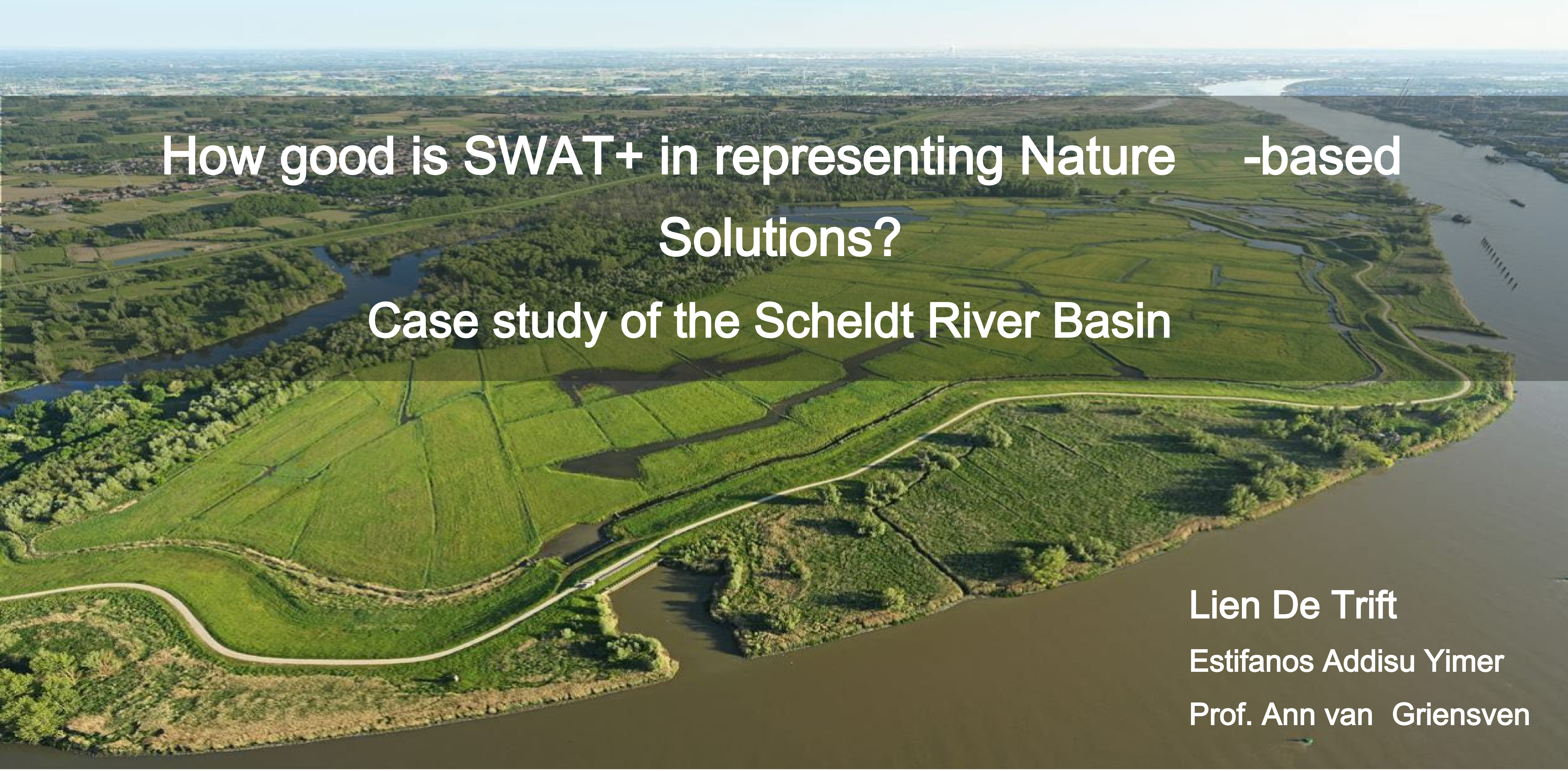
How good is SWAT+ in representing Nature-based Solutions?

Case study of the Scheldt River Basin



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WATER AND CLIMATE DEPARTMENT

AXA Research Fund

The Scheldt River Basin

Source: Interreg North Sea Region IMMERSE

- Catchment area: 21,863 km²
- River length: 360 km
- Transboundary: Belgium (61%), France (31%), The Netherlands (8%)
- Highly urbanized
- Scheldt Estuarium: influence of the tides up to Ghent

The Scheldt basin (under pressure…)

Flood

Occurs in various basins

Flemish flooding incidents from 2024 recognised as disasters

Friday 6 December 2024

By The Brussels Times with Belga

This aerial drone image shows floods after heavy rainfall in Zandbergen, Geraardsbergen on 3 January 2024. Credit: Belga/Kurt Desplenter.

Source: Belga/Kurt Desplenter Baert

Water quality pollution

Mainly from fertilizer runoff

ton Koene

Water quality in Flanders is deteriorating instead of improving: fertilization remains a problem

The water quality in Flanders deteriorated last winter instead of improving. The standard for nitrate was exceeded in a quarter of the watercourses examined. And the amount of nitrate in the groundwater has also risen again, to the highest level since 2010. The main culprit remains the fertilization of Flemish fields.

Source: vrt news (21 February 2024), journalist: Denny

Drought

More frequent and intense

Prolonged dry spell lowers water levels in Flanders and across Europe

6 May 2025

Exceptionally dry conditions in March and April have led to a rapid drop in water levels and flows in both navigable and non-navigable rivers in Flanders. Similar dry conditions can be observed in other parts of Europe.

Source: Belga news agency (6 May 2025)Baert

Nature -based Solutions in action

But still limited…

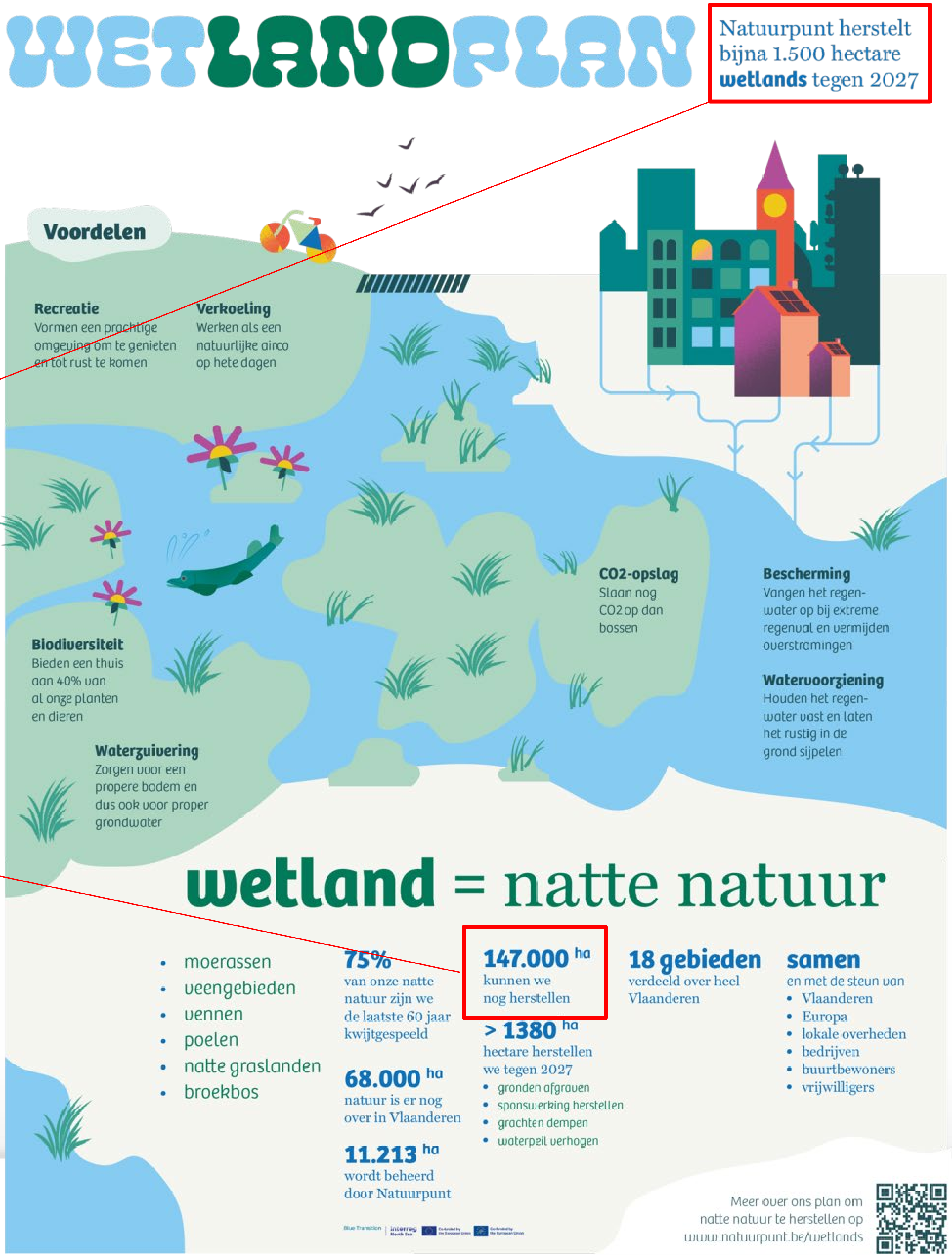
Sigmaplan: wetlands and flood control areas

Source: Sigmaplan (Flanders Government)

Goal: 1,500 ha wetland restoration by 2027

Still to restore: 1,380 ha

Potential area to restore in Flanders: 147,000 ha



Source: Natuurpunt (2023)

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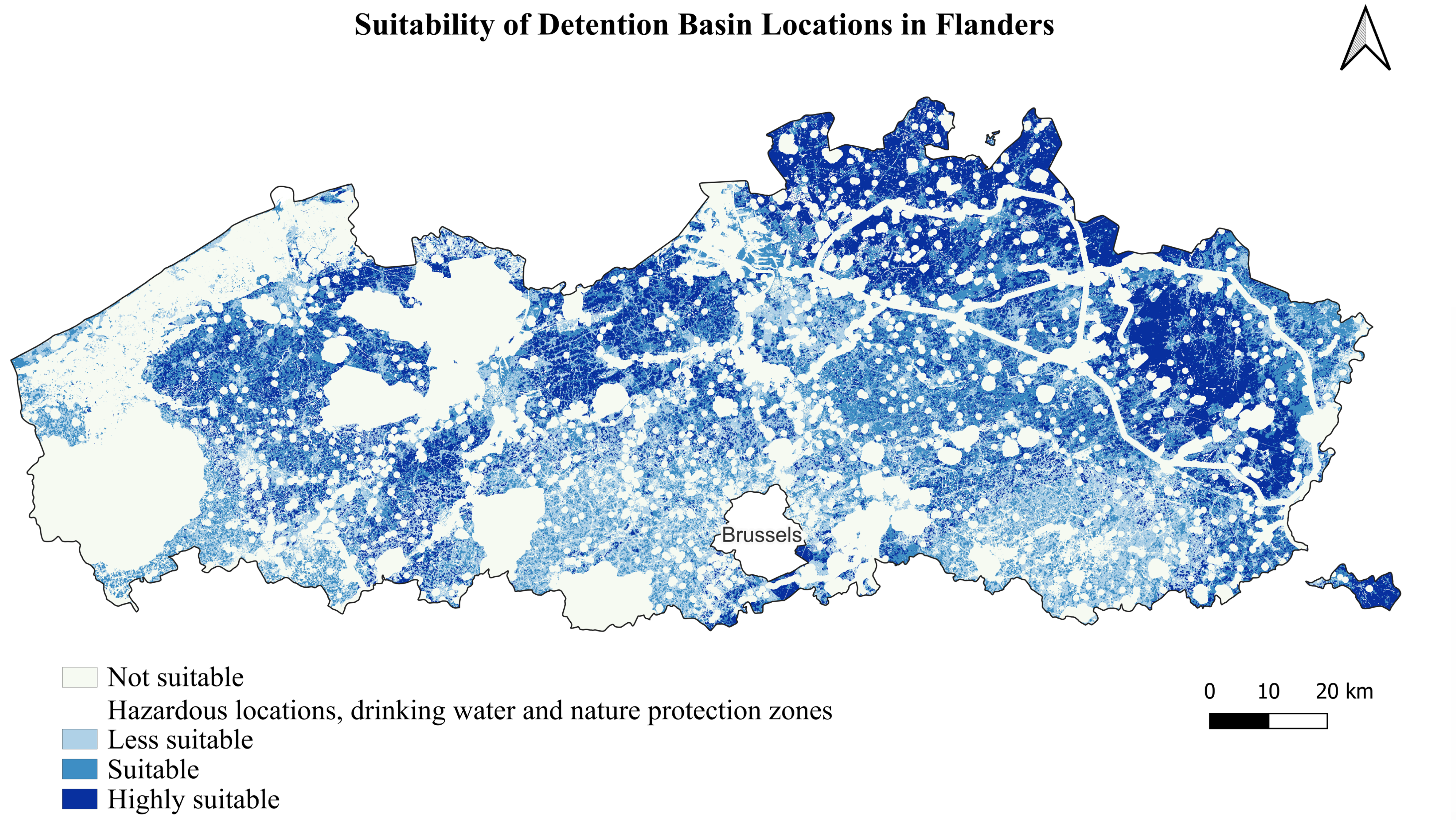
High potential for wetlands in Flanders

147,000 ha of potential

+/ - 250,000 ha of highly suitable areas identified

Scan to read more:



Source: Yimer & De Trift, 2024 (Journal of Water Research)

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Objective(s)

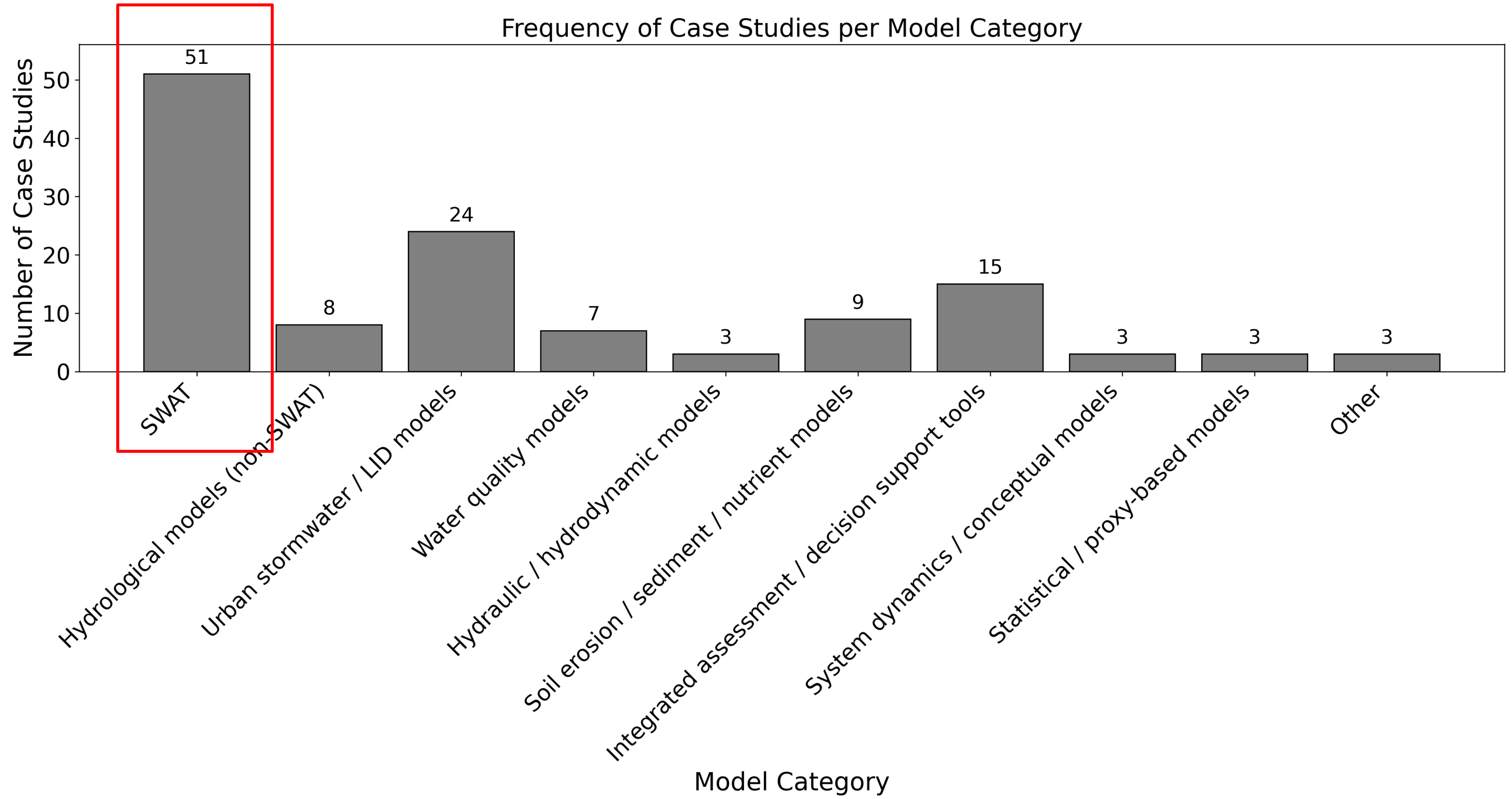
Main goal:

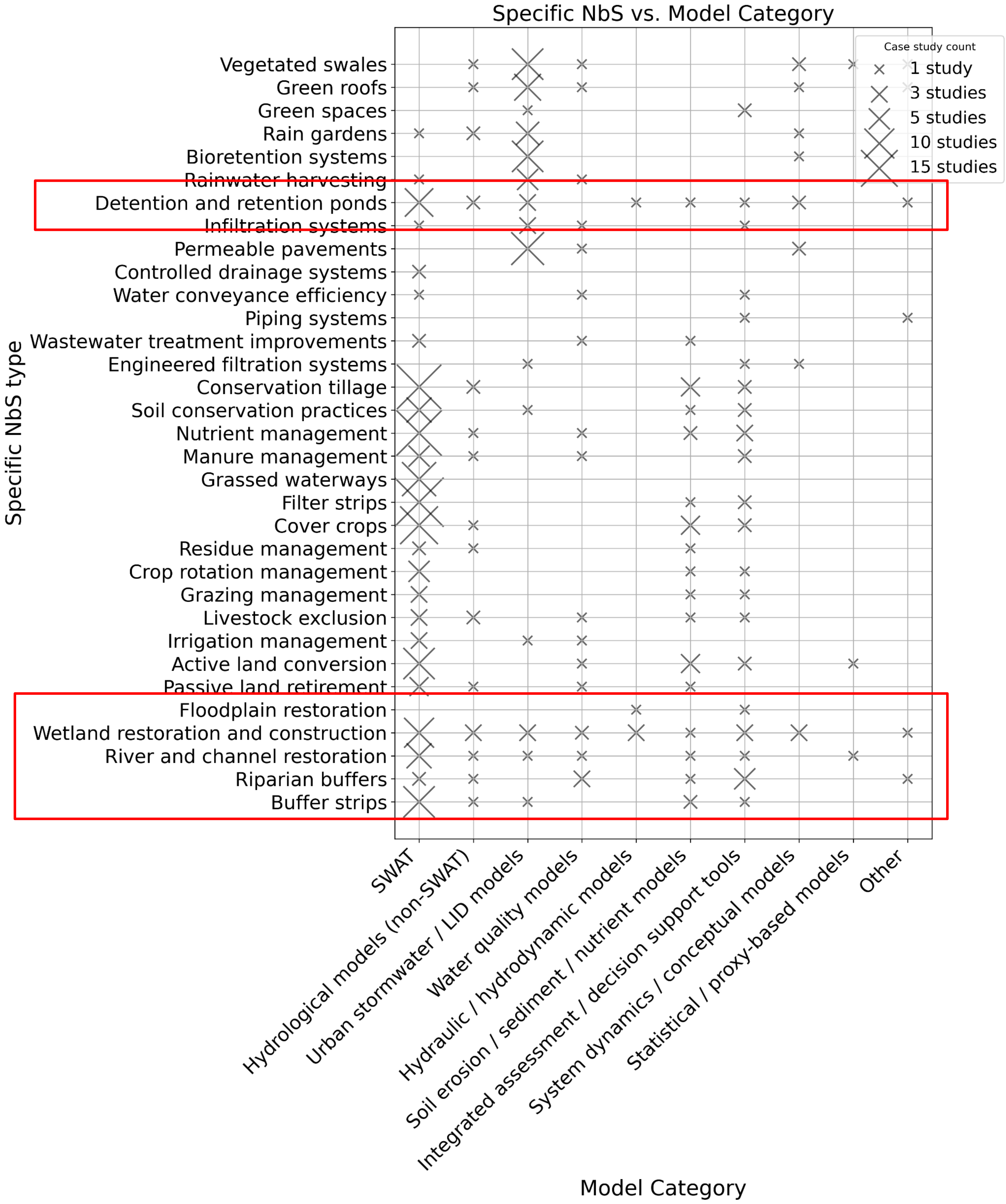
Assess how well SWAT+ can represent wetlands as Nature-based Solutions (NbS) in the Scheldt Basin.

Specific objectives:

- Review the current state-of-the-art in modelling NbS for water quality, with a focus on SWAT
- Test SWAT+ (standalone and coupled with the GWflow module) to simulate wetland impacts on flow
- Evaluate changes in river flow and water balance with and without wetlands
- (Prepare for integration of water quality components (e.g., nitrate removal))

State-of-the-art in modelling NbS for water quality





51 out of 125 reviewed case study applications use SWAT

State-of-the-art in modelling NbS for water quality

- Uncertain impact of wetlands on nitrogen: studies show positive, negative, or mixed results
- SWAT and other models often simplify key wetland processes (e.g., denitrification)

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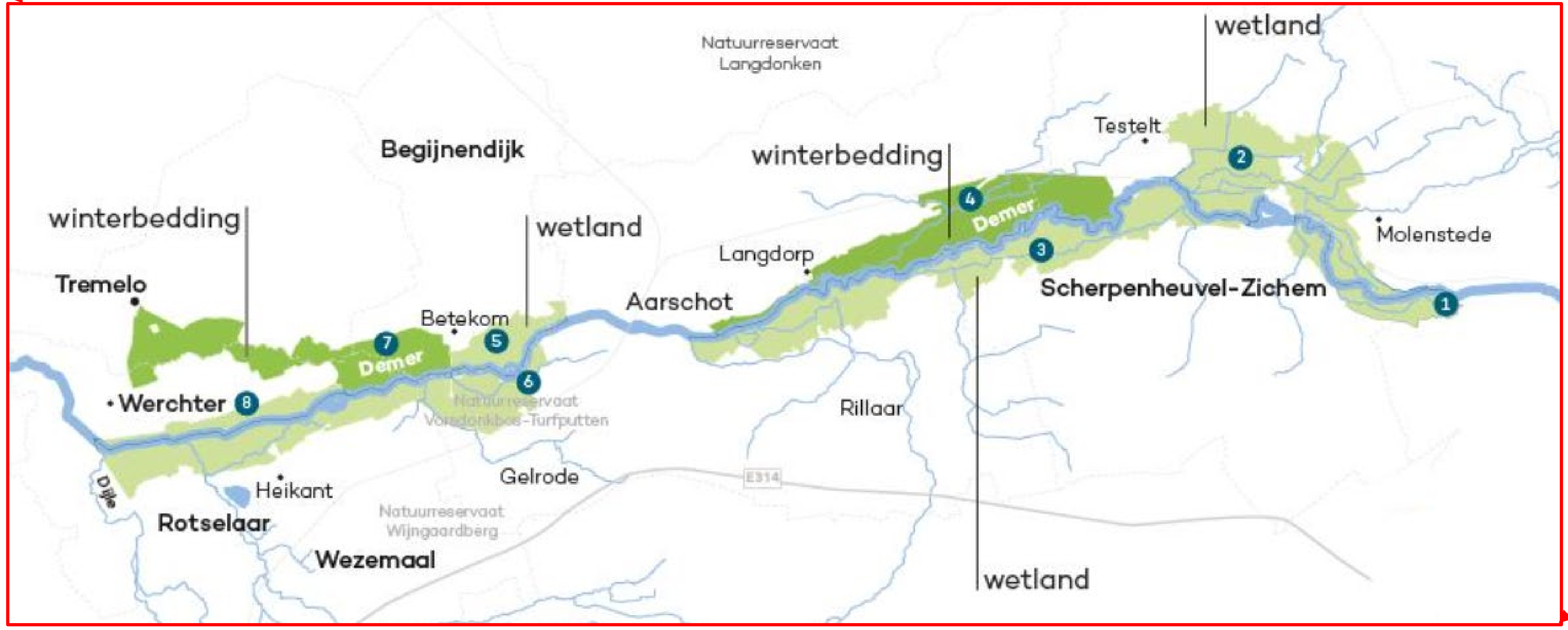
Reported Effectiveness per Specific NbS Type and Pollutant

	Biological oxygen demand (BOD)	Chemical oxygen demand (COD)	Chlorofyll a (ChlA)	Dissolved oxygen (DO)	Faecal coliform (FC)	Pathogens	Inorganic nitrogen (IN)	Organic nitrogen (ON)	Total nitrogen (TN)	Inorganic phosphorous (IP)	Organic phosphorous (OP)	Total phosphorous (TP)	Sediment-attached phosphorous (SEDP)	Sediment load/yield	Total dissolved solids (TDS)	Total suspended solids (TSS)	Trace elements / heavy metals	Organic micropollutants	Oil/grease	Temperature (T)
Vegetated swales	✓ (3)	✓ (3)	-	-	✓ (1)	-	✓ (2)	-	~ (2) ✓ (6)	-	-	~ (1) ✓ (7)	-	✓ (1)	-	~ (1) ✓ (12)	~ (1) ✓ (3)	✓ (1)	✓ (1)	-
Green roofs	✓ (1)	✓ (2)	-	-	-	-	✗ (1)	-	✓ (7) ✗ (1)	-	-	✓ (7) ✗ (1)	-	-	✓ (1)	✓ (8) ✗ (1)	✓ (3) ✗ (1)	✓ (1)	-	-
Green spaces	-	-	-	-	-	-	-	-	✓ (1)	-	-	✓ (1)	-	-	-	✓ (1)	-	-	-	-
Rain gardens	✓ (2)	✓ (3)	-	-	✓ (1)	-	-	-	~ (3) ✓ (5)	-	-	~ (2) ✓ (5)	-	-	-	~ (2) ✓ (5)	~ (1) ✓ (2)	-	✓ (1)	-
Bioretention systems	✓ (1)	✓ (1)	-	-	-	-	-	-	✓ (5)	-	-	✓ (5)	-	✓ (1)	-	✓ (8)	-	-	-	-
Rainwater harvesting	✓ (1)	✓ (1)	-	-	-	-	-	-	✓ (5)	-	-	✓ (5)	-	✓ (2)	-	✓ (4)	✓ (1)	-	-	-
Detention and retention ponds	✓ (1)	✓ (1)	-	-	✓ (1)	-	✓ (1)	-	~ (2) ✓ (8)	✓ (2)	-	~ (2) ✓ (11)	-	✓ (5)	-	✓ (9)	✓ (3)	✓ (1)	✓ (1)	-
Infiltration systems	✓ (1)	✓ (1)	-	-	-	-	-	-	✓ (3)	-	-	✓ (3)	-	✓ (3)	-	✓ (2)	✓ (1)	-	-	-
Permeable pavements	✓ (2)	✓ (2)	-	-	-	-	✓ (1)	-	~ (1) ✓ (6)	-	-	~ (1) ✓ (5)	-	-	-	~ (1) ✓ (11)	~ (1) ✓ (1)	-	-	-
Controlled drainage systems	-	-	-	-	-	-	~ (1)	-	-	-	-	-	-	-	-	✓ (2)	-	-	-	-
Water conveyance efficiency	-	-	-	-	-	-	✓ (2)	-	-	✓ (1)	-	-	-	-	-	-	✓ (1)	-	-	-
Piping systems	-	-	-	-	-	-	-	-	✓ (1)	-	-	~ (1)	-	✓ (1)	-	✓ (1)	✓ (1)	✓ (1)	-	-
Wastewater treatment improvements	-	-	-	-	-	-	✓ (2)	-	~ (1) ✓ (1)	-	-	~ (1) ✓ (2)	-	-	-	-	-	-	-	-
Engineered filtration systems	-	-	-	-	-	-	-	-	✓ (2)	-	-	✓ (2)	-	-	-	✓ (1)	-	-	-	-
Conservation tillage	-	-	-	-	-	-	~ (1) ✓ (4)	-	~ (1) ✓ (14)	~ (2) ✓ (3)	-	~ (2) ✓ (21)	-	~ (2) ✓ (20)	-	✓ (1)	-	-	-	-
Soil conservation practices	-	-	-	-	-	-	✓ (1) ✗ (1)	✓ (1)	✓ (8)	-	✓ (1)	~ (1) ✓ (8)	-	✓ (7)	✓ (1)	✓ (1)	-	-	-	-
Nutrient management	-	-	-	-	-	-	~ (1) ✓ (8)	-	~ (1) ✓ (16)	~ (2) ✓ (3)	-	✓ (17)	-	✓ (10)	-	✓ (3)	✓ (1)	-	-	-
Manure management	-	-	-	-	✓ (1)	-	✓ (1)	-	~ (1) ✓ (3)	-	-	~ (2) ✓ (3)	-	✓ (2)	-	✓ (1)	-	-	-	-
Grassed waterways	-	-	-	-	-	-	✓ (4)	✓ (1)	✓ (9)	~ (1) ✓ (1) ✗ (1)	✓ (1)	✓ (11)	-	✓ (7)	-	✓ (1)	-	-	-	-
Filter strips	-	-	-	-	-	-	~ (2) ✓ (8)	✓ (1)	✓ (17)	~ (2) ✓ (3)	✓ (1)	~ (3) ✓ (20)	-	~ (1) ✓ (16)	-	✓ (3)	-	-	-	-
Cover crops	-	-	-	-	-	-	~ (1) ✓ (6)	-	✓ (13)	~ (2) ✓ (2)	-	~ (1) ✓ (16)	-	~ (1) ✓ (12)	-	✓ (3)	-	-	-	-
Residue management	-	-	-	-	-	-	✓ (1)	-	✓ (3)	~ (1)	-	✓ (3)	-	✓ (2)	-	-	-	-	-	-
Crop rotation management	-	-	-	-	-	-	✓ (1)	-	✓ (5)	~ (1)	-	✓ (6)	-	✓ (5)	-	-	-	-	-	-
Grazing management	-	-	-	-	-	-	✓ (2)	✓ (1)	✓ (4)	~ (1)	-	~ (1) ✓ (4)	-	✓ (2)	-	✓ (1)	-	-	-	-
Livestock exclusion	-	-	-	-	✓ (1)	-	✓ (2)	✓ (2)	✓ (4)	✓ (1)	✓ (2)	✓ (5)	~ (1)	✓ (3)	-	~ (1) ✓ (1)	-	-	-	-
Irrigation management	-	-	-	-	-	-	✓ (3)	-	✓ (1)	✓ (1)	-	✓ (2)	-	-	-	✓ (2)	✓ (1)	-	-	-
Active land conversion	-	-	-	-	-	-	✓ (2)	-	✓ (8)	~ (2)	-	~ (1) ✓ (10)	-	✓ (6)	-	✓ (1)	-	-	-	-
Passive land retirement	-	-	-	-	-	✓ (1)	✓ (1)	-	✓ (5)	-	-	✓ (6)	-	✓ (5)	-	-	✓ (1)	-	-	-
Floodplain restoration	-	-	-	-	-	-	-	-	-	-	-	✓ (1)	-	-	-	-	-	-	-	-
Wetland restoration and construction	✓ (2)	-	-	✓ (1)	-	-	~ (1) ✓ (6) ✗ (1)	-	~ (3) ✓ (12)	✓ (2)	-	~ (2) ✓ (17)	-	~ (1) ✓ (2)	✓ (1)	✓ (6)	✓ (2)	-	-	-
River and channel restoration	~ (1) ✓ (2)	-	-	~ (1)	-	-	~ (2) ✓ (2)	~ (1) ✓ (1)	~ (3) ✓ (6)	~ (1) ✓ (1)	~ (1) ✓ (1)	~ (2) ✓ (6)	-	✓ (5)	-	✓ (2)	-	-	-	-
Riparian buffers	-	-	✓ (1)	~ (1) ✓ (1)	✓ (1)	-	~ (1) ✓ (1)	-	✓ (1)	~ (1) ✓ (1)	-	✓ (2)	-	✓ (1)	-	✓ (1)	✓ (1)	-	-	✓ (2)
Buffer strips	✓ (1)	-	-	-	-	-	✓ (1)	-	~ (1) ✓ (12)	-	-	~ (1) ✓ (11)	-	✓ (4)	-	✓ (1)	-	-	-	-

Model setup for a subbasin of the Scheldt River Basin

Demer Basin
2,334 km²
Wetlands (Sigmaplan)
28.51 km²
But much more potential!

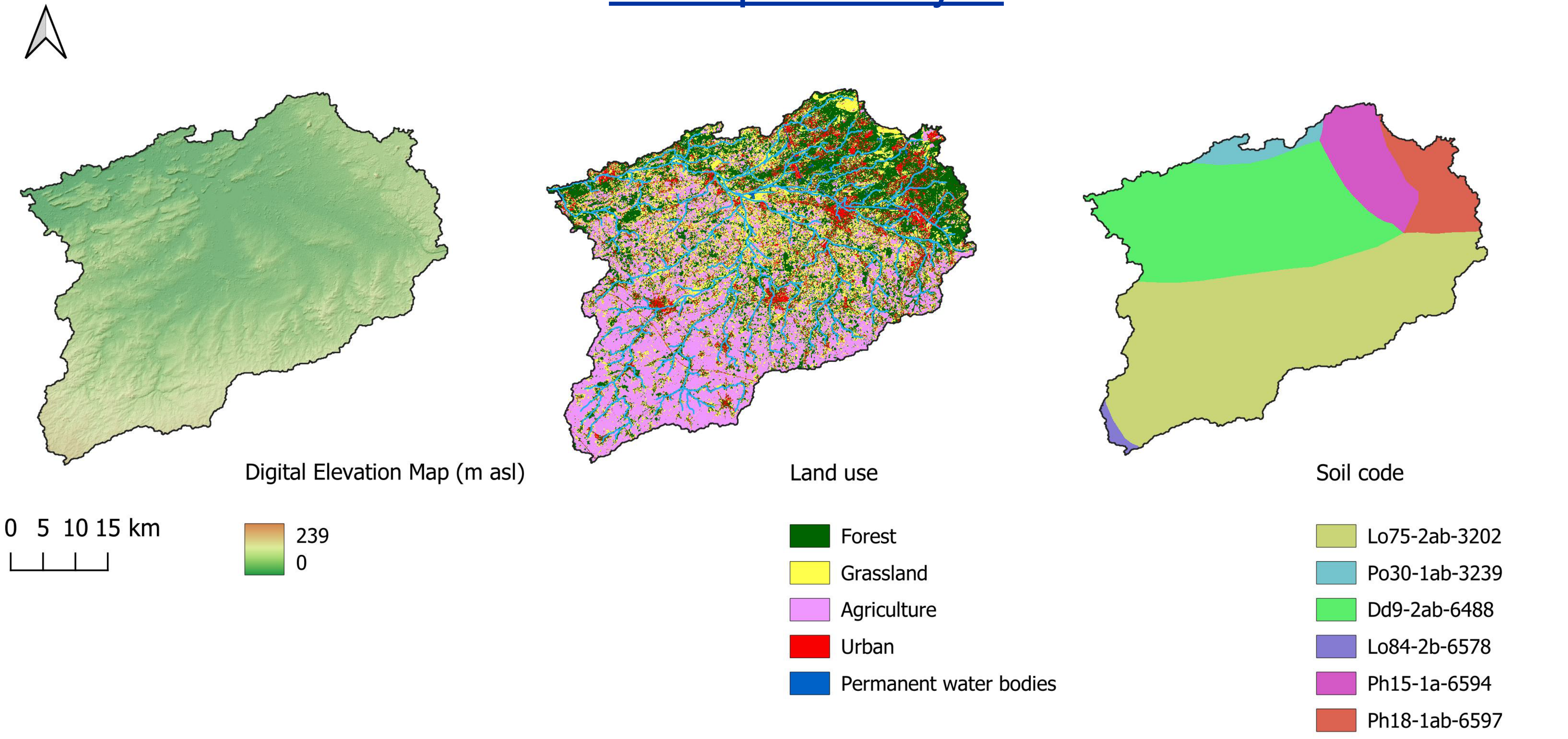
Source: Interreg North Sea Region IMMERSE



Source: Sigmaplan (Flanders Government)

Model setup for a subbasin of the Scheldt River Basin

Core input data layers



SRTM (30m) ESA (10m) FAO Soil Map of the World

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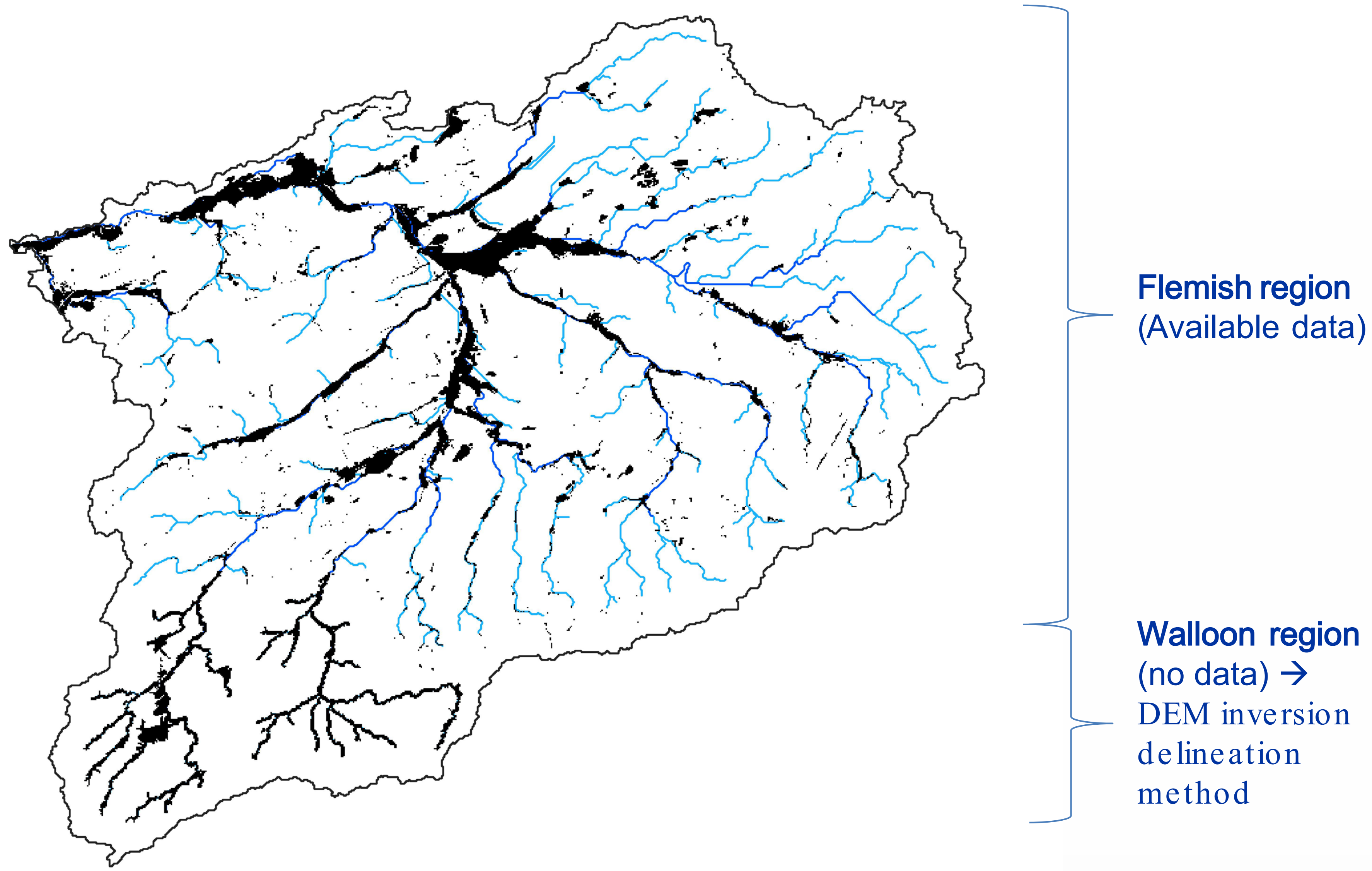
Model setup for a subbasin of the Scheldt River Basin

Model customization and configuration

1) Floodplain map integration



2) Modified routing unit connection file (rout_unit.con)

→ Default routing caused excessive subsurface flow in upland areas
→ Manually adjusted flow distribution percentages to direct more water through floodplain areas

➢ Reduction of the surface runoff component to a more realistic value

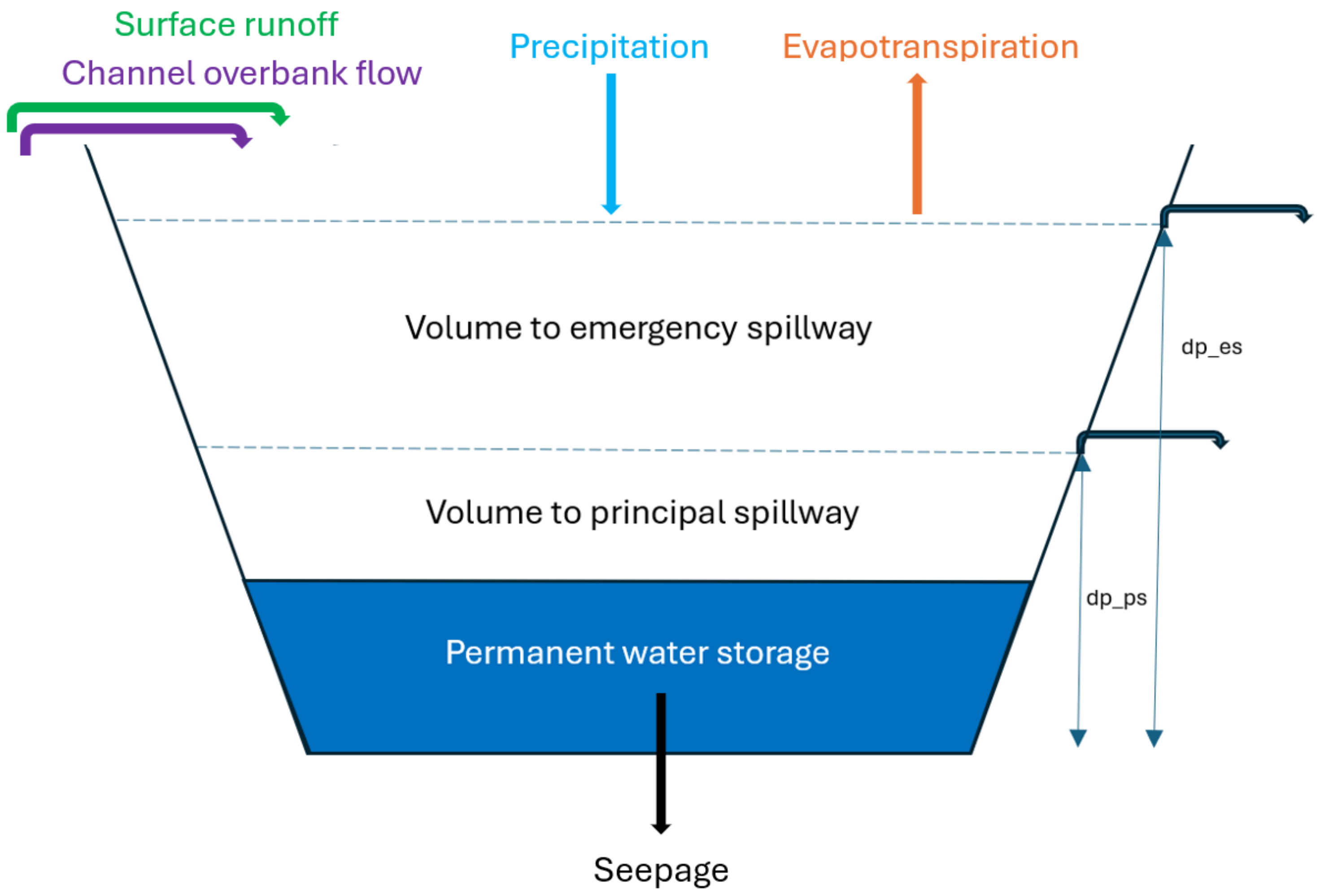
Model setup for a subbasin of the Scheldt River Basin

Model customization and configuration

3) Implementation of wetlands through wetland module

- Manual implementation of wetlands at all HRUs identified as "highly suitable" (wetland.wet)
- Wetland parameters → dp_ps, dp_es, k, evap (hydrology.wet)
- Control of release of wetland through decision table (res_rel.dtl)
- Linkage between channels and floodplains (chan-surf.lin)

```
chan-surf.lin:  Channel Floodplain  Linkage
 176
NUMB    NAME     NSPU    OBTYP   OBTYP_NO
1  cha001   1    ru   1
2  cha002   1    ru   3
3  cha003   1    ru   5
4  cha004   1    ru   7
5  cha005   1    ru   9
6  cha006   1    ru   11
7  cha007   1    ru   13
8  cha008   1    ru   15
9  cha009   1    ru   17
11  cha011   1    ru   21
```



dp_ps = Average depth of water at principal spillway

dp_es = Average depth of water at emergency spillway

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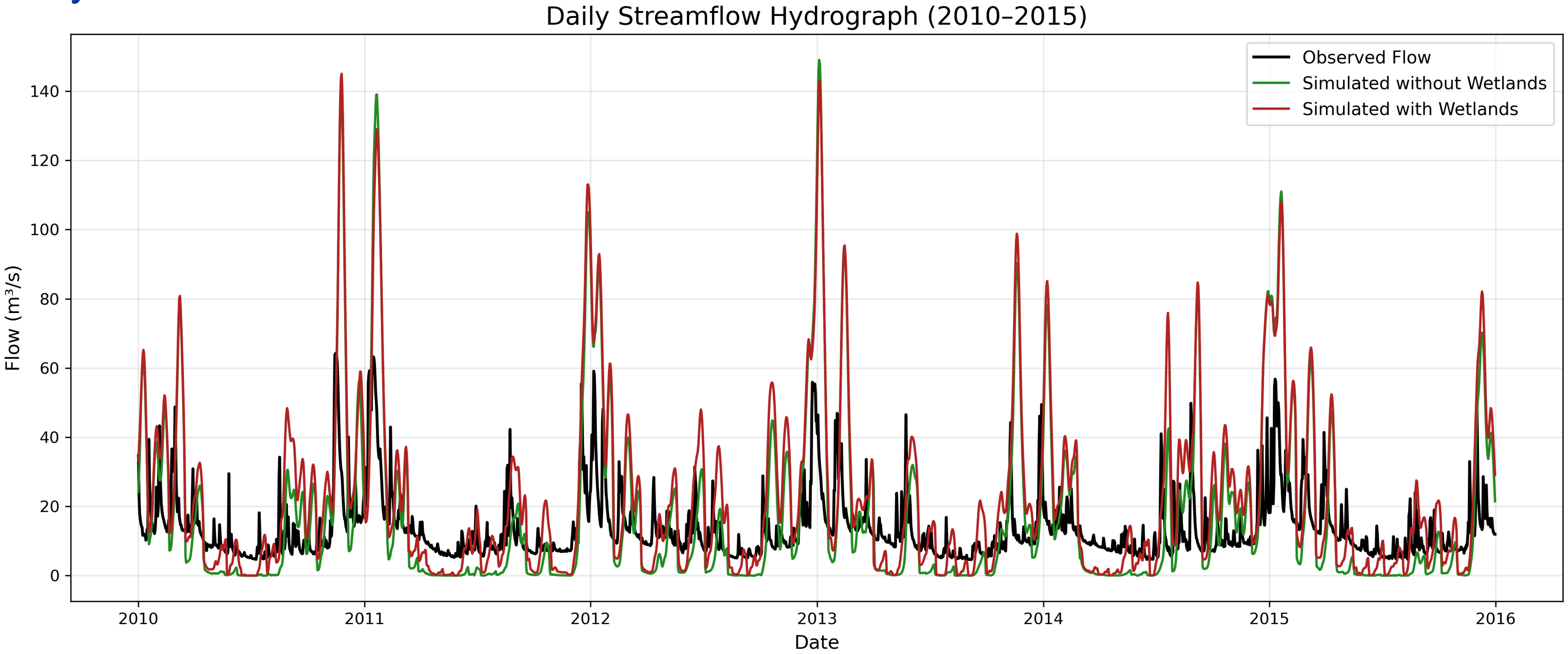
Model results of the Demer subbasin (SWAT+)

Simulation period: 2005 -2015
Warming-up period: 5 years

7703 HRUs 303 cha 581 rtu 78 aqu



Unrepresentation of the baseflow & limited changes in baseflow when changing groundwater - related parameters → Coupling with groundwater model needed!

Model results of the Demer subbasin (SWAT+gwflow)

Coupling with the groundwater module (Bailey et al., 2020)

→ Wetland-groundwater exchange (gwflow)

→ New channel subroutine to simulate overbank flow from rivers to floodplains (SWAT+)

River flow drops to nearly zero when subroutine is activated

Wetland–groundwater exchange is functioning well, but the routing between floodplain-channel is not when gwflow is activated

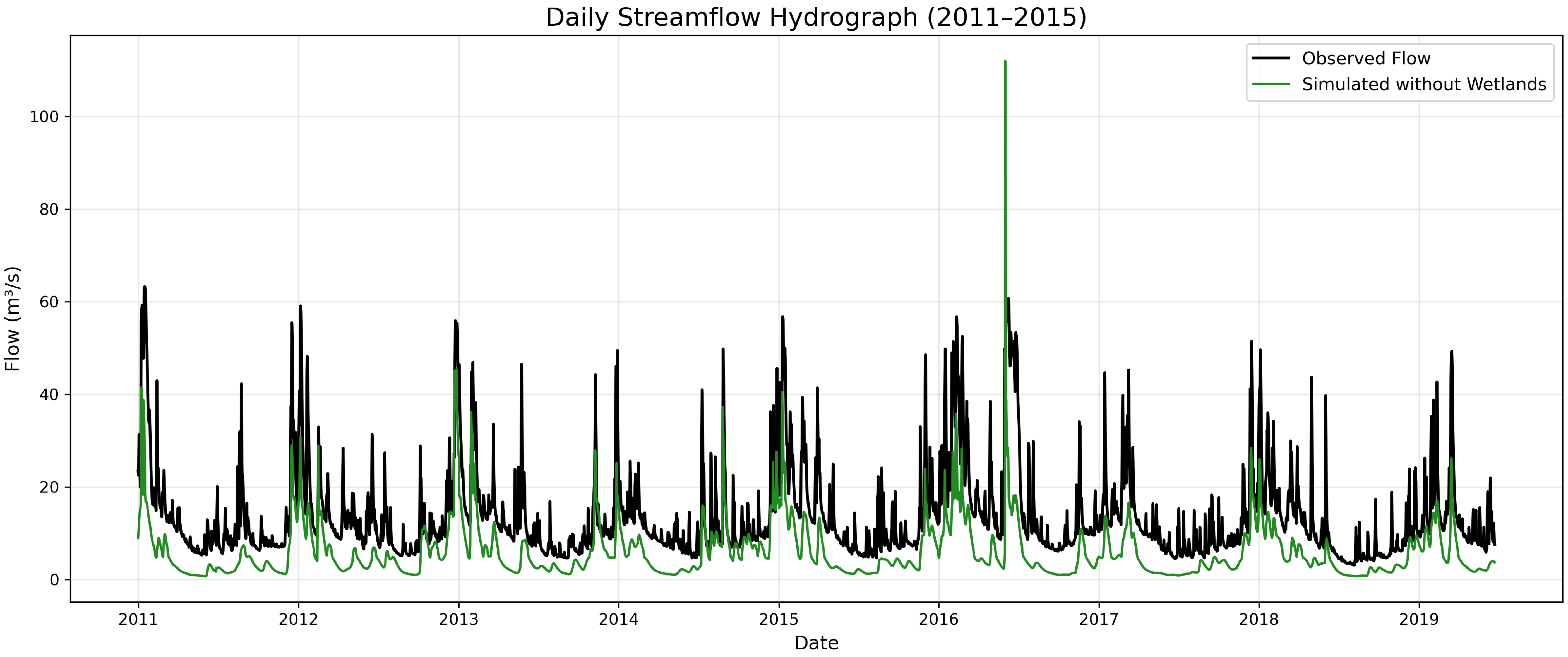
Still under investigation…

Water balance summary

Component	Value (mm)	Interpretation
Precipitation (precip)	792	Normal input
Evapotranspiration (et)	580	Dominant water loss
Surface runoff (surq_gen)	205	Too high
Percolation (perc)	306	Too high
Lagged lateral flow (laglatq)	2,785	Unrealistically high - water retained in subsurface
Lagged saturated flow (lagsatex)	1,420	Excess baseflow held in aquifer, not reaching river
Wetland overflow (wet_oflo)	47,331	Extremely high – but isn't routed to river?
River discharge (flo_out)	+/- 0	No river flow, outflow

Model results of the Demer subbasin (SWAT+gwflow)

Simulation with wetland -groundwater exchange
Simulation period: 2005 -2015
Warming-up period: 5 years



Sum of squared residuals
7149.8

Water balance summary

Component	Value (mm)
Precipitation	792.459
Evapotranspiration	515.705
Lateral flow	265.326
Surface runoff	31.184
Percolation	18.889
	-38.655

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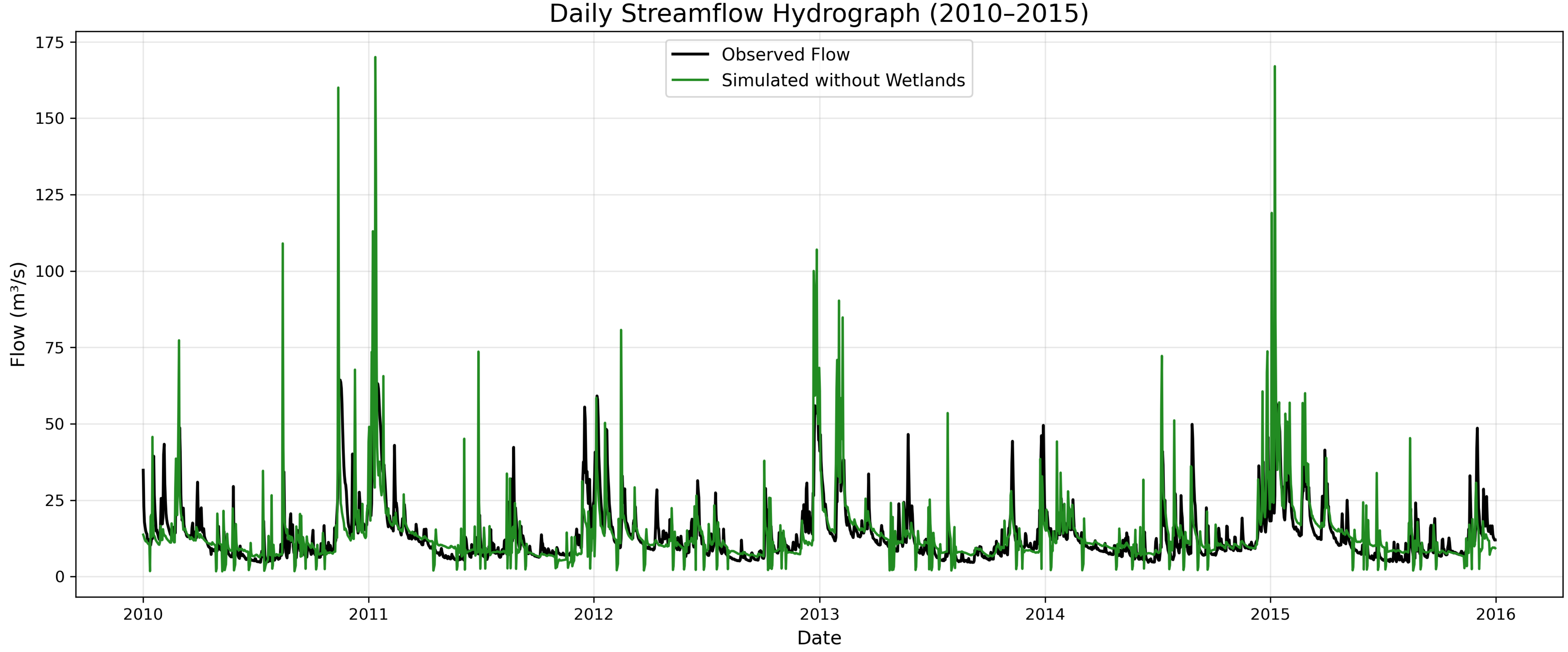
Model results of the Demer subbasin (SWAT+gwflow)

Calibration (monthly) with wetland -groundwater exchange using PEST
Simulation period: 2005 -2015
Warming-up period: 5 years



Sum of squared residuals
860.4

Water balance summary

Component	Value (mm)
Precipitation	792.459
Evapotranspiration	582.168
Surface runoff	72.249
Percolation	150.28
Lateral flow	2.868
	-15.106

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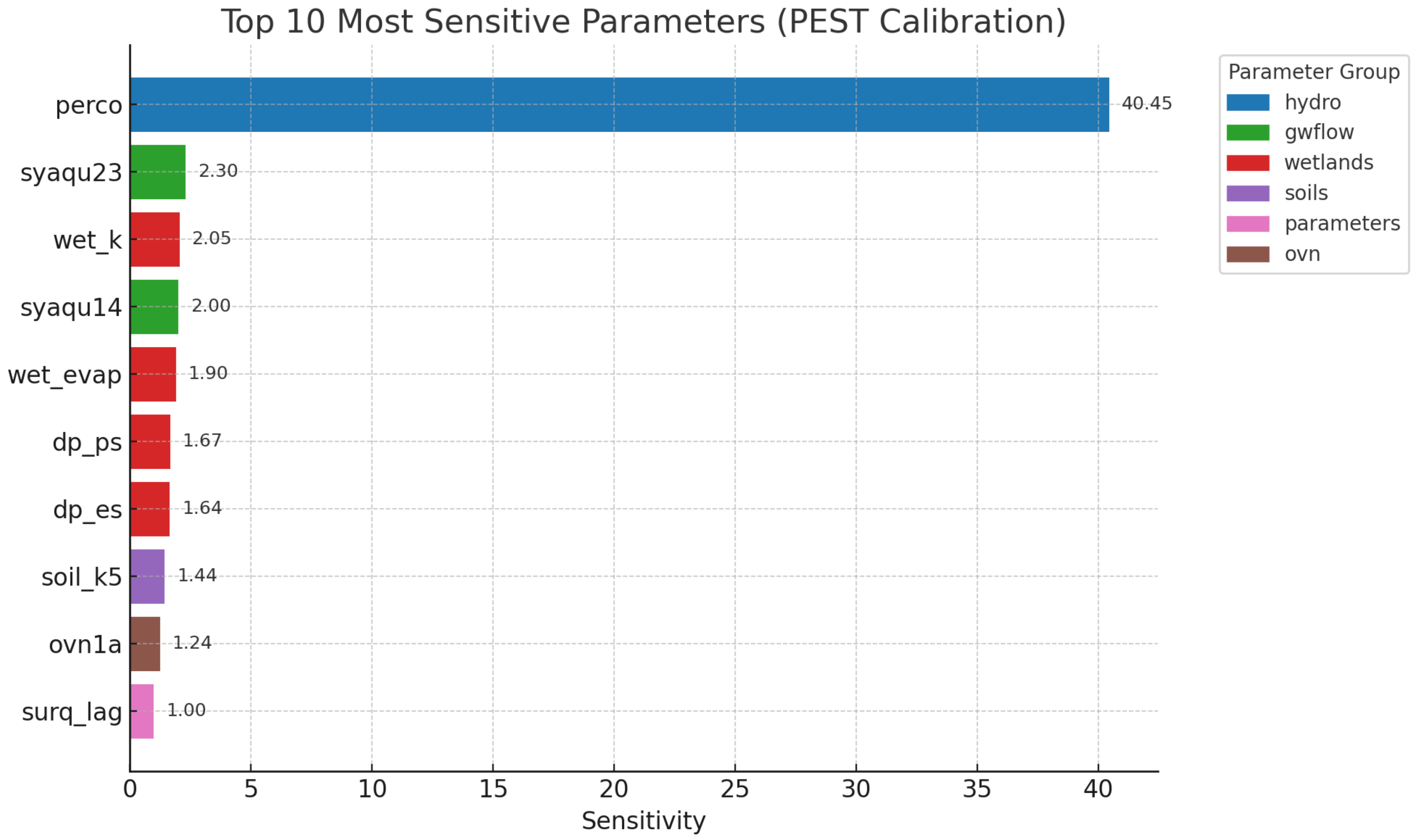
Model results of the Demer subbasin (SWAT+gwflow)

Parameter values and sensitivities from PEST

- Percolation coefficient = 0.97
- Specific yield of the aquifer is mostly 0.2-0.3
- Hydraulic conductivity of wetland bottom sediments = 0.068 m/d
- Evaporation from wetlands = 0.74
- Depth of principal spillway > depth of emergency spillway
- Hydraulic conductivity of soil ranges between 0.04 to 79 m/d
- Overland manning coefficient is generally not sensitive except of " convtill_res"
- Surface runoff lag time = 0.224 d



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Work in progress & future directions

Key highlights:

- Wetlands play a key role in addressing water quantity and quality challenges
- However, current implementation ambition is low (there is high potential!).
- Existing models show mixed results on their effectiveness — more research is needed on how to represent wetlands more accurately in hydrological models to support upscaling and policy adoption.

Work in progress and future directions:

- Further calibration using global optimization tools (OSTRICH)
- Resolving issues with SWAT+gwflow simulation, including interactions between groundwater, channels and wetlands

- Integration of water quality processes and quantification of nitrate removal by wetlands

Thank You

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