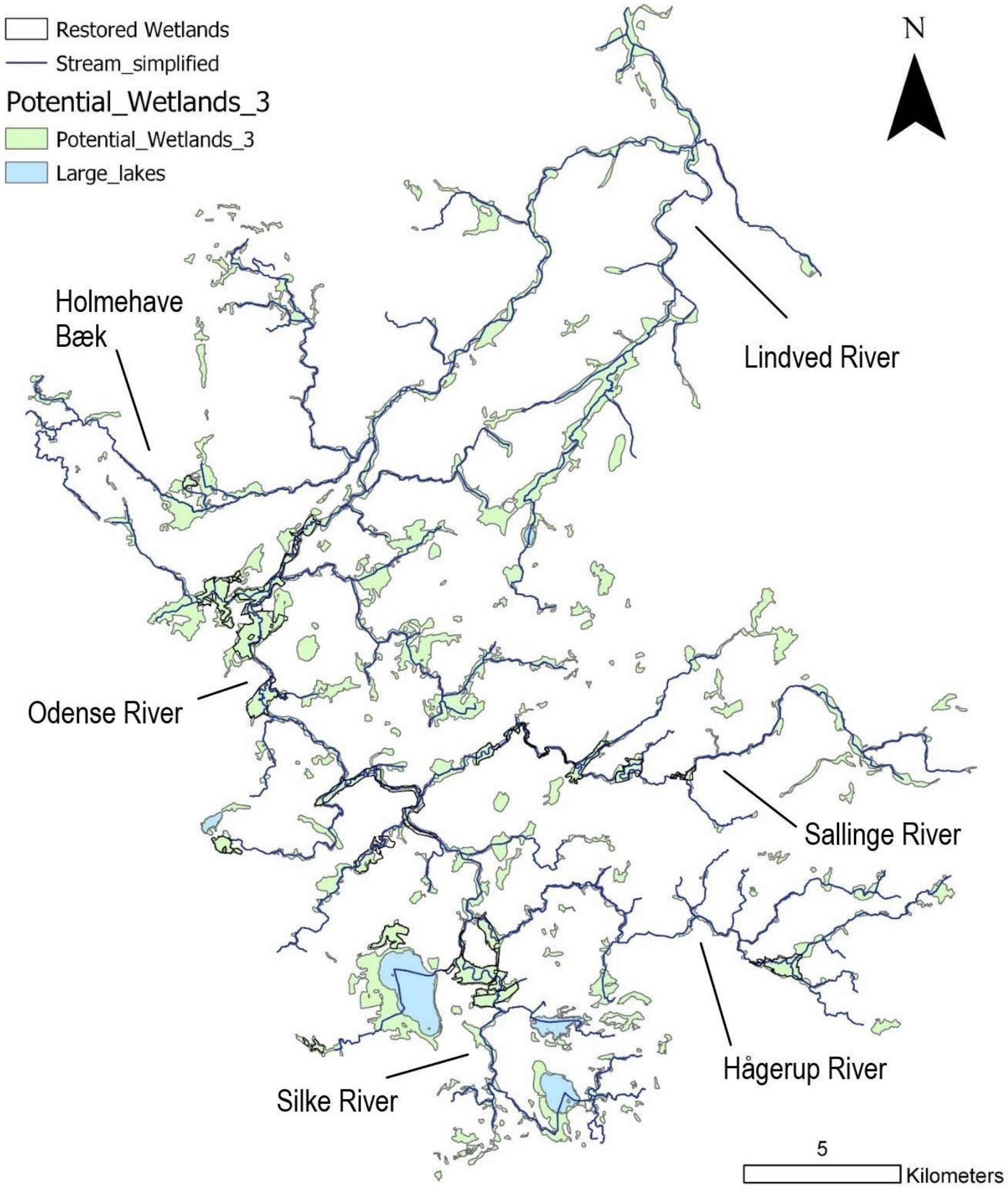


Figure 4.3.1.1. An overview of the potential wetlands suggested by the index model that are connected to the stream network and have a minimum wetland area of 1 ha. The stream shown in this figure has been simplified, and that's why many wetlands don't seem to be adjacent to a stream.

As can be seen in Figure 4.3.1.1, the index model has suggested many potential wetland areas. There is a large number of smaller wetlands, but a large portion of the potential wetlands area is continuous and follows the river network. There was a total of 278 potential wetlands, that had a minimum area of 1 ha, and were connected to the stream network.

Several areas already restored have been pointed out by the model, and generally fit well with the estimated potential wetlands. In some of the areas, for example Odense River Etape 2 - VMPII/SVNI (WetID=6), the restored reduced in size compared to their probable original size. The restored area of Sandholt Moellebaek – VMPII (WetID=2), is out of boundary compared to the wetland area predicted in this location.

4.3.2. Direct uplands

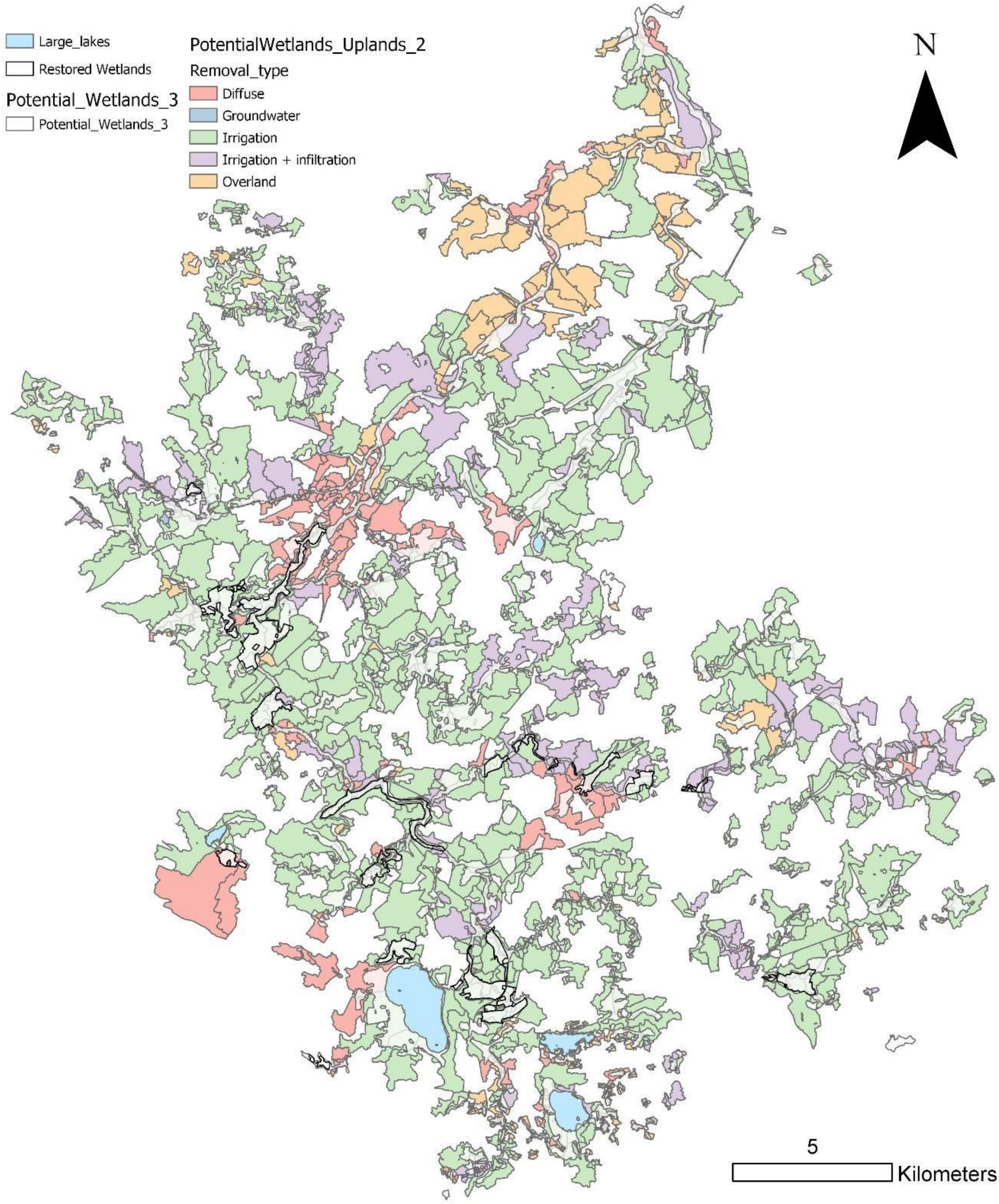


Figure 4.3.2.1. The calculated direct uplands and the estimated removal type based on drainage probability and soil type. Irrigation with drainage water is the most dominant removal type, the second type being irrigation with infiltration occurring within the wetland. The third most common type was diffuse flow, and overland flow was the fourth most common type. Groundwater flow was very uncommon and less than 0.1% of the direct upland area was estimated to have groundwater flow into the wetland area.

As seen in Figure 4.3.2.1, it is suggested that the N coming from a total of 20378.6 ha upland area can be removed by irrigation with drainage water. The second largest removal type is irrigation with infiltration, where N load from 4247.7 ha of upland area is expected to be removed that way. The diffuse and overland flow are estimated to take place on 3011.8 and 2850.0 ha of upland are, respectively, while upland area with possible groundwater flow is only 13.4 ha.

4.3.3. N loss from direct upland area and potential removal

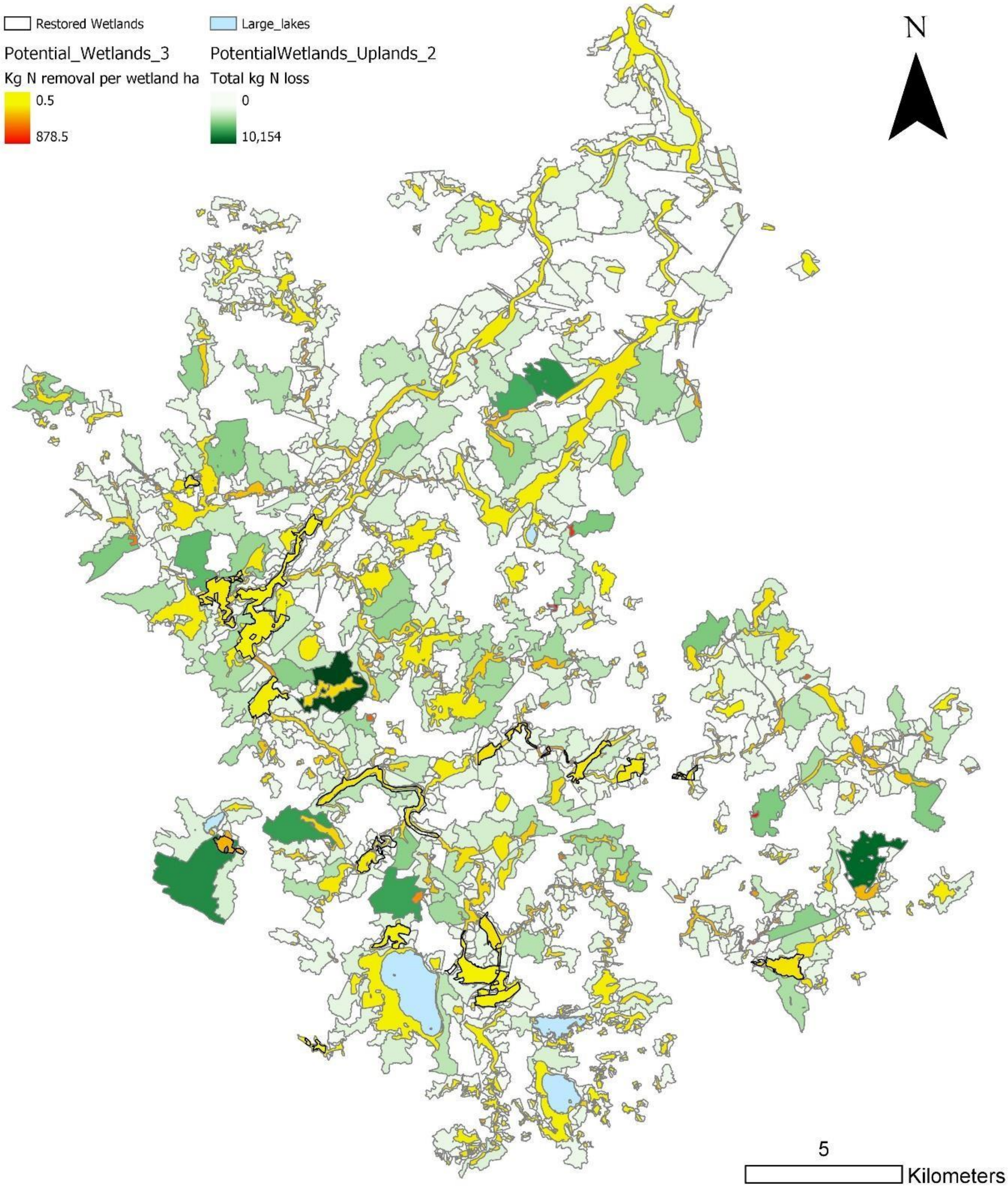


Figure 4.3.3.1. The calculated total N loss from each direct upland and estimated N removal of the load from direct uplands expressed as kg N per ha of wetland area. The N load varies greatly between direct upland areas, as it is ultimately dependent on presence of agricultural land use.

As can be seen in Figure 4.3.3.1, the total kg N loss from uplands is highly variable, the highest estimated amount being 10,154 kg N. The estimated removal from direct uplands varies from 0.5 to 878.5 kg N per ha of wetland area. The estimated mean removal was 97 kg N per wetland ha, while the median was 50.5 kg N per wetland ha.

4.3.4. Flood N removal

The estimated minimum flood N removal is shown in Figure 4.3.4.1.

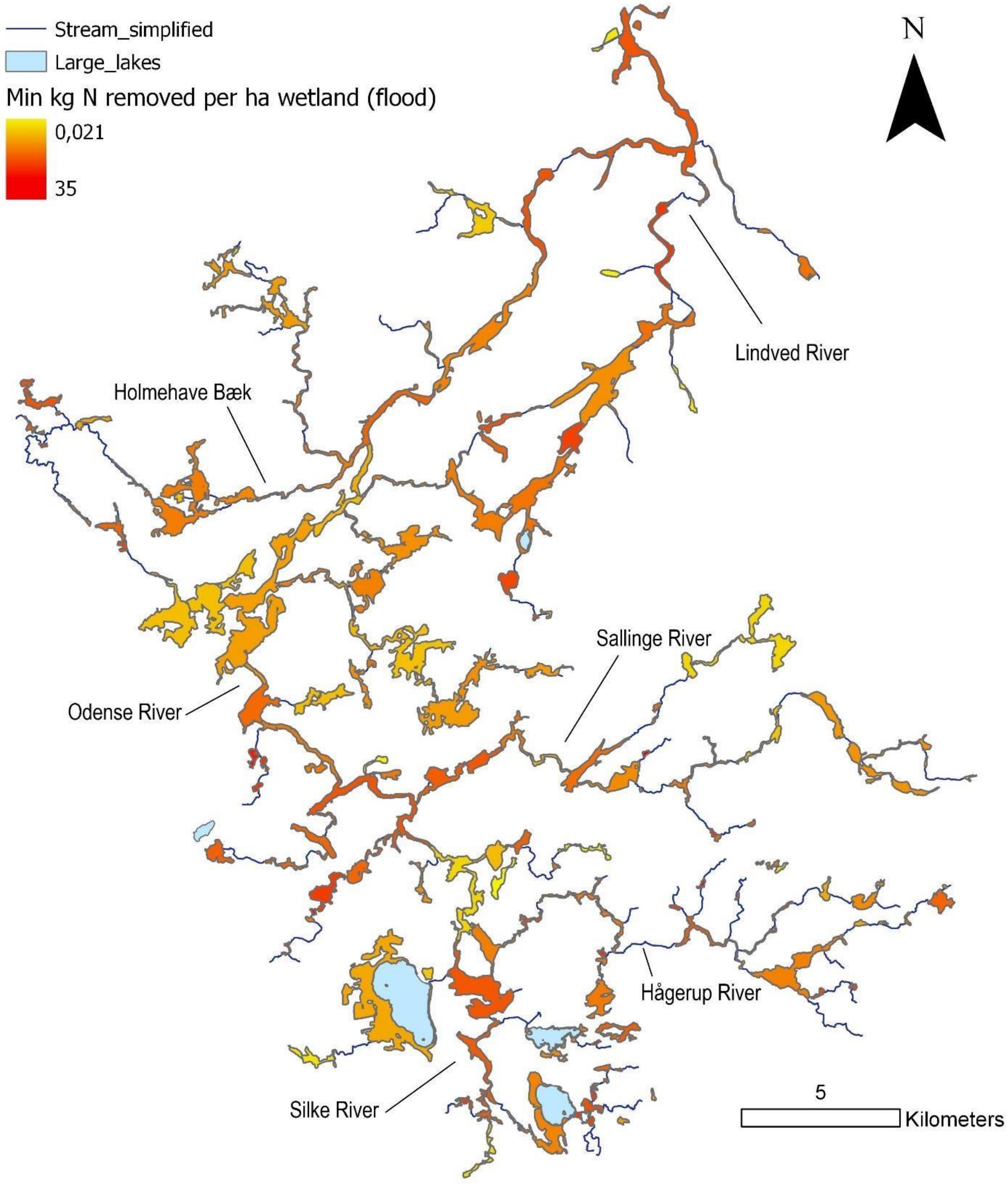


Figure 4.3.4.1. The estimated N removal per ha wetland area by flood inundation, assuming the low N removal of 1 kg N per ha flooded area within a 100m distance from the stream. The calculated N removal per ha varies

between the wetlands due to differences in the extent of flood within the wetland areas as well as the proportion of flooded area within a 100m distance from the stream within the wetland area.

The estimated minimum flood removal varies from 0 to 35 kg N per ha of wetland area. The highest values are visible in several smaller wetlands. A relatively large removal was also estimated in the larger riparian areas downstream of Odense River and Lindved River.

Table 4.3.4.1. The area, direct upland area, upland/wetland ratio, total load and load per ha wetland, estimated total removal and removal per ha of the potential wetlands classified by removal type. Total values as well the lower 2.5% (p0.025), median (p.05), mean and upper 2,5% (p0.975) values are presented for each variable. The removal is estimated assuming the high flood removal rate of 1.5 kg N per ha flooded area within a 100m distance from the stream.

		Wet-land area, ha	Direct upland area, ha	Upland/wetland ratio	N load, total kg N	N load, kg N per ha wetland	Estimated total removal	Estimated re-moval per ha wetland
Irrigation (+Infiltration) (71 wetlands)								
	p0.025	1.2	2.6	2.1	42.4	13.5	24.7	8.7
	p0.5	4.4	31.6	5.7	891.5	141.4	471.3	71.3
	mean	10.4	61.1	7.9	1806.3	248.6	949.1	134.0
	p0.975	45.9	207.4	29.9	8065.9	1016.7	4374.9	523.7
	Total	**736.9**	**4337.7**	-	**128245.5**	-	**67389.5**	-
Irrigation + Nat ural flow (13 wetlands)								
	p0.025	1.3	1.9	1.0	25.9	11.4	13.0	6.7
	p0.5	2.3	9.2	3.9	108.6	45.0	54.3	22.5
	mean	4.0	25.7	4.9	673.3	127.2	350.5	64.9
	p0.975	13.4	103.4	11.4	2457.5	530.4	1335.9	265.2
	Total	**51.5**	**333.5**	-	**8753.5**	-	**4556.8**	-
Flood Inundatio n (32 wetlands)								
	p0.025	1.6	1.8	0.5	12.6	3.3	53.8	20.4
	p.5	5.6	73.1	6.3	1570.6	167.6	214.2	36.0
	mean	20.9	119.7	7.8	2723.3	211.0	662.5	35.5
	p.975	127.2	599.7	27.7	9897.5	646.0	3502.8	51.0
	Total	**668.6**	**3829.6**	-	**87145.5**	-	**21199.8**	-
Flood Inundatio n + Irrigation (+ Infiltration) (18 wetlands)								
	p0.025	1.3	7.1	2.0	181.8	28.8	158.5	34.2
	p0.5	14.9	132.7	5.8	3842.9	179.9	2808.2	143.6
	mean	31.5	179.4	10.2	4581.2	341.2	3539.8	233.7
	p0.975	145.1	636.0	34.7	13500.1	1447.7	10957.7	877.0
	Total	**567.2**	**3229.6**	-	**82461.1**	-	**63717.0**	-

Flood Inundatio n + Irrigation (+Infiltration) + Natural flow (22 wetlands)								
	p0.025	2.5	22.9	2.2	252.8	27.7	203.1	32.8
	p0.5	36.5	198.6	5.4	4447.8	90.3	4054.7	69.2
	mean	69.8	273.8	5.8	5406.1	135.2	4877.9	104.2
	p0.975	335.6	848.1	13.2	16094.3	453.1	14043.2	295.8
	Total	**1535.2**	**6023.5**	**-**	**118934.2**	**-**	**107314.0**	**-**

Flood Inundatio n + Natural flow (87 wetlands)								
	p0.025	1.2	2.7	1.3	19.7	9.5	39.7	23.3
	p.5	10.6	75.7	4.0	1729.5	69.0	1390.9	63.2
	mean	31.9	139.0	5.4	3166.6	136.4	2426.7	97.1
	p.975	170.6	505.0	15.9	12393.8	570.0	9279.1	311.9
	Total	**2778.4**	**12089.0**	**-**	**275495.3**	**-**	**211119.4**	**-**
Natural Flow (33 wetlands)								
	p0.025	1.1	1.5	0.5	11.1	3.5	5.6	1.7
	p.5	2.3	6.0	2.5	43.8	17.2	23.5	10.6
	mean	6.3	20.0	4.3	235.5	43.3	157.2	28.4
	p.975	31.6	109.6	14.9	1339.3	181.9	1004.5	136.4
	Total	**207.3**	**658.6**	**-**	**7771.5**	**-**	**5189.1**	**-**
Total		6545.2	30501.5		708806.5		480485.6	
Restored wetlands		1001.3	3864.7		81407.4		75093.9	
Netto removal by potential wetlands		**5543.9**	**26636.8**		**627399.1**		**405391.7**	

The restoration of the suggested potential wetlands in Odense River catchment is calculated to remove additional 405,392 kg N per year, in addition to the estimated 75,094 kg N removed by the already restored wetlands.

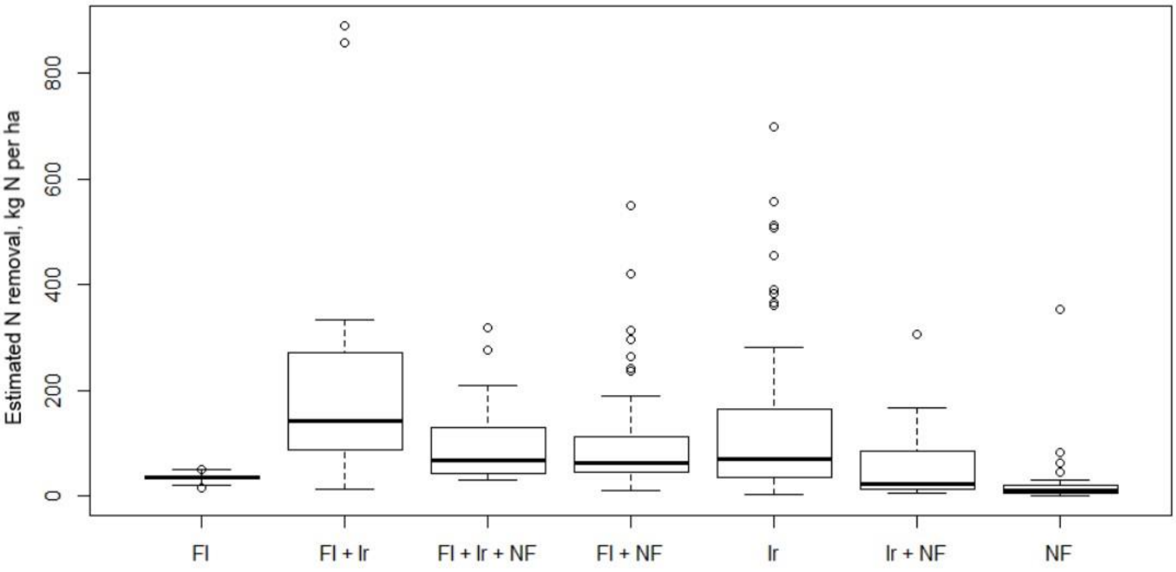


Figure 4.3.4.2. A boxplot of the estimated N removal expressed as kg N per ha plotted by removal type.

NF = Natural flow (overland or diffuse flow)

FI = Flood inundation (1.5 kg N per ha flooded area within 100m from the stream)

FI + NF = Flood Inundation + Natural flow (flood removal + 1.5 kg N per ha flooded area within 100m from the stream + overland or diffuse flow from direct upland)

FI + Ir = Flood Inundation + Irrigation (+ Infiltration) (flood removal of 1.5 kg N per ha flooded area within 100m from the stream)

FI + Ir + NF = Flood Inundation + Irrigation (+ Infiltration) + Natural flow (flood removal of 1.5 kg N per ha flooded area within 100m from the stream)

Ir = Irrigation

Ir + NF = Irrigation + Natural flow

As seen in Figure 4.3.4.3, the wetlands classified as Natural Flow and Flood Inundation had the lowest N removal per ha, with mean removal of 28.4 and 35.5 kg N per ha, respectively. The other groups, where a portion or all upland area was drained had higher removal rates. The highest mean removal of 233.7 kg N per ha was found in flood inundated wetlands with irrigation with drainage water. The second highest removal rate was found in wetlands, where irrigation with drainage water was the only removal type, as the mean N removal was 134 kg N per ha. Inundated wetlands with natural flow (FI + NF) and inundated wetlands with irrigation and natural flow (FI + Ir + NF) had similar removal rates with mean removal of 97.1 and 104.2 kg N per ha. Irrigated wetlands with natural flow (Ir + NF) had a mean N removal of 64.9 kg N per ha. As can be seen in Table 4.3.4.1., the wetlands where a portion or all of the transport of N load is classified as natural flow have lower N load per ha compared to wetlands where all of the direct upland is drained.

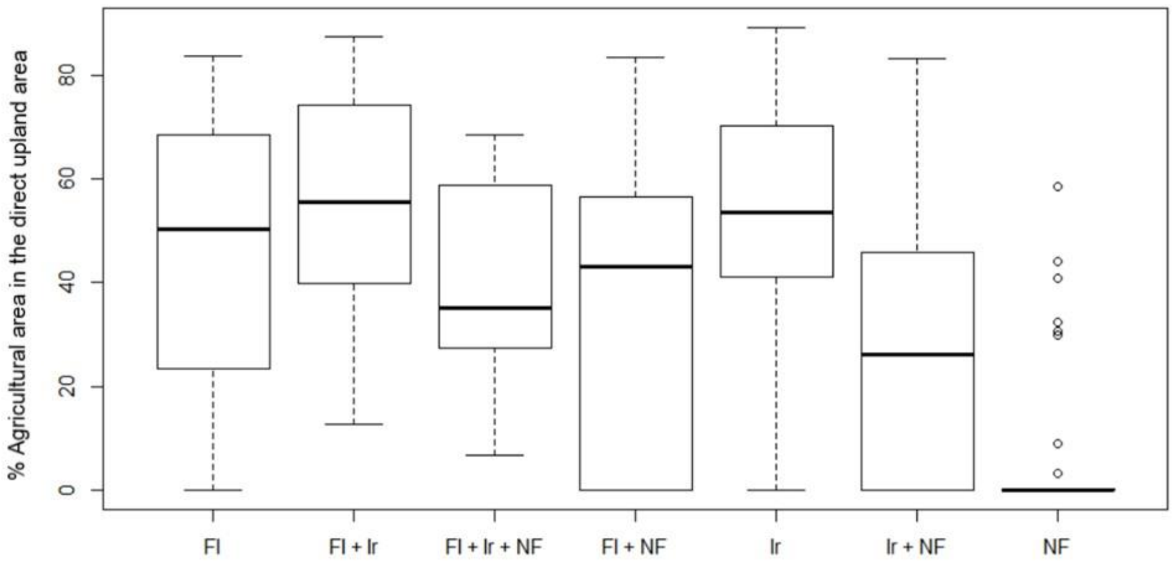


Figure 4.3.4.3. A boxplot showing percentage of agricultural area in the direct upland area plotted by wetland type.

NF = Natural flow (overland or diffuse flow)

FI = Flood inundation (1.5 kg N per ha flooded area within 100m from the stream)

FI + NF = Flood Inundation + Natural flow (flood removal + 1.5 kg N per ha flooded area within 100m from the stream + overland or diffuse flow from direct upland)

FI + Ir = Flood Inundation + Irrigation (+ Infiltration) (flood removal of 1.5 kg N per ha flooded area within 100m from the stream)

FI + Ir + NF = Flood Inundation + Irrigation (+ Infiltration) + Natural flow (flood removal of 1.5 kg N per ha flooded area within 100m from the stream)

Ir = Irrigation

Ir + NF = Irrigation + Natural flow

It was found that the wetlands with Natural Flow only had the lowest percentage of agricultural use in the direct upland area (see Figure 4.3.4.3). In fact, the mean percentage of agricultural in wetlands classified as Natural flow was only 7.6%. The highest percentage agriculture found in the upland area to a wetland classified as Natural flow was 58%. As the boxplots in Figure 4.3.4.3 show, 25% of wetlands classified as FI + NF and Ir + NF have 0% agricultural activity in the direct upland area.

4.3.5. Land use

The current land use in the potential wetland area is shown in Figure 4.3.5.1.

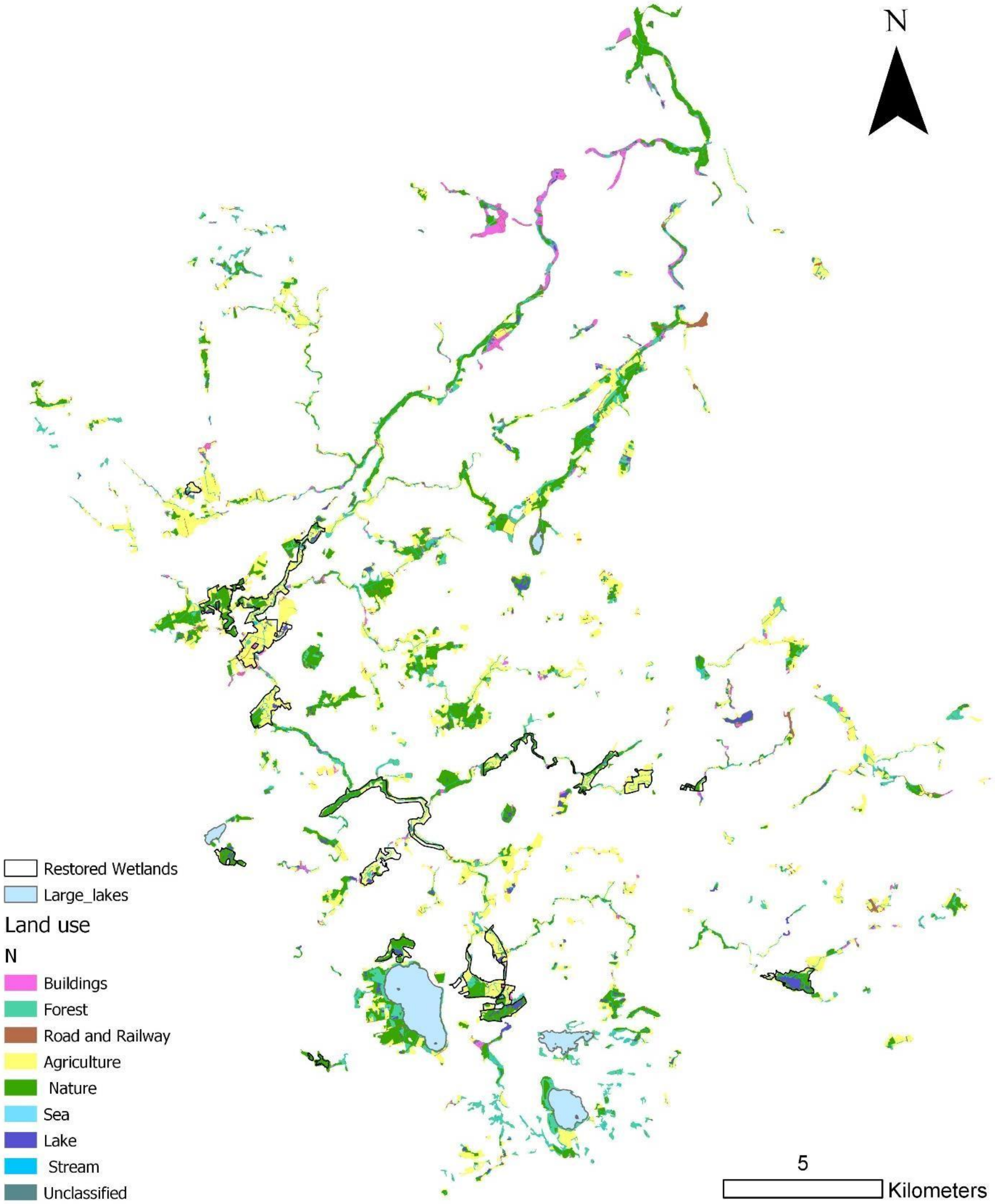


Figure 4.3.5.1. An overview of landuse in the potential wetland area. The majority of the wetland area is classified as open nature or agriculture. Land use classification as nature does not equal natural state or origianl hydrology, as extensive agricultural land use is allowed. Several areas are covered by buildings, roads and forests.

Several areas are already accounted for as natural areas, for example the majority of the area around Arreskov Sø or the downstream area of Odense River. Several areas located downstream of Odense River are almost completely covered by buildings. In some of these areas a high flood removal was also predicted – in one of the wetlands, a minimum flood kg N removal was calculated as 22.9 kg N per ha, while 54% of the wetland area consisted of buildings and 9% consisted of roads and railways. Exclusion of the wetlands with at least 10% building coverage would reduce the total calculated N removal with 38,496.7 kg N and a reduction of the suggested wetland area with 754 ha.

Additionally, 93% of the natural area was found to be §3 protected natural types. 97% of the natural area is classified as wet soil, of which 71% is under extensive agricultural use (data not shown).

Table 4.3.5.1. The variation in the land use in the potential wetlands.

	% nature	% forest	% agriculture	% buildings	% roads
Min	0.0	0.0	0.0	0.0	0.0
p0.05	2.2	0.5	4.8	0.1	0.3
p0.25	12.3	4.5	25.3	0.8	1.3
p0.5	25.9	13.1	45.8	2.1	3.2
Mean	29.6	28.6	47.4	7.1	5.0
p0.75	44.9	38.5	67.6	7.5	6.6
p0.95	70.3	98.6	93.4	31.4	16.7
Max	92.4	100.0	100.0	73.3	30.8

As can be seen in Table 4.3.5.1, the area potential wetland area covered by buildings could be as high as 73.3% in some wetlands, and up to 30.8% of a potential wetland area could consist of roads and railways.

5. Discussion

5.1. Flood estimation

The Upstream Length Flood Model (UPM) estimated flood events in some areas that seem unrealistic as high amount of flood were predicted to occur in upstream ends of small streams. As mentioned earlier, according to the orthophoto the digitalized stream didn't fit perfectly with the actual stream. That could be the reason why flood was predicted in these areas – during the flood calculation the elevation is increased on land rather within the stream channel. That suggests the need for more methodic approach during stream simplification.

The main goal here was to remove small branches that disrupt interpolation in “Topo to Raster”, especially ditches in forests, and remove many of the piped streams as well. During this process the size of the stream wasn’t considered but checking the morphology of the stream with available orthophotos could help with stream selection during the simplification process.

Other than that, the UPM delivers quite a good fit both upstream and downstream, considering that it is only based on data from 13 measuring stations from the past 10 years (some of the stations only containing only a year’s worth of data) and upstream river length. In comparison to MIKE11, UPM has a smaller overlap with Agrosinks Extended Wetlands (AEW) and digitalized Høje Målebordsblade (HM), suggesting that MIKE11 fits better with the past wetland area. However, as shown, MIKE11 predicts a large flooding event in Holmehave Bæk, as it estimates the water level to be over 5 meters higher compared to DEM, which is a very high increase – the highest increase found in data from measuring stations was found in station 45000003 with a 1.5 meters water level increase compared to DEM. The higher overlap found in MIKE11 could be attributed to the overestimation as it simply covers a larger area, rather than a better fit.

MIKE11 modelled stream level elevation is a result of many input variables. It includes stream water levels as well as water flow measured at stations 45000003, 45000004, 45000043, 45000036, 45000080 and 45000047. Furthermore, the model also contains stream slope, the cross-sectional area and cross-sectional profiles. The water elevation in MIKE11 is even calculated according to plant biomass cutting regimen in the stream (no removal, 1 removal or 2 removals) (Thodsen, 2010).

Indeed, all these variables affect the stream water level. Cutting plant biomass reduces water level, as well as increases the water flow (Hoffmann et al., 2005). The cross-sectional profile also plays a role in stream water elevation, as a shallow and wide cross-section will be more prone to overflooding than a narrow, deep stream channel profile (Şen, 2018). The crosssectional area also provides information about water flow (Şen, 2018). Streams with a low slope are also more prone increases in stream water level than streams with a higher slope, due to a slower flow (Şen, 2018).

In certain areas UPM predicts large amounts of flood to originate from very short stream sections located far upstream. The reason for that could be caused by the water level elevation being distributed evenly across the whole stream network without any consideration to the stream slope.

Considering the amount of input data, MIKE11 flood estimation should be more accurate. However, the extreme overestimation in Holmehave Bæk reduces the credibility of MIKE11. The UPM provides a valid flood estimate, as it is easy to calculate and does provide a good estimate of flood evenly distributed across the whole catchment. Another issue worthy of discussion is what is preferable: overestimation or underestimation of flooding in the context of wetland restoration and calculation of N removal. Obviously, a higher flooded area leads to a higher estimation of N removal, as the N removal is expressed per ha of flooded area. That could lead to an actual N removal lower than expected, lower N removal efficiency as well as lower economic efficiency of a restored wetland. On the other hand, if the estimated flood event is smaller than the actual, restoration of a potential wetland might be declined, as it is not estimated to deliver the N removal efficiency necessary for restoration.

5.2. Restored wetlands

5.2.1. N removal

The actual direct upland to Karlmosen covers an area of 140 ha, while the GIS analysis resulted in an upland area of 233 ha (Hoffmann et al., 2003). The difference in the upland area could be explained by the reported number being simply accurate – there are 18 disconnected drains, and the area that is drained by the tiles is probably known. A part of the calculated upland can be drained with outlets outside of Karlmosen. This suggests a major error in N load calculation: if the actual direct upland area is smaller than estimated, the calculated N load to a wetland and estimated N removal will be flawed as well. The are no measurements of the actual N load from drains in Karlmosen and it is impossible to compare the estimated and actual N load and removal from the direct upland (Hoffmann and Baattrup-Pedersen, 2007).

Gedebækken has a reported upland of 229 ha (Hoffmann et al., 2018a), while the upland area of estimated in the GIS analysis is 130 ha. The reported upland is the whole upland, not only the direct upland, as the project area includes a lake. According to Hoffmann and BaattrupPedersen (2007), Gedebækken has an upland of 284 ha, including the through-flowing stream. The estimated N load per ha is 272 kg N, while the measured load is 230 kg N per ha (Hoffmann and Baattrup-Pedersen, 2007). The N load estimated in the GIS analysis is 68.5 kg N per ha, but that number is also based on the direct upland, excluding the stream.

Therefore, the estimated N removal by irrigation was calculated as 34 kg N per ha. According to Hoffmann and Baattrup-Pedersen (2007), the measured N removal in Gedebækken was 90 kg N per ha in contrast to the expected 215 kg N per ha, while Hoffmann et al. (2018a) reports N retention of only 24 kg TN per ha. The latter number however, only accounts for 20 ha of the project area and according to Hoffmann et al. (2018a) only two small ponds seem to have an active N removal.

Odense River Etape 2 - VMPII/SVNI (WetID=6) has an estimated removal at least 150 kg N per ha (Naturstyrelsen, 2008) and the removal types include flood inundation, shallow lakes and drainage irrigation. According to the GIS analysis, the N removal from the direct upland is estimated to be 38 kg N per ha, and a flood removal of 17.6 kg N per ha with the 0.9^{th} percentile. That is far of the official estimated amount, but during the GIS analysis no removal for the shallow lakes could be estimated, due to lack of data on lake residency time.

Silke River - VMPII/SVNI (WetID=3), where the stream has been re-meandered, has a reported estimated N removal of 150 kg N per ha (Naturstyrelsen). According to the GIS analysis, the removal from direct is 27.6 kg N per ha, and flood N removal of 21.6 kg N per ha for the 0.9th percentile.

The calculated N load to Sallinge River rest (WetID=16) from the direct upland was 786.4 kg N per ha, with an upland/wetland ratio of 33. In this wetland irrigation with drainage water is expected. It is recommended for the ratio to not exceed 30, as the N removal efficiency is decreased, when the load is too large (Naturstyrelsen, 2014). It is possible that the upland area was overestimated as it happened in Karlmosen. In fact, most of the upland area was estimated to be drained, and a large portion of the upland area could be overestimated, if a portion of the drains have an outlet outside of the restored wetlands.

As shown, the flooded area in Brahetrolleborg Gods (WetID=6) didn't increase between the 0.9^{th} and 0.9995^{th} percentile as much as it did in Odense River Etape 2 - VMPII/SVNI (WetID=6). That suggests that Brahetrolleborg Gods is a lower laying area and is more prone to flood. It is also known that Karlmosen (WetID=9) is a very low laying wetland and is flooded 45% of the time (Hoffmann et al., 2006). The use of the 0.9^{th} offers therefore a very limited knowledge on the amount of N removed by flooding events, as it only covers 10% of the year. In Denmark, the highest precipitation occurs during several winter months (DMI, 2019). To estimate a more realistic flood removal lower percentiles should be used, such as the 0.75^{th} percentile, or even the 55^{th} percentile, to more accurately estimate the flood removal in low laying areas like Karlmosen. As result, Karlmosen is only estimated to remove 77.5 kg N per ha in contrast to the official estimate of 270 kg N per ha and measured 337 kg N per ha in 2003 (Hoffmann et al., 2006). However, the N removal in Karlmosen is variable, as large waterflow inputs area necessary for high N removal. In fact, Karlmosen was found to only remove 93 kg N per ha in 2002 (Hoffmann et al., 2003). The total measured N removal in Karlmosen in 2003 was 22,000 kg N. The total N removal calculated here is 4846.5 kg N per year.

Clearly, the values estimated in the GIS analysis do not fit well with the measured values or the official estimates. Of course, there are only two projects areas that the estimates can be compared to, one of which including a lake. Furthermore, due to lack of measured data it is unsure how well the official estimates fit with actual N removal.

The total N removal by the 1001.3 ha restored wetlands in the Odense River catchment has been calculated to amount to 75.094 tons N per year. Windolf et al. (2016) has estimated the 860 ha of wetlands restored at that time to result in a N load reduction of 124 tons per year. The N removal calculated in the GIS analysis is an underestimate and could be treated as a minimum N removal to be expected.

5.3. Potential wetlands

5.3.1. N removal

The N removal by restoring additional 5543.9 ha of wetlands was calculated to 405,392 kg N per year. The actual N removal could be higher, as N removal in shallow lakes has not been calculated in this analysis. Ødis Lake has a removal of 182 kg N per ha, Årslev Engsø has a removal of 252 kg N per ha, Nakkebølle Inddæmningen has a removal of 125 kg N per ha, Wedellsborg Hoved has a removal of 117 kg N per ha, Skibet Enge has a removal of 125 kg N per ha, Slivsø has a removal of 244 kg N per ha, Gødstrup Engsø has a removal of 100 kg N per ha and Hals Sø has a removal of 40 kg N per ha (Hoffmann et al., 2006). These removal rates were measured during the first year after restoration, and in many of the lakes were lower than the expected removal due to the N load being lower than expected. Nonetheless, the N removal in shallow lakes is not accounted for in this analysis, and there could be potential for additional. Kronvang et al. (1999) suggests that permanent nutrient sinks (shallow lakes) can be an important part of nutrient removal in river basins.

Windolf et al. (2016) has estimated the already restored wetlands to result in a N load reduction in Odense River to 124 tons n per year. As discussed earlier, the N removal calculated in this analysis was much lower, suggesting that the actual removal by the potential wetlands could be much higher than the calculated values.

The wetlands, where N load from direct uplands was assumed to be delivered by natural flow have lower N loads compared to drained upland areas. That is a result of the lower percentage of agricultural area in the direct upland. The natural flow pathway was classified in areas, where the drainage probability was under 50%, or the upland area was not at all covered by the Probable Drainage layer. As drainage is put in place mainly to make the soil suitable for agricultural production, the lack of probable drainage itself can be seen an indicator of low intensity of agricultural production. As agricultural production is the main driver of N loss to aquatic environment, these wetlands can be expected to receive low N loads and hence have low potentials for N removal. With an estimated mean removal of 28 kg N per ha, these wetlands do not qualify to being restored, as a minimum removal of 90 kg N per ha is required (Miljøstyrelsen, 2018). However, the N removal by natural flow might have been underestimated. As there is no available information on which streams area groundwater fed, the direct uplands with a calculated high permeability were assumed a diffuse flow path with a removal rate of 75%. The soil water might very well move from the unsaturated zone to the saturated zone and finally enter the wetland as groundwater (Richardson et al., 2000). Therefore, the N load from many of the direct uplands with high soil permeability could be expected to be 90% removed. That would improve the N removal efficiency of the wetlands receiving natural flow.

As the N removal in wetlands is dependent on N load from the direct upland area, which is highly dependent on the area in agricultural use, the classification into agricultural rotation will eventually influence the calculated N removal. Here, permanent grass fields were not classified as agriculture, as they have lower N leaching compared to annual agricultural crops (Bondgaard and Zacho, 2016). The N_{loss} equation calculates the N loss to be approximately 6 kg N per ha, when there is no agricultural rotation in the upland area. However, N loss of 1530 kg N per ha can be expected from permanent grass fields (Poulsen and Knudsen, 2018). Therefore, the N load to the potential wetlands can be higher than calculated in the analysis, leading to a higher N removal.

Additionally, several wetlands were found to be bigger than their direct upland area, as their upland/wetland ratio was under 1. That can be a result of the ditches being present and can be modified (Hoffmann et al., 2005). Therefore, various direct uplands could in fact be bigger that what has been estimated in the GIS analysis, resulting in a higher N load to a wetland,

and finally a higher removal potential. Furthermore, as shown, the N load varies greatly in the direct uplands according to agricultural use, the wetland area could be modified to optimize the N removal per ha. That way, many wetlands could be reduced in size, without a proportional decrease in their total N removal.

The N removal by irrigation with drainage water has been estimated as 50 % of the N input, or 75%, if infiltration through wetland soil is possible. However, that is not always accurate. In 2002, the irrigated wetland of Ulleruplund had a measured removal of 133 kg N per ha out of a N load of 198 kg N per ha, resulting in a removal rate of 67%. The Ulleruplund wetland has an upland/wetland ratio of 4.6 (Hoffmann et al., 2006). The Lindkær wetland was found to remove 64% of the N load, or 191 kg N per ha in 2004-2005 (Hoffmann et al., 2006). The retention in Egeskov wetland was 43 and 75% of total N during the periods of 2007-2008 and 2008-2009, respectively. The total load was 282 kg N per ha in 2007-2008 and 37 kg N per ha in 2008-2009 (Hoffmann et al., 2012). The N removal in the irrigated wetland of Stor Å was 32% in 1996-1997 and 26% in 1997-1998. However, the loads were 719 and 626 kg N, respectively, and the respective removal was 219 and 150 kg N per ha (Hoffmann et al., 2012). That could suggest, that the calculated retention for irrigated wetlands might be too high for wetlands with a very high load, such as what was observed in Stor Å. The maximum calculated N removal per ha via irrigation was almost 700 kg N, which seems highly unlikely. Based on the measured N removal in irrigated wetlands, N removal of up to approximately 200 kg N per ha seems realistic. Actually, estimated removal of over 500 kg N per ha is perceived as very high, and resulting in a risk of P release (Naturstyrelsen, 2014). In this case it is recommended that the project area is modified to decrease the N removal. In the Stor Å wetland, P losses of 22% and 127% were found in 1996-1997 and 1997-1998, respectively. Also, the upland/wetland ratio was over 30 in certain irrigated wetlands. A too high ratio and too high load per wetland area vastly reduces the N removal efficiency (Naturstyrelsen, 2014).

The potential wetlands classified as flood inundation have a low kg N removal per ha. As 90 kg N removal per ha is needed for a restoration to be fulfilled, assuming the low removal of 1 kg N per ha, inundation would need to occur for 90 days, or 60 days if the N concentrations in the water inundating the area is higher than 5 mg N per L, with an estimated N removal of 1.5 kg N per ha. In the year of 2005, the calculated removal in flood inundated wetlands was 256 kg N per ha on average (Hoffmann et al., 2006). Assuming the high removal rate of 1.5 kg N per ha, the wetlands would be inundated in 171 days, or 47% of the year. However, the estimated and measured values don't always comply (Hoffmann et al., 2003). Nonetheless, it is possible that many of the inundated wetlands are inundated for a longer period of time than the 36 days a year accounted for in this analysis. Actually, the restoration of Karlmosen has been designed to be flood inundated for such a long period of time (Hoffmann et al., 2006). It is therefore likely that the other restored wetlands with such a high N removal by flood inundation were designed to be inundated for an unnaturally long time. The potential flood inundated wetlands found in this analysis could possibly be modified as well, to ensure long duration of flood and high N removal. In river Brede, flood inundation after restoration lasted 33 days and in river Cole, the flooding lasted 10 days after restoration (Kronvang et al., 1998). Therefore, a flood duration of approximately a month can be expected to be valid in general. If the flood duration in most areas does not significantly exceed the 36 days accounted for, the calculated flood removal will not be underestimated to the same extent as it was in case of Karlmosen.

Additionally, many stream sections did not flood at all, which could be a result of stream channelization conducted to prevent flooding. In these areas the calculation of the stream slope would be useful, as it could indicate the potential for flood inundation and suggest modification of the stream channel to restore its natural shape and properties.

Another benefit of restoring streams and allowing for flood inundation is the high sedimentation rate, which also results in the deposition of bound phosphorus (Kronvang et al., 2007). Kronvang et al. (2007) found that a flooded area of 22.6 ha in Odense River during a period of 20 days resulted in a sediment deposition of 3,170 g per square meter (dry weight) and a P deposition of 2.4 g P per square meter. Kronvang et al. (2007) estimated the storage efficiency of the deposited P to be 5.1%.

However, restoration of wetland with flood inundation is associated with a risk of Phosphorus release from the soil (Hoffmann et al., 2018b). Before conducting a restoration, the soil would be tested for P content, to estimate a potential risk of release (Hoffmann et al., 2018b). If there is a substantial risk of P loss from the wetland, a restoration would not be conducted, as a wetland restoration for either nitrogen or phosphorus removal or preservation of lowlaying soils is not acceptable if it leads to additional P release (Miljøstyrelsen, 2018).

5.3.1. Implications for wetland restoration

As shown, some of the area suggested for potential wetland restoration consists of buildings. These areas are also predicted to be flooded, which seems unlikely, hence the area must be drained or the water flow is increased by vegetation harvest in the stream (Hoffmann et al., 2005). Due to the coverage by buildings the restoration of these type of areas seems unlikely – the restoration projects are performed on agricultural land or natural areas, as there must be local support for the projects (Naturstyrelsen).

A lot of the potential wetland area is classified as wet natural areas, suggesting they function as wetland soils. It is unknown whether these areas have their original hydrology, or if they have been affected by drainage – the latter seems more applicable, since 72% of the wet soils are under some form of agricultural use. Drainage lowers the water level in the soil, increasing the oxygen level (Hohlmann Bennetzen, 2017). Therefore, the conditions for denitrification become less favorable, decreasing potential for removal.

Many of these areas are designated as §3 protected natural areas, which means that they cannot be modified, but are not prohibited from being used as they have been until the nature protection legislation was passed (Miljøministeriet, 2009). Extensive use of these areas is allowed, as long as vegetation is not negatively impacted (Miljøministeriet, 2009). Therefore, it seems safe to assume that most of the areas classified as nature probably do not have their original hydrology and can be an object to restoration.

Some of the potential wetland area is forested. For example, the area near Arreskov Sø, which originally has been open nature has been overgrown with trees, and the forested area constitutes most of the area. The denitrification rates in forests are low, but they increase if N inputs to the forest system increase (Gundersen, 1991). The current N removal in these areas is unknown. The wetland area near Arreskov Sø has a moderate ecological status (Naturstyrelsen, 2016a). The Natura 2000 aims to restore wetlands and young forests are to be removed to re-establish the previous natural state (Naturstyrelsen, 2016c). That is not only the case in the forested area near Arreskov Sø, but Odense River, Hågerup River, Sallinge River and Lindved River as well (Naturstyrelsen, 2016b). One of the potential wetland areas downstream, near Odense Fjord is classified as mainly natural area. Some of the area has previously been drained or negatively affected by eutrophication and has a low ecological status (Naturstyrelsen, Naturstyrelsen). Some of the area is now under EU-LIFE Nature with the aim of improving the ecological status and restoring hydrology in Odense River and the low laying soil (Naturstyrelsen). This suggests an interest in potential restoration of these areas mainly for natural protection, and they will very likely be restored in the near future.

Many farmers do not wish to participate in restorations projects that remove drainage to allow flood inundation on their fields, despite the compensation, as some dislike the idea of losing the land that has been in the family for generations. In case of some farmers, even 90 ha of their land was to be included in restoration projects (Mikkelsen, 2005a). The farmers also claim that the agricultural fields located at wetland boundary will have inadequate drainage, resulting in the soil being wet and unusable for agricultural crops (Mikkelsen, 2005a). However, land consolidation is beneficiary for many farmers, as it offers them agricultural land of better quality. Many farmers also enjoy the restored areas for recreative purposes (SEGES, 2017). Therefore, the negative attitude of the farmers might not be a significant obstacle. On the other hand, if the farmers choose land consolidation, the process of figuring out a satisfactory exchange can take up to two years (Mikkelsen, 2005b). The more farmers are included in the restoration project, the longer the restoration process (Naturstyrelsen). Based on that, small wetlands might be preferable to restore, as they would require a small number of farmers to participate. Another solution could be prioritizing the restoration of areas, that mainly consist of §3 areas, with a small proportion of agricultural land, so the change in land use is minimalized.

The Danish government has recently devoted additional 10 million DKK to so called synergy-projects, where climate adaptation, N removal and nature protection are combined (Naturstyrelsen). That suggests an especially high interest in areas that both remove N and result in increased value to nature and could suggest a priority to restore wetlands in areas designated as protected nature. In regard to nature protection, the continuity of an area is crucial regarding maintaining or increasing arthropod biodiversity. If the natural habitats are dispersed in an agricultural landscape, there is loss of species turnover between local communities. As result the species with low spreading capability are eventually replaced with generalists with high spreading abilities (Hendrickx et al., 2007). Therefore, restoration of wetlands to provide the continuity of nature is a valid priority – restoring the stream sections between the already restored wetlands could further improve their ecological benefits.

There is also high interest in wetland restoration on soils, where the carbon content exceeds 12%. Due to drainage, these soils have become sources of CO_2 emissions, and wetland restoration of these areas is a tool in combating climate change (Miljøstyrelsen, 2019). There are areas with peat within the potential wetlands (see Figure 8.5 in Appendix) and could have a high potential of being restored.

Wetland restoration is not the only method of limiting N load to aquatic environment by dentification. A number of buffer strips already is established in the landscape and is a recognized tool to combat N load to streams (MFVM, 2017). However, buffer strips are ineffective, if they are established next to drained agricultural land, as the drained water containing nitrate will surpass the buffer strip (Kahle et al., 2013). Another possibility are intelligent buffer strips, which are designed to efficiently remove N, but they are a new concept and their extent of their efficiency is yet to be verified (Bondgaard et al., 2017). Another solution are saturated buffer strips, where the drainage water is distributed along the stream, allowing it to infiltrate the soil (Bondgaard, 2016). The saturated buffer strips have an estimated N removal efficiency of 49%, and can be as little as 9-10 meters wide (Bondgaard, 2016, Hvid, 2017). Therefore, saturated buffer strips can be a competitive alternative to irrigated wetlands, at least in case of direct upland with an area of up to 15 ha (Hvid, 2017). The benefits of buffer strips can be expected to be mainly N removal, as vegetated buffer strips were found to have low impacts on biodiversity (Hille et al., 2018). Therefore, wetland restoration seems to overall be most beneficial, as it improves N removal, enhancement of nature as well as storage of carbon in soil.

Since the funds for wetland restoration are limited, the wetlands with the highest N removal per ha could be expected to be prioritized. As discussed earlier, the removal efficiency of many wetlands could be improved, and many wetlands might have a higher removal than what was calculated here. However, the highest N removal efficiency does not equal the highest economic efficiency. Hansen et al. (2011) found that wetlands with permanent grass were cheapest to establish. Large wetland restoration projects such as re-establishment of shallow lakes did have a high N removal, but were also associated with high restoration costs and compensation to land owners (Hansen et al., 2011). This suggest that small wetlands with low restoration costs should be prioritized, and they can be expected to be easy to enforce as well, since small restoration area will affect fewer land owners. However, low biodiversity benefits could be expected of restoration of small wetlands, if the area isn't continuous (Hendrickx et al., 2007).

6. Conclusion

Odense River catchment has been a subject of intensive wetland restoration to mitigate N loss. Areas for potential restoration of additional wetland area in Odense River Catchment were found with the help of an index model. Direct upland area to each wetland was calculated in ArcGIS, N loss from each upland was calculated and removal from the direct upland was estimated based on soil type and drainage probability. N removal by flood inundation was based on a flood estimate accounting for 10% of the time, which was calculated based on measured data of stream water level increase from monitoring stations and the upstream river length (Upstream Length Model, UPM). The flood based on the UPM provided a very good flood estimate, that evenly distributed flood upstream as well as downstream and required minimum data inputs. Compared to flood based on MIKE11 calculations of water level increase, the UPM performed better, as MIKE11 resulted in a very unlikely overestimation, which shouldn't be the case considering the amount of input data used to calculate water level elevations in MIKE11. The UPM can be further improved during stream simplification, which is a necessary step to provide a satisfying interpolation of elevation raster used in flood calculation in ArcGIS.

N removal by the restored wetlands has been calculated to 75,094 kg N. The comparison between calculated N removal against measured data from to restored wetlands showed the calculated values to be underestimated. That is due to the flood calculation accounting for only 36 days, while many restored wetlands are designed to be flooded for longer time period.
Another issue is that N removal in shallow lakes couldn't be calculated due to lack of data on lake residency time.

The restoration of additional 5543.9 ha of wetlands was calculated to remove 405,392 kg N. That calculation didn't include N removal in shallow lakes, so the potential N removal could be higher. The highest N removal per ha was found in wetlands irrigated with drainage water – 736.9 ha of irrigated wetlands were estimated to remove 67,389.5 kg N per year (mean of 134 kg N per ha), and 567.2 ha of irrigated wetlands that also were flood inundated were estimated to remove 63,717.0 kg N per year (mean of 233.7 kg N per ha). Wetlands with natural water flow (upland area not drained) had a mean removal of 28.4 kg N per ha, with the total area covering 207.3 ha and estimated total removal of 5189.1 kg N per year. Irrigated wetlands, where only a portion of the upland area was drained, and the rest consisted of natural flow had an estimated removal of 64.9 kg N per ha (total area of 51.5 ha, total removal of 4556.8 kg N per year). Partially irrigated wetlands that also were flood inundated had a mean estimated removal of 104.2 kg N per ha (total area of 1535.2 ha, total removal of 107 314.0 kg N per year), while flood inundated wetlands with only natural flow from the direct upland area had a calculated mean removal of 97.1 kg N per ha (a total area of 2778.4

ha and a total removal of 211,119.4 kg N per year). Wetlands with flow inundation as only removal type, the mean N removal was 35.5 kg N per ha (total area of 668.6 ha, total removal of 21,199.8 kg N per year).

The high removal in irrigated wetlands was due to higher percentage of agricultural cropping in the direct upland area compared to non-drained upland area. Several irrigated wetlands had a calculated N removal much higher 200 kg N per ha, but high N loads are associated with N removal rate lower than 50% N removal assumed here. The N removal in wetlands with nondrained upland area could be higher than calculated, as many of them could be groundwater fed. The calculated flood N removal could be more accurate in potential wetlands than restored wetlands, as many streams overflood for approximately a month yearly. However, during restoration the flooded areas could be modified to prolong the flood duration and increase N removal. Additionally, many stream sections didn’t overflood, which is likely due to stream channelization and can be modified during restoration.

Most importantly, as N loss varies between the direct upland areas, the potential wetland area can be modified to yield higher N removal per wetland area. As result, less area would need to be restored to provide high N removal.

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AARHUS_KOMMUNE Egå Engsø. Rensningsanlæg, naturperle og rekreative muligheder.

8. Appendix

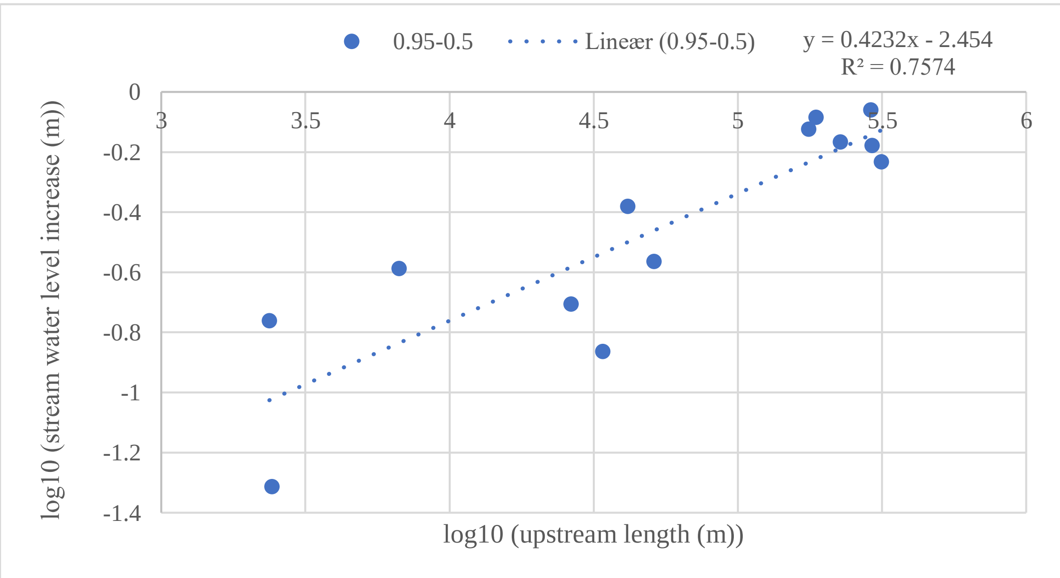

Figure 8.1. The linear relationship between the log10 transformed upstream length and log10 transformed stream water level increase between the 0.5th and 0.95th percentiles.

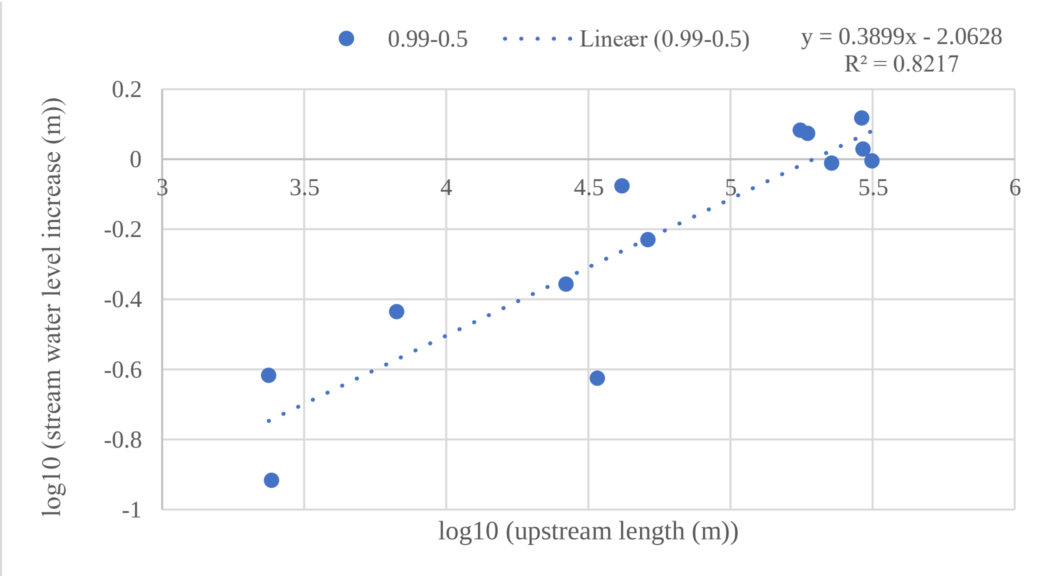

Figure 8.2. The linear relationship between the log10 transformed upstream length and log10 transformed stream water level increase between the 0.5th and 0.99th percentiles.

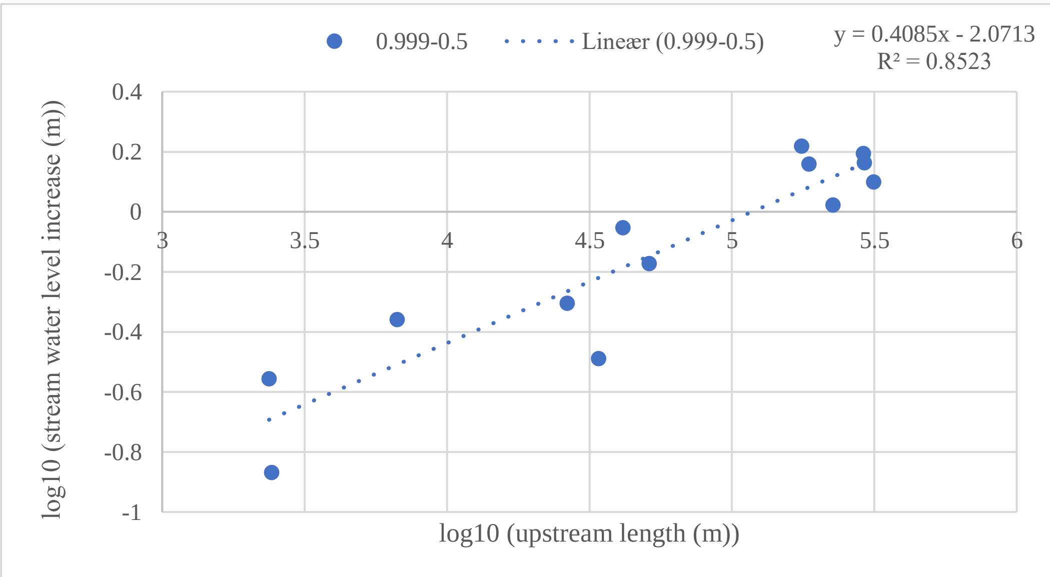

Figure 8.3. The linear relationship between the log10 transformed upstream length and log10 transformed stream water level increase between the 0.5th and 0.999th percentiles.

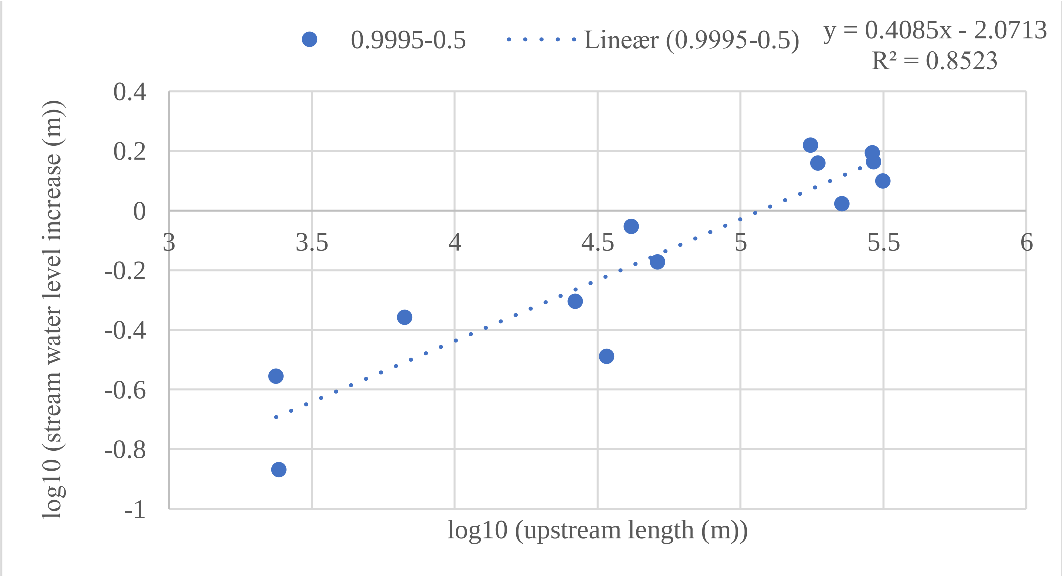

Figure 8.4. The linear relationship between the log10 transformed upstream length and log10 transformed stream water level increase between the 0.5th and 0.9995th percentiles.

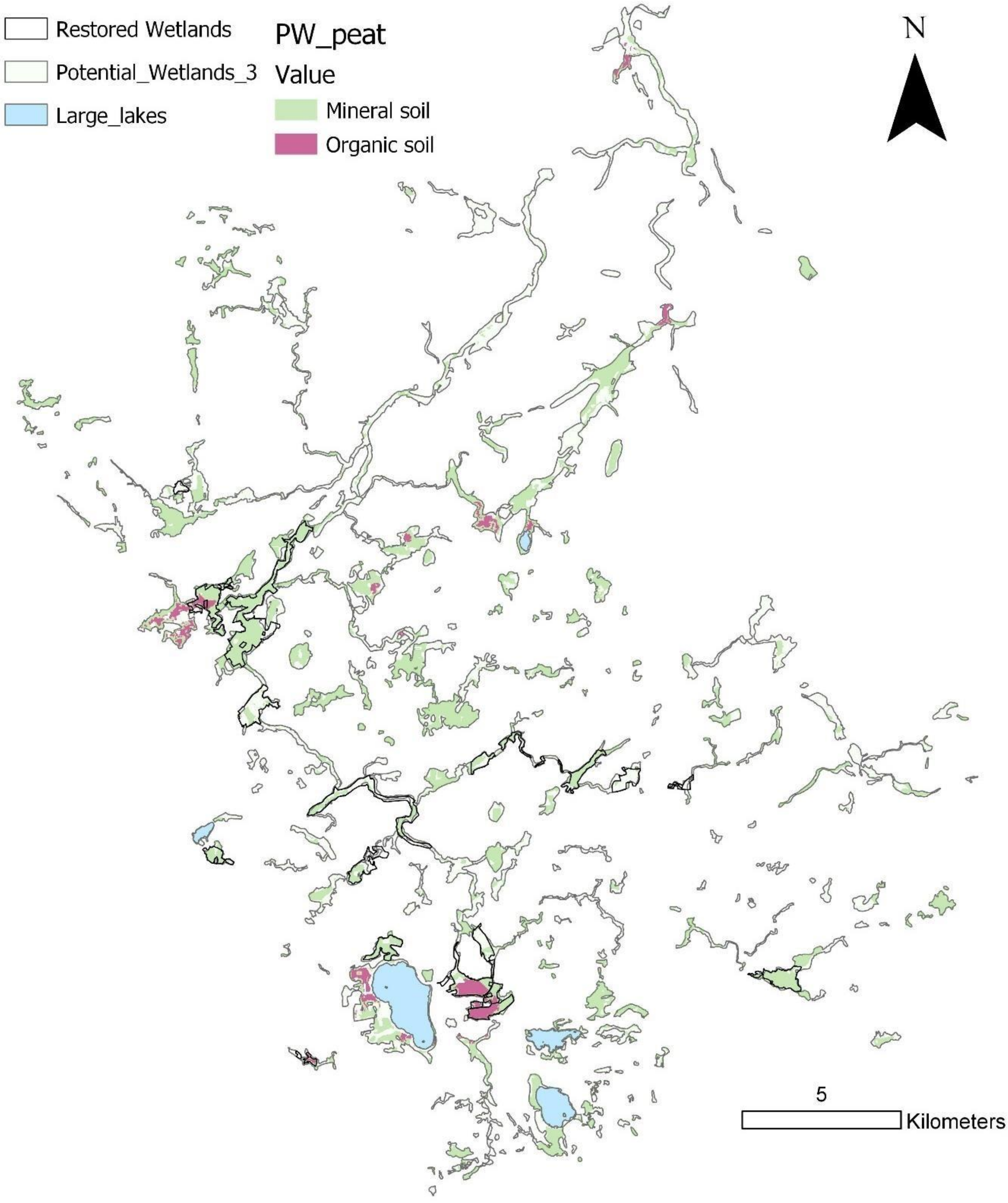

Figure 8.5. Distribution of peat soils in the potential wetlands in Odense River catchment. Green colour signifies mineral soils and pink shows peat soils (Gyldenkærne and Greve, 2015).

Table 8.1. The individual potential wetlands, their size, direct upland area, upland/wetland ration, total N load, N load per ha, estimated total removal, estimated removal per ha and type.

FI = Flood inundation

NF = Natural flow

Ir = Irrigation with drainage water

WetID	Area, ha	Direct upland area, ha	Upland/ wetland ratio	N load, total kg N	N load, kg N per ha	Estimated total re-moval, kg N	Estimated removal, kg N per ha	Type
0	4.9	17.5	3.6	197.2	40.5	306.2	62.9	FI + NF
1	11.6	7.0	0.6	47.5	4.1	23.7	2.0	NF
2	2.8	23.5	8.5	163.7	59.1	81.9	29.6	NF
3	9.8	71.0	7.3	422.7	43.3	211.4	21.6	NF
4	2.6	24.9	9.4	159.1	60.2	79.6	30.1	NF
5	1.1	15.8	14.4	114.0	103.6	81.5	74.1	FI + NF
6	240.6	1035.5	4.3	7291.7	30.3	12365.7	51.4	FI + NF
7	8.9	107.9	12.1	3723.5	419.2	296.1	33.3	FI
8	8.7	45.7	5.3	398.2	45.9	306.3	35.3	FI + Ir + NF
9	12.5	80.0	6.4	1187.8	94.9	593.9	47.4	FI + Ir + NF
10	5.4	19.0	3.5	137.1	25.4	229.0	42.4	FI + NF
11	4.8	33.8	7.1	726.2	152.6	363.1	76.3	Ir
12	2.6	3.5	1.4	25.1	9.7	12.6	4.9	NF
13	2.4	9.4	3.9	108.6	45.0	54.3	22.5	Ir + NF
14	1.3	8.7	6.6	164.7	125.0	82.4	62.5	Ir
15	3.2	154.8	48.1	1355.8	421.2	125.3	38.9	FI
16	4.1	65.2	15.9	415.6	101.5	289.7	70.8	FI + NF
17	1.2	2.7	2.3	14.8	12.4	11.1	9.3	Ir
18	1.1	4.3	3.8	31.6	28.1	15.8	14.0	Ir + NF
19	5.7	53.1	9.3	1031.5	181.6	696.8	122.7	Ir
20	4.0	2.3	0.6	15.7	3.9	101.8	25.3	FI
21	3.5	6.1	1.8	36.3	10.5	23.4	6.8	Ir + NF
22	62.5	248.0	4.0	1729.5	27.7	1426.9	22.8	FI + NF
23	1.2	1.8	1.5	12.5	10.5	6.8	5.7	NF
24	3.0	18.1	6.1	156.5	52.8	89.1	30.1	FI + Ir + NF
25	4.2	8.7	2.0	52.3	12.4	124.0	29.3	FI + NF
26	1.9	10.2	5.5	190.0	102.7	95.0	51.3	Ir + NF
27	2.0	9.2	4.6	119.2	60.2	59.6	30.1	Ir
28	4.9	31.7	6.5	438.2	90.3	219.1	45.2	NF
29	9.3	63.0	6.8	463.6	49.8	231.8	24.9	Ir
30	23.2	44.3	1.9	295.5	12.7	798.7	34.4	FI + NF
31	34.7	150.4	4.3	1248.5	36.0	1292.7	37.3	FI + Ir + NF
32	48.8	227.6	4.7	1636.1	33.5	2786.6	57.1	FI + NF
33	91.8	360.9	3.9	6733.1	73.4	5858.9	63.8	FI + Ir
34	14.8	114.3	7.7	2471.8	166.5	1389.0	93.6	Ir + NF
35	12.1	54.4	4.5	1695.3	139.9	847.7	69.9	Ir
36	3.7	9.2	2.5	51.1	13.9	25.5	7.0	Ir
37	11.0	184.6	16.8	1738.3	158.0	261.7	23.8	FI
38	2.1	100.2	46.6	2180.0	1014.1	1090.0	507.1	Ir
39	11.4	95.6	8.4	3466.9	303.4	382.4	33.5	FI

40	22.4	140.7	6.3	5341.6	238.4	2670.8	119.2	Ir
41	36.1	168.6	4.7	4829.6	133.6	3663.9	101.4	FI + NF
42	2.3	6.0	2.6	44.2	19.0	70.5	30.2	FI + NF
43	14.1	165.1	11.7	7944.3	561.9	3972.2	280.9	Ir
44	9.6	272.7	28.4	4690.5	488.8	2609.3	271.9	FI + Ir
45	1.2	5.9	5.1	232.4	201.5	155.6	134.9	FI + NF
46	3.2	12.0	3.7	330.2	103.2	247.3	77.3	FI + NF
47	1.4	7.2	5.0	43.1	30.0	22.4	15.6	Ir
48	3.5	42.0	12.0	323.3	92.2	349.7	99.8	FI + NF
49	15.6	67.7	4.3	1768.1	113.1	1139.5	72.9	FI + NF
50	22.8	240.0	10.5	9369.3	411.3	5487.1	240.9	FI + NF
51	5.8	14.1	2.4	102.9	17.6	243.6	41.7	FI + NF
52	1.3	2.6	2.1	19.2	15.0	36.4	28.4	FI + NF
53	2.2	6.0	2.7	43.5	19.5	117.8	52.7	FI + NF
54	19.9	167.0	8.4	4003.5	201.4	2628.1	132.2	FI + NF
55	1.9	3.4	1.7	24.5	12.6	12.2	6.3	NF
56	1.1	1.5	1.4	11.2	10.2	5.6	5.1	NF
57	35.9	139.6	3.9	3589.4	100.1	1794.7	50.1	Ir
58	1.4	7.4	5.4	96.3	70.7	72.2	53.0	Ir
59	3.3	43.6	13.2	916.3	278.2	458.2	139.1	Ir
60	7.4	104.1	14.0	3178.1	428.0	2473.1	333.0	FI + Ir
61	6.5	1.7	0.3	11.9	1.8	76.5	11.7	FI + NF
62	38.4	309.4	8.1	9700.2	252.5	8039.0	209.2	FI + Ir + NF
63	4.9	24.9	5.1	408.0	83.5	306.0	62.6	NF
64	1.3	20.2	15.7	986.2	766.2	493.1	383.1	Ir
65	7.0	30.5	4.4	956.8	137.0	856.2	122.6	FI + Ir
66	184.5	839.3	4.5	16161.6	87.6	13509.3	73.2	FI + Ir
67	20.9	130.7	6.3	5137.5	245.9	3213.6	153.8	FI + NF
68	5.0	108.8	21.8	6964.8	1398.0	3482.4	699.0	Ir
69	6.0	131.2	21.8	5036.5	836.4	222.0	36.9	FI
70	1.2	2.4	2.0	38.0	32.2	28.4	24.1	NF
71	6.1	32.9	5.4	515.1	84.3	386.3	63.2	NF
72	13.8	31.4	2.3	678.0	49.1	339.0	24.5	Ir
73	1.3	7.3	5.9	40.3	32.2	30.2	24.2	Ir
74	1.3	40.9	30.9	1203.9	910.1	601.9	455.1	Ir
75	30.0	71.6	2.4	1565.6	52.2	1105.3	36.8	FI
76	39.5	5.4	0.1	38.9	1.0	19.5	0.5	NF
77	4.4	45.6	10.5	1828.7	419.9	914.4	210.0	Ir
78	1.2	5.6	4.8	273.8	233.9	136.9	117.0	Ir
79	2.5	12.5	5.0	103.3	41.4	77.5	31.1	Ir
80	3.8	79.4	21.1	4412.6	1171.3	3356.4	890.9	FI + Ir
81	2.2	12.4	5.7	138.4	63.6	80.6	37.1	FI
82	13.4	94.1	7.0	3329.6	248.6	1667.0	124.5	Ir
83	1.4	21.2	14.8	511.3	356.9	383.5	267.7	Ir
84	3.6	23.5	6.5	1230.9	341.4	615.4	170.7	Ir
85	6.6	2.6	0.4	53.5	8.1	31.1	4.7	Ir
86	2.8	12.1	4.4	318.7	115.1	190.8	68.9	Ir
87	2.2	12.7	5.7	537.1	242.4	402.8	181.8	Ir
88	3.1	12.0	3.9	349.1	112.6	174.6	56.3	Ir

89	5.6	55.2	9.9	3198.7	573.1	1755.3	314.5	FI + NF
90	41.2	138.5	3.4	2527.4	61.4	1263.7	30.7	Ir
91	3.2	29.3	9.1	1402.9	433.3	768.2	237.3	FI + NF
92	1.3	5.0	3.7	89.6	67.8	67.2	50.8	Ir
93	123.9	614.6	5.0	17744.8	143.2	8872.4	71.6	Ir
94	26.0	213.2	8.2	8179.3	314.1	5698.8	218.9	FI + Ir
95	4.2	38.6	9.2	1408.6	336.1	704.3	168.1	Ir + NF
96	2.3	9.2	4.0	250.8	108.3	125.4	54.2	Ir + NF
97	3.7	17.6	4.8	490.0	132.4	367.5	99.3	Ir
98	2.4	43.7	17.8	1822.2	744.3	1366.7	558.2	Ir
99	1.5	17.8	12.2	762.4	521.3	571.8	391.0	Ir
100	17.6	162.9	9.3	1254.8	71.5	627.4	35.7	Ir
101	25.6	143.4	5.6	7066.4	276.0	4080.2	159.4	FI + NF
102	3.6	10.2	2.8	91.9	25.3	153.2	42.2	FI + NF
103	56.0	269.0	4.8	11428.1	204.1	6359.3	113.6	FI + NF
104	3.4	51.4	15.2	2432.2	721.2	1216.1	360.6	Ir
105	17.3	38.8	2.2	707.1	40.8	357.9	20.6	Ir
106	2.5	23.1	9.1	969.9	383.6	485.0	191.8	Ir
107	2.0	13.5	6.9	620.3	317.6	351.1	179.8	FI + NF
108	24.6	106.6	4.3	805.0	32.7	402.5	16.4	NF
109	3.8	53.5	14.2	3854.3	1024.5	1927.1	512.2	Ir
110	1.1	1.8	1.5	66.7	58.7	33.3	29.3	Ir
111	47.3	230.5	4.9	5279.6	111.6	4260.1	90.1	FI + Ir
112	4.9	17.7	3.6	527.8	107.2	263.9	53.6	Ir
113	2.7	16.6	6.1	848.8	313.8	138.9	51.3	FI
114	27.9	363.3	13.0	6978.1	250.5	4831.4	173.5	FI + Ir + NF
115	1.7	14.9	8.6	754.0	432.3	580.0	332.5	FI + Ir
116	11.2	75.1	6.7	3781.4	338.2	522.7	46.8	FI
117	5.9	19.6	3.3	457.8	77.7	468.7	79.5	FI + NF
118	1.0	2.6	2.5	76.7	73.7	38.4	36.9	Ir
119	2.3	19.7	8.6	1008.8	439.7	504.4	219.8	Ir
120	4.7	26.3	5.6	1127.3	241.0	563.7	120.5	Ir
121	5.0	25.9	5.2	675.8	135.4	206.4	41.4	FI
122	1.0	1.2	1.2	9.3	9.0	12.8	12.4	FI + Ir
123	57.2	172.7	3.0	3418.8	59.7	3555.0	62.1	FI + Ir + NF
124	82.0	575.9	7.0	19688.1	240.2	15128.9	184.6	FI + Ir + NF
125	29.0	151.6	5.2	2548.6	88.0	2534.6	87.5	FI + Ir
126	27.4	194.5	7.1	5427.0	197.9	2713.5	99.0	Ir
127	11.0	68.6	6.3	2202.4	201.0	1285.3	117.3	Ir
128	26.6	121.8	4.6	2907.8	109.5	2180.8	82.1	NF
129	20.3	69.5	3.4	891.5	43.8	445.8	21.9	Ir
130	12.0	69.4	5.8	1416.7	117.8	708.4	58.9	Ir
131	2.8	111.8	39.4	4687.1	1652.0	2434.8	858.2	FI + Ir
132	2.7	20.0	7.3	297.7	108.4	112.4	40.9	FI
133	3.1	1.4	0.4	8.2	2.6	94.7	30.4	FI + NF
134	5.7	170.0	29.6	1807.8	314.5	903.9	157.2	Ir
136	36.9	237.6	6.4	8510.4	230.5	5394.0	146.1	FI + NF
137	17.1	108.7	6.4	3733.8	218.7	1887.8	110.6	FI + NF
138	31.2	506.6	16.3	9820.6	315.2	8265.0	265.3	FI + NF

139	1.6	7.7	4.9	300.4	189.8	80.6	50.9	FI
140	4.9	9.2	1.9	192.2	39.6	217.7	44.9	FI + NF
141	2.8	38.5	13.8	2205.2	789.1	1177.6	421.4	FI + NF
142	14.9	119.6	8.0	3131.6	209.8	447.5	30.0	FI
143	4.4	22.7	5.1	616.5	138.7	325.3	73.2	FI + NF
144	1.8	3.3	1.8	24.0	13.4	12.0	6.7	Ir + NF
145	38.6	147.9	3.8	3374.2	87.5	2932.9	76.1	FI + NF
146	1.1	4.8	4.3	37.2	33.0	36.5	32.4	FI + NF
147	3.3	29.1	8.9	1178.1	359.4	164.1	50.1	FI
148	3.4	21.3	6.3	446.1	131.4	272.8	80.3	FI + NF
149	13.2	96.6	7.3	4049.3	307.6	2024.6	153.8	Ir
150	25.1	71.0	2.8	2074.7	82.7	1037.4	41.4	Ir
151	1.6	2.5	1.6	17.2	10.7	61.6	38.2	FI
152	12.1	98.8	8.1	2916.0	240.4	1650.0	136.0	FI + NF
153	17.2	143.7	8.4	5535.3	322.3	3271.5	190.5	FI + NF
154	4.0	48.9	12.4	2424.2	613.7	1212.1	306.9	Ir + NF
155	26.5	272.2	10.3	11717.5	441.4	6452.6	243.1	FI + NF
156	3.2	40.6	12.6	1908.4	590.8	126.6	39.2	FI
157	47.0	155.5	3.3	3732.7	79.5	1866.4	39.7	FI
158	9.3	191.3	20.5	6831.6	731.8	3415.8	365.9	Ir
159	28.7	93.8	3.3	1726.4	60.0	1753.5	61.0	FI + NF
160	2.4	6.3	2.6	74.7	31.0	174.0	72.2	FI + NF
161	3.9	6.0	1.5	43.8	11.2	21.9	5.6	NF
162	5.3	33.8	6.4	1381.4	262.4	186.2	35.4	FI
163	3.9	21.5	5.5	850.1	216.3	425.1	108.2	Ir
164	3.3	29.9	9.1	548.4	165.8	498.2	150.7	FI + NF
165	1.8	1.3	0.7	30.3	17.3	15.1	8.6	Ir + NF
166	3.4	4.2	1.2	30.6	9.0	116.6	34.2	FI + NF
167	5.0	22.7	4.5	345.3	69.0	252.5	50.5	FI + NF
168	2.0	27.2	13.5	1148.4	568.1	642.0	317.6	FI + Ir + NF
169	12.6	74.6	5.9	3996.7	317.1	458.9	36.4	FI
170	1.4	12.1	8.5	725.3	511.3	362.6	255.6	Ir
171	4.1	12.5	3.1	302.6	74.7	151.3	37.3	Ir
172	40.2	270.5	6.7	12451.3	309.6	7313.6	181.9	FI + NF
173	4.9	134.8	27.7	5154.0	1060.6	2667.0	548.8	FI + NF
174	3.7	41.0	11.0	232.9	62.7	323.3	87.0	FI + NF
175	3.7	28.6	7.8	1432.6	389.4	155.5	42.3	FI
176	29.4	230.5	7.8	8130.8	276.6	966.6	32.9	FI
177	4.4	12.3	2.8	425.8	96.2	335.8	75.9	FI + NF
178	8.2	51.6	6.3	1106.7	135.6	553.3	67.8	Ir
179	1.7	0.4	0.2	2.2	1.3	27.0	15.7	FI
180	2.0	74.1	36.9	947.2	471.4	710.4	353.5	NF
181	1.2	6.4	5.4	169.0	142.6	84.5	71.3	Ir
182	2.2	16.9	7.6	640.2	286.6	79.3	35.5	FI
183	9.6	28.4	3.0	462.8	48.4	323.3	33.8	FI + NF
184	3.1	7.8	2.6	53.8	17.6	114.7	37.6	FI
185	113.5	444.0	3.9	13182.0	116.1	9415.3	83.0	FI + NF
186	4.6	12.7	2.7	312.2	67.6	161.6	35.0	FI
187	18.2	103.8	5.7	2579.5	141.4	1289.8	70.7	Ir

188	54.2	124.7	2.3	2741.6	50.6	2795.1	51.5	FI + NF
190	1.8	1.5	0.9	11.0	6.3	5.5	3.1	NF
191	6.8	43.0	6.3	1174.9	171.9	587.4	85.9	Ir
192	4.9	12.4	2.5	80.3	16.3	46.2	9.4	NF
193	33.4	91.3	2.7	1575.5	47.2	1057.0	31.7	FI
194	1.9	3.9	2.1	27.2	14.5	112.5	59.8	FI + NF
196	3.7	13.3	3.6	103.1	27.7	72.5	19.5	NF
197	319.0	853.3	2.7	12842.7	40.3	12414.3	38.9	FI + Ir + NF
198	30.1	114.1	3.8	2402.2	79.8	653.8	21.7	FI
199	1.2	2.9	2.5	17.6	15.1	12.4	10.6	NF
200	10.2	31.6	3.1	702.5	68.8	471.3	46.1	Ir
201	29.6	31.1	1.0	178.0	6.0	131.2	4.4	NF
202	6.1	17.6	2.9	113.6	18.8	263.9	43.6	FI + NF
203	1.5	4.1	2.8	28.7	19.7	70.6	48.4	FI + NF
204	1.1	4.3	3.8	25.4	22.9	17.9	16.1	NF
205	1.1	2.8	2.6	18.6	17.2	9.3	8.6	NF
206	1.4	4.8	3.4	34.8	24.2	58.0	40.3	FI + NF
207	1.3	3.3	2.6	22.8	17.6	29.7	22.9	FI + NF
208	4.8	8.4	1.7	60.9	12.7	221.5	46.1	FI + NF
209	1.9	4.1	2.2	30.1	15.9	15.0	8.0	NF
210	2.8	28.7	10.2	415.2	147.0	355.7	125.9	FI + Ir
211	7.3	42.1	5.7	506.3	69.1	253.2	34.6	Ir
212	8.8	32.4	3.7	234.6	26.5	459.2	51.9	FI + NF
213	15.2	29.8	2.0	340.0	22.3	701.7	46.0	FI + Ir + NF
214	2.1	5.9	2.9	35.6	17.3	25.3	12.3	Ir + NF
215	1.9	7.6	3.9	45.7	23.6	34.3	17.7	NF
216	3.5	20.4	5.9	869.1	251.8	573.6	166.2	FI + Ir
217	2.5	7.5	3.0	48.8	19.3	159.5	63.2	FI + NF
218	74.6	261.3	3.5	3535.5	47.4	2451.7	32.8	FI
219	4.6	8.0	1.7	59.3	12.8	116.9	25.2	FI + NF
220	5.7	9.4	1.7	70.0	12.4	258.1	45.7	FI + NF
221	2.3	5.2	2.3	36.2	15.9	18.1	8.0	NF
222	1.4	9.1	6.4	537.9	379.1	268.9	189.6	Ir
223	3.3	6.5	1.9	47.6	14.3	23.8	7.2	NF
224	1.1	2.2	2.0	16.3	14.5	8.2	7.2	NF
225	1.8	4.1	2.3	44.1	24.9	22.0	12.4	Ir + NF
226	1.2	6.3	5.4	45.7	39.3	22.9	19.7	NF
227	2.2	4.5	2.1	32.5	15.0	16.3	7.5	NF
228	1.3	5.6	4.2	71.2	52.9	35.6	26.4	Ir
229	114.7	320.3	2.8	4140.9	36.1	4999.3	43.6	FI + Ir + NF
230	20.1	78.6	3.9	1061.4	52.8	530.7	26.4	Ir
231	1.2	6.4	5.3	83.9	69.7	41.9	34.9	Ir
232	7.0	20.5	2.9	425.4	61.2	318.6	45.8	Ir
233	5.0	19.2	3.8	366.0	72.5	274.5	54.4	Ir
234	1.4	5.7	4.1	35.8	25.5	23.4	16.7	NF
235	1.4	5.8	4.1	39.2	27.2	23.5	16.3	NF
236	21.2	99.4	4.7	2424.0	114.1	1318.8	62.1	FI + NF
301	185.5	813.0	4.4	17845.8	96.2	13285.5	71.6	FI + NF
302	70.5	177.8	2.5	1886.0	26.8	2945.8	41.8	FI + NF

303	47.1	181.7	3.9	4166.3	88.4	3891.6	82.6	FI + NF
306	131.0	449.3	3.4	8657.7	66.1	5878.0	44.9	FI + NF
308	148.5	495.5	3.3	12067.7	81.3	7784.9	52.4	FI + NF
316	174.5	352.8	2.0	5233.4	30.0	8507.7	48.8	FI + NF
317	51.9	247.6	4.8	6713.0	129.4	4685.2	90.3	FI + NF
318	10.6	167.8	15.8	5869.6	552.8	3155.0	297.1	FI + NF
320	77.2	237.0	3.1	4113.6	53.3	4401.8	57.0	FI + NF
322	56.6	336.7	6.0	9532.6	168.5	7238.3	128.0	FI + Ir + NF
324	54.7	224.6	4.1	4690.5	85.8	4173.0	76.3	FI + Ir + NF
326	124.9	517.5	4.1	15982.9	127.9	4333.6	34.7	FI
328	39.3	162.2	4.1	3238.3	82.5	2096.7	53.4	FI + NF
333	42.6	173.1	4.1	6202.6	145.5	3157.6	74.1	Ir
334	55.6	246.2	4.4	8430.4	151.5	5582.9	100.3	Ir
335	17.9	94.1	5.3	3551.7	198.1	3172.8	177.0	FI + NF
337	53.3	160.6	3.0	2962.5	55.6	3446.0	64.6	FI + Ir
339	32.0	189.2	5.9	3636.4	113.8	3303.4	103.4	FI + NF
341	28.9	113.9	3.9	3273.2	113.2	3007.1	104.0	FI + Ir
343	14.3	162.5	11.4	4978.5	349.1	3936.4	276.0	FI + Ir + NF
345	46.5	265.7	5.7	9899.1	212.8	7505.6	161.3	FI + Ir
347	125.5	344.4	2.7	8127.1	64.7	6418.3	51.1	FI + NF
349	10.6	75.7	7.1	3526.8	332.9	1909.1	180.2	FI + NF
351	122.1	332.9	2.7	8344.5	68.4	5604.0	45.9	FI + NF
352	38.8	212.3	5.5	7215.6	186.1	4139.2	106.7	FI + NF
354	81.8	254.3	3.1	5038.4	61.6	4564.6	55.8	FI + NF
356	23.1	128.1	5.5	3267.6	141.3	3017.8	130.5	FI + Ir + NF
360	11.4	42.8	3.8	1290.7	113.3	979.6	86.0	FI + Ir + NF
362	353.9	843.4	2.4	11505.2	32.5	13060.9	36.9	FI + Ir + NF
364	109.1	316.2	2.9	5008.4	45.9	6047.0	55.4	FI + Ir + NF
366	134.8	882.9	6.5	8025.3	59.5	3261.7	24.2	FI
368	20.2	229.9	11.4	7451.2	368.3	4644.7	229.6	FI + Ir
370	102.3	264.3	2.6	4205.0	41.1	5354.3	52.4	FI + Ir + NF
372	28.6	117.8	4.1	1199.5	41.9	1390.9	48.6	FI + NF
374	101.5	390.6	3.8	4864.7	47.9	5310.5	52.3	FI + NF
375	28.6	157.7	5.5	4935.3	172.7	3020.8	105.7	FI + Ir + NF
376	39.0	136.5	3.5	2692.7	69.0	2501.0	64.1	FI + NF
378	66.0	601.3	9.1	8272.1	125.3	7892.3	119.5	FI + Ir + NF
380	38.1	304.4	8.0	6761.5	177.2	989.9	25.9	FI
382	60.4	456.4	7.6	2930.0	48.5	3712.6	61.5	FI + NF
390	13.6	89.2	6.6	2611.6	192.3	1671.6	123.1	FI + NF
391	10.0	77.9	7.8	1697.7	169.7	863.1	86.3	Ir + NF