Climate change and agricultural development: Adapting Polish agriculture to reduce future nutrient loads in a coastal watershed

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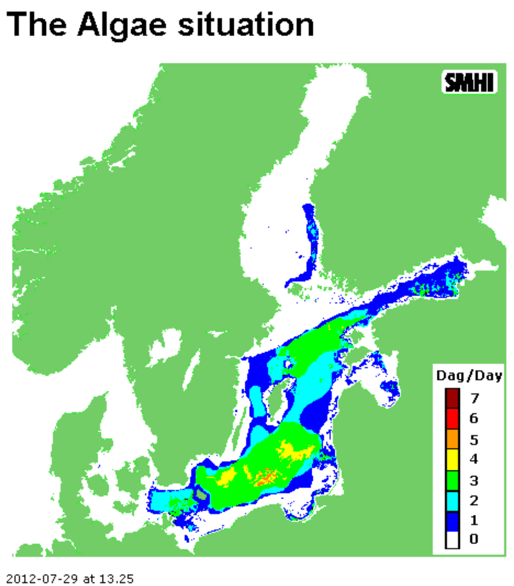
Background

- Aquatic eutrophication caused by excessive nutrient loads transported by rivers to sea waters is now the primary environmental issue related to the Baltic Sea
- Poland’s share of the generated load (originating mainly from agricultural diffuse sources) is assumed as the largest among the Baltic states (HELCOM)
- Stimulus for implementing measures preventing diffuse pollution is coming not only from the EU Directives but also from the Baltic Sea Action Plan (country-specific reduction targets)



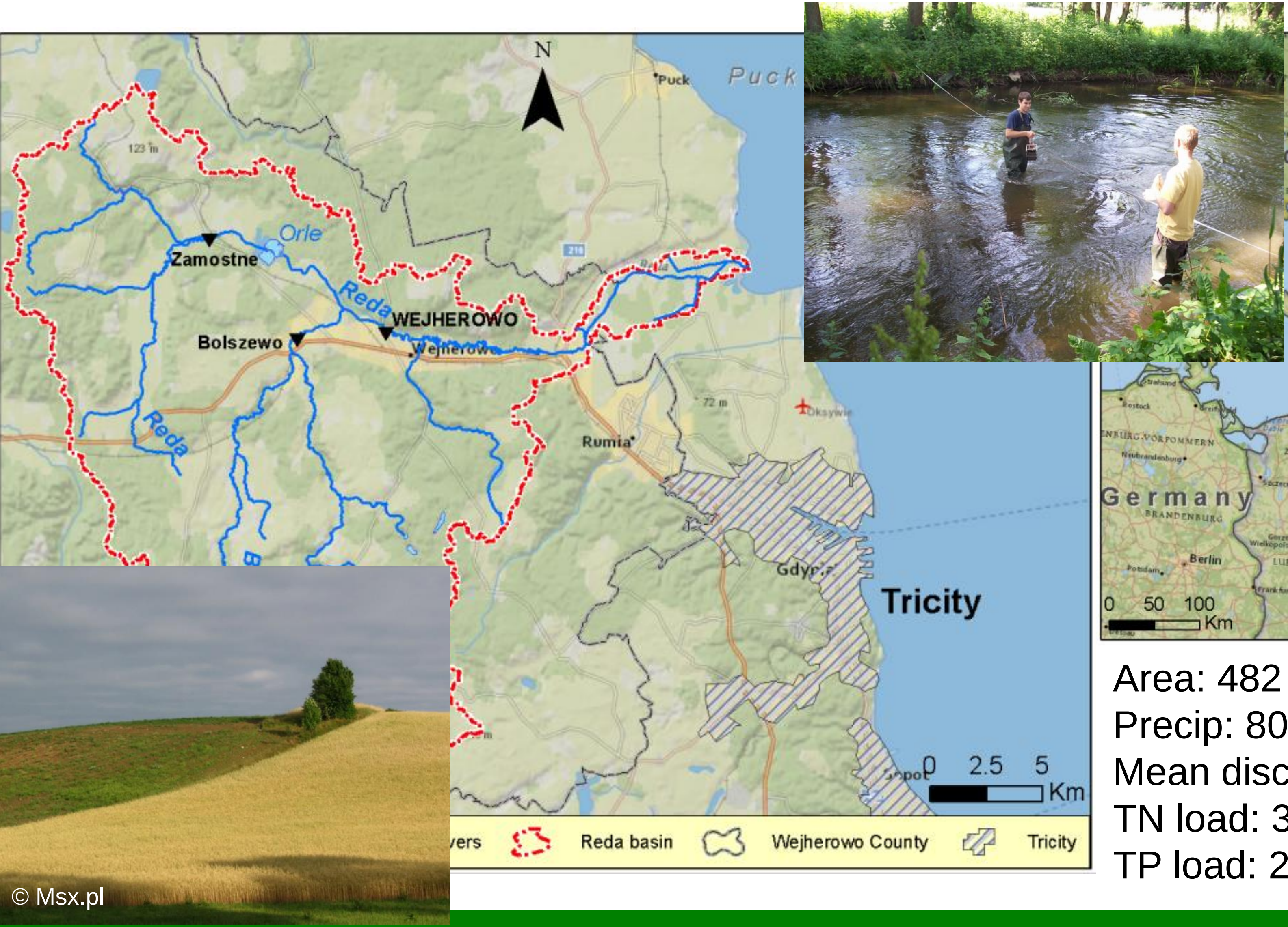
Objective

This study, set in a small coastal watershed in Poland, has 2 objectives:

- To quantify nutrient loads discharged to the sea under future climate and land use change scenarios until 2050
- To estimate the effect of agricultural adaptation measures aimed at nutrient load reduction under future conditions

Several recent studies at the Baltic Sea Basin scale (Arheimer et al. 2012; Meier et al. 2012) had similar goals, but there is a need for a smaller-scale catchment studies with more physically-based models

Study area: The Reda watershed



Area: 482 km^2

Precip: 800 mm

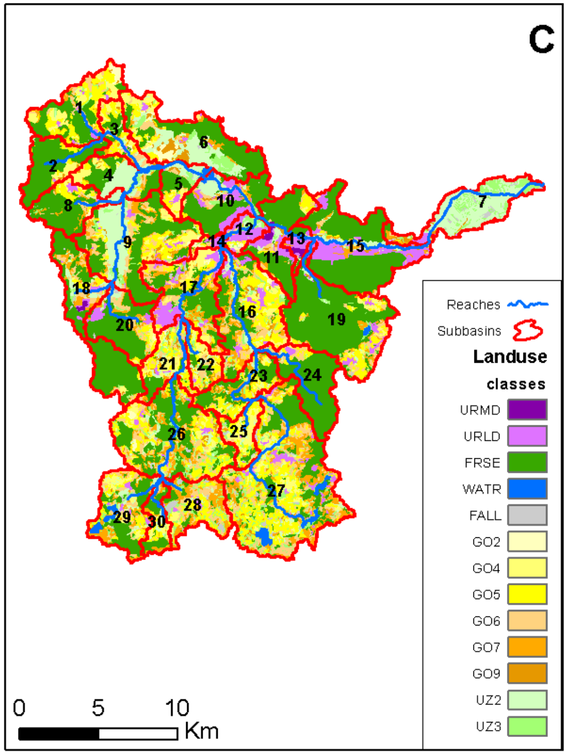
Mean discharge: 5.4 m^3/s

TN load: 320 t/a

TP load: 23 t/a

Model setup – key features

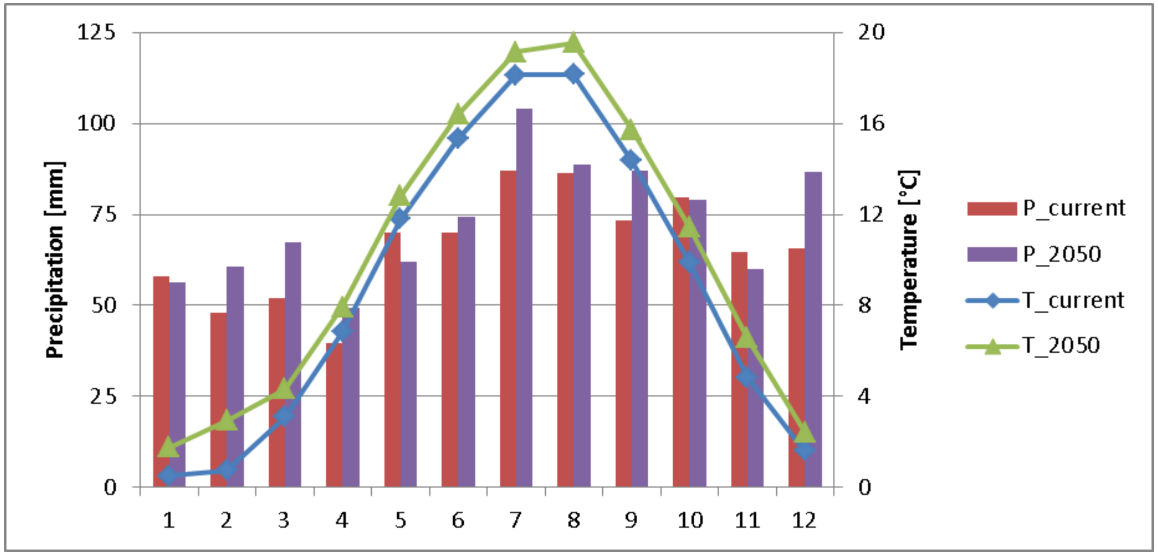
- SWAT2009
- 50m resolution DEM
- Delineation into 30 subbasins
- Corine Land Cover map – 13 classes of land use
- Soil maps – 17 classes of soils
- 465 HRUs
- Precipitation data from 5 stations, and other climate variables from 4 stations



- Management practices based on detailed commune-level data and interviews with agricultural extension services
- SUFI-2 algorithm applied for model calibration

Climate change projections for 2050s

- Precipitation and temperature projections from the ECHAM5-RCA3 RCM driven by A1B GHG emission scenario (SMHI)
- Delta change approach (monthly change factors representing the future time slice)
- Atmospheric CO_2 increased by 50% (A1B scen.) => impact on actual ET



Mean ΔT 1.3°C (range 0.8°C - 2.2°C)
Mean Δ P 80 mm (10%)

Land use change scenarios for 2050s

- Two main drivers in land use change are **urban** land cover change and **agricultural** land use change
- **Urban** => one scenario based on population growth projections
  - Urban sprawl of the cities
  - Conversion of marginal land in rural areas into low density residantial land cover (URLD)
- **Agricultural** => two scenarios
  - Business-As-Usual (spontaneous development)
  - Major Shift in Agriculture (rapid intensification)
    - Current **Danish** agriculture set as the model to which Poland will converge

Agricultural land use change scenarios

Business-As-Usual scenario

- Traditional (extensive), oriented on own farm needs (driven by local socio-economic conditions and EU policies)

Major Shift in Agriculture scenario

- Intensive, export-oriented (driven by global food demand)

Agricultural land use change scenarios

Scenario feature	Business-As-Usual (BAU-2050)	Major Shift in Agriculture (MSA-2050)
Population density	Increase by **32%** (~200 pers/km^2) compared to 2011 => URLD area increased by **30%**	
Urban population	Decrease from **58%** in 2011 to **56%** in 2050	
Type of agriculture	Traditional (extensive), oriented on own farm needs	Intensive, export-oriented (driven by global food demand)
Crop structure (% of agricultural land)	Spring Cereals 36% Winter cereals 17% Grassland 26% Potatoes 9% Corn silage 2% Other 10%	Spring cereals 48% **(+)** Winter cereals 2% **(-)** Grassland 17% **(-)** Potatoes 3% **(-)** Corn silage 10% **(+)** Other 20% **(+)**
Livestock density	0.56 LSU ha^{-1}	1.43 LSU ha^{-1} **(+150%)**
Fodder source	Locally produced fodder	Imported fodder
Fertilizer rates	Average: **37 kg N** ha^{-1}, **12 kg P** ha^{-1} (mainly mineral fert.)	Average: **102 kg N** ha^{-1}, **53 kg P** ha^{-1} (mainly slurry and manure)

Experimental design (core scenarios)

Driving forces		Climate	
		Current	2050
Land use	Current	1. Baseline	4. CC-2050
	2050 (Business-As-Usual)	2. BAU-2050	5. BAU-CC-2050
	2050 (Major Shift in Agriculture)	3. MSA-2050	6. MSA-CC-2050

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- Design enables to distuinguish between climate and land use change effects
- Indicators comparing scenarios 2-6 with the baseline (1)

Adaptation measures (ag-BMPs)

- Measures selected with stakeholder participation based on the list of prioritized measures elaborated by the Baltic COMPASS project (http://www.balticcompass.org/)

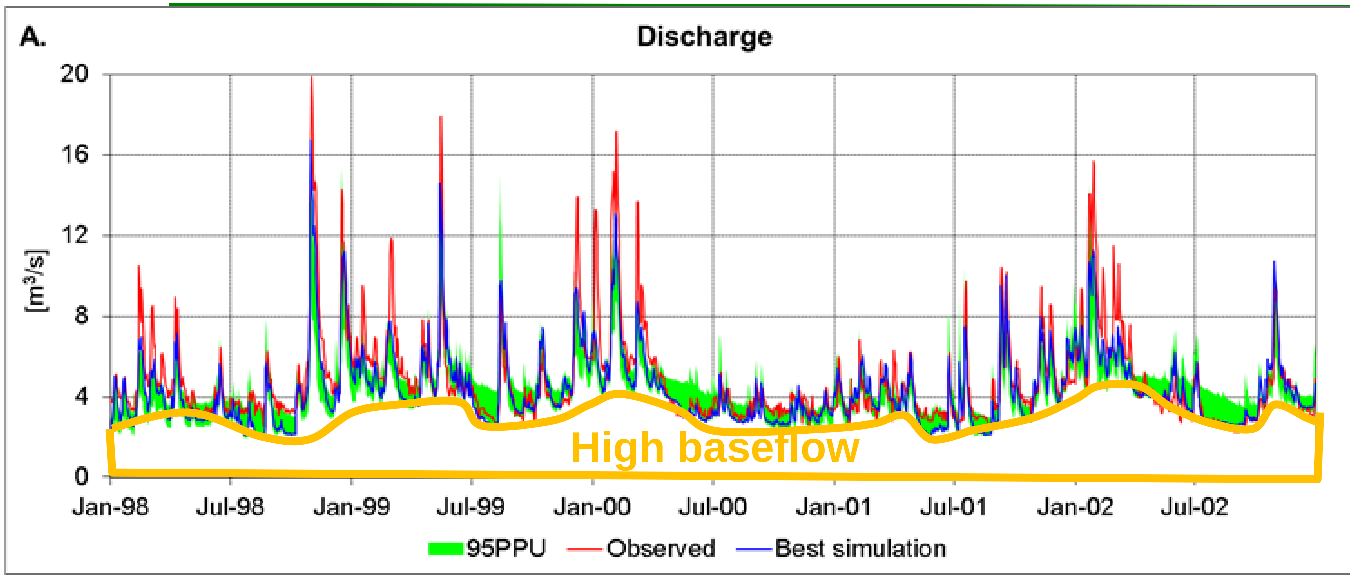
1. *Vegetative cover in autumn and winter* (VC) – defined in ca. 50% of agricultural land. Rye and red clover were used as cover crops.
2. *Buffer zones along water areas* (BZ) - the Vegetative Filter Strip sub-model was applied in all agricultural land HRUs.
3. *Avoiding fertilization in risk areas* (RA) – fertiliser rates reduced by 50% in HRUs with agricultural land use that satisfied at least one of the following conditions: (1) slopes > 10%; (2) existing drainage ditches; (3) heavy soils.
4. *Constructed wetlands for nutrient reduction/retention* (CW) – wetlands activated in all sub-basins with a share of agricultural land use above 50%

Experimental design (adaptation scenarios)

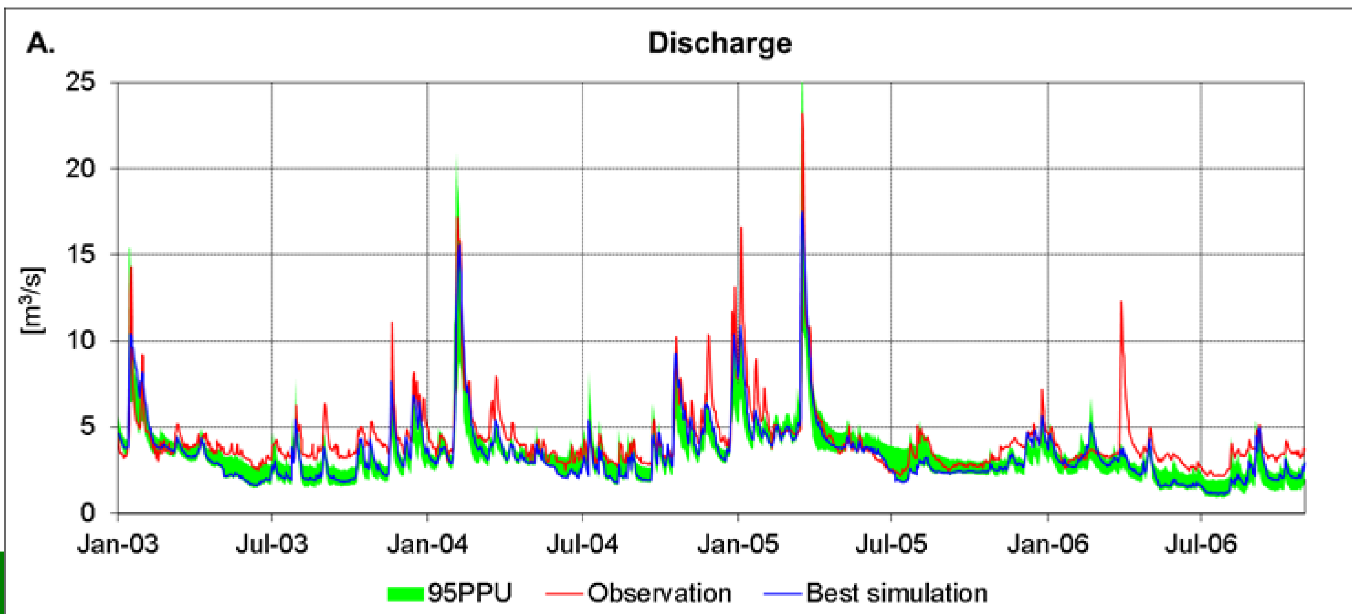
Driving forces → / Land use ↓		Climate		
		Current	2050	2050 + Adaptation measures (BMPs)
Land use	Current	1. Baseline	4. CC-2050	
Land use	2050 (Business-As-Usual)	2. BAU-2050	5. BAU-CC-2050	7. BAU-CC-2050 + VC 8. BAU-CC-2050 + BZ 9. BAU-CC-2050 + RA 10. BAU-CC-2050 + All
Land use	2050 (Major Shift in Agriculture)	3. MSA-2050	6. MSA-CC-2050	11. MSA-CC-2050 + VC 12. MSA-CC-2050 + BZ 13. MSA-CC-2050 + RA 14. MSA-CC-2050 + CW 15. MSA-CC-2050 + All

- VC – vegetative cover in autumn and winter; BZ – buffer zones; RA – reducing fetilisation in risk areas; CW – constructed wetlands

Calibration & validation of daily discharge

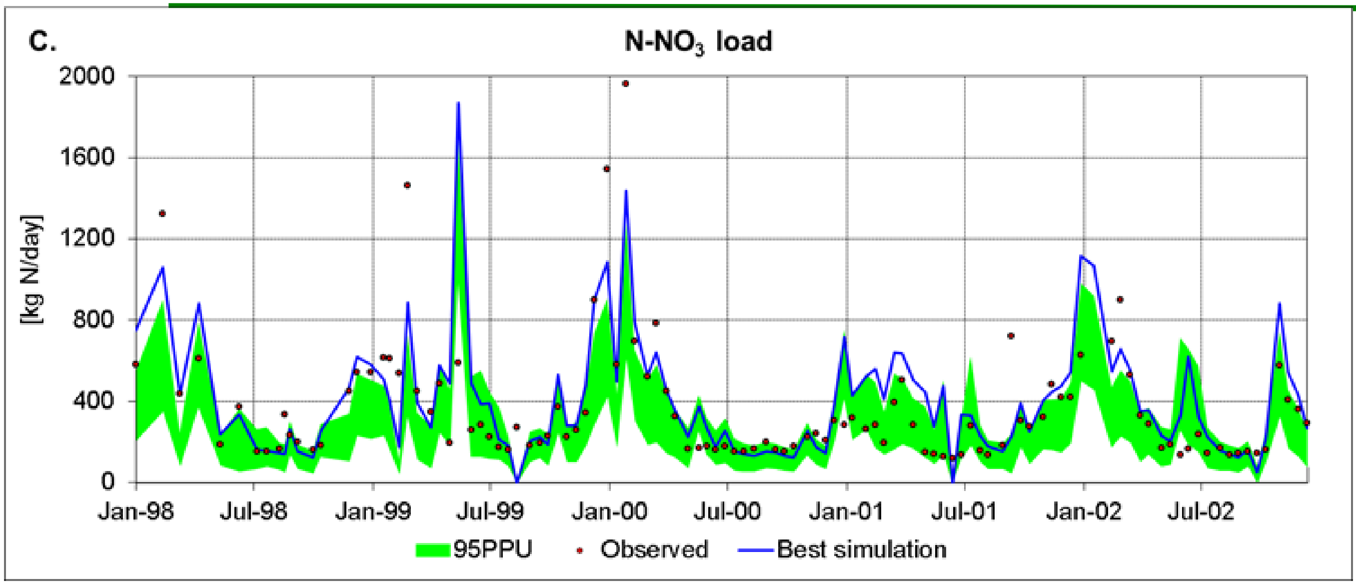


Cal. 1998-2002
NSE: 0.75
PBIAS: -8%

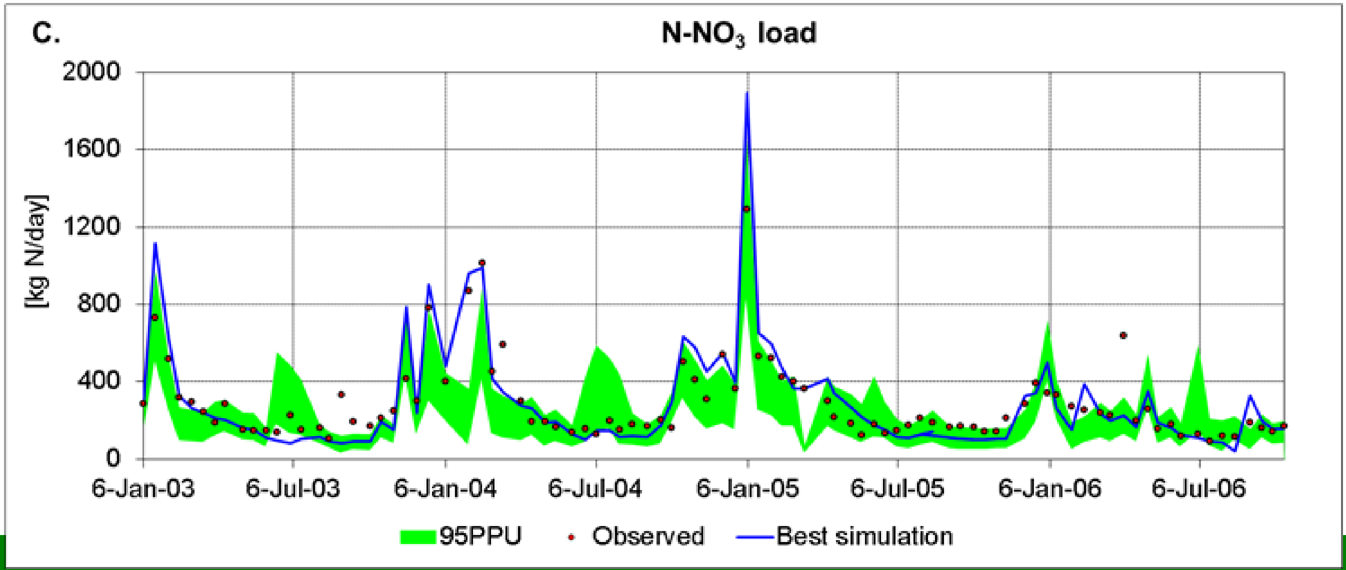


Val. 2003-2006
NSE: 0.61
PBIAS: -18%

Calibration & validation of bi-monthly N-NO$_3$ loads

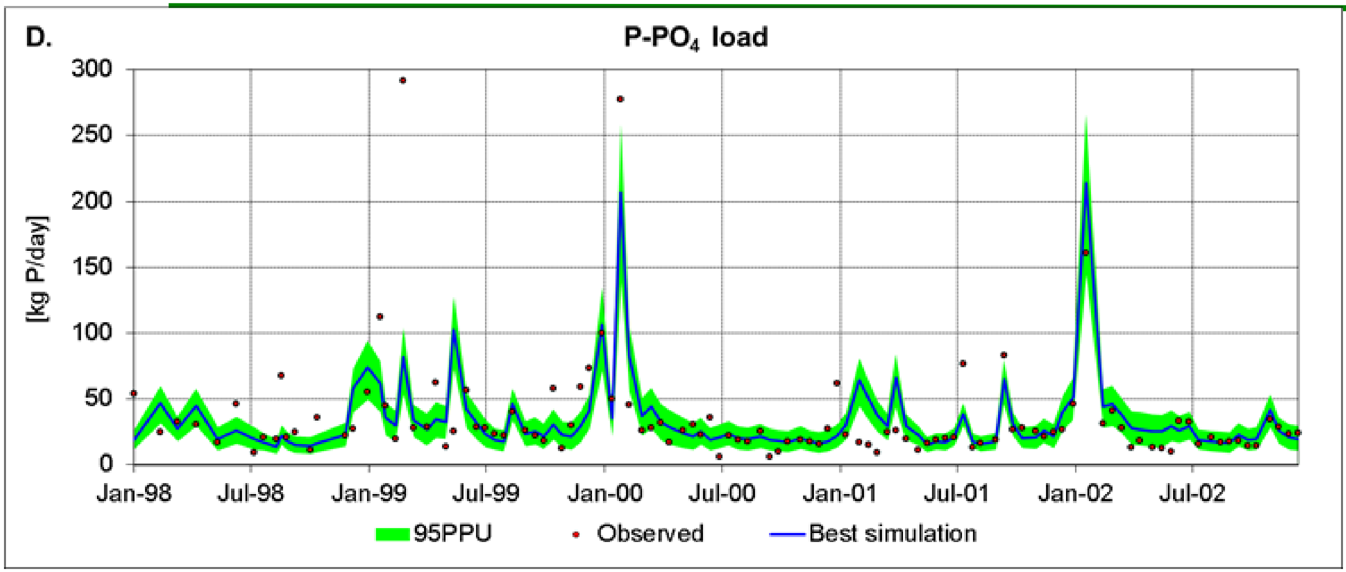


Cal. 1998-2002
NSE: 0.62
PBIAS: -4%

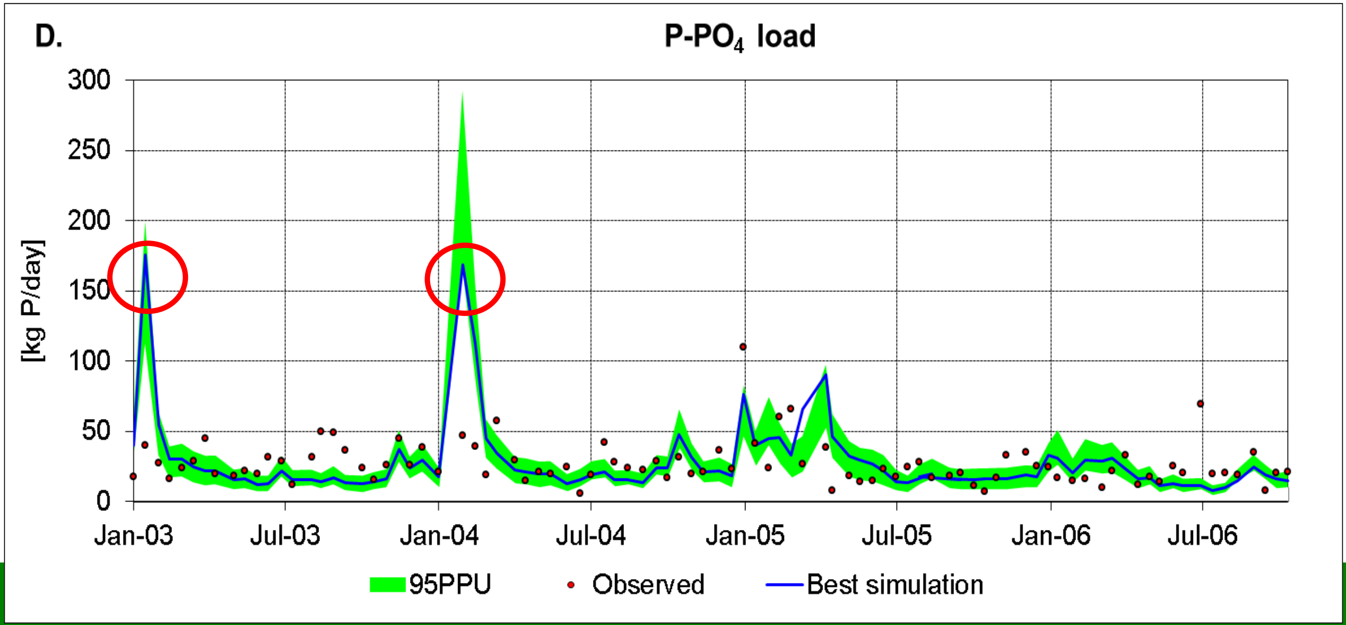


Val. 2003-2006
NSE: 0.64
PBIAS: 3%

Calibration & validation of bi-monthly P-PO_4 loads

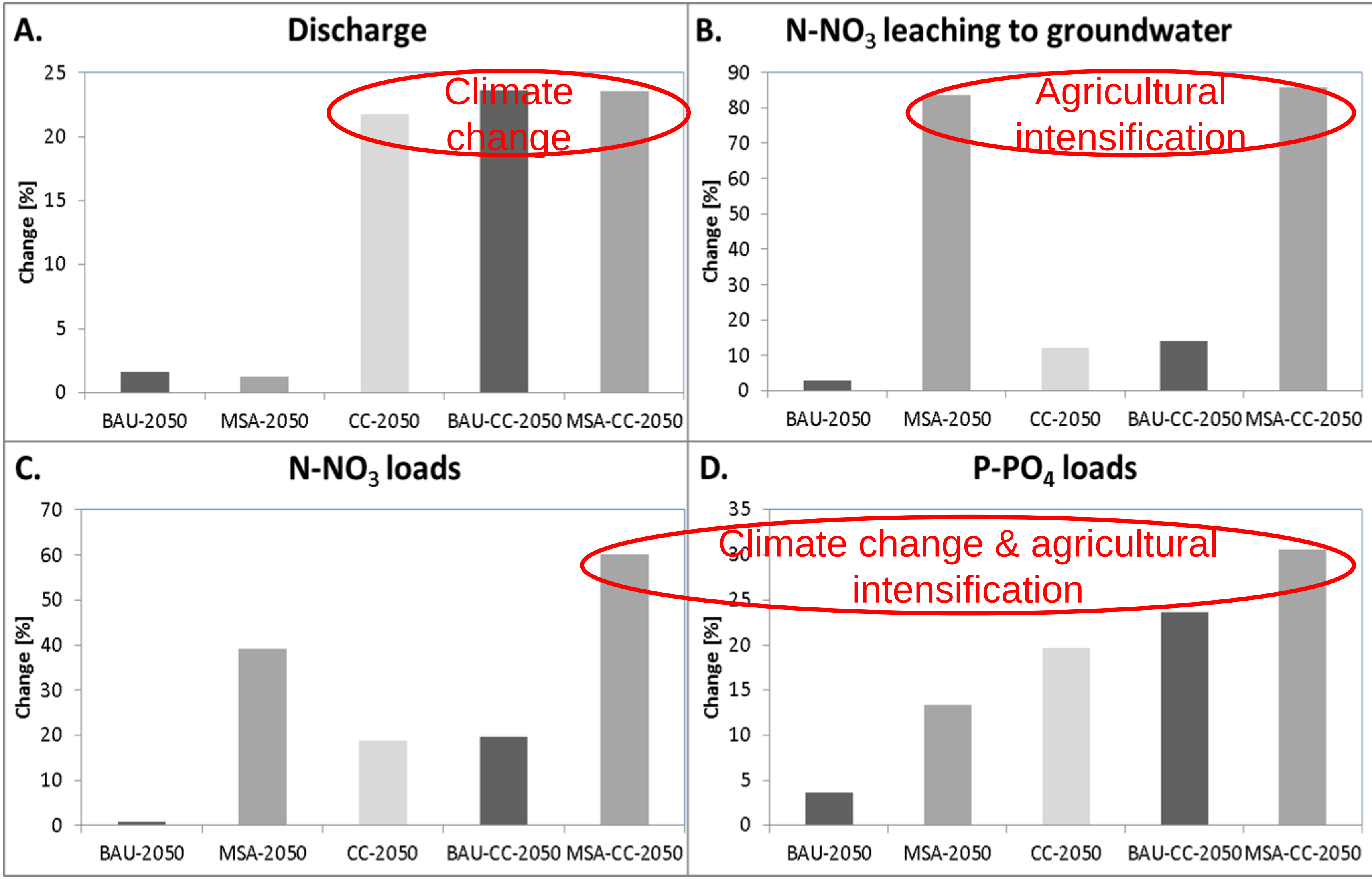


Cal. 1998-2002
NSE: 0.53
PBIAS: -6%



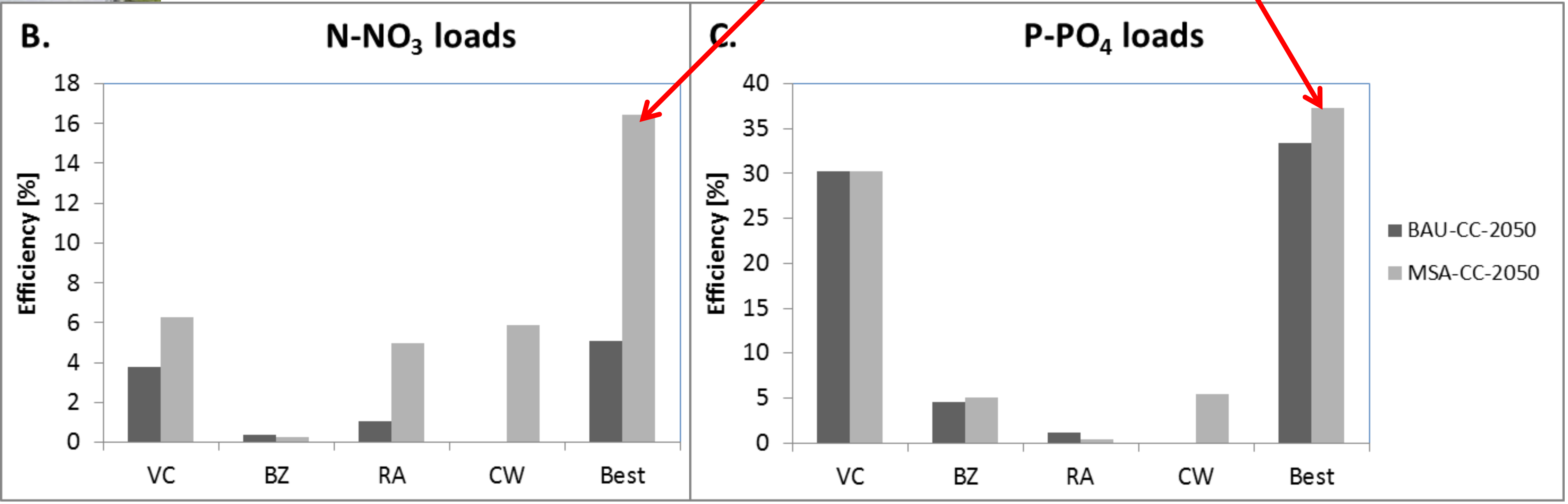
Val. 2003-2006
NSE: -1.78
PBIAS: 7%

Scenario results: Percent changes with respect to the baseline



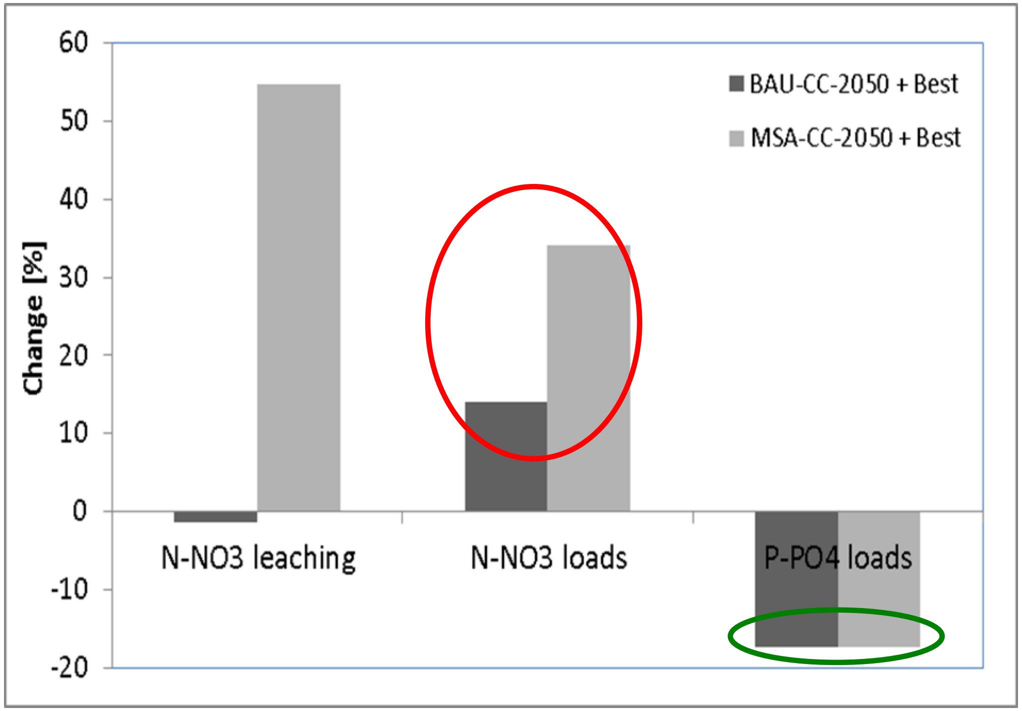
Scenario results: Efficiency of selected adaptation measures under future scenarios

- Vegetative cover in autumn and winter (VC) reduces P loads by preventing erosion and reduces N leaching to groundawater
- Low efficiency (up to 6%) of buffer zones (BZ), reducing fertilisation (RA) and constructed wetlands (CW)
- Max. efficiency under MSA 16% for N-NO_3 and 36% for P-PO_4



Percent change between „best combination of measures under future scenarios" and the baseline

- For N-NO_3 loads even the best combination of measures would not help to remediate the negative effects caused mainly by climate change and by agricultural intensification
- Nutrient dominant transport pathways playing the key role (leaching / sorption to sediment)



Conclusion

- Climate change and intensification of agriculture are expected to have a strong effect on future nutrient loads
- Urban land cover change driven by urban sprawl has little effect on future nutrient loads
- Intensification of agriculture under MSA-2050 will cause major deterioration of water quality, but will bring economic profit in the form of crop yields increased by 31%
- Cover crops would be the most efficient adaptation measure in 2050s, while other measures would have little efficiency

Literature & Acknowledgements

- Further reading
  - ➢ http://www.climate-impacts-2013.org/files/wism_gielczewski.pdf
  - ➢ Piniewski, M., Kardel, I. Giełczewski, M., Marcinkowski, P., Okruszko, T. 2013. Climate change and agricultural development: Adapting Polish agriculture to reduce future nutrient loads in a coastal watershed. *Ambio* (under review).

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Thank you!