Drainage filters targeting nutrient removal in agricultural drainage discharge: A new cost-effective mitigation strategy in Denmark

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STØTTET AF
Promilleafgiftsfonden for landbrug

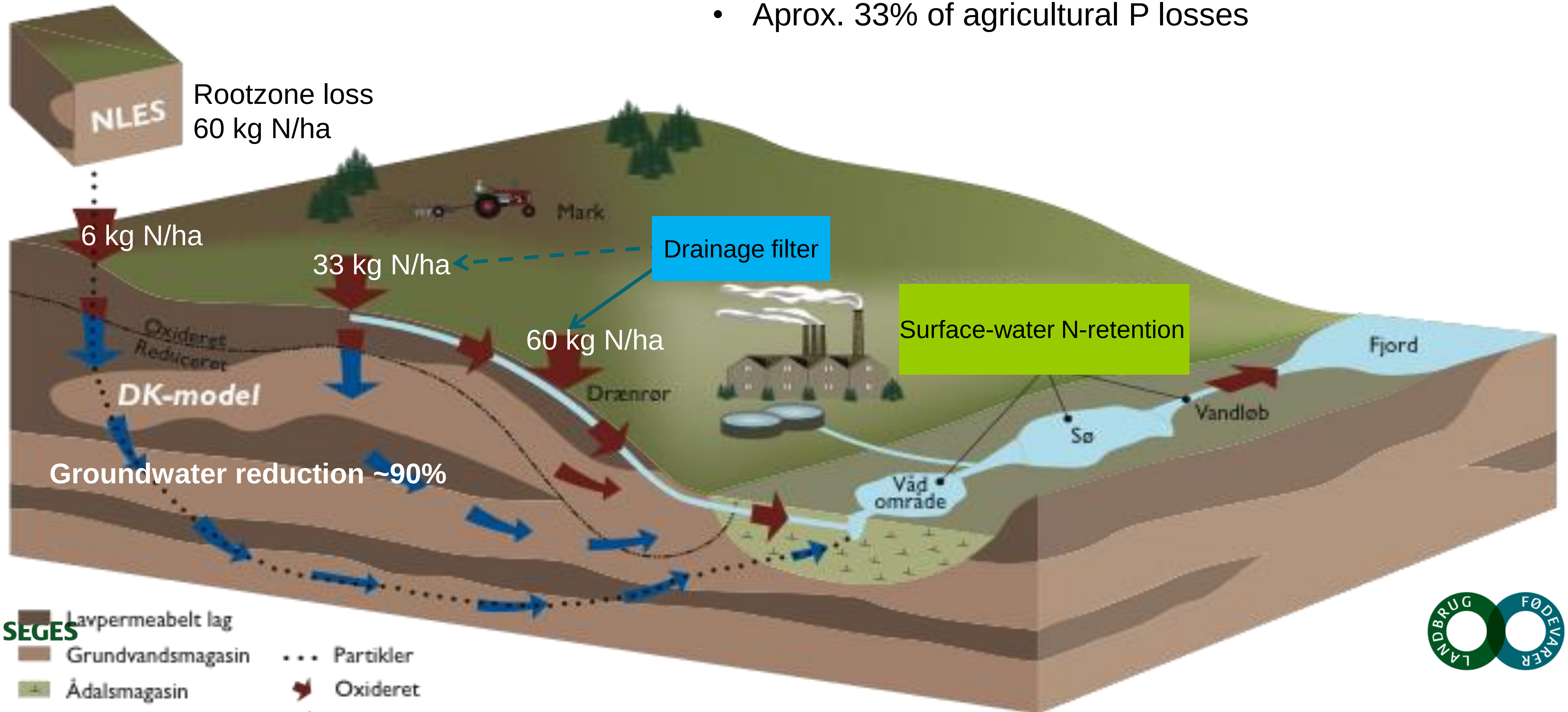
SEGES

Workshop – Input and output based N regulation
SEGES, June 7th, Aarhus, Denmark

Drainage filters a new targeted mitigation strategy

Drainage losses of nutrients accounts nationally for:

- 50-60% of agricultural N losses -> locally up to 90%
- Aprox. 33% of agricultural P losses



Wetlands as natural landscape filters – before and now

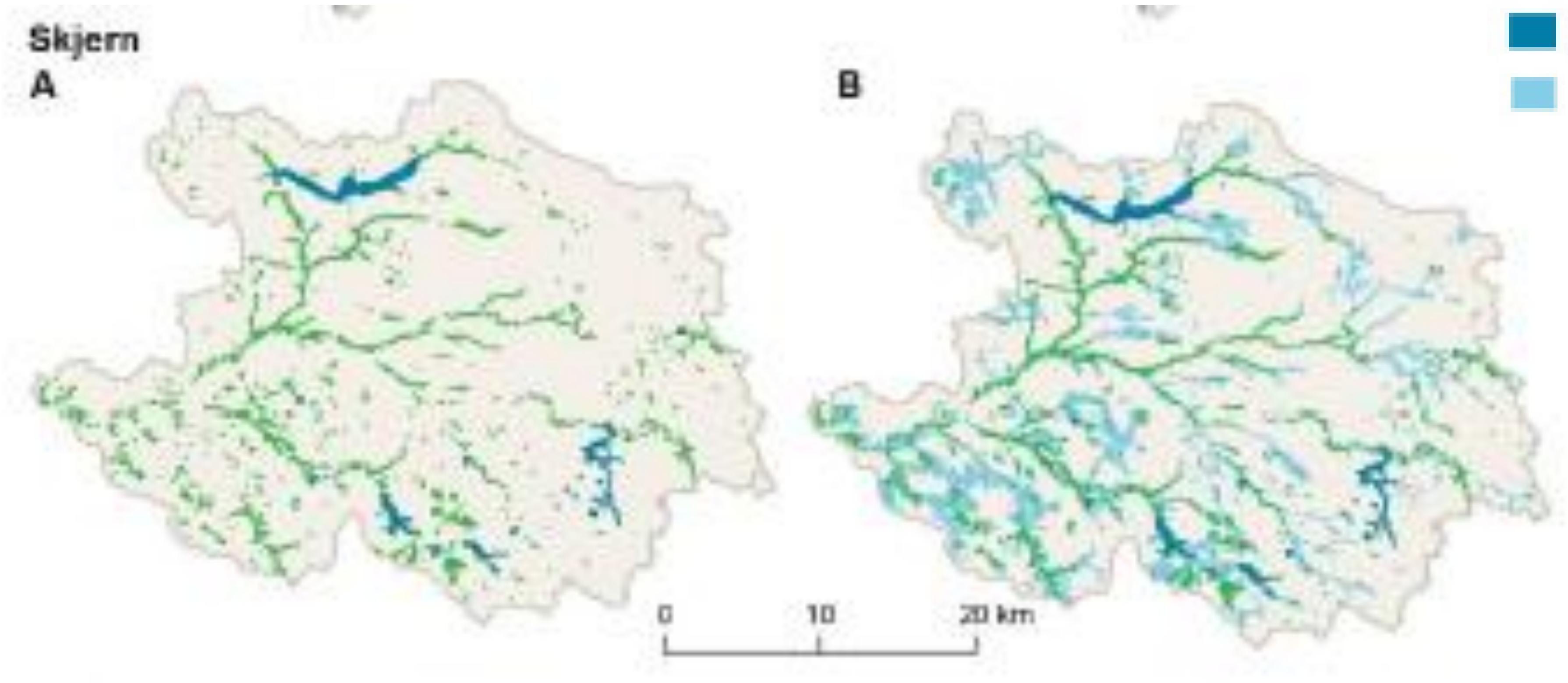
Low N-retention (anno 2017)

Higher N-retention (anno 1890)

Natural wetlands

Restored wetlands

Potential wetlands 1890



Jensen, P.N. (Ed.) 2017. Estimation of Nitrogen Concentrations from root zone to marine areas around year 1900. Aarhus University, DCE-Danish Centre for Environment and Energy, 126 pp. Scientific Report No. 241. http://dce2.au.dk/pub/SR241.pdf

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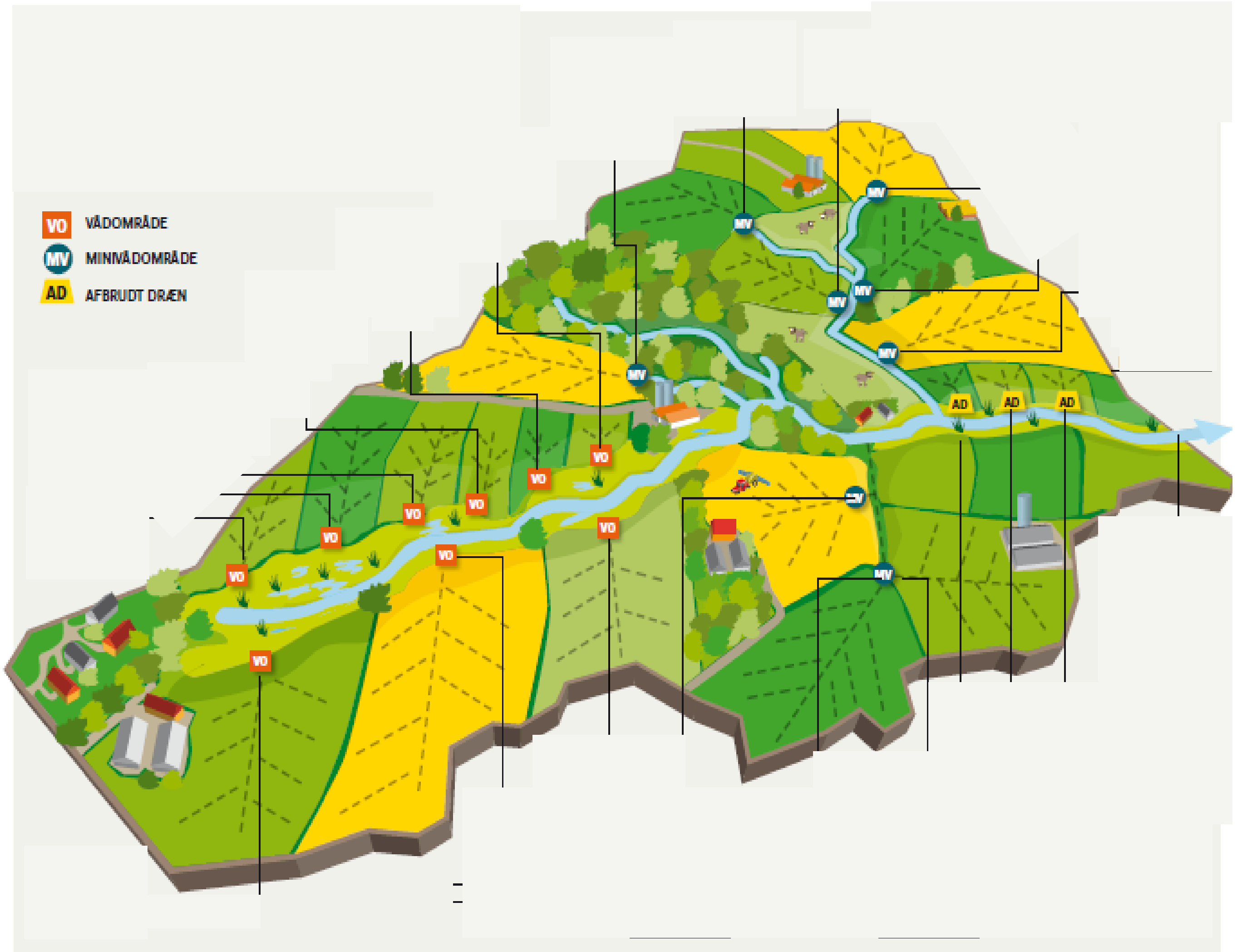
Visions for the targeted nutrient mitigation – restore landscape filters



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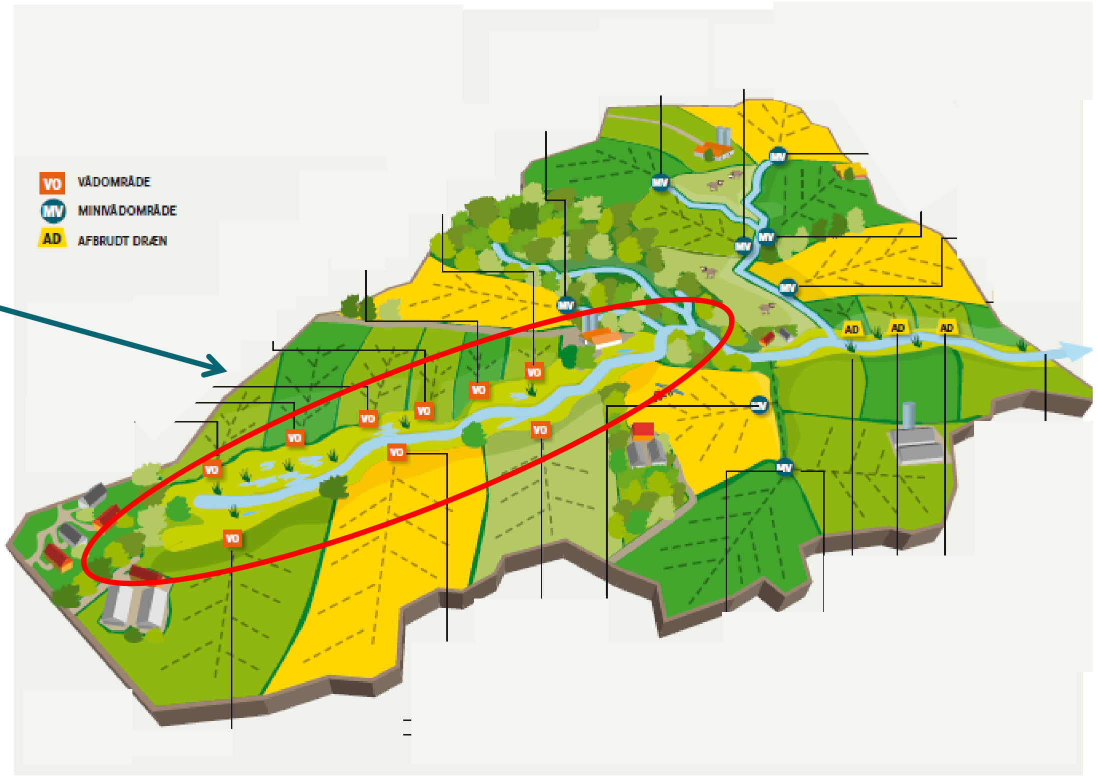
Visions for the targeted nutrient mitigation – restore landscape filters

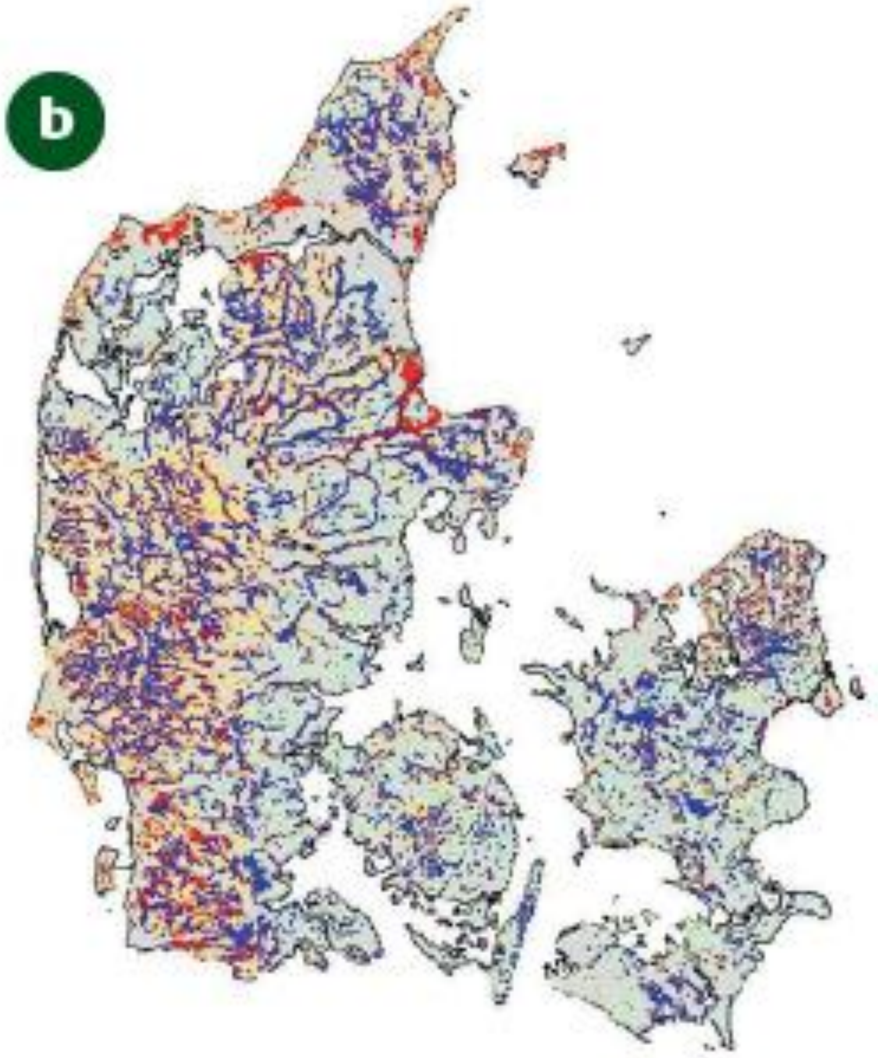
Riparian lowland



Riparian lowland

- Wetland restoration
- Disconnected tile drains

Significance of the N-reduction potential using riparian lowland



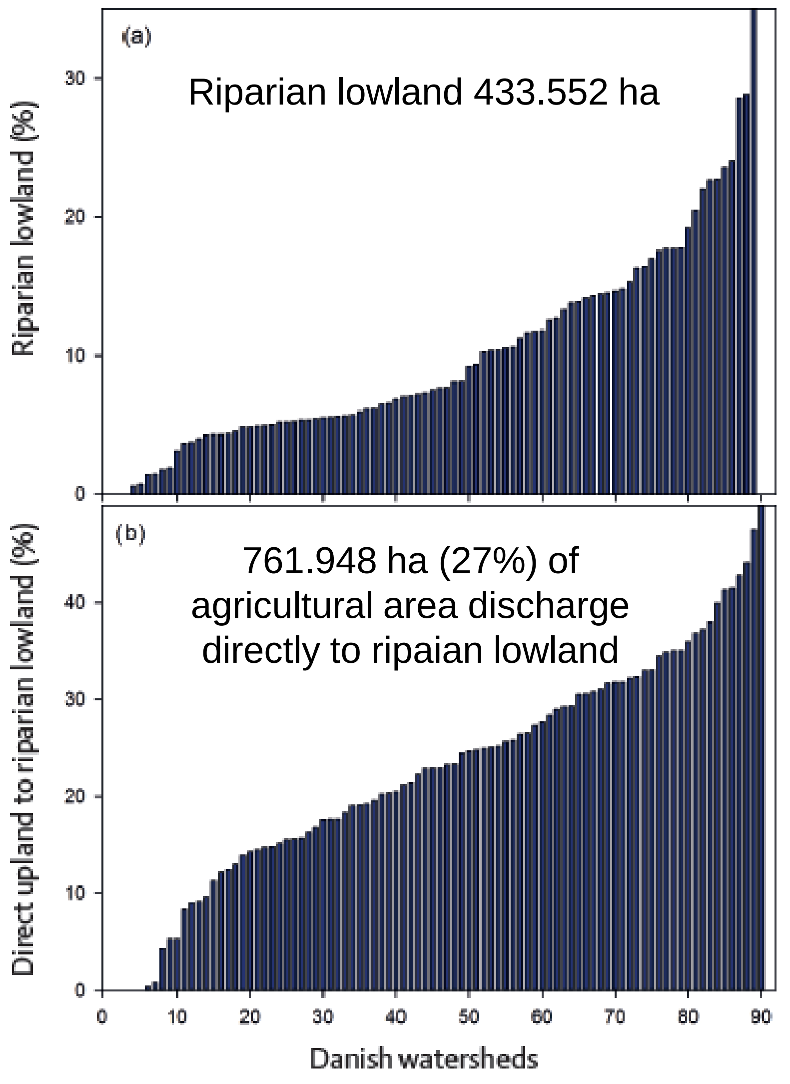
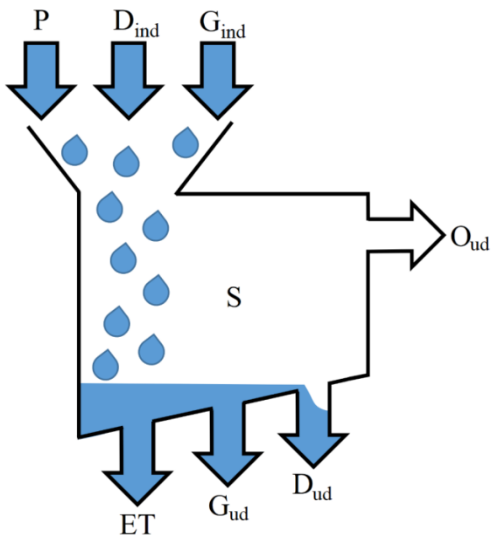
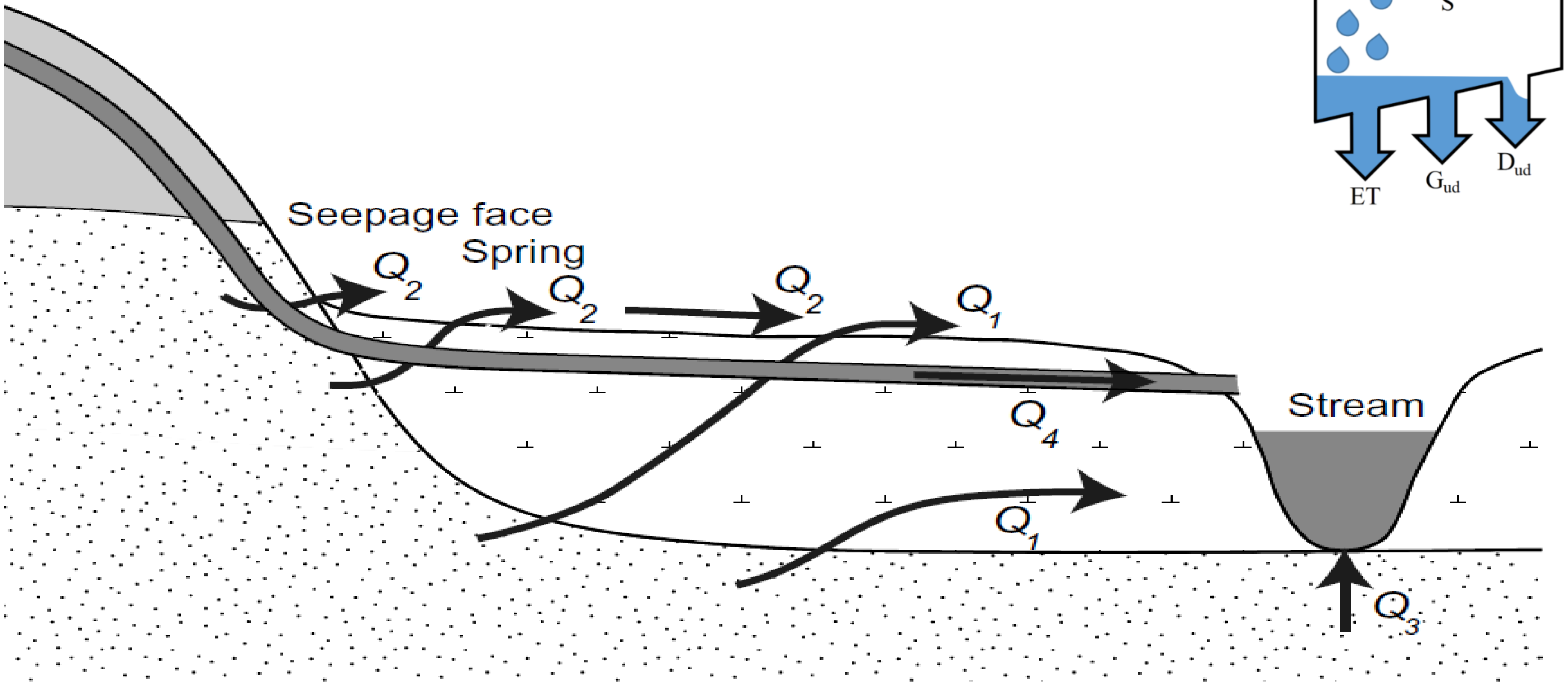


FIGURE 2. (a) Riparian lowland area, and (b) agricultural upland intercepted by riparian lowland in the Danish watersheds.

Challenges in predicting N-reduction in riparian lowlands

Innovation Fund project TReNDS:
Water-balance model to distribute flow-pathways
(Petersen et al., submitted)





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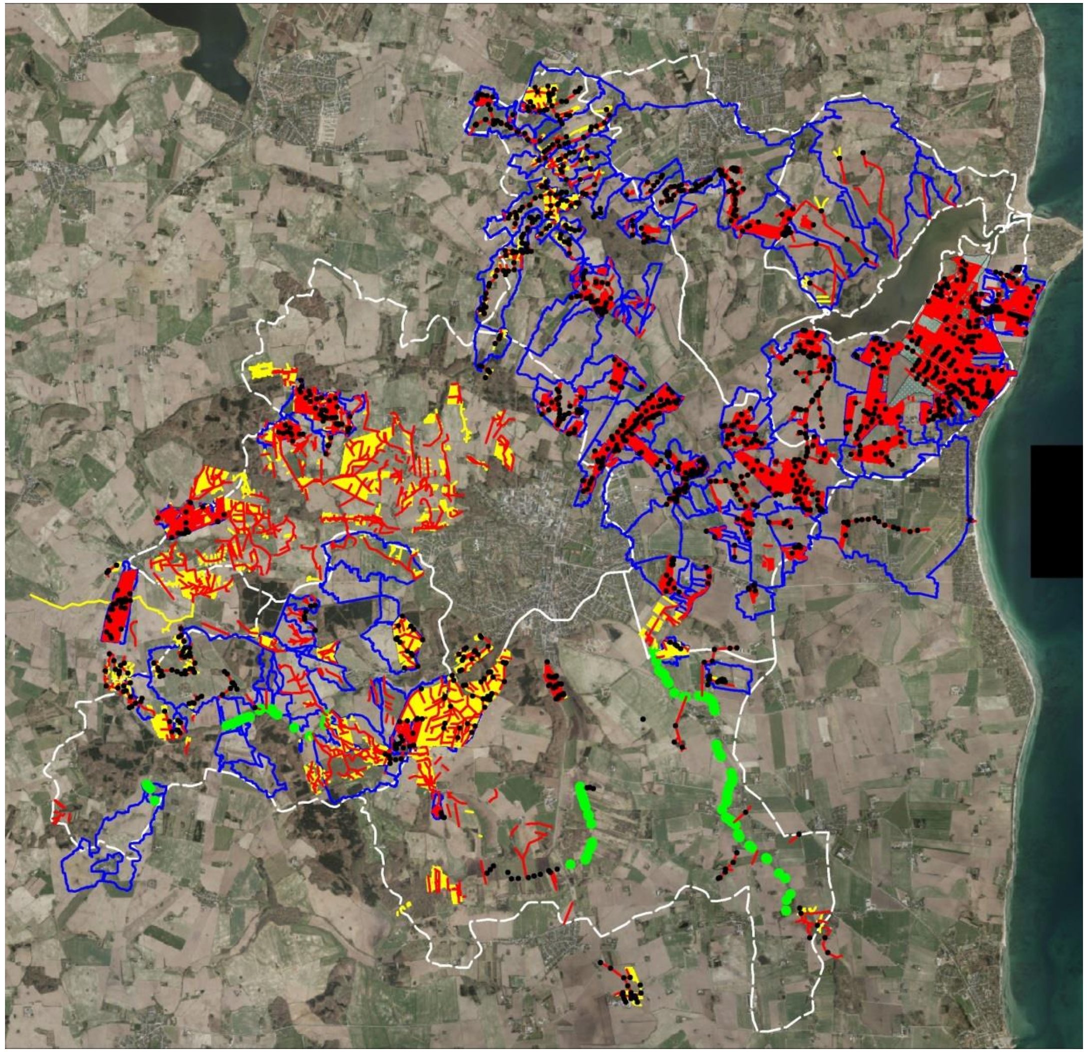
Visions for the targeted nutrient mitigation – restore landscape filters

Riparian lowland

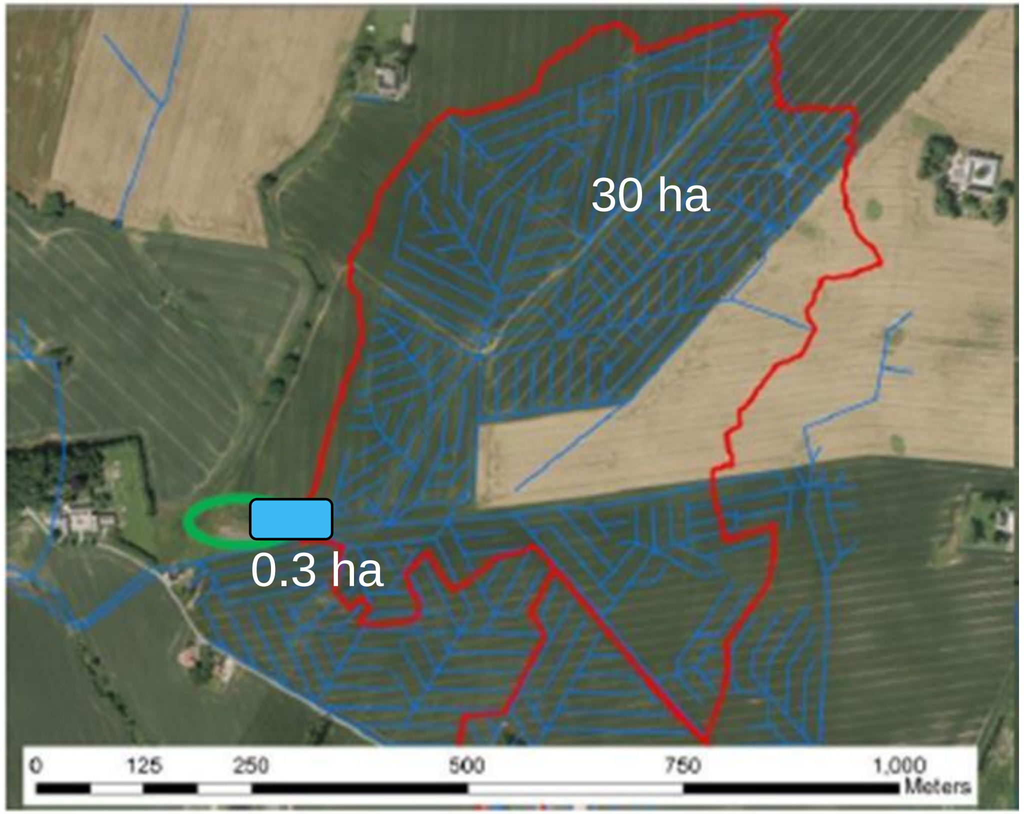
Constructed wetlands

Drainage filters a new targeted mitigation strategy

Norsminde Fjord catchment (10.100 ha ~7.500 ha agricultural area) - intensively tile-drained (<5 ha to >100 ha)

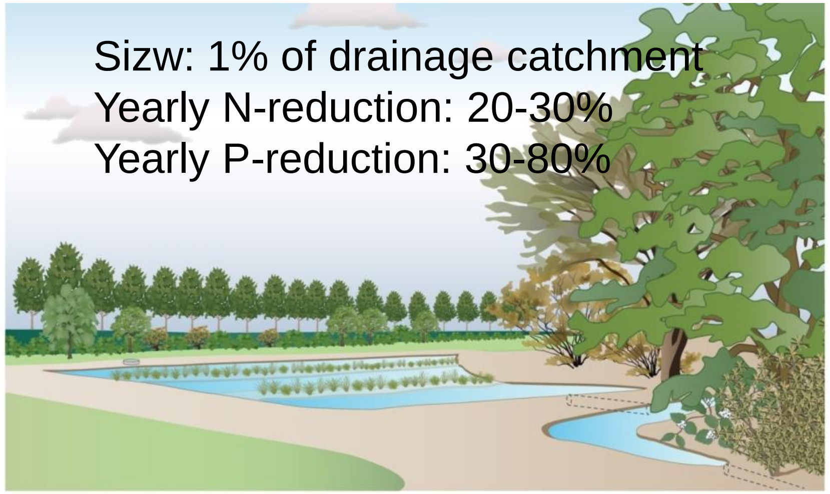


Deliniated drainage catchment

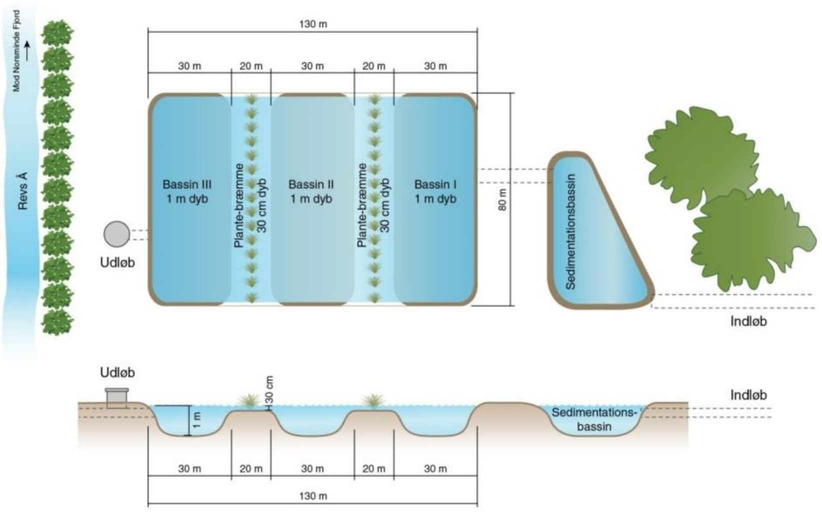


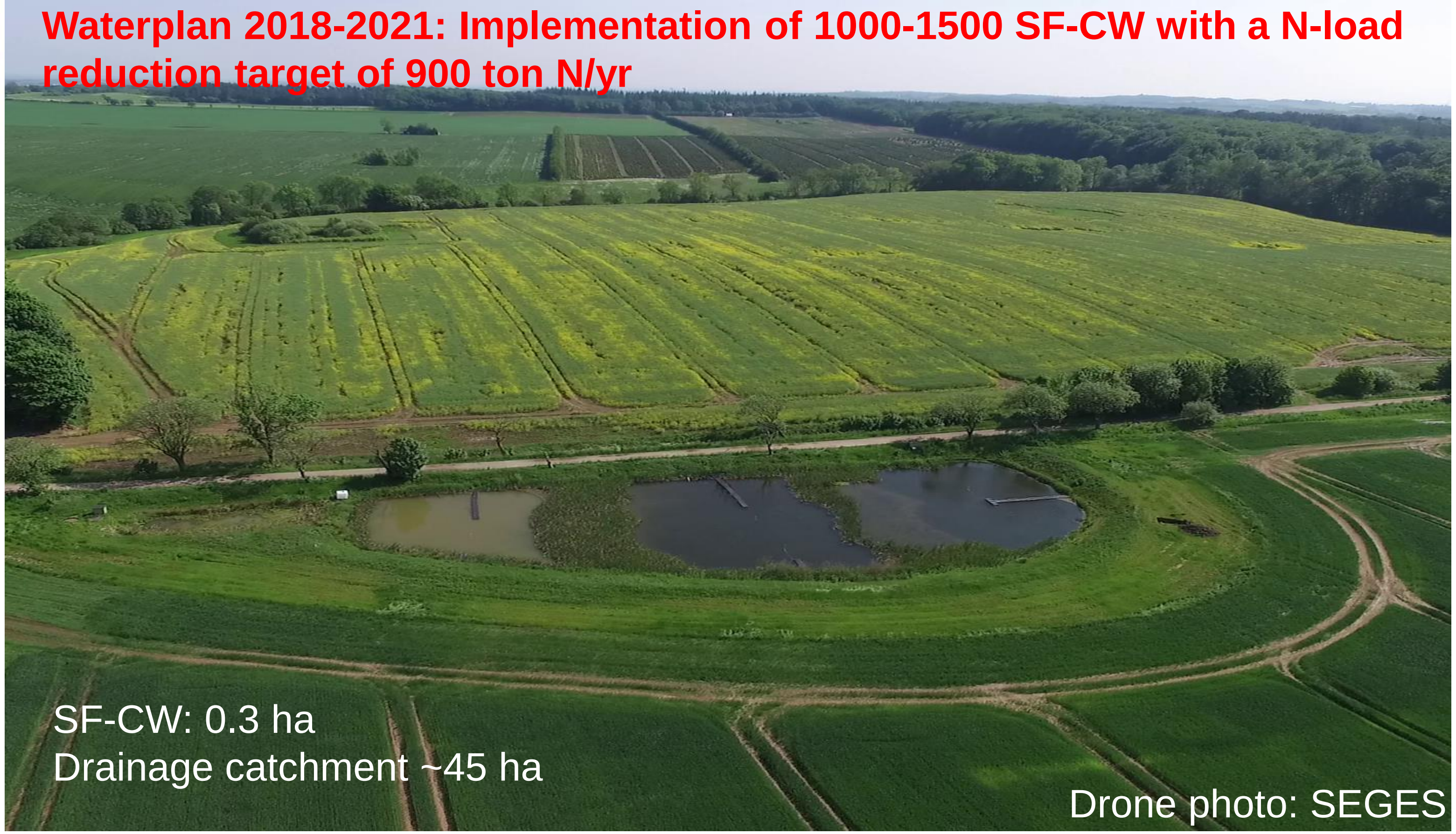
The first Danish surface-flow constucted wetland – Fillerup

Constructed in 2010 in the Norsminde Fjord Catchment, Odder, Denmark by DLMO, SEGES, AU



Sizw: 1% of drainage catchment
Yearly N-reduction: 20-30%
Yearly P-reduction: 30-80%





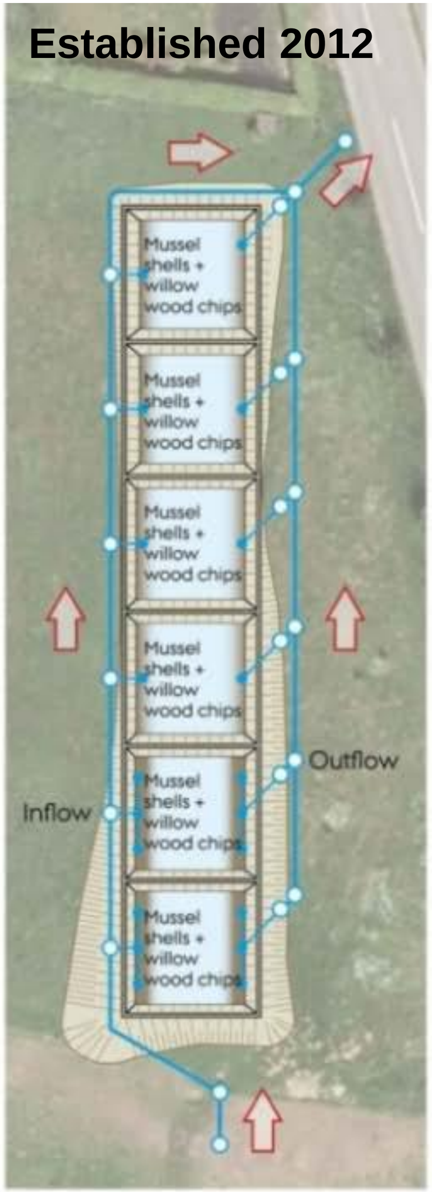
Waterplan 2018-2021: Implementation of 1000-1500 SF-CW with a N-load reduction target of 900 ton N/yr

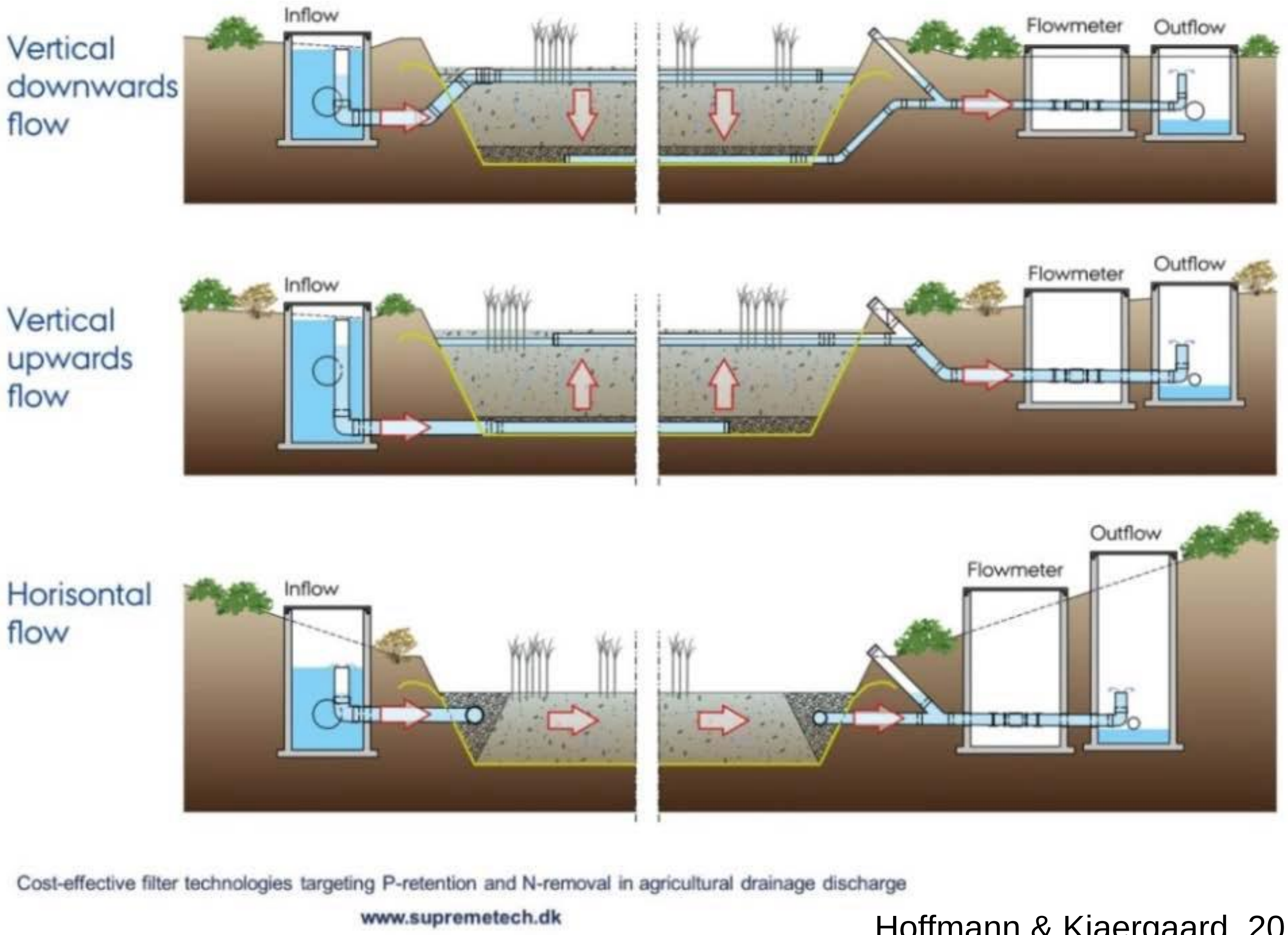
SF-CW: 0.3 ha
Drainage catchment ~45 ha

Drone photo: SEGES

25 SF-CW constructed in DK in 2010-2015
Kjaergaard et al., (2014; 2017; 2019)

Subface-flow constucted wetlands (woodchips based bioreactors)





www.supremetech.dk

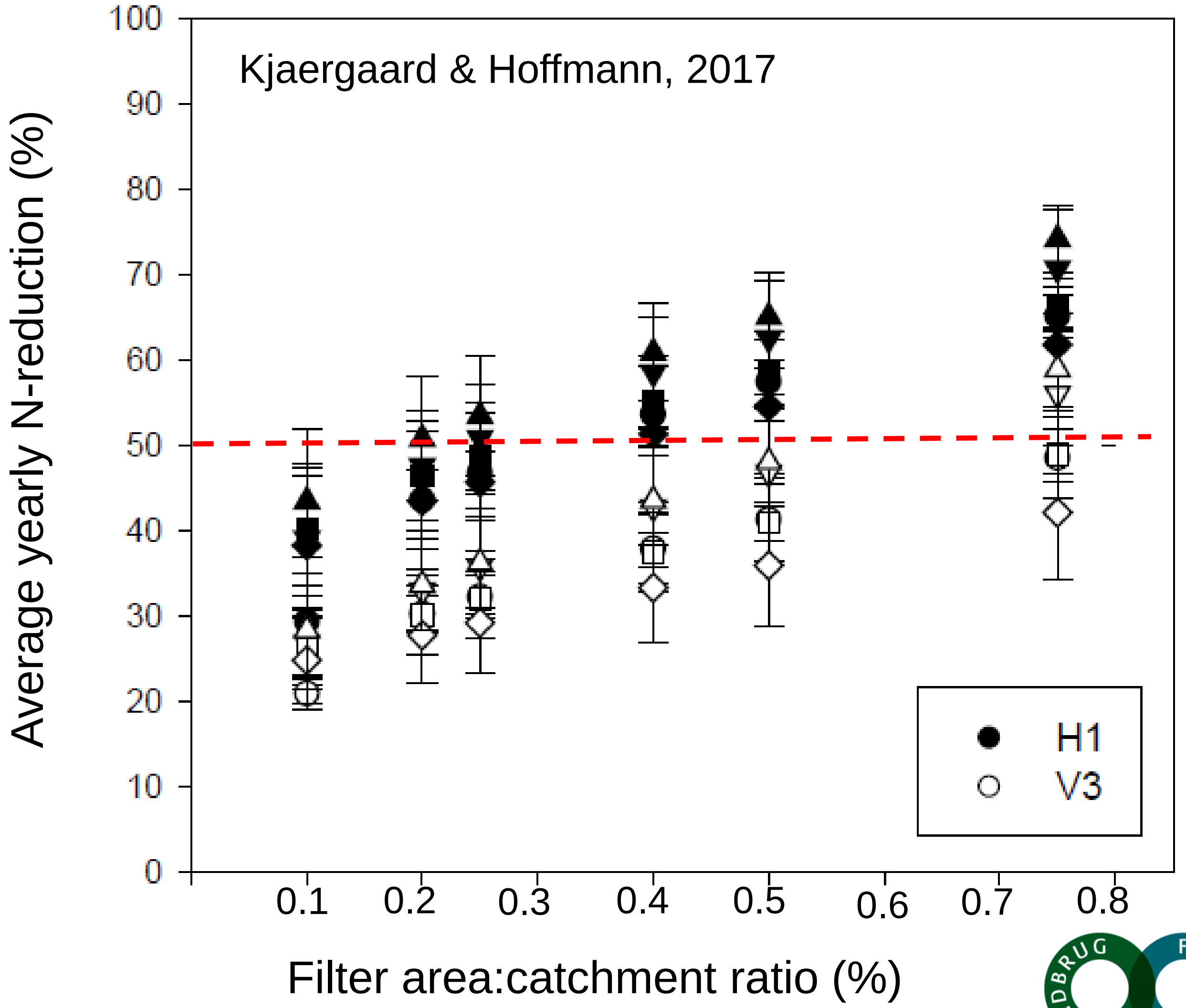
Hoffmann & Kjaergaard, 2019

Operational model for estimating bioreactor efficiency

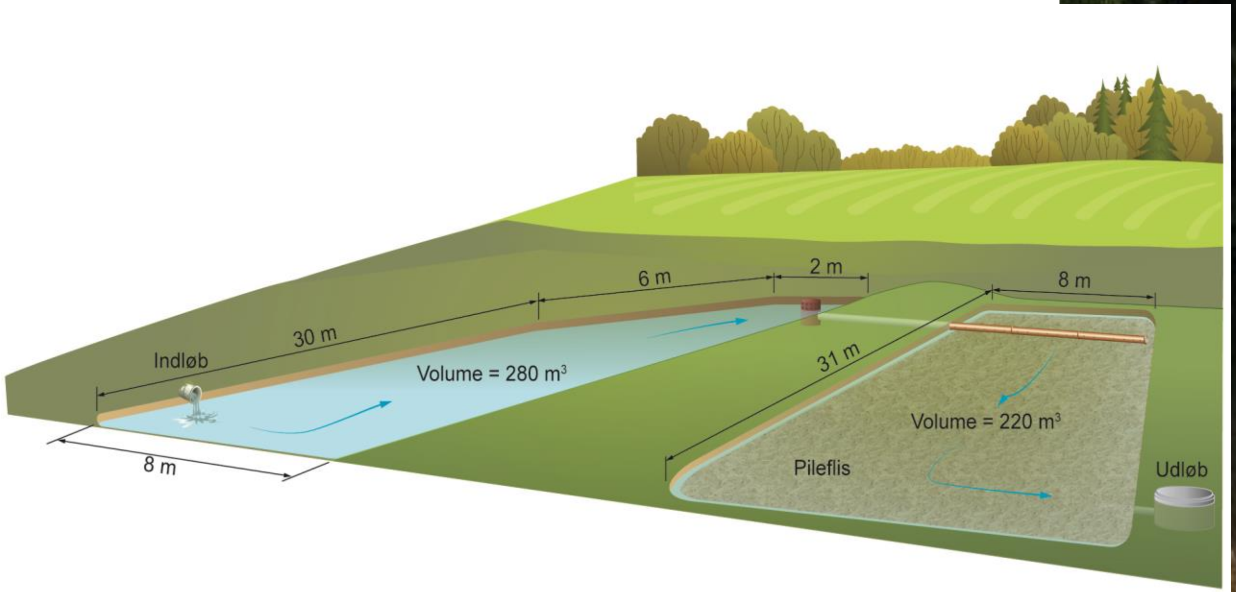
NO_3-N_{eff} (%) = *a*×WT + *b*×HRT
R^2 = >0.85

Carl Christian Hoffmann*, Charlotte Kjaergaard** and Søren Erik Larsen. Accepted may 2019

Nitrogen removal in woodchip-based biofilters of variable designs treating agricultural drainage discharges



Full-scale bioreactor prototype including storage pond



iDRÆN – matrice vådområde (www.idraen.dk)

Woodchips filter-bed with storage pond
Size: 0,2-0,25% of drained catchment

Hoffmann & Kjaergaard, 2017

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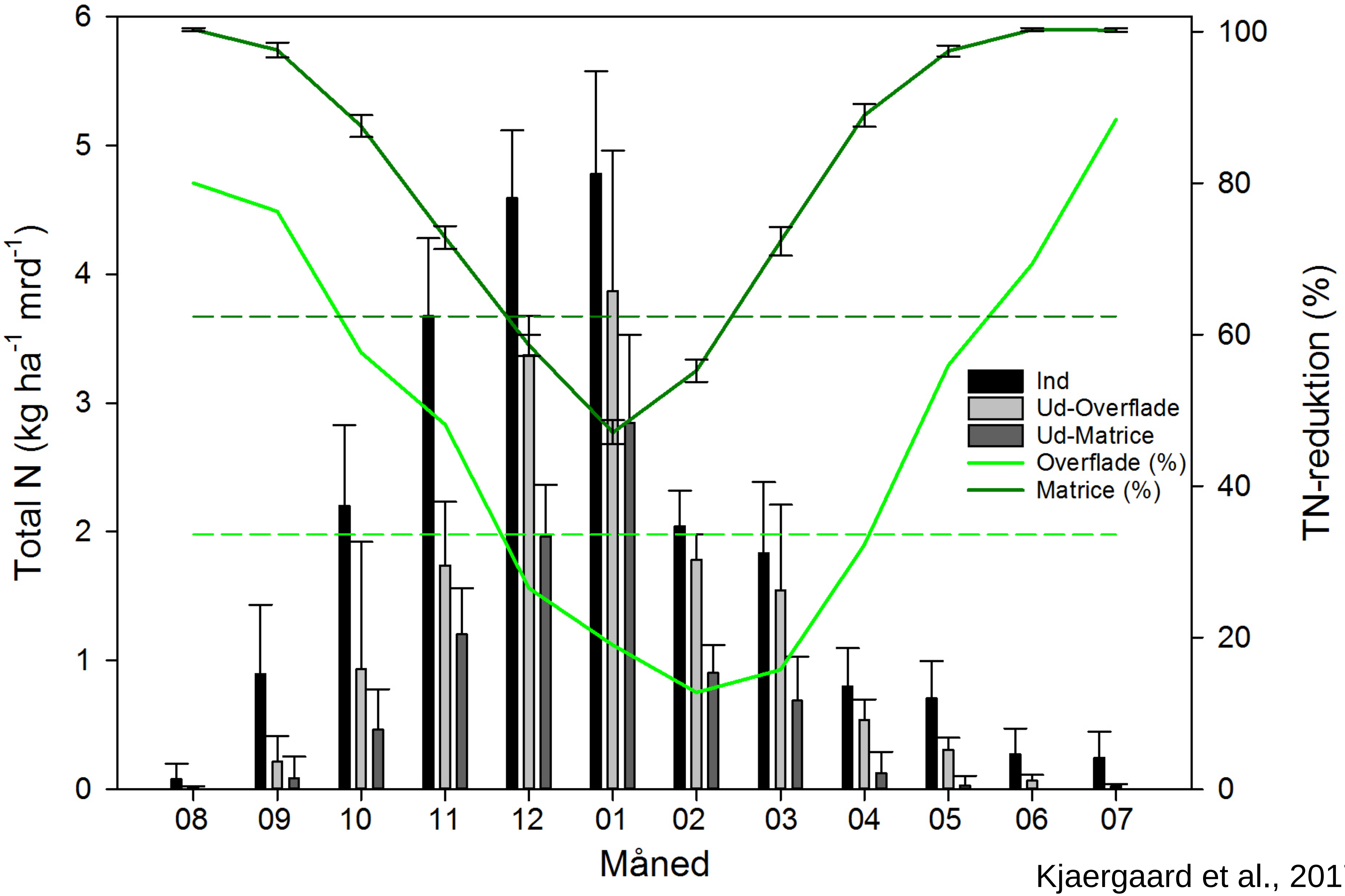
- Guidelines for the Danish Ministry (Hoffmann & Kjærgaard, 2018)
- Guidelines for advisers and constructors (Kjærgaad, 2019)

Surface-flow versus bioreactor



Kjaergaard et al., 2017

Small local wet-areas within field – potential not investigated

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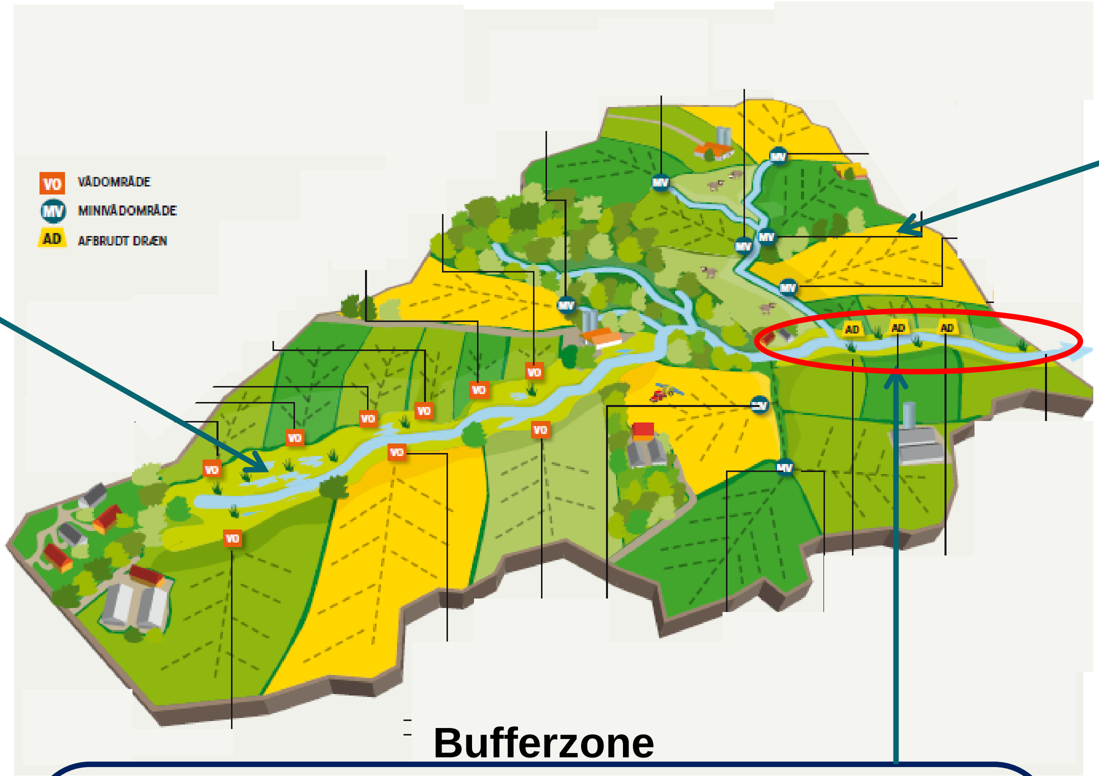
Visions for the targeted nutrient mitigation – restore landscape filters

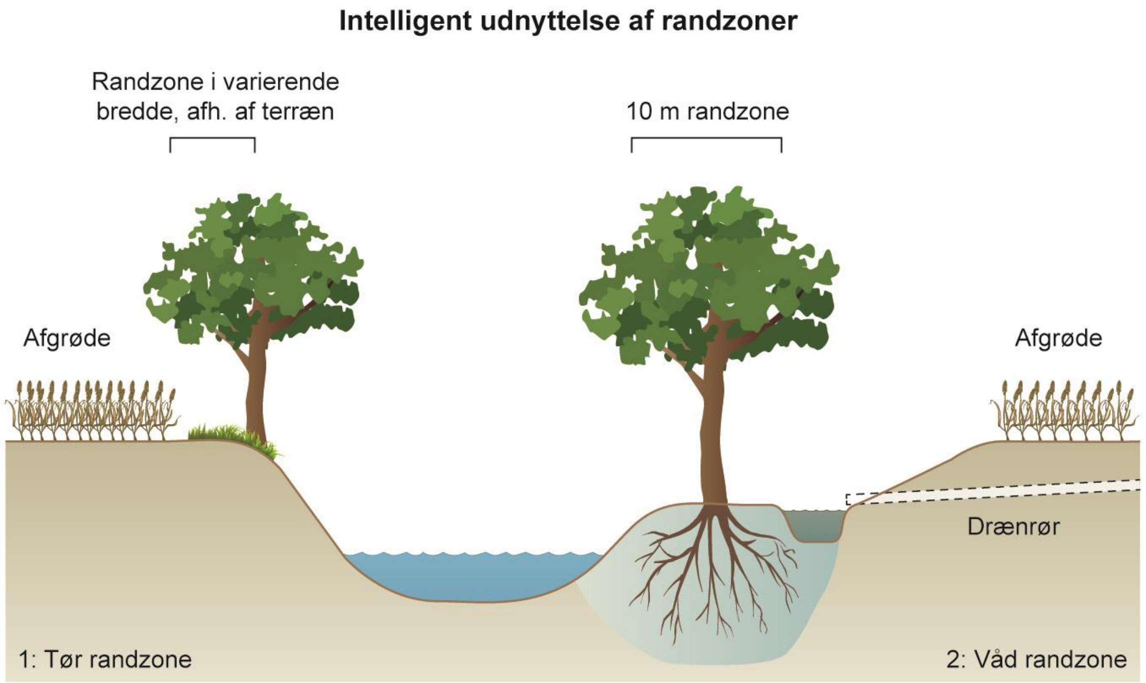
Riparian lowland



Constructed wetlands

Bufferzone

Intelligent bufferzone (IBZ)



Kronvang et al., (2017)
Size: x% of drainage catchment (infiltation of soil)
Yearly N-reduction: 20-30%
Yearly P-reduction: 40-50%

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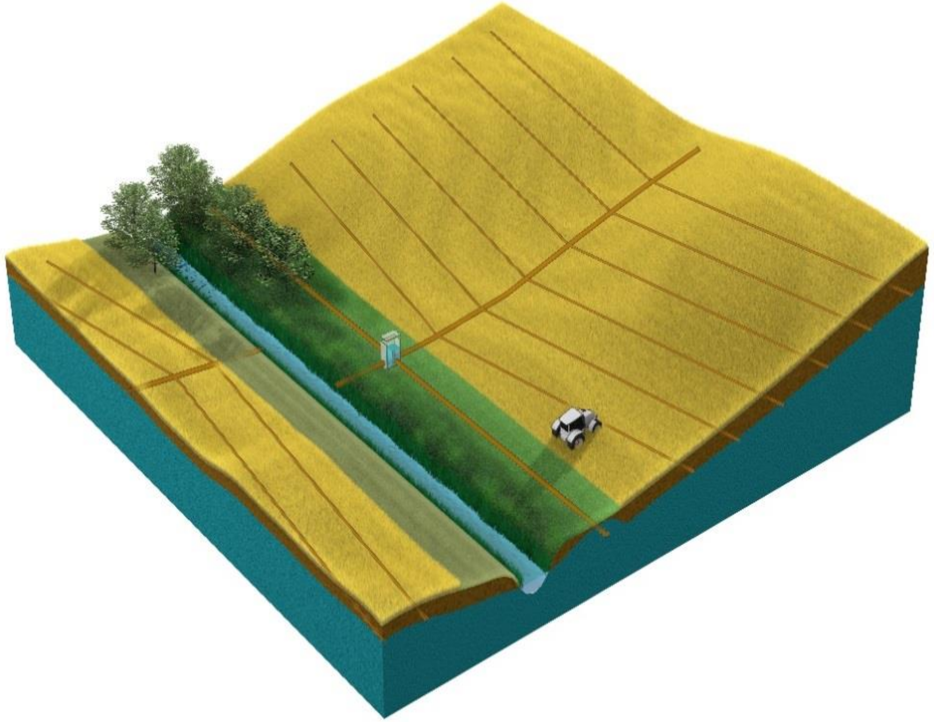
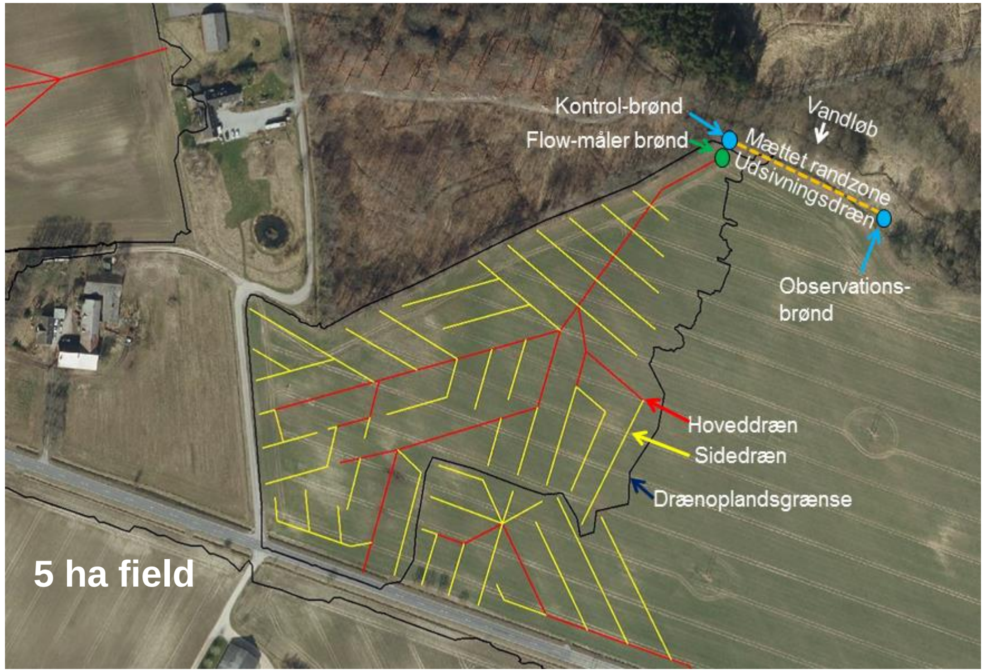
Saturated buffer zones

First Danish projects started in 2018 (SEGES)

- Denitification in the bufferzone (soil type, geochemistry)
- Retention of particulate-P (risk of *in situ* P-mobilization)
- Hydraulic capacity -> buffer zone: draiange catchment ratio





Implementation strategy

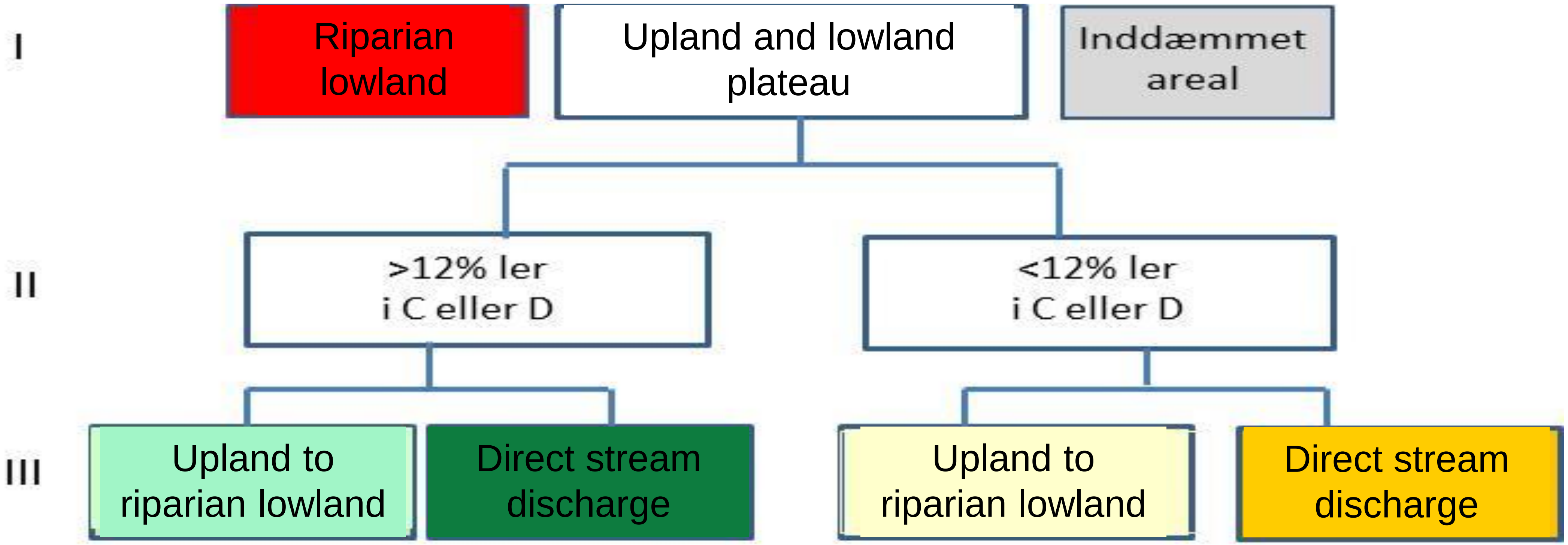
Where should we implement targeted drainage measures to ensure a cost-efficient mitigation strategy?

Strategy for implementing targeted measures

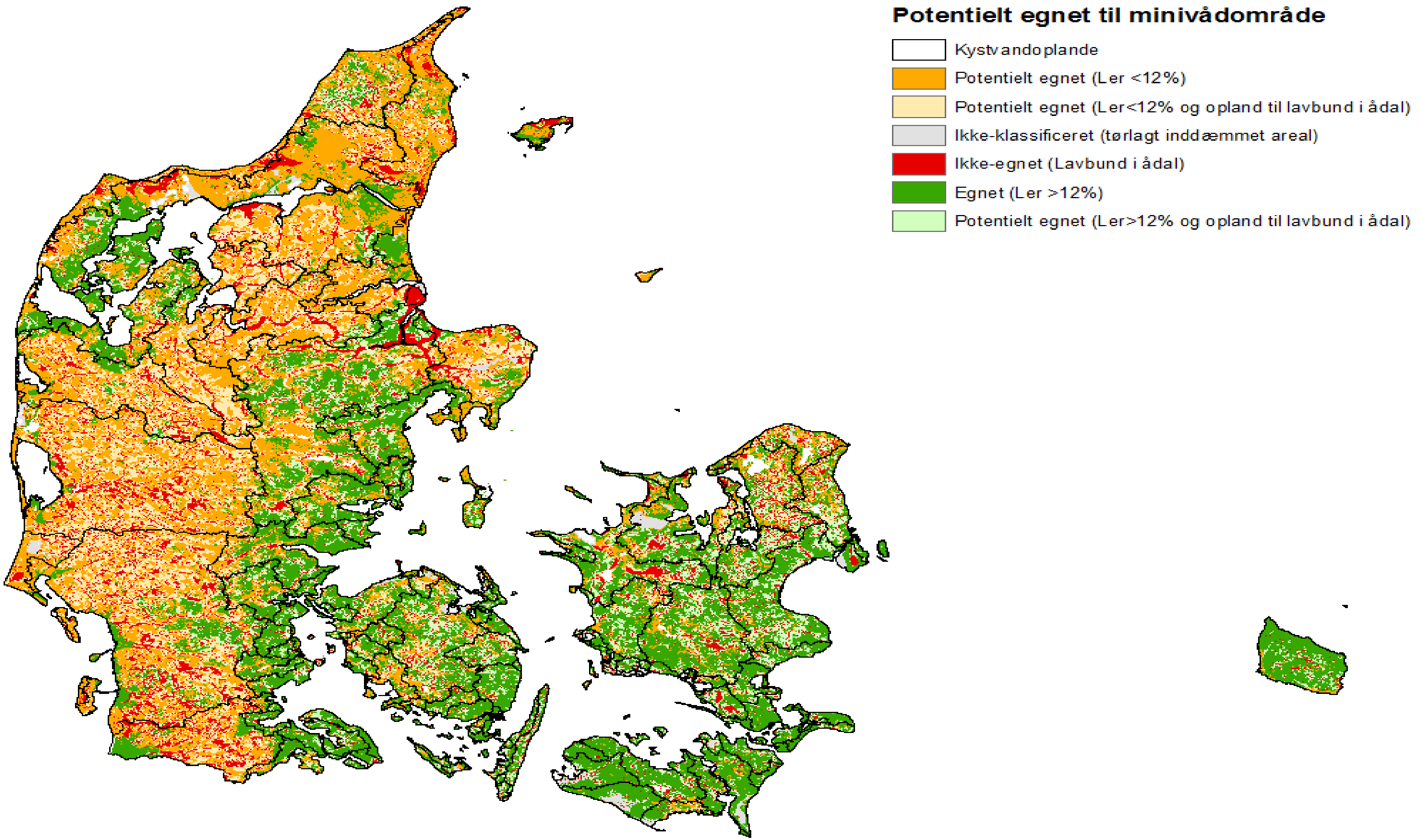
Criteria

1. Reduction requirement (coastal targets)
2. **Suitability of agricultural areas (drainage discharge dominated areas)**
3. Nutrient losses by drainage - quantitative significant
4. Quantitative environmental impact on coastal water (N)

Nationalt suitability map for implementing drainage measures



Nationalt suitability map for implementing drainage measures



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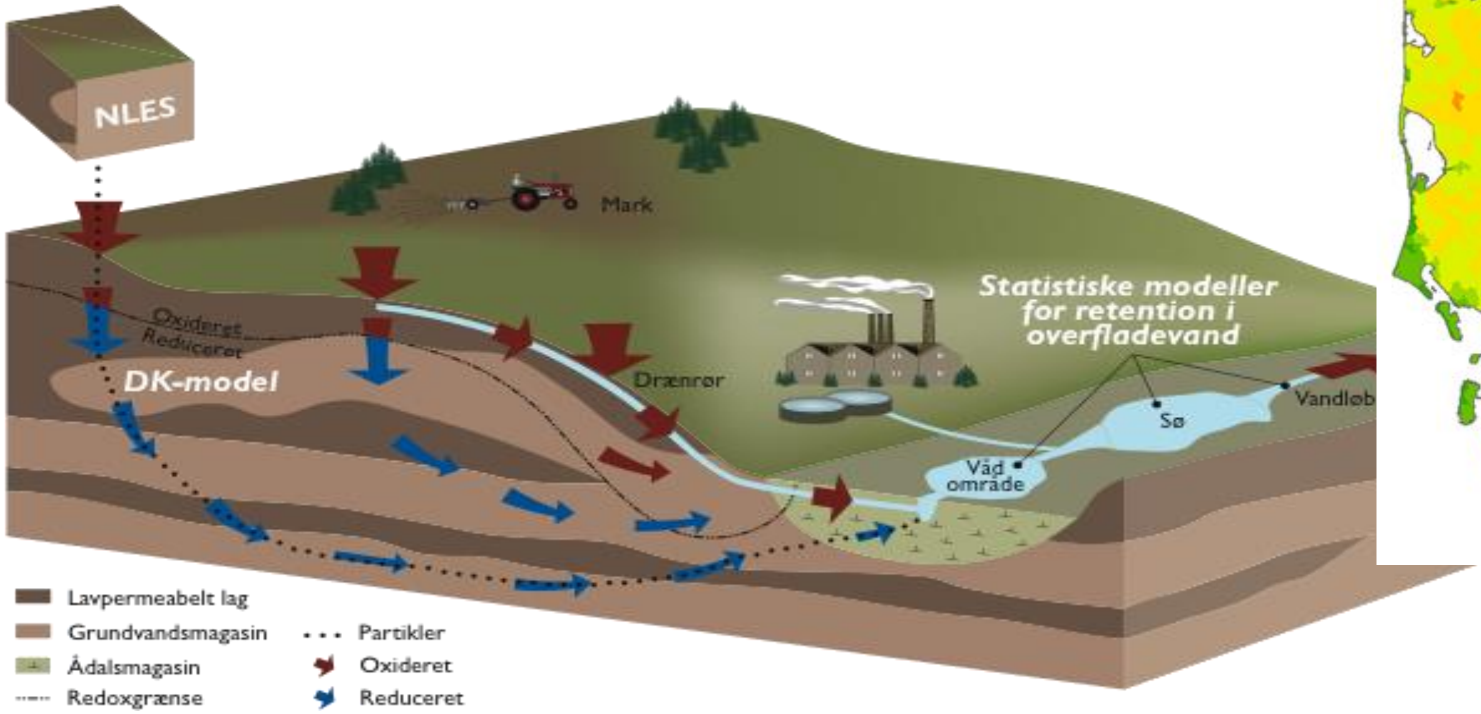
Strategy for implementing targeted measures

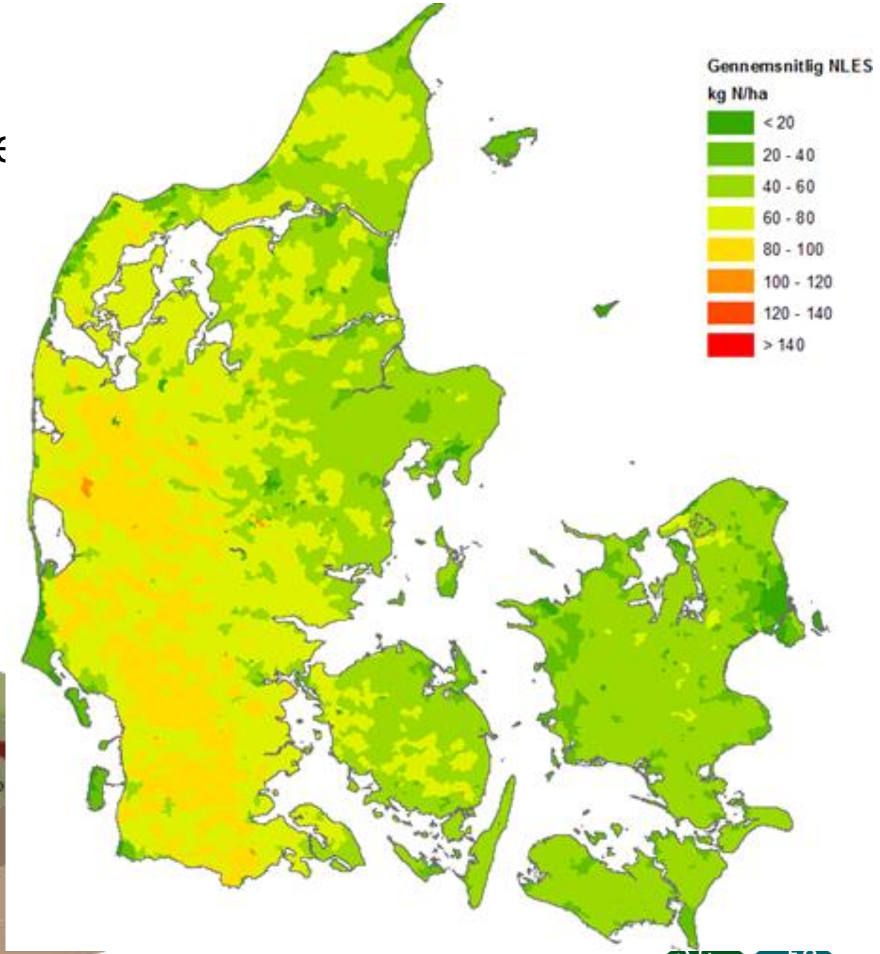
Criteria

N-losses from rootzone

1. Reduction requirement (coastal targets)
2. Suitability of agricultural areas (drainage discharge dominate
3. **N-losses by drainage - quantitative significant**
4. Quantitative environmental impact on coastal water (N)



N-loss from the rootzone corrected for the drainage fraction



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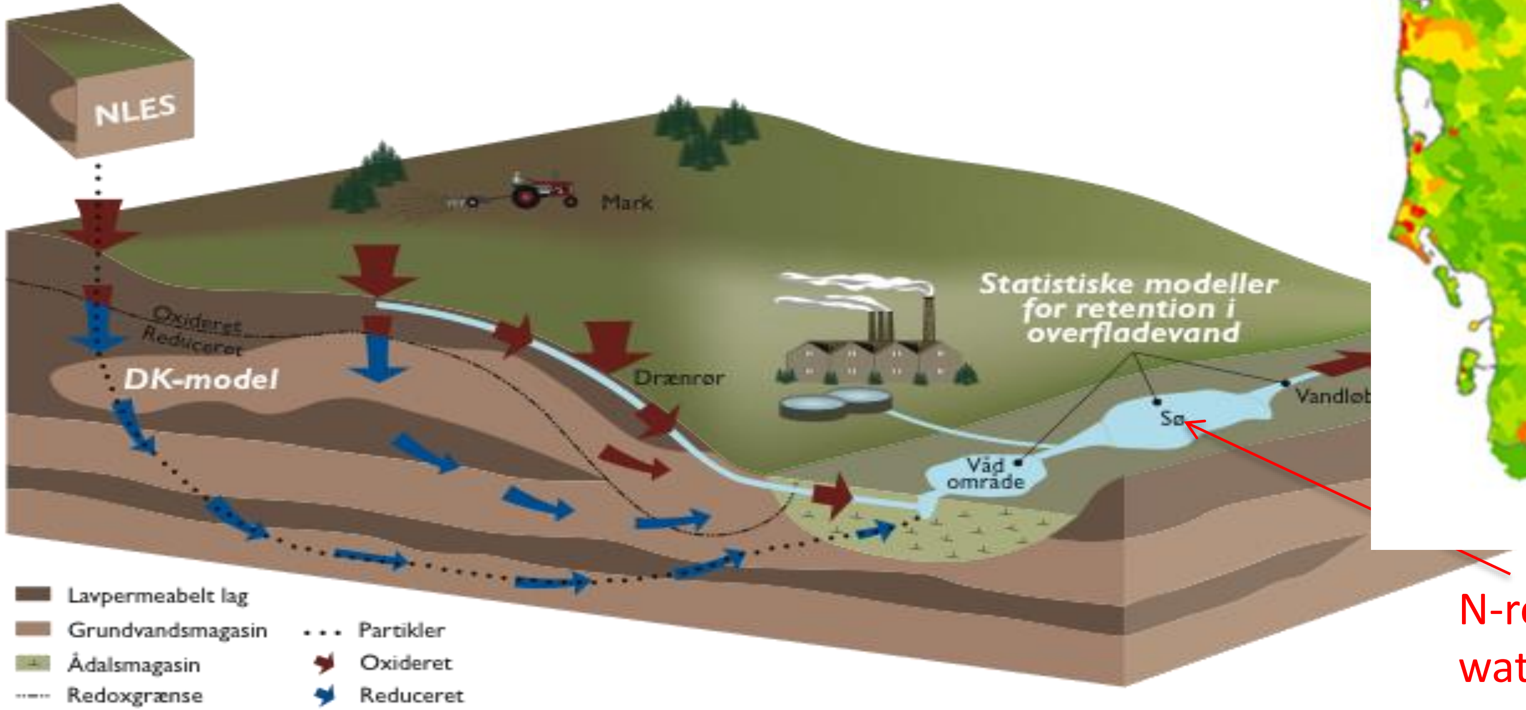
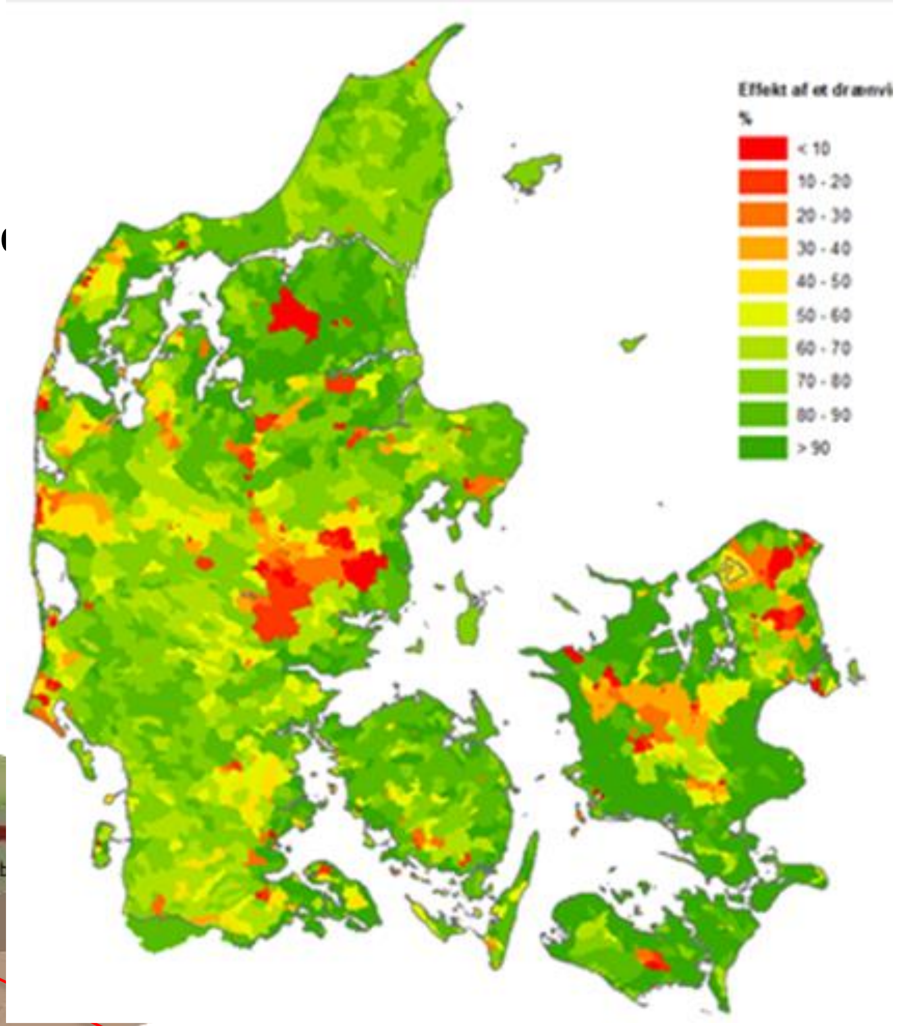
Strategy for implementing targeted measures

Criteria

1. Reduction requirement (coastal targets)
2. Suitability of agricultural areas (drainage discharge dominate
3. Nutrient losses by drainage - quantitative significant
4. **Quantitative environmental impact on coastal water (N)**



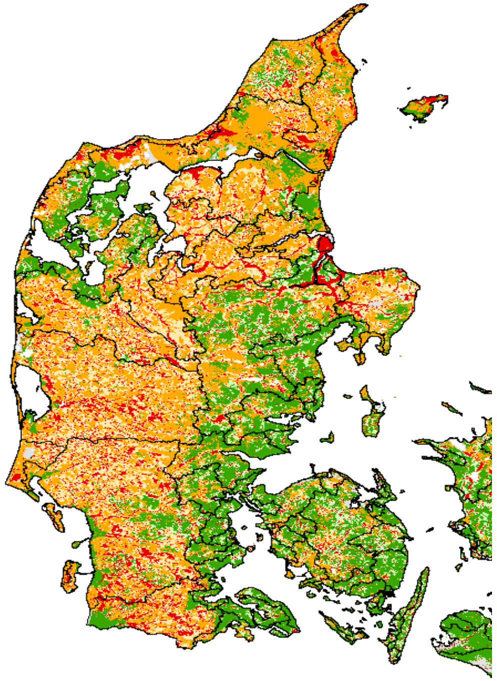


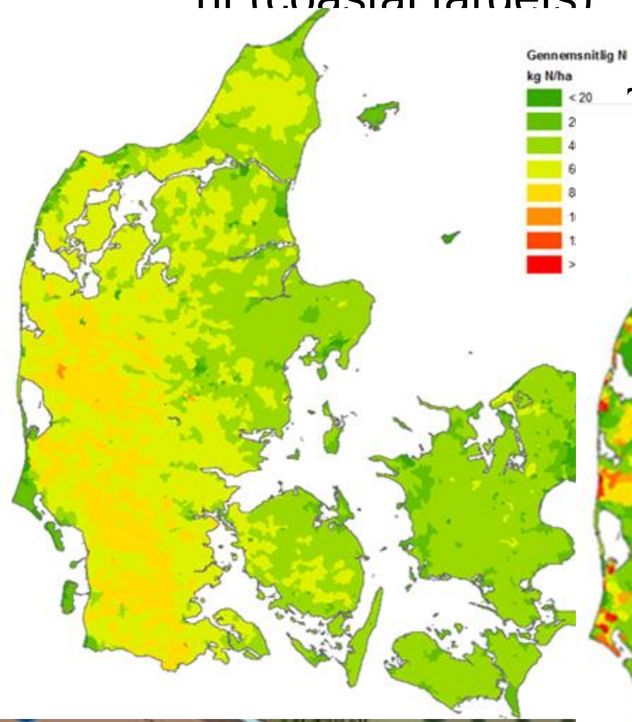
N-reduction in surface water from 0-100%

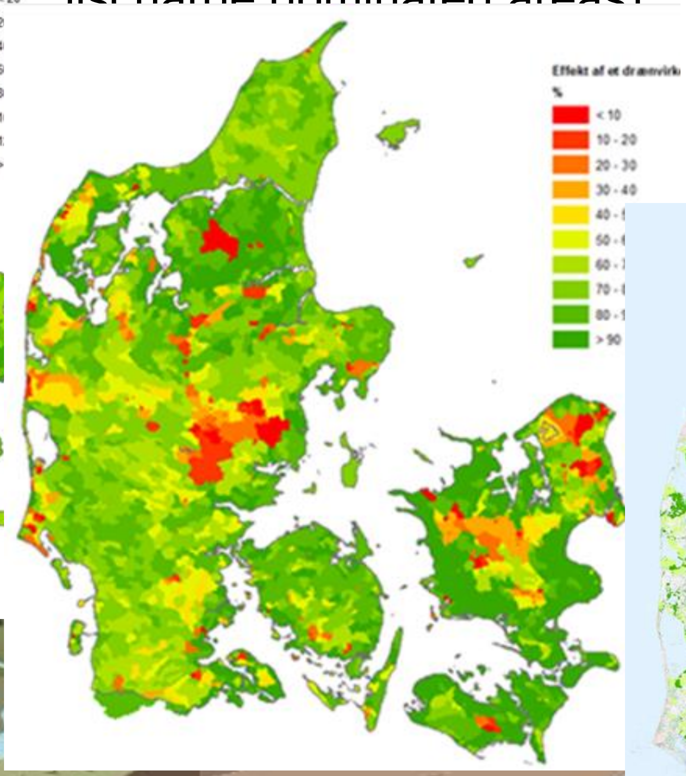
National deignation maps for implementing drainage filters

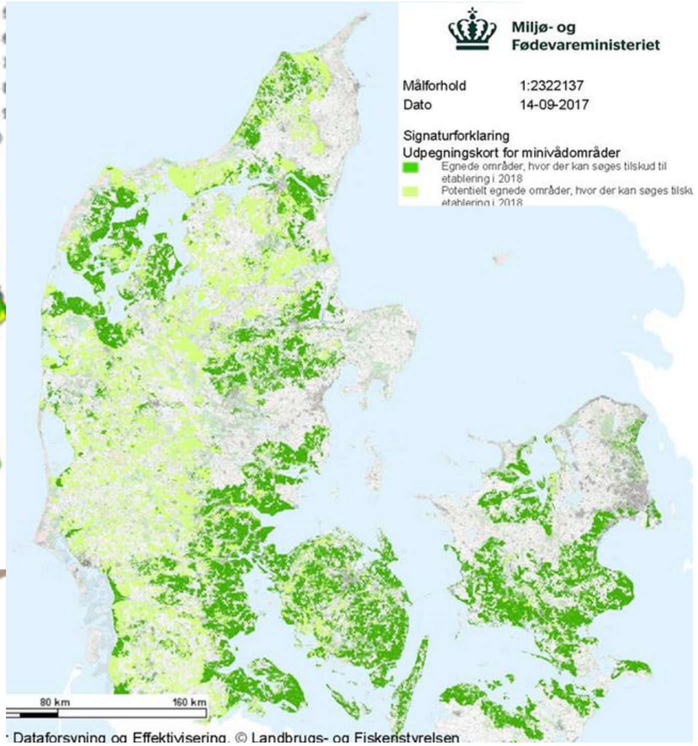
nt (coastal targets)

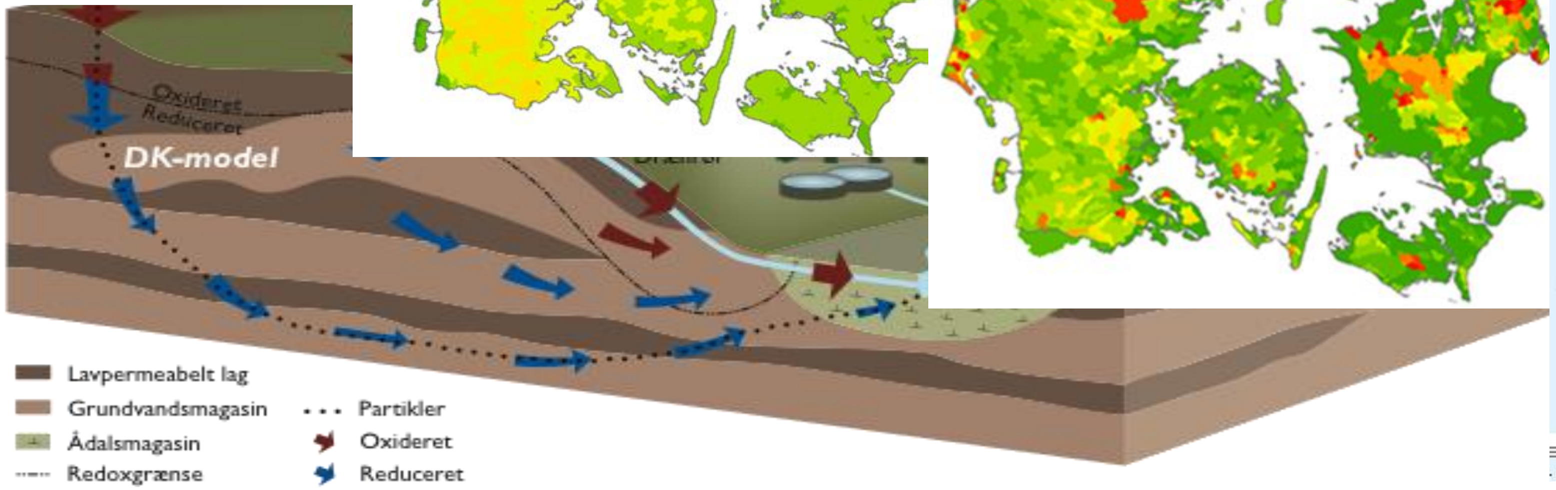
discharge dominated areas)











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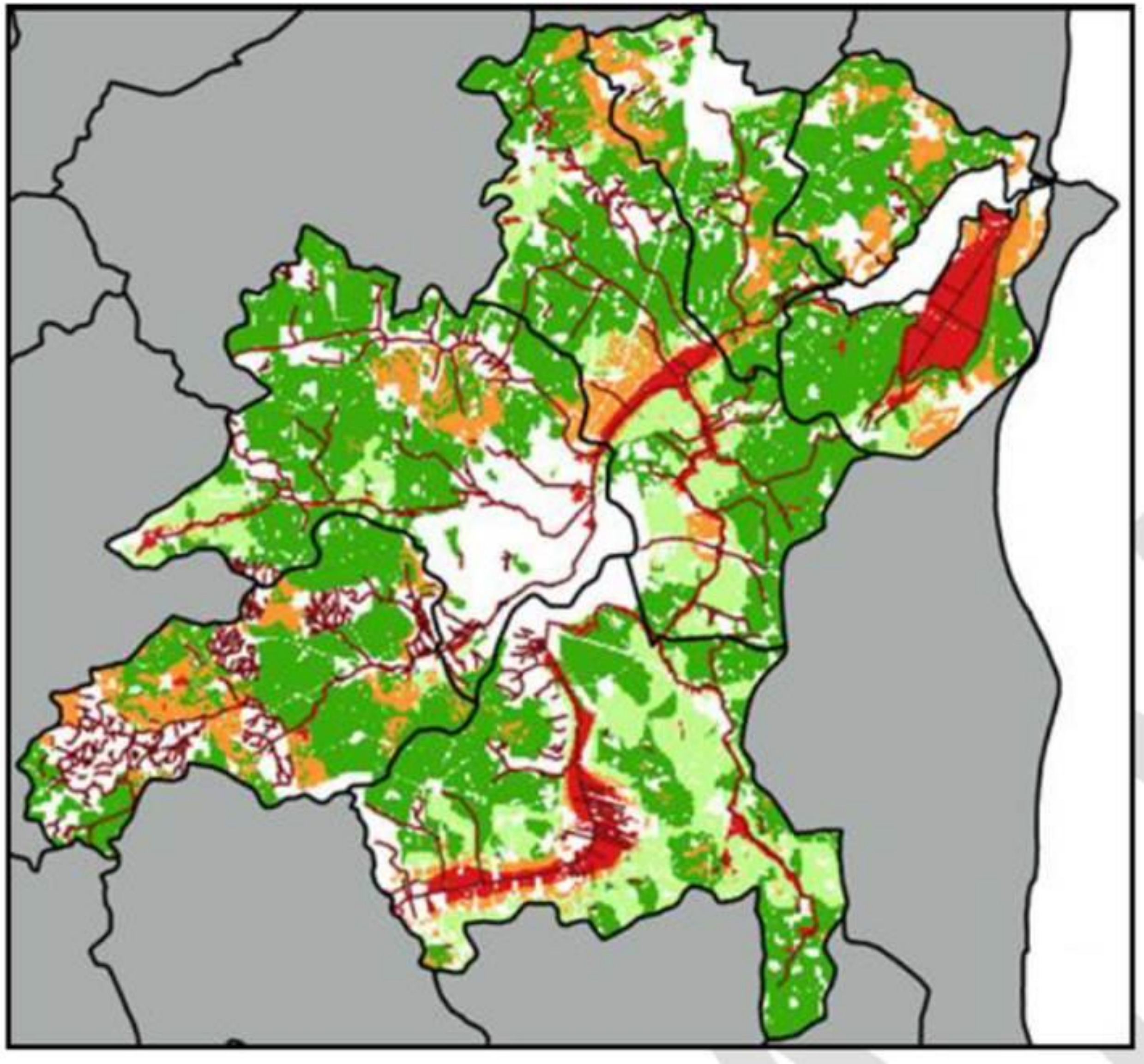
Case: Mitigation strategy – Norsminde Fjord catchment

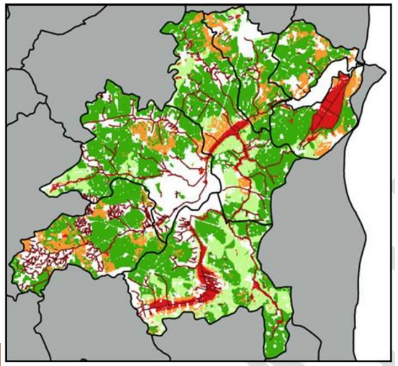


Catchment (10.100 ha) including six ID15 subcatcments (1500 ha units)

ID15 subcatchment	Suitable for CWs (%)	Upland drained to riparian lowland (%)	Riparian lowland (%)
43600028	61	4,4	16
43600041	50	33	11
43600042	75	11	2,5
43600043	61	22	6,2
43600051	73	1,1	0,9
43602599	72	5,4	1,1
Total	**4.815 (63)**	**1.224 (16)**	**541 (7)**

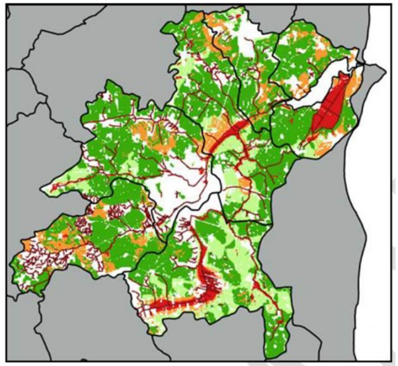
Kjærgaard, C., Hoffmann, C.C., Iversen, B.V. 2017. Filtre i landskabet øger retentionen. I: Filtre i landskabet, Vand & Jord, nr. 3, s. 106-110

Case: Mitigation strategy – Norsminde Fjord catchment



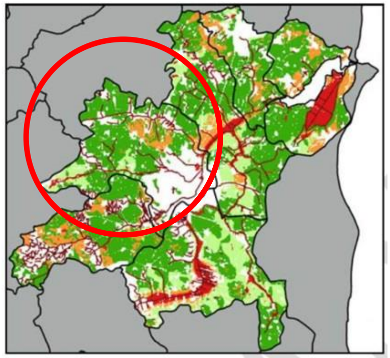
Mitigation measure	Position in landscape	Area required (% of drainage catchment)	N-red. eff (%)	P-ret. eff (%)
Riparian wetlands	Riparian lowland	10*	20-100	Risk evaluation
Surface-flow constructed wetlands	Upland	1	20-30	30-80
Subsurface-flow constructed wetlands	Upland	0,2-0,25**	50-70**	N.A.

Case: Mitigation strategy – Norsminde Fjord catchment



Measure	Catchment	Area	Yearly N-effect		Mitigation potential scenarios	
	ha	ha	Ton N/yr	Kg N/ha	Ton N/yr	Ton P/yr
Baseline	7.500	7.500	-	-	173	4,7
Riparian wetlands	1.224	122	18-35	148-287	18-35 (N-red. 10-20%)	Risk eval.
Surface-flow CW	4.815	48	51	1.063	69-86 (N-red. 40-50%)	1.9-2.4 (43-54%)
Subsurface-flow CW	4.815	12	95	7.917	113-130 (N-red. 67-75%)	N.D.

Mitigation strategy – Norsminde Fjord catchment



Subcatchment (ID15) N-reduction taget in 2021 = 2.594 kg N/yr

- Calculations conducted for a ID15 subcatchment (1500 ha) with 70% agricultural area (1050 ha)
- Average N-leaching from rootzone ~60 kg N/ha and average N-retention is 62%

Mitigation measure	N-reduction target (kg N/yr)	N-effect rootzone (kg N/ha/yr)	N-effect on coastal load (kg N/ha/yr)	Required area of measure (ha)	Cost of measure (€/ha/yr)	Cost of mitigation strategy (ID15) €/yr
Catch crops	2.594	30	11.4	**228**	94	21.319
Set-aside	2.594	50	19.0	**137**	535	73.092
SF-CW	2.594	14	6.75	**3.84**	87*	33.433
Bioreactor	2.594	27	13.5	**0.38**	51**	9.773

*Construction cost depreciation in 10 years
** Constuction cost depreciation in 5 years (not including new supply of woodchips every 5 years)

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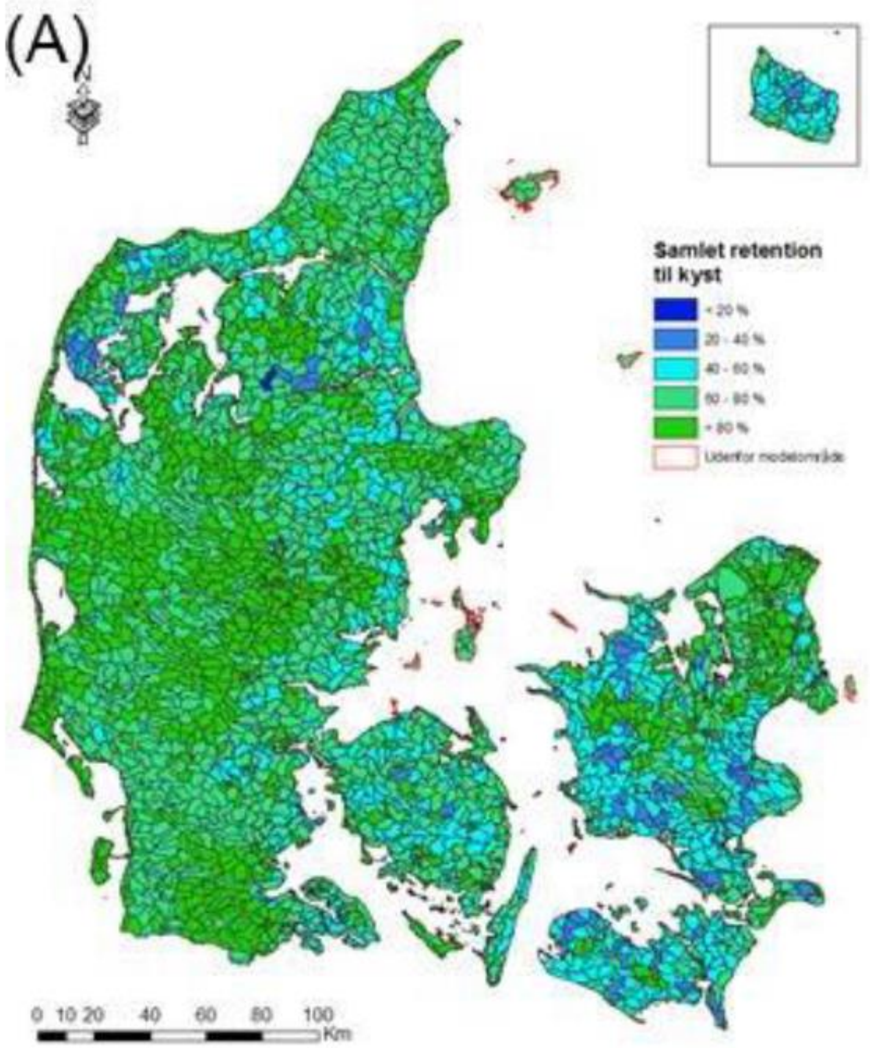
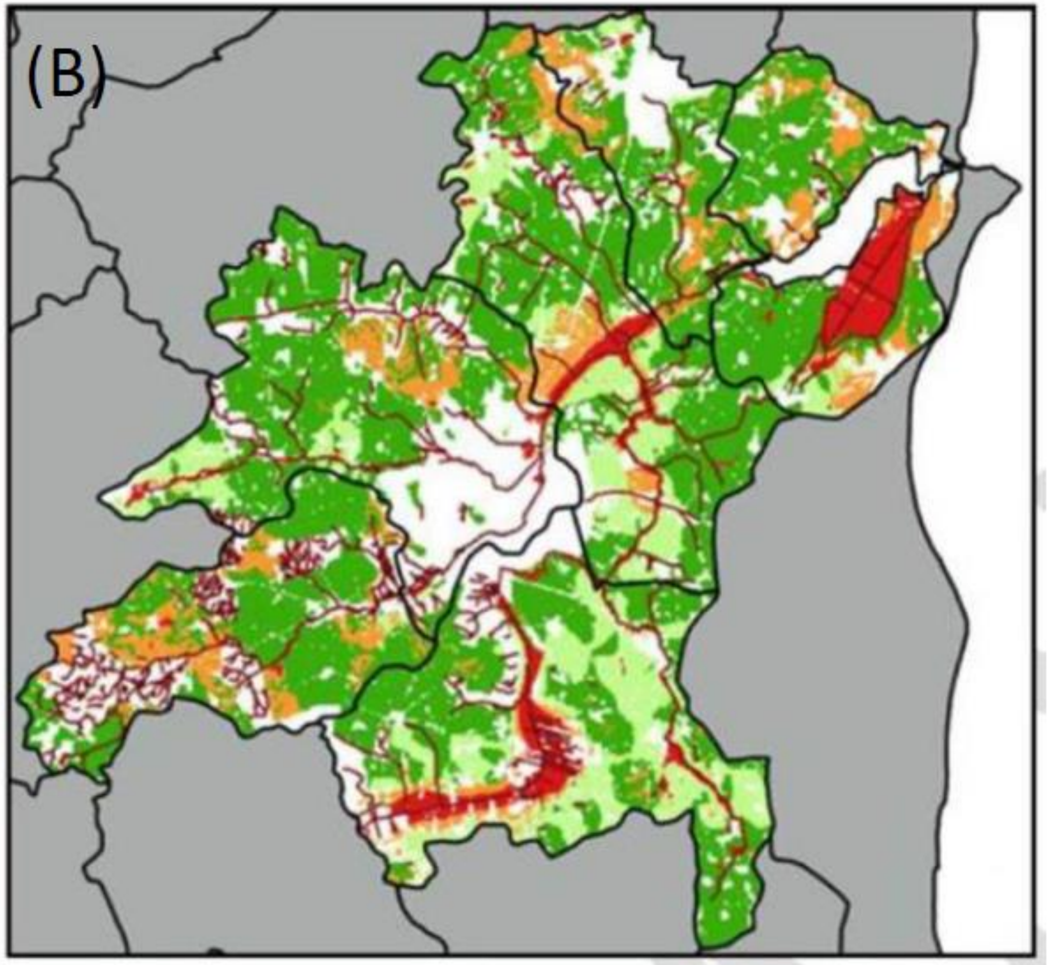
Vision for a more targeted implementation of measures

Targeted regulation ID15-scale (Højberg et al., 2015)



Targeted implementation within ID15-catchments



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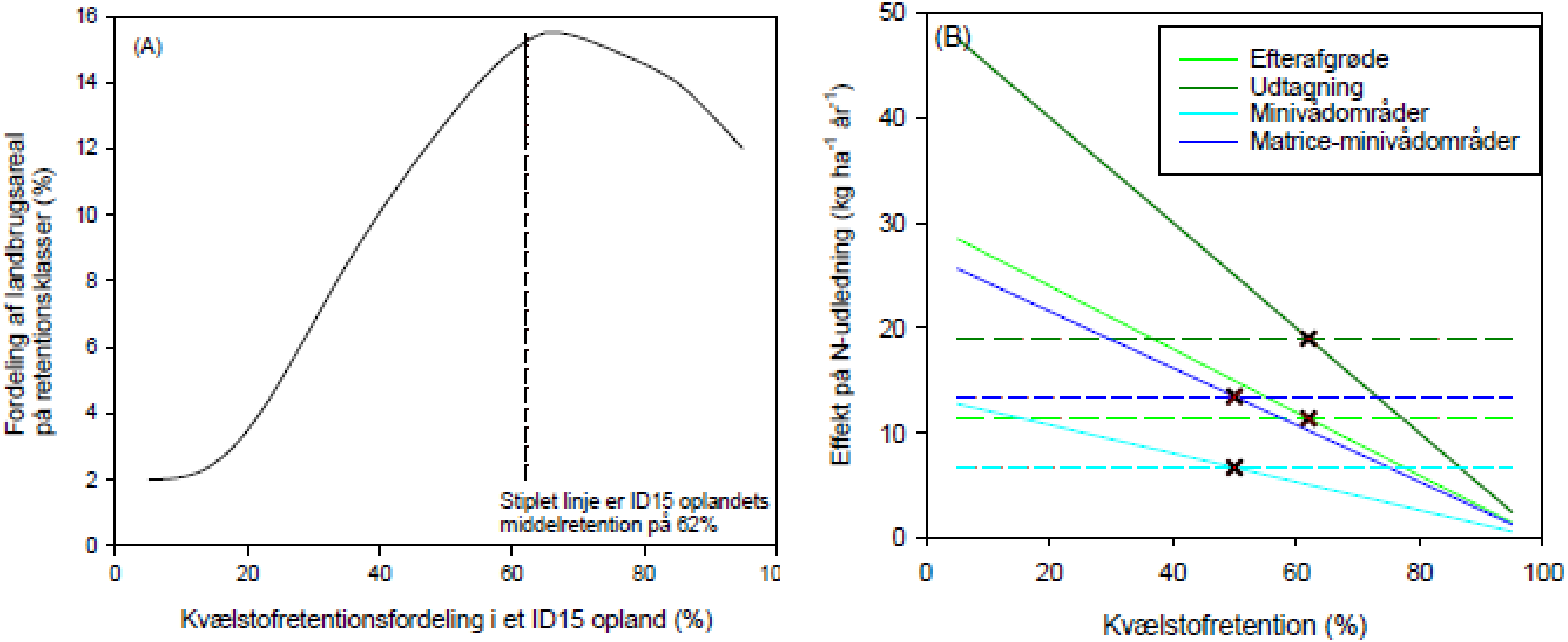
Targeted implementation within ID15 catchments



Targeted implementation within ID15 catchments

		Virkemiddelspotentiale uden ID15-målretning		Virkemiddelspotentiale med ID15-målretning	
	Målår	Nuværende N-effekt på udledningen kg N ha^{-1} $år^{-1}$	Arealkrav ved nuværende regulering ha	Målrettet effekt på udledningen kg N ha^{-1} $år^{-1}$	Arealkrav ved målrettet indsats ha
Efterafgrøder	2021	11,4	228	20,8	125
	2027		333	19,2	197
Udtagning	2021	19,0	137	43,0	60
	2027		200	41,2	92
Minivådområder	2021	6,75	384 (3,84)*	10,9	238 (2,4)*
	2027		562 (5,62)*	10,6	356 (3,6)*
Matrice-minivådområder	2021	13,5	192 (0,38)*	23,6	110 (0,22)*
	2027		281 (0,56)*	23,5	161 (0,32)*

Thanks

Photo surface-flow constructed wetland: Carsten Søbog

Differentiering af den målrettede indsats indenfor ID15 opland

Økonomisk potentiale

Omkostninger ved målopfyldelse med 2019-reguleringen og en differentieret målrettet indsats for fire virkemidler hhv. efterafgrøder, udtagning, minivådområder og matriceminivådområder for 2021 og 2027

	Indsatsår	Omkostning virkemiddel kr ha^{-1} år^{-1}	ID15 arealkrav ha	Omkostning ID15 opland kr år^{-1}
Efterafgrøder	2021	700	228	159.250
	2027	700	333	232.750
Udtagning	2021	4000	137	546.000
	2027	4000	200	798.000
Minivådområder	2021	650*	384 (3,84)*	249.744
	2027	650*	562 (5,62)*	365.011
Matrice-minivådområder	2021	380**	192 (0,38)*	73.002
	2027	380**	281 (0,56)*	106.696

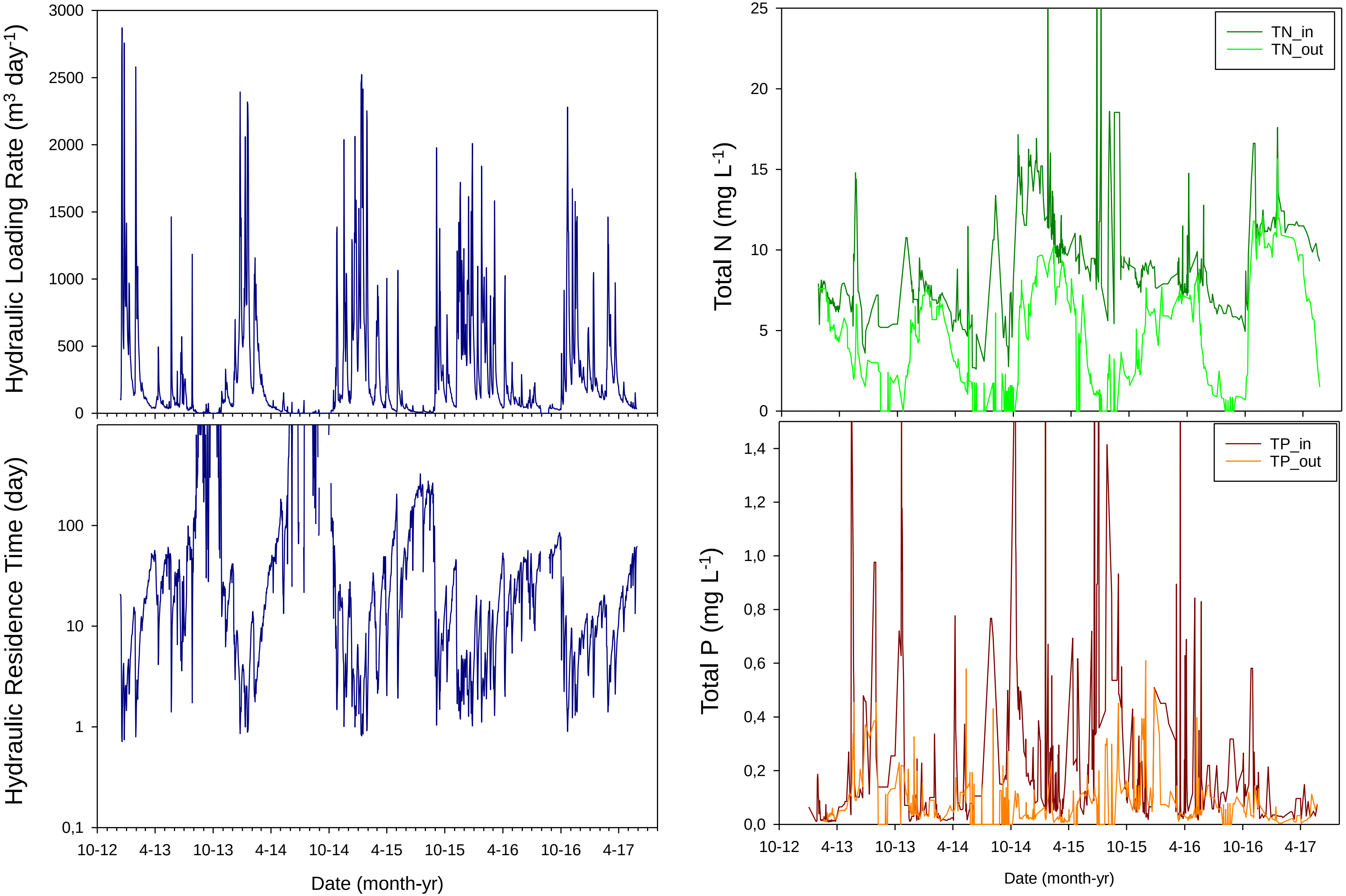
ID15 arealkrav ha	Pris ID15 opland kr år^{-1}
125	87.309
197	138.091
60	240.240
92	367.920
238 (2,4)*	154.666
356 (3,6)*	231.511
110 (0,22)*	33.102
161 (0,32)*	61.354

*Omkostning ved minivådområder er opgjort som etableringsomkostninger afskrevet over 10 år

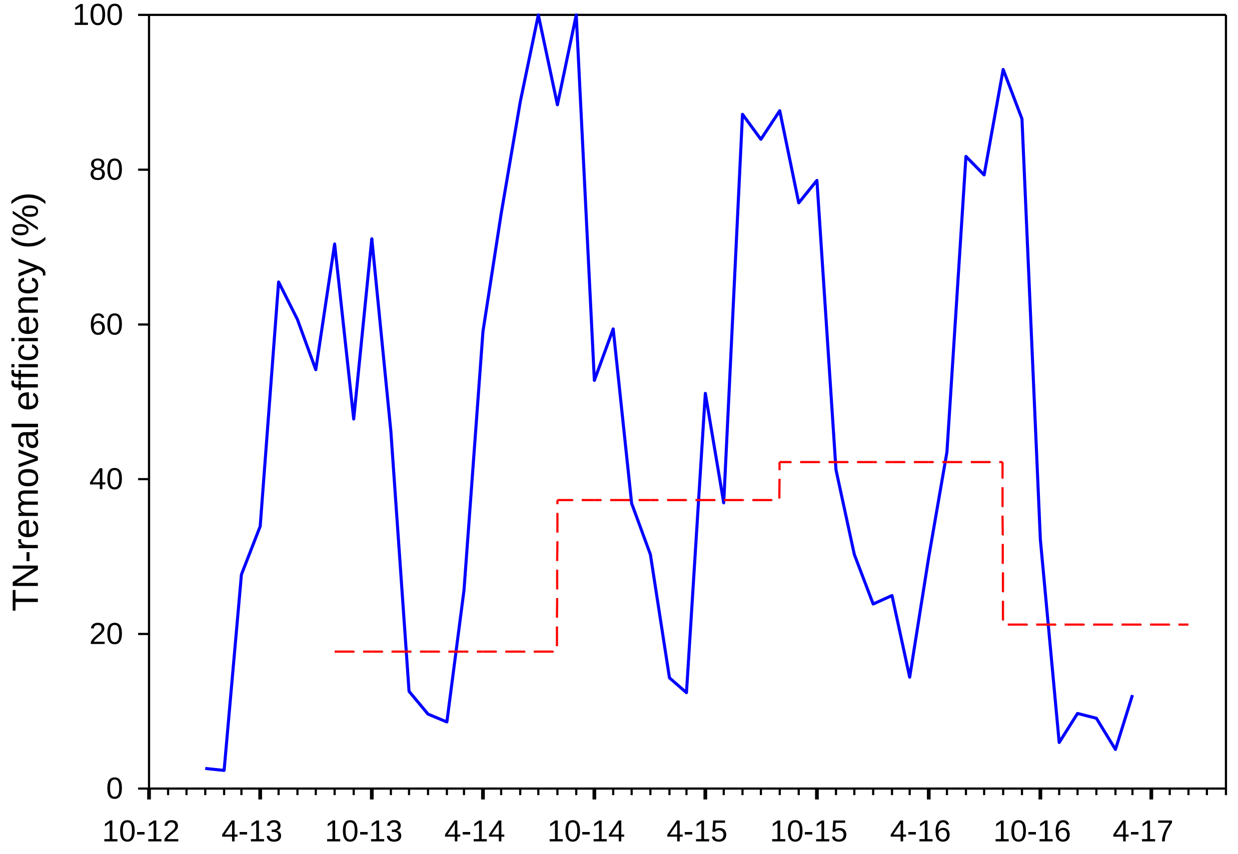
** Omkostningen ved matriceminivådområder er opgjort som etableringsomkostninger afskrevet over 5 år

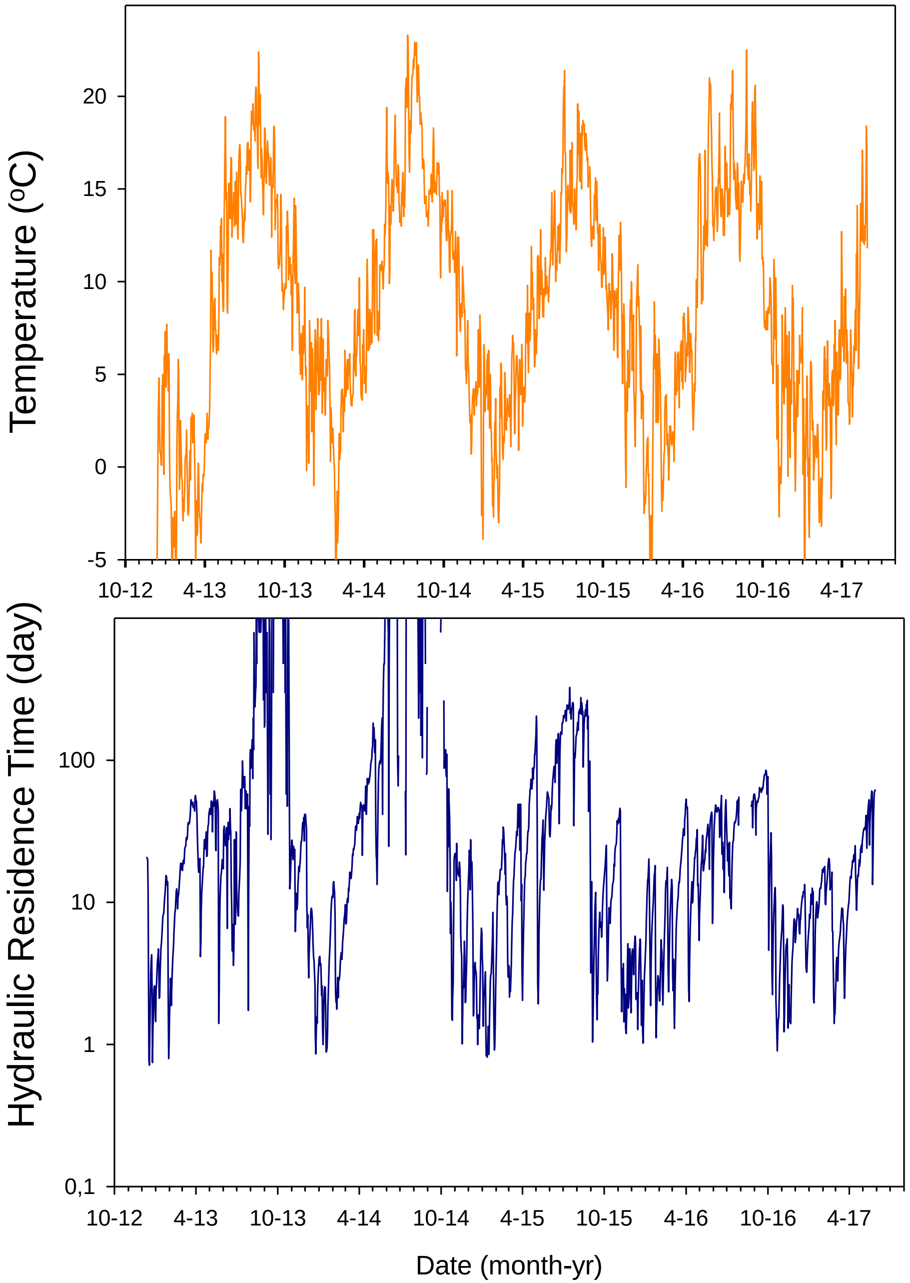
C. Kjaergaard, LuWQ2019

Nutrient retention in surface-flow constucted wetlands



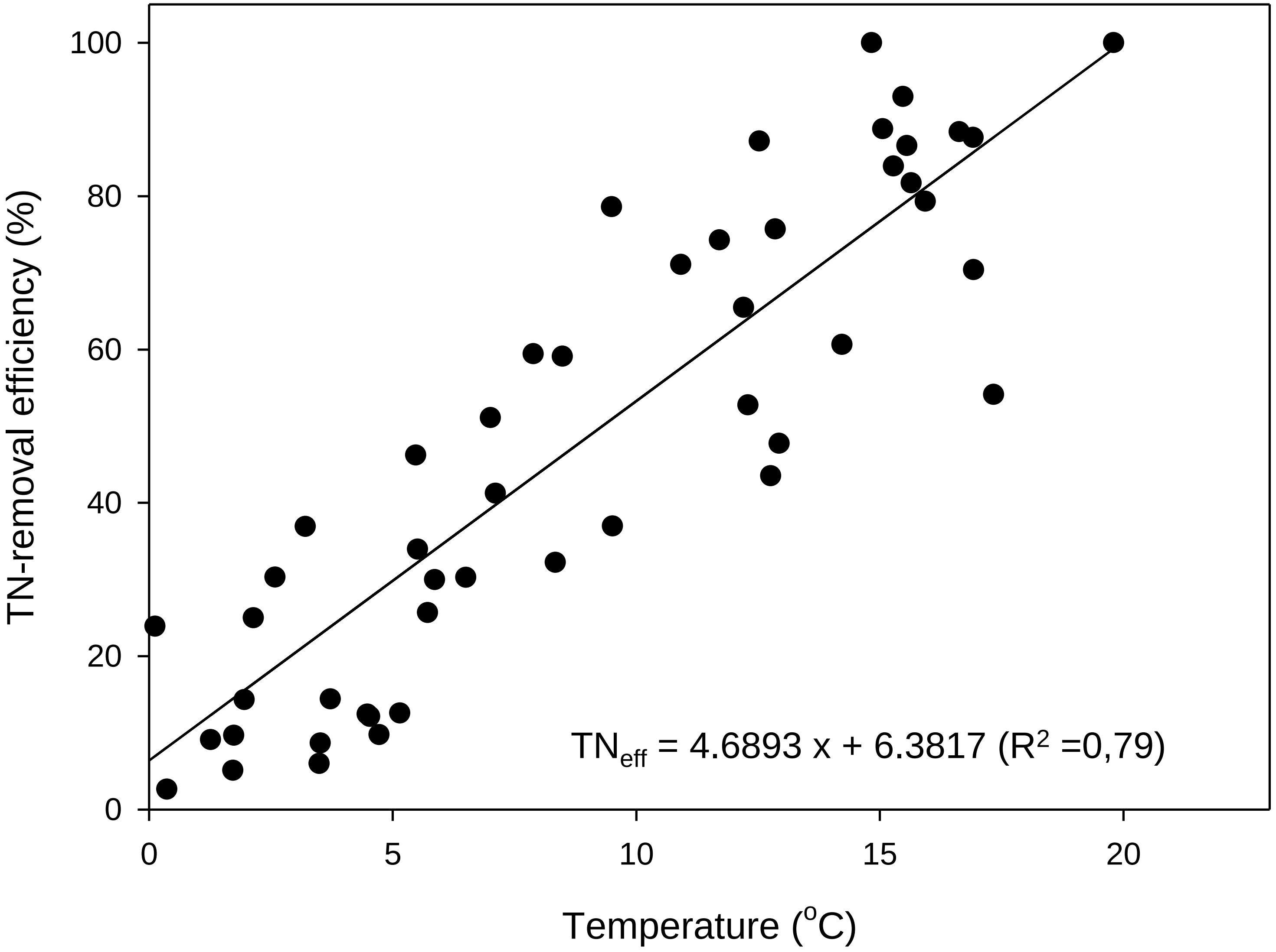
Seasonal and annual variation in N-removal efficiency





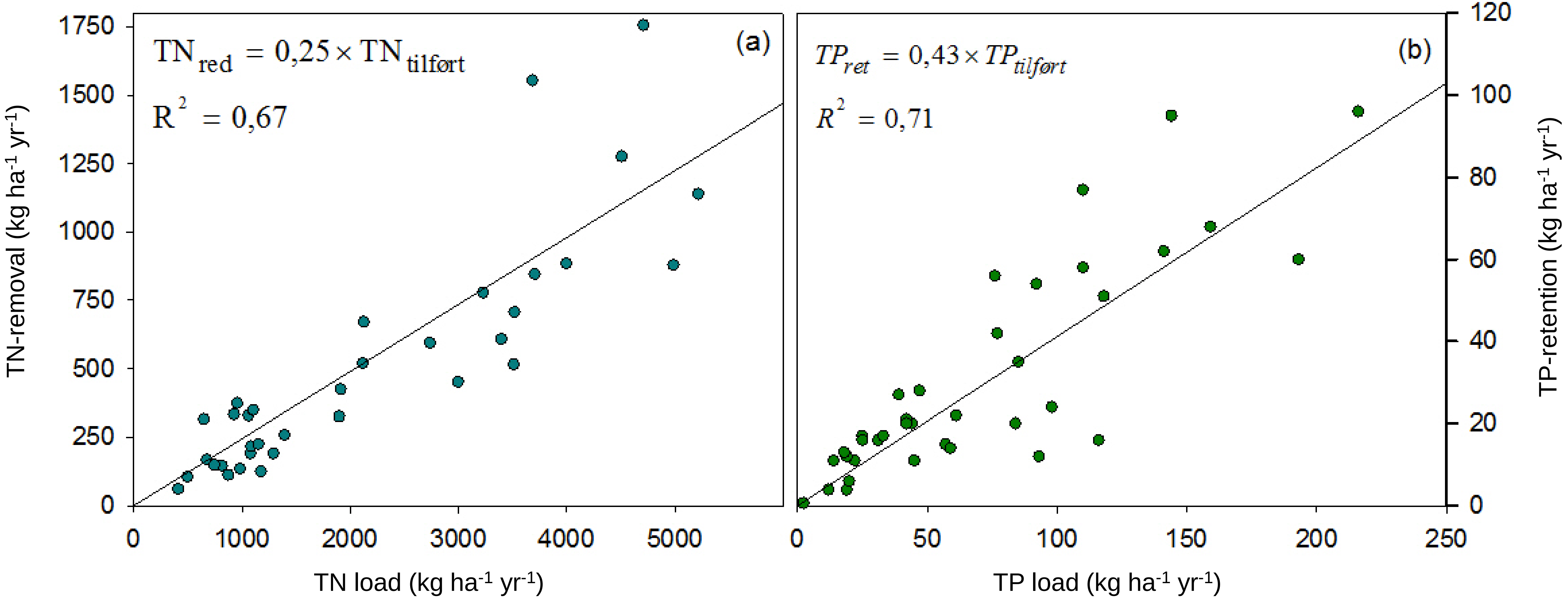
Red dotted line is the yearly average in the four years

Temperature is the major controlling parameter for TN_{eff}



Overall results of Danish constructed wetlands (2013-2017)

TN-reduction average 25% | TP-retention average 43%



Controlling parameters (N):

- Temperature, (HRT) (*Kjaergaard et al., In prep*)
- Nitrate-N reduction in the anaerobic sediment

Controlling parameters (P):

- PLR, HLR, P-form, Fe:P-ratio *(Mendes et al, 2018)*
- P-stability *(Mendes et al., 2018*

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