Assessment of the impact of different land use management scenarios on nutrient loading using SWAT+ and their consequences for eutrophication control in a Danish coastal lagoon.

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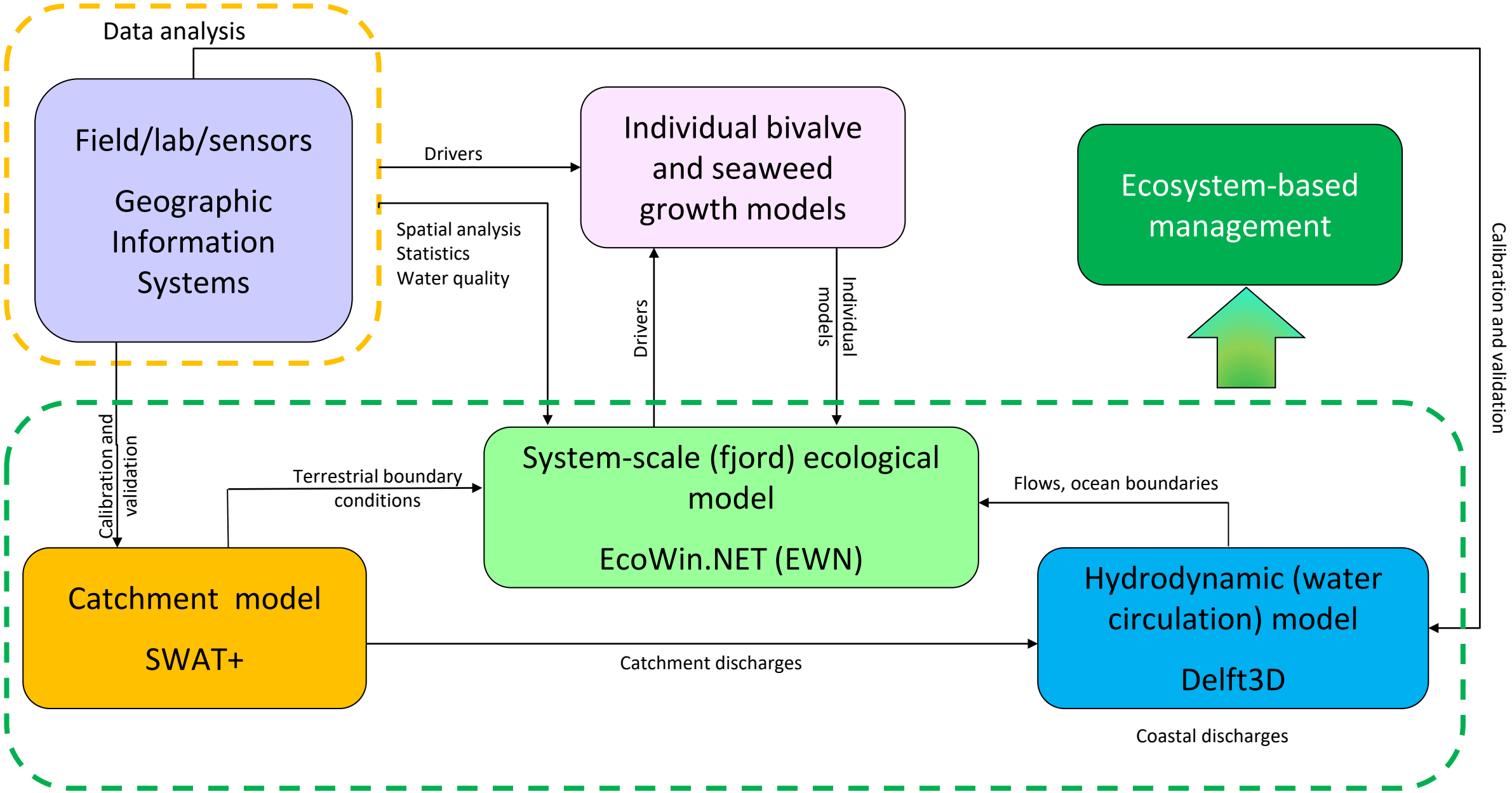
Water quality in Ringkøbing Fjord

- Shallow lagoon located in western Denmark (300 km^2) controlled by a sluice
- Water Framework Directive (WFD) classification:
  - Heavily Modified Water Body (HMWB)
  - Ecological potential value: *Poor* (target: at least *Good*)
- The classification results from complex interactions between pressure from land, connection with the sea, physical characteristics, environmental drivers and biota.
- **Objective 1**: Provide a thorough understanding of the interactions between the catchment, the fjord, and the sluice
- **Objective 2:** Offer insights into how the stakeholders can work together effectively to achieve the targets set by the WFD
- **Objective 3:** Support policy makers in achieving these targets, ensuring both social and environmental sustainability

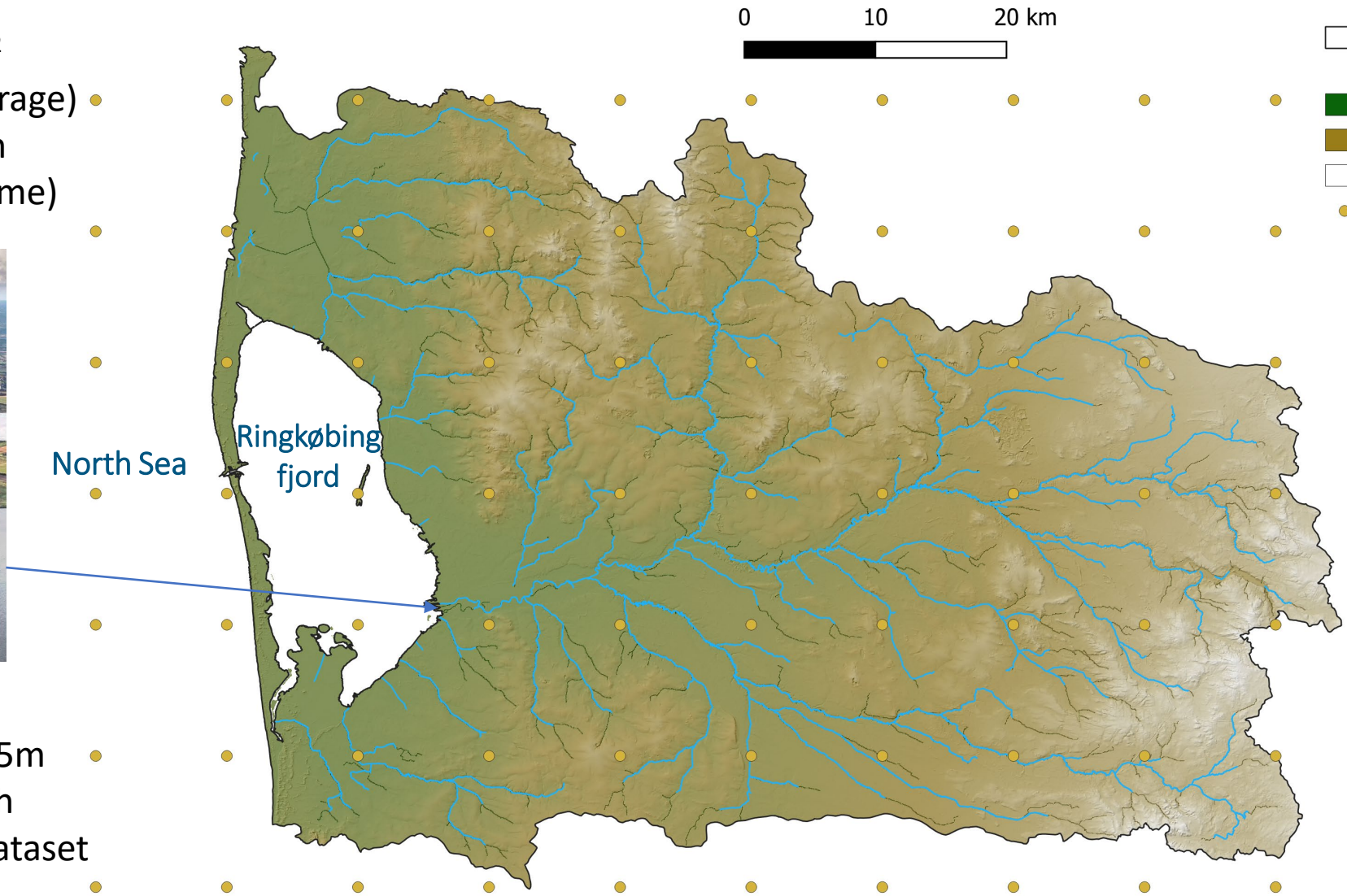
A review of the classification criteria and indicative measures required to move Ringkøbing Fjord from *Poor* to *Good* is critical.



SUCCESS framework – models for integrated management

Catchment overview

- Catchment area: 3372 km^2
- Lowland area (39 m in average)
- Skjern river: largest river in Denmark (in terms of volume)



Data:

- Elevation: National DEM 25m
- Climate data: 10 km Danish Meteorological Institute dataset

Model implementation: crop rotation

The agricultural area has been divided into 11 farm types and 20 crop rotations

- Includes organic and conventional farming
- Detailed information on management practices

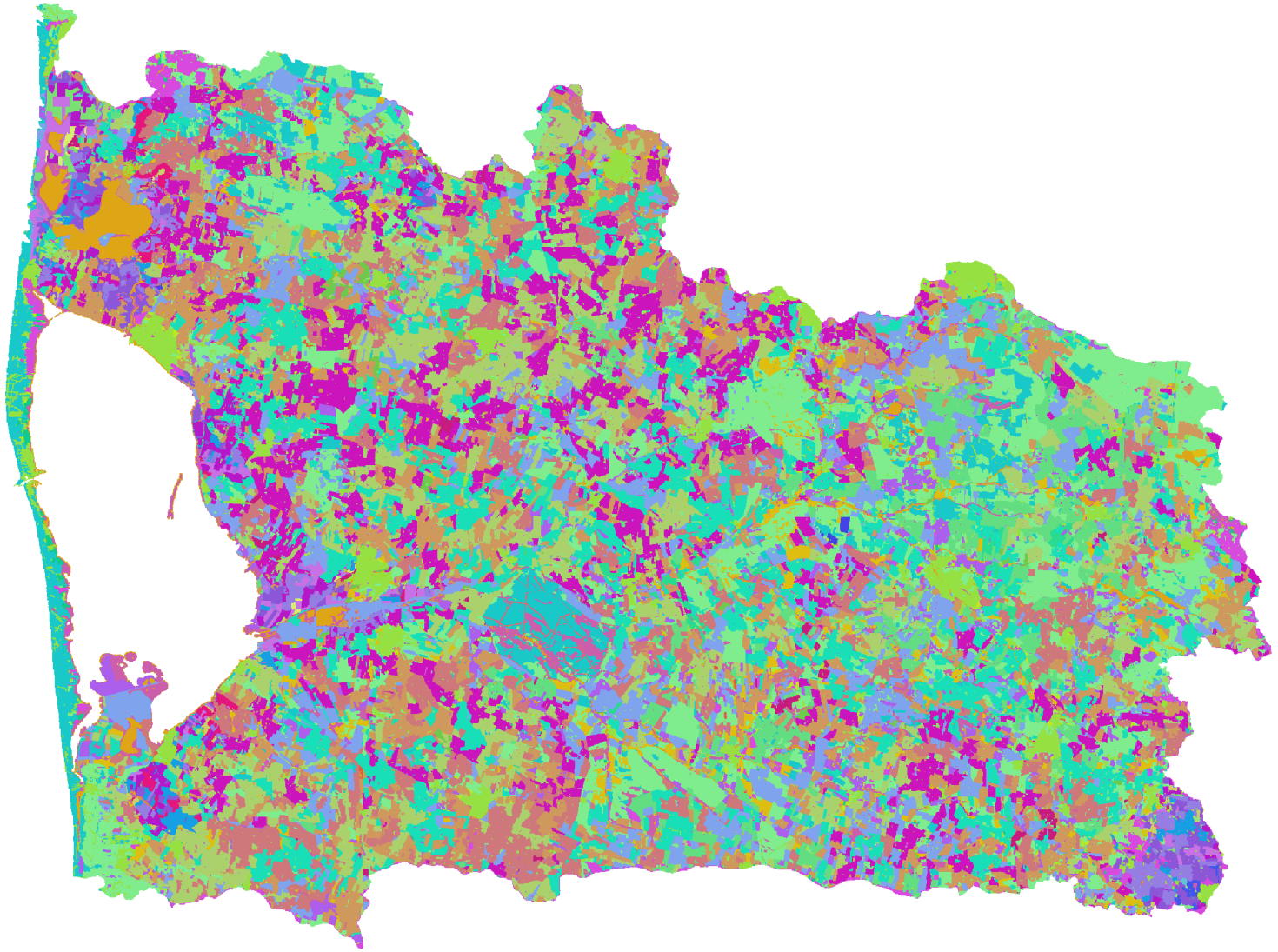
Farm type	Number of rotation
Plant farm	4
Cattlefarm with less than 20% wholecrop for fodder	2
Pig farm with more than 80 kg N pr ha fertilizer	4
Cattlefarm with more than 20% wholecrop for fodder	2
Other crop production	1
Cattle > 170 kg N	1
Potato farm	1
Nitrogen quota 50%	1
Pig farm with less than 80 kg N pr ha fertilizer	1
Seed production	1
Vegetables	1

Crop rotation 1 (Plant farm)	Main crop	Catch crop	Animal manure (kg N/ha)	Mineral fertilizer (kg N/ha)
Crop 1	Spring barley		76	59
Crop 2	Winter barley		113	87
Crop 3	Winter rape		125	96
Crop 4	Winter wheat		103	80
Crop 5	Spring barley	Oil radish	76	59
Crop 6	Spring barley	Oil radish	76	59

	plowing	sowing1	sowing2	harvest1	fertilizer1	fertilizer2
Crop 1	01-Apr	02-Apr	02-Apr	10-Aug	13-Apr	
Crop 2	19-Sep	20-Sep	10-Aug	01-Aug	01-Mar	01-Apr
Crop 3	19-Sep	20-Sep		01-Aug	01-Mar	15-Apr
Crop 4	19-Sep	20-Sep		20-Aug	01-Mar	01-Apr
Crop 5	01-Apr	02-Apr	02-Apr	10-Aug	13-Apr	
Crop 6	01-Apr	02-Apr	02-Apr	10-Aug	13-Apr	

Implementation through Management Schedule Operations

Model implementation: land use units



Combination of:

- Land use base map
- Drainage area maps
- Farm type map

Gives a total of 27 land use classes

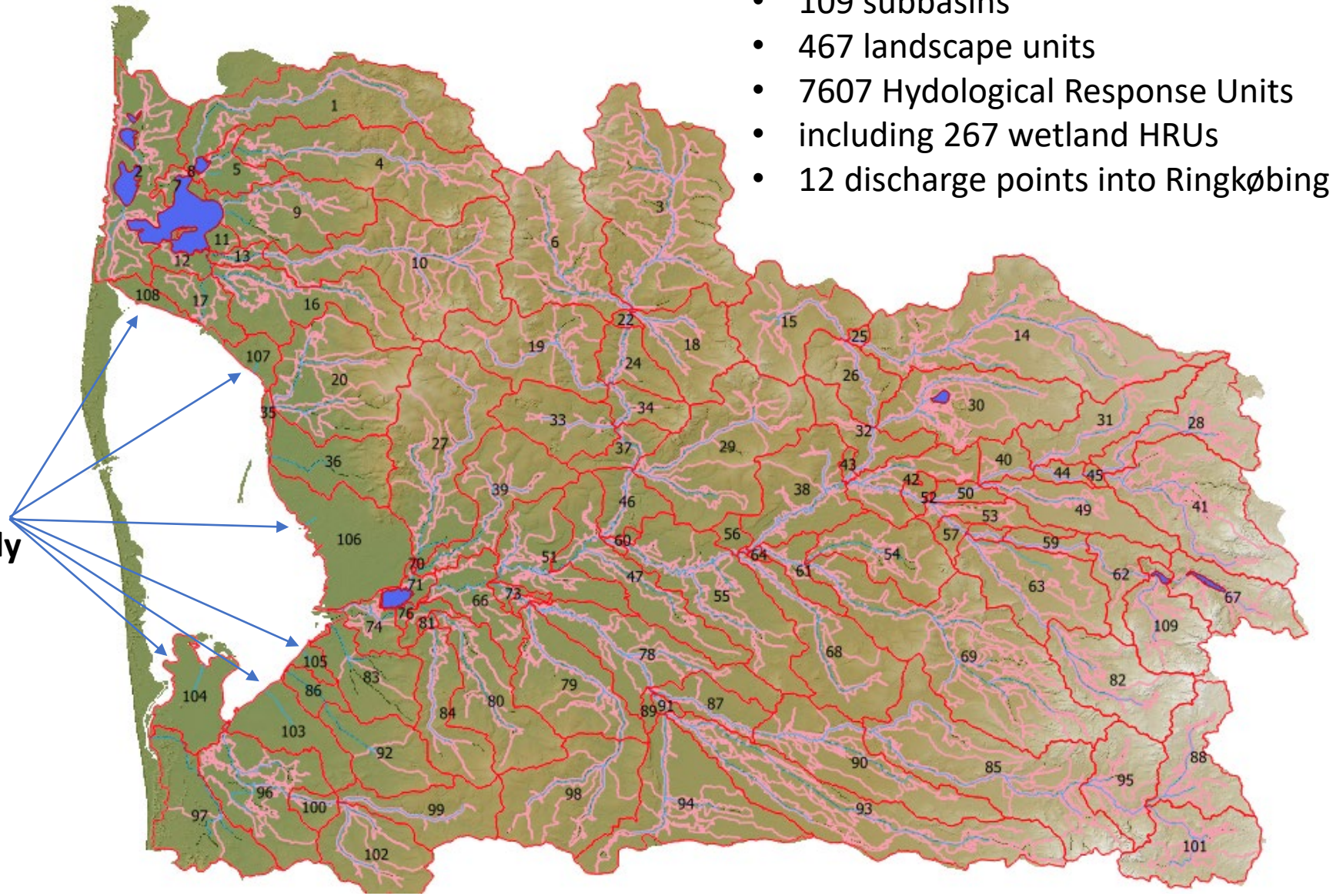
Detailed implementation of agricultural practices.

Watershed delineation

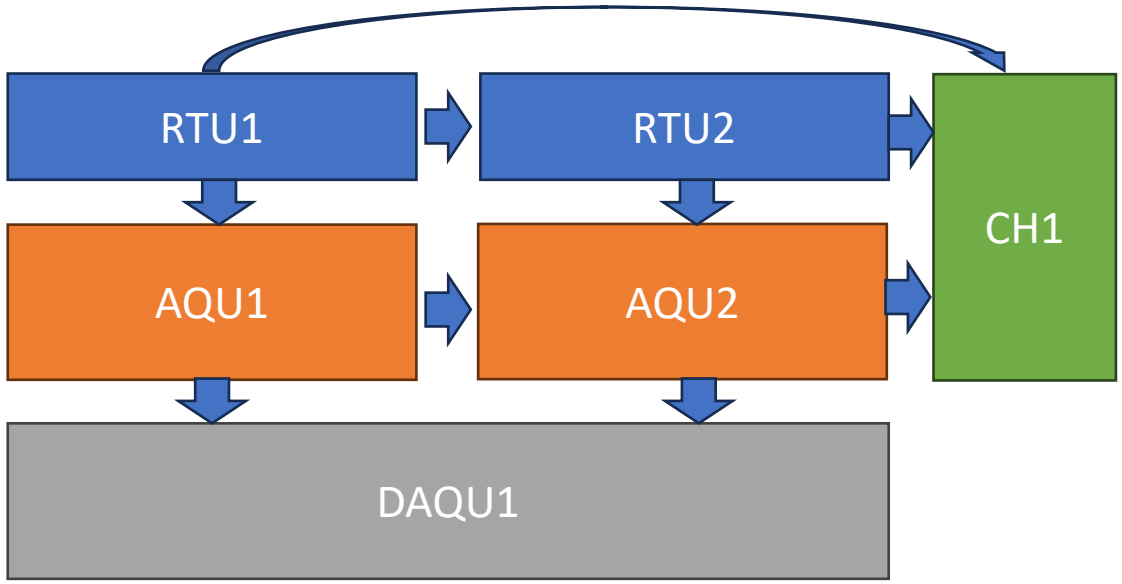
Watershed delineation characteristics:

- 9 lakes
- 109 subbasins
- 467 landscape units
- 7607 Hydological Response Units
- including 267 wetland HRUs
- 12 discharge points into Ringkøbing Fjord

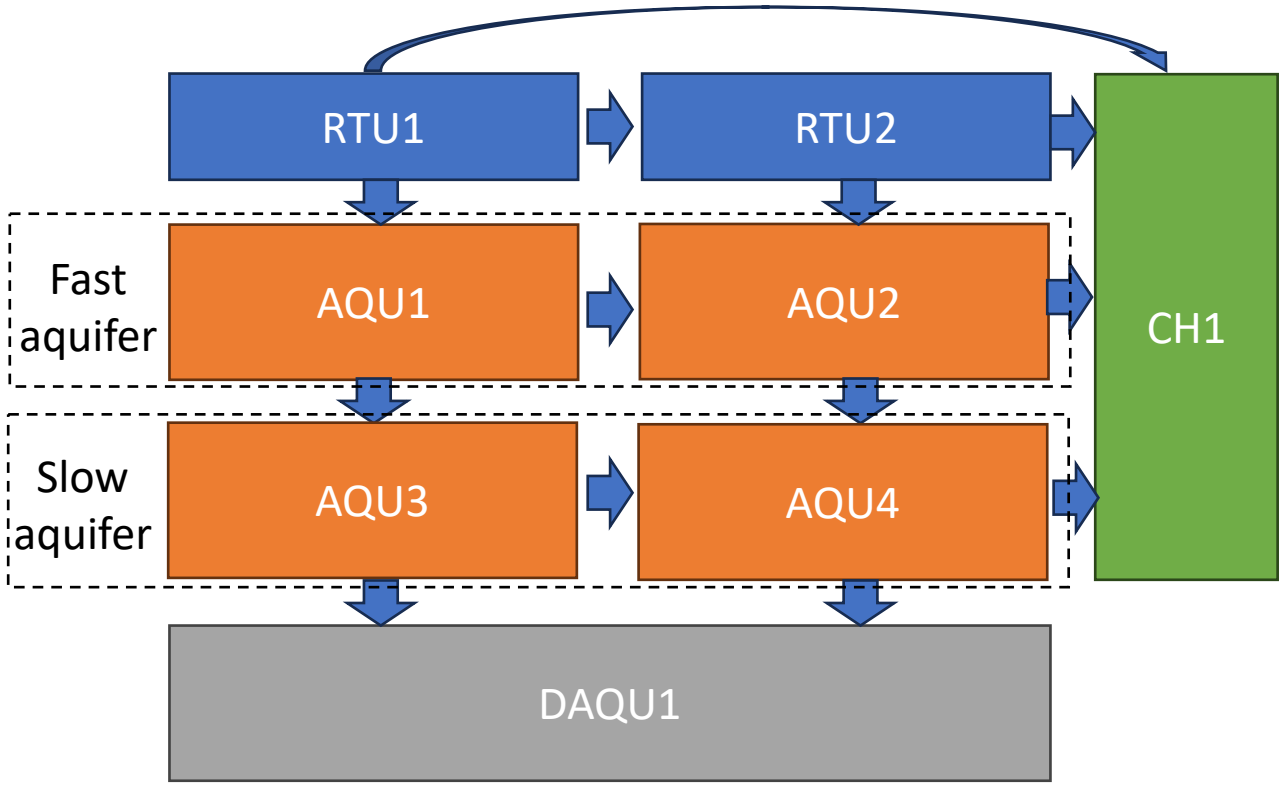
6 coastal subbasins implemented manually



Lowland area: dual aquifer implementation



QSWAT+/SWAT+ Editor default implementation

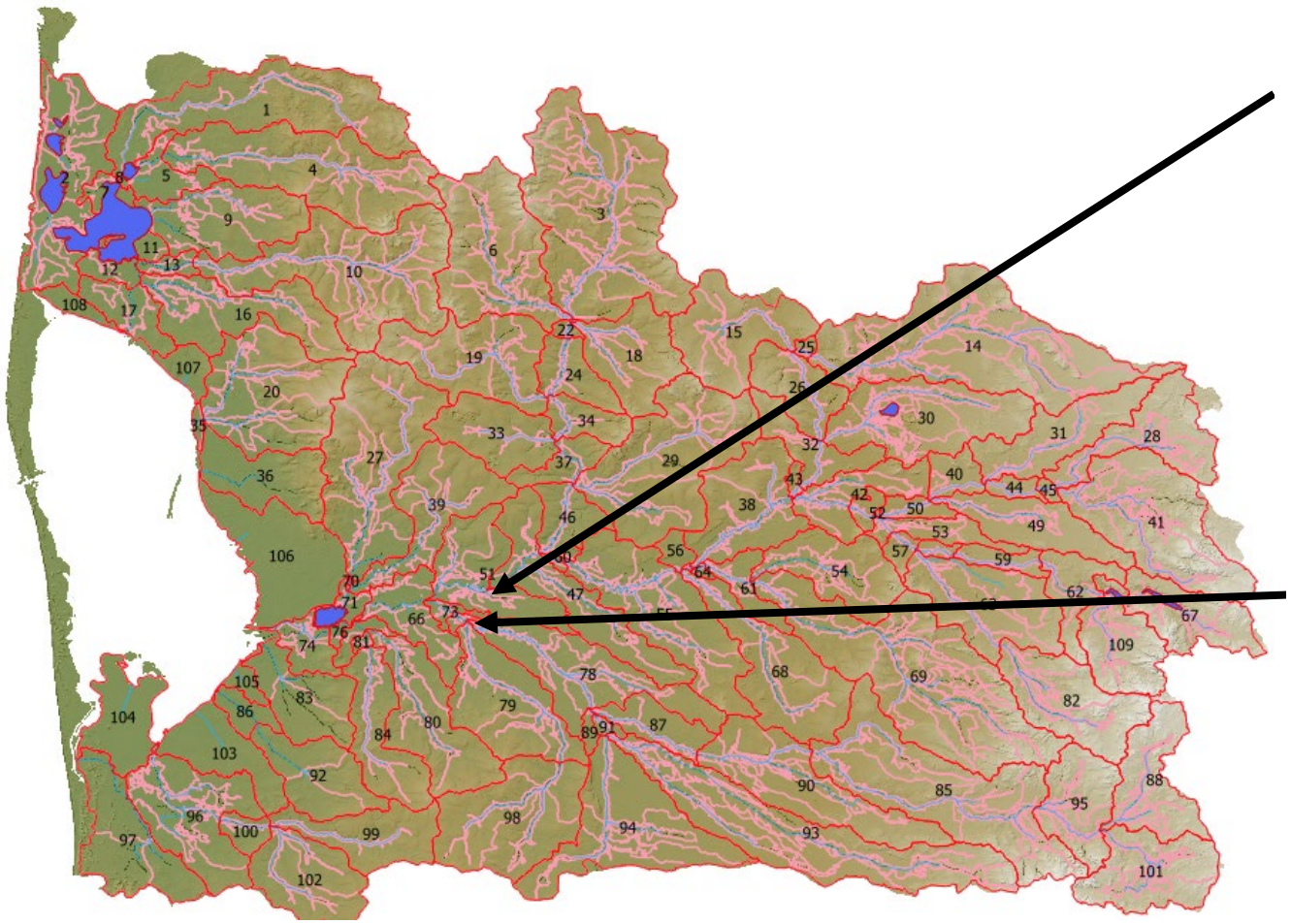


Dual aquifer implementation

Wagner et al. (2022)

Adding an aquifer layer improves baseflow simulation.

Results: streamflow simulation



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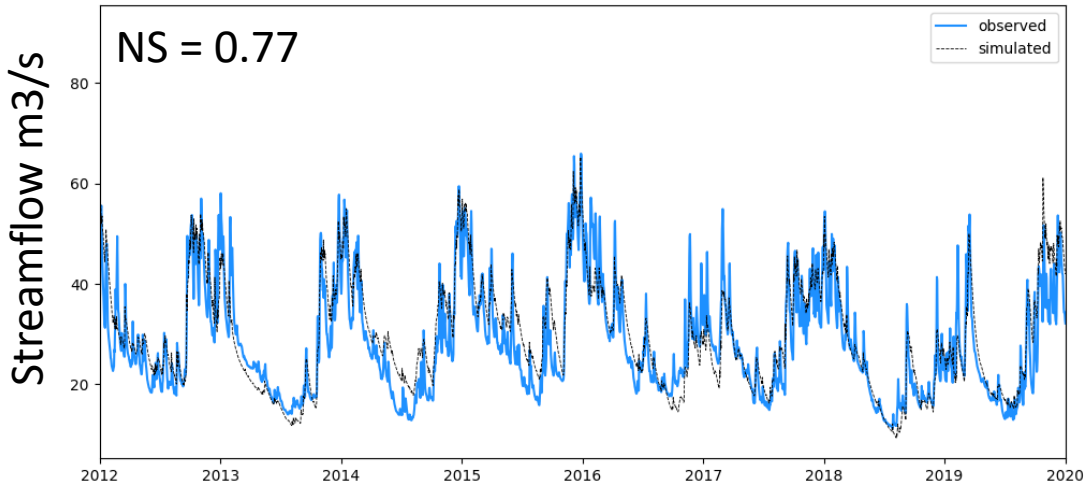

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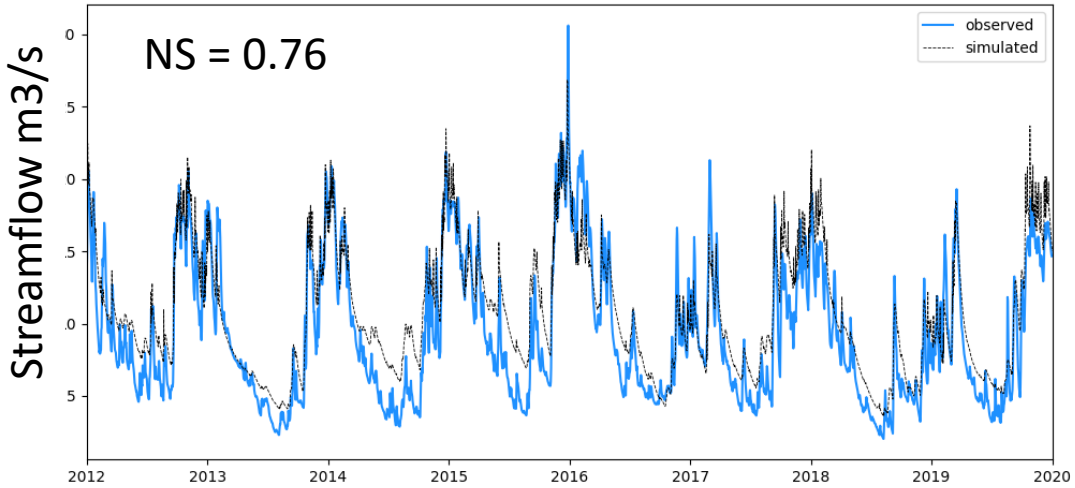
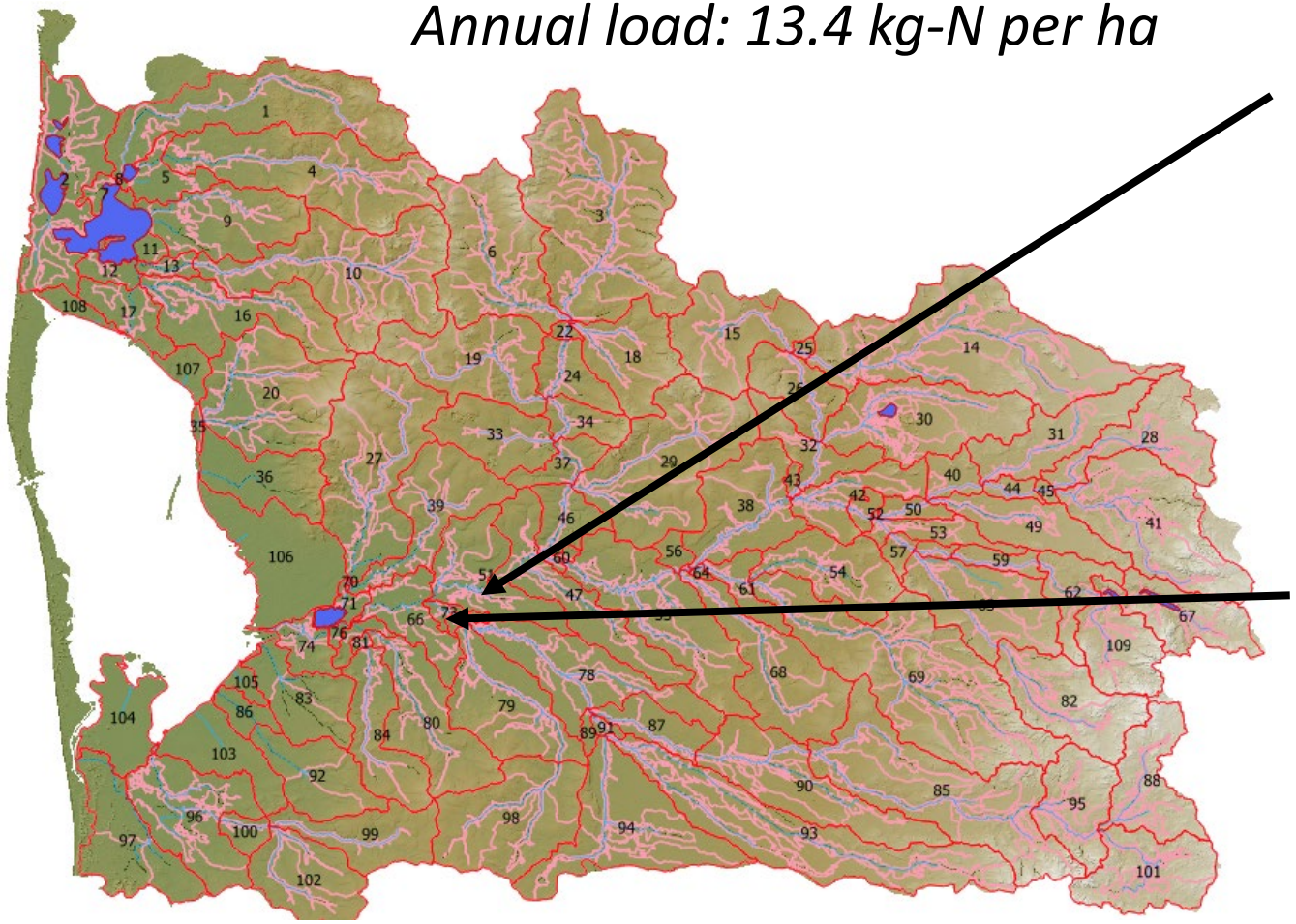


The model correctly reproduces the observed flow and the water balance in the catchment area is simulated correctly.

Results: nitrate loads simulation

Annual load: 13.4 kg-N per ha



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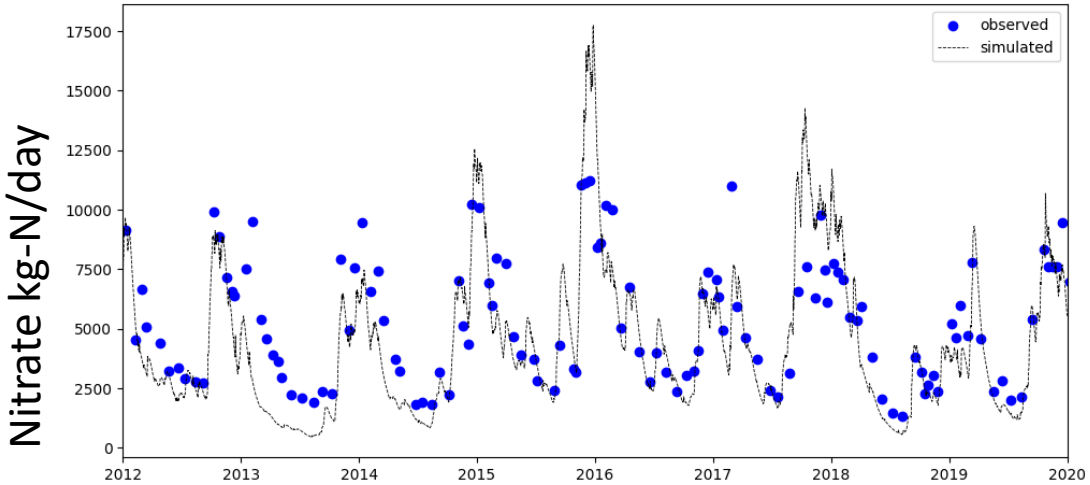

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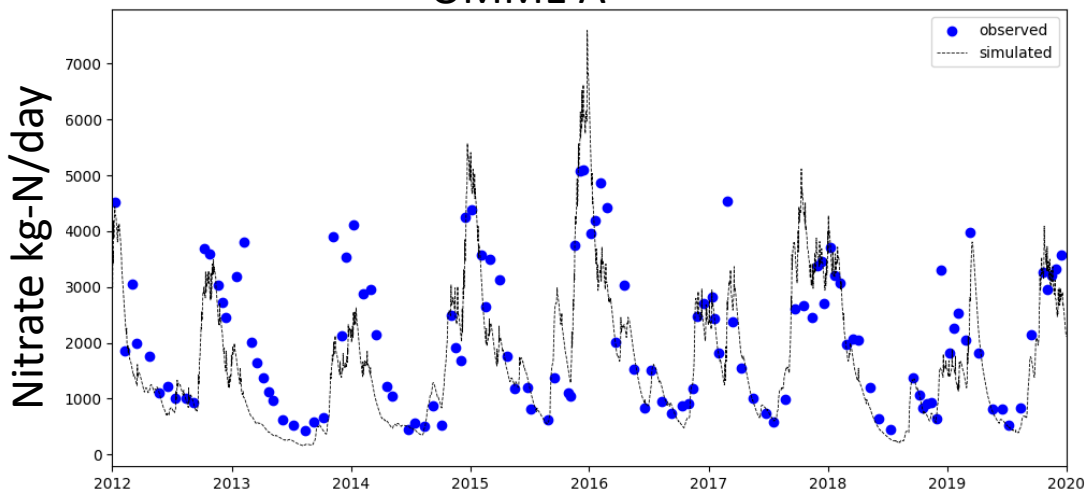
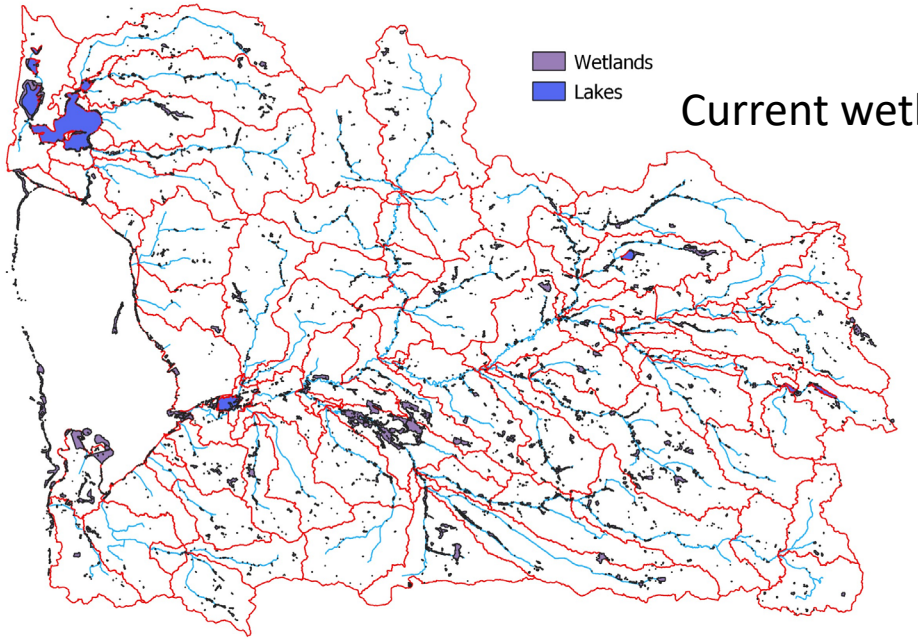


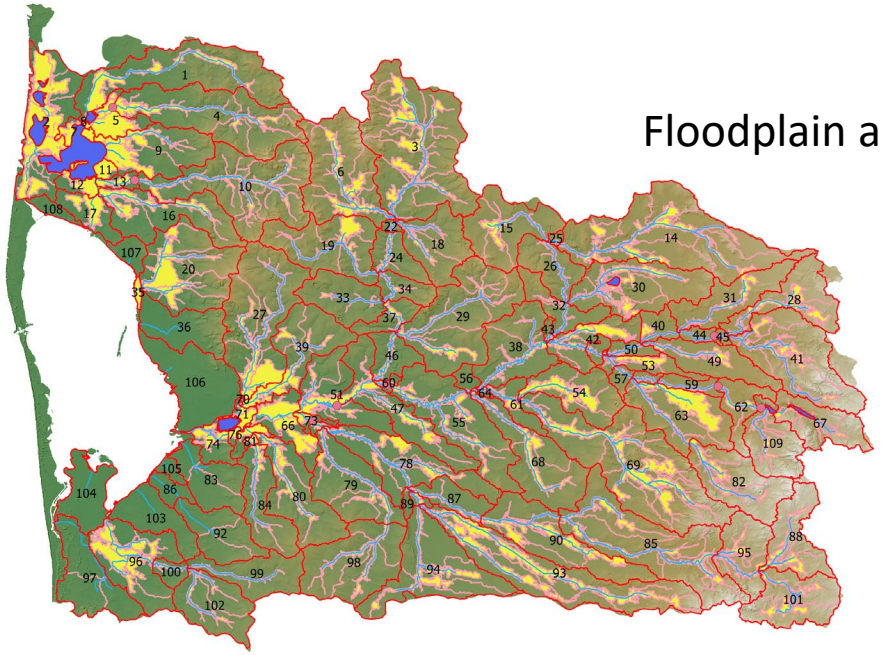
The model correctly reproduces the observed nitrate loads.

Scenarios

- Restoration of wetlands in the floodplain at different percentages (5 scenarios)
- Conversion of all agricultural land to natural grassland in order to assess the impact of agriculture.



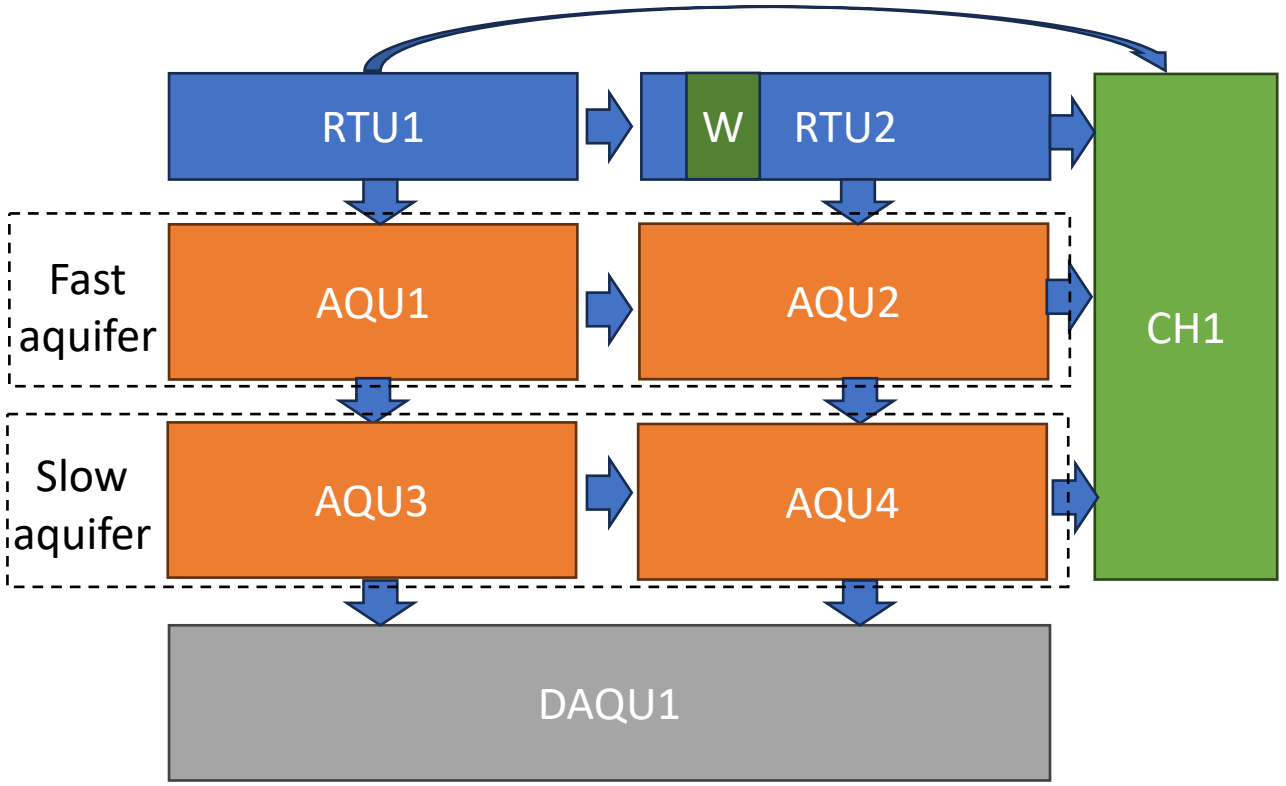
Current wetlands



Floodplain area

Scenarios have the potential to impact the water quality in the catchment and in the lagoon in different ways, and it is essential to study their effects to develop sustainable and resilient water management strategies.

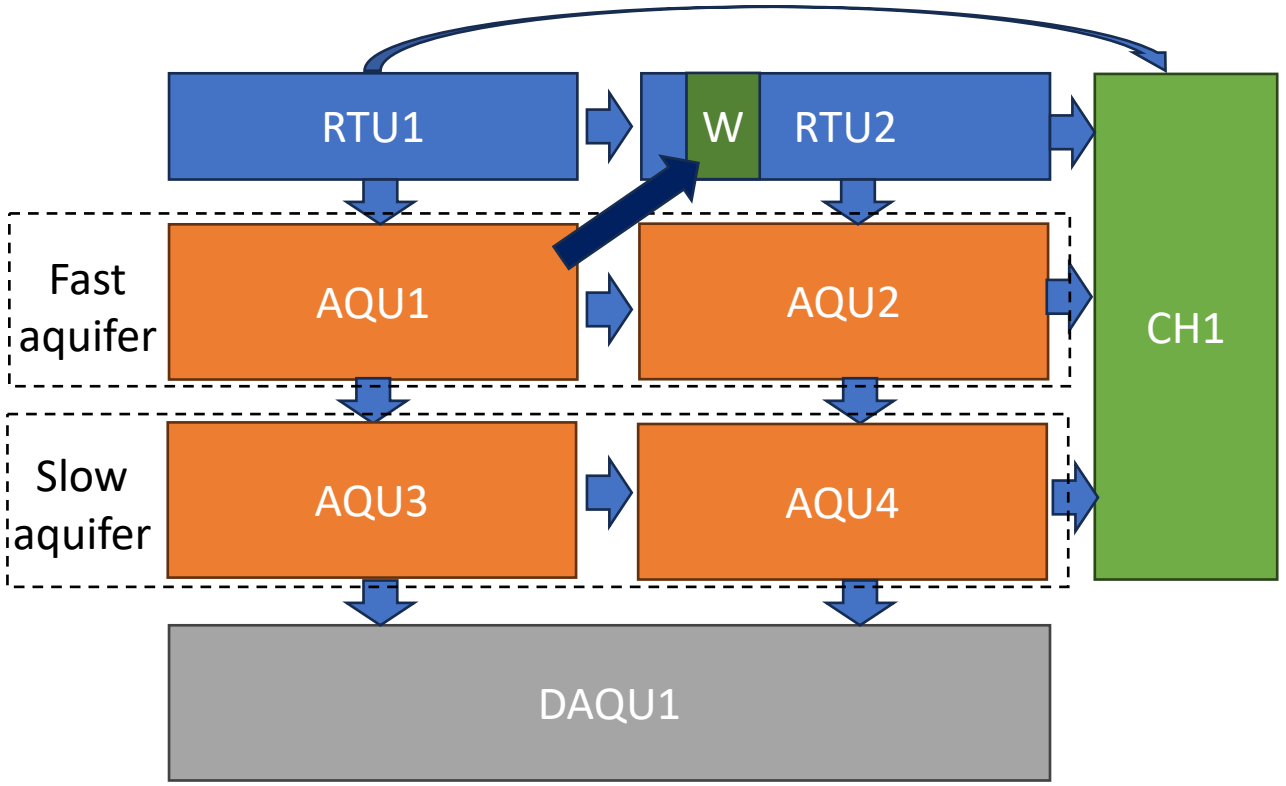
Wetland routing in SWAT+



In the default setting, only surface water is routed through wetland.

Problem: in Ringkøbing, most of the water and nutrients pass through the groundwater (flat, sandy soils), which is not connected to the wetlands in SWAT+, contrary to reality.

Wetland routing in SWAT+



In the default setting, only surface water is routed through wetland.

Problem: in Ringkøbing, most of the water and nutrients pass through the groundwater (flat, sandy soils), which is not connected to the wetlands in SWAT+, contrary to reality.

The model was modified to allow a part of the flow from the fast aquifer to be routed to the wetland.

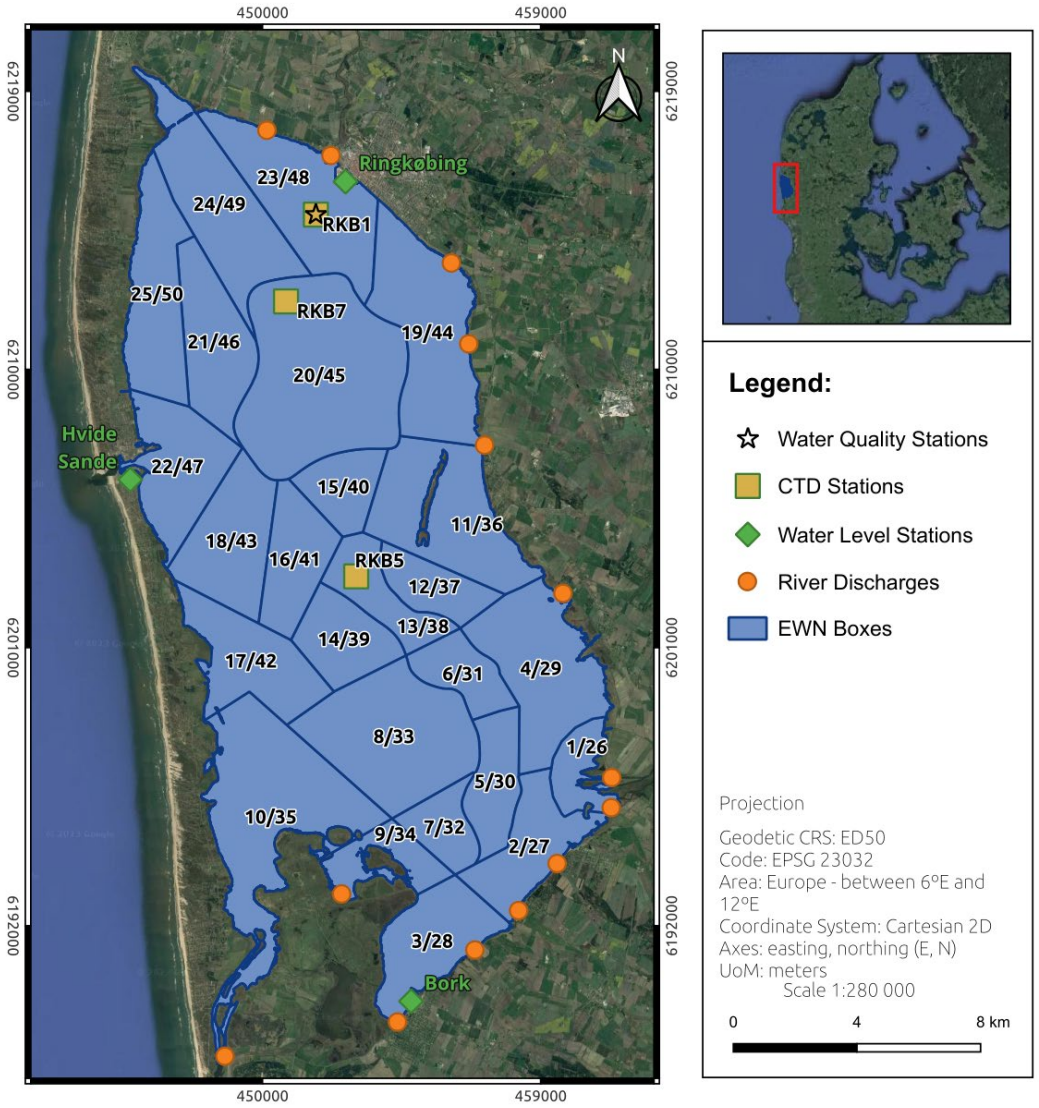
Results

Scenario	Fertiliser inputs (kg-N.ha-1)	Exports to Ringkøbing Fjord (kg-N.ha-1)	Export reduction compared to baseline	Wetland area (ha)
0 – Baseline	135	13.4		4 031
1 – No farming	0	6.7	50%	4 031
2 – Full wetland	112	3.5	74%	53 937
3 – 60% wetlands	122	7.2	46%	32 029
4 – 50% wetlands	124	8.3	38%	26 966
5 – 40% wetlands	126	9.4	30%	21 903

Restoring 23,000 hectares of wetlands (7% of the Ringkøbing Fjord catchment) could potentially reduce nitrogen loading to the fjord by approximately 38%.

Converting all farming areas to natural grasslands could decrease nitrogen loads by 50% which is less than when restoring wetlands in the whole floodplain area (Full wetland scenario).

Ecological model: EcoWin

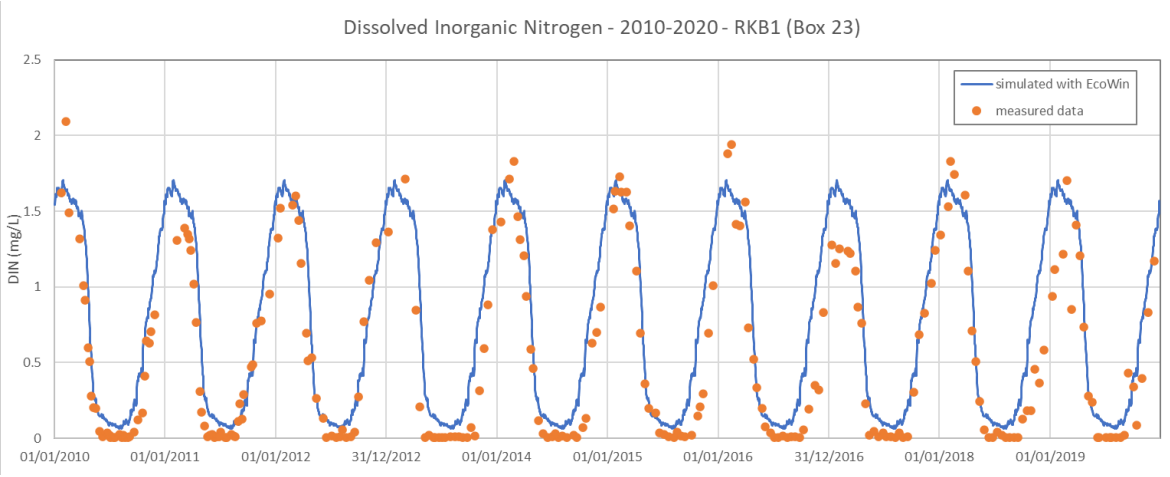


EcoWin integrates water circulation from a detailed hydrodynamic model and nutrients loads from SWAT+.

Main simulated processes:

- Pelagic primary production (phytoplankton)
- Benthic primary production (seagrasses and epiphytes)
- Benthic secondary production (*Mya arenaria*)

EcoWin provides long term simulation of environmental conditions in the Fjord

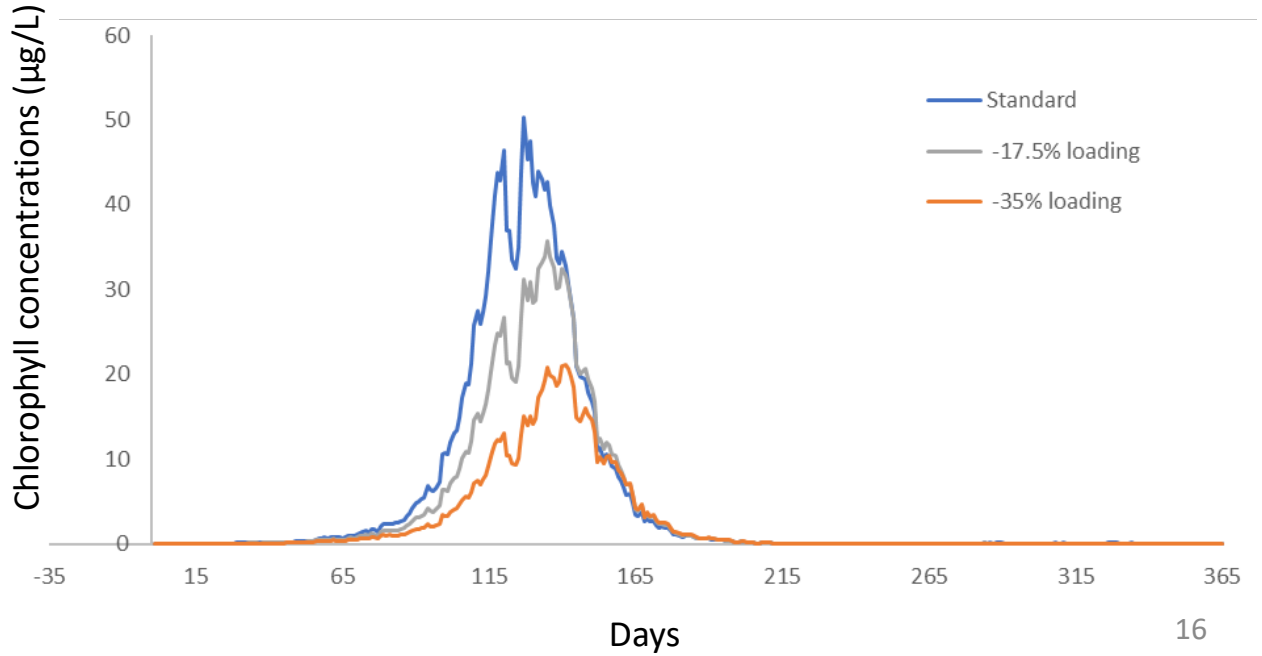


Management scenarios

The modelling framework can be used to assess, among other things, the impact of land-based loads on the main water quality indicators.

Reducing nutrient loads from the catchment improves water quality throughout the fjord, in particular by reducing eutrophication indicators such as concentrations of dissolved inorganic nitrogen (DIN) and chlorophyll.

Indicator	Scenario	Box 29	Box 45	Box 47
Summer chla (µg.L^{-1})	Standard loading	1.3	1.3	1.6
	-17.5% loading	1.0	1.1	1.2
	-35% loading	0.7	0.7	0.8
Winter DIN (mg.L^{-1})	Standard loading	1.8	1.6	1.6
	-17.5% loading	1.5	1.3	1.2
	-35% loading	1.1	0.96	0.90
Epiphyte risk score	Standard loading	3.42	1.10	2.70
	-17.5% loading	3.26	1.09	2.39
	-35% loading	3.02	1.06	2.21



Conclusion

- A SWAT+ model is developed and calibrated for the Ringkøbing fjord catchment in order to estimate nutrient loads entering the coastal lagoon for different management scenarios.

- The model indicates that restoring wetlands is a relevant measure for reducing nitrogen loads.

- The SWAT+ model is integrated into a catchment-to-coast ecosystem modelling framework that enables managers to understand the influence of land loads on water quality in Ringkøbing Fjord.

- Reducing nutrient loads from land improves water quality throughout the fjord, reducing concentrations of dissolved inorganic nitrogen (DIN) and chlorophyll.