PREPARING FOR THE FUTURE: SIMULATING AGRICULTURAL PRACTICES, HYDROLOGY AND NUTRIENT EXPORTS UNDER FUTURE CLIMATES

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BACKGROUND

Project funded by the Danish Strategic Research Foundation,

with the overall aim to:

- Quantify and rank the uncertainty relating to future projections of hydrology and nutrient transport, when combining:
  - Multiple climate model projections
  - Multiple eco-hydrological models
  - Multiple land use scenarios

Additionally to:

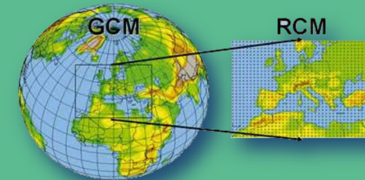
- Assess the effects of the combined climate and land use change scenarios on agricultural productivity and aquatic ecosystems in Denmark

Climate models

Climate model simulations by the Danish Met. Institute (**DMI**) and others.

INPUT/OUTPUT

- Meteorology (daily)
- precipitation
- radiation
- air temperature
- wind speed
- relative humidity
- cloud cover



Downscaling by the National Geological Survey of Denmark and Greenland (**GEUS**)

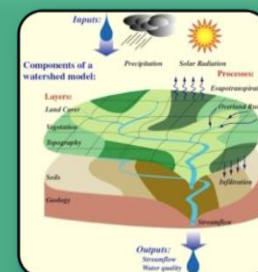
Climate data

Hydrological models

Eco-hydrological modeling by **Aarhus University and GEUS**

INPUT

- DEM
- Land use and management
- Point sources
- Soil type (and geology)
- Stream network and lakes



Crop yields
N and P transports

Discharge
Nutrient transport.

Ecosystem models

Ecosystem modeling by **Aarhus University**

INPUT

- Morphology (depth profile)
- Nutrient load
- Inflow and outflow volumes (residence time)
- Meteorology

Water quality

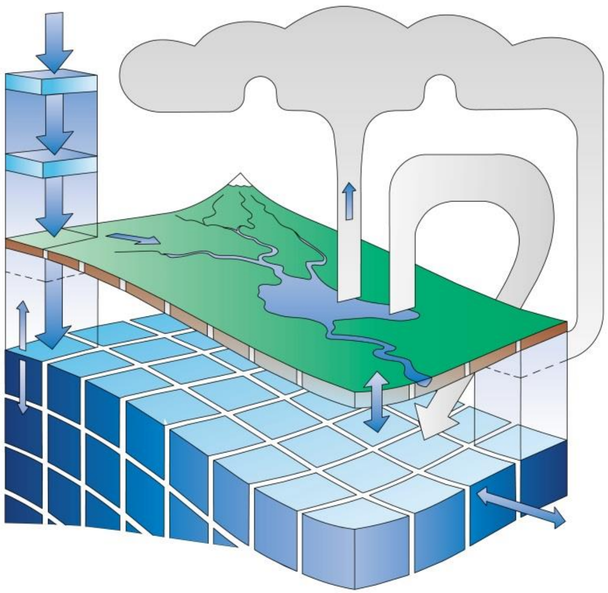
HYDROLOGICAL MODELS

MIKE SHE/MIKE11

- 3D groundwater flow
- 2D overland flow
- Drain flow (pipes, ditches)
- 1D river routing
- 1D unsaturated zone, Two-layer module (ET)
- Degree-day snow melt/accumulation

Daisy

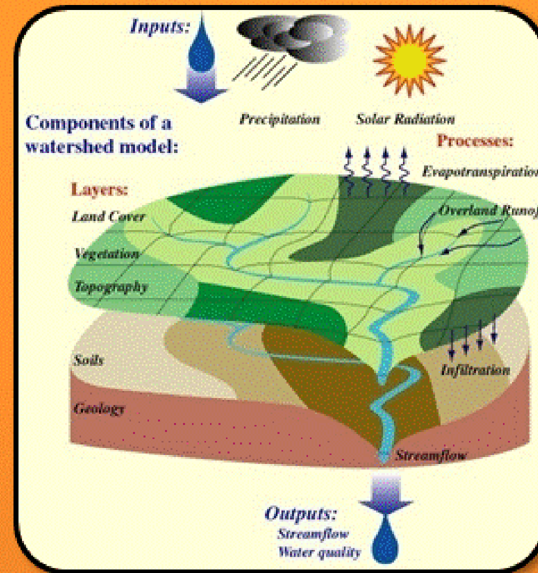
- 1D dynamic crop-climate model
- Nitrogen transformations and fluxes



CATCHMENT MODEL

SWAT: Soil and Water Assessment Tool

Developed at the Grassland, Soil and Water Research Laboratory, Texas A&M University



Input:

- Meteorology (daily averages)
  - Precipitation
  - Solar radiation
  - Air temperature
  - Wind speed
  - Relative humidity
- Topography, *Digital Elevation Model (DEM)*
- Land use, land/cropping practises, point sources
- Soil types
- Stream (and lake) networks

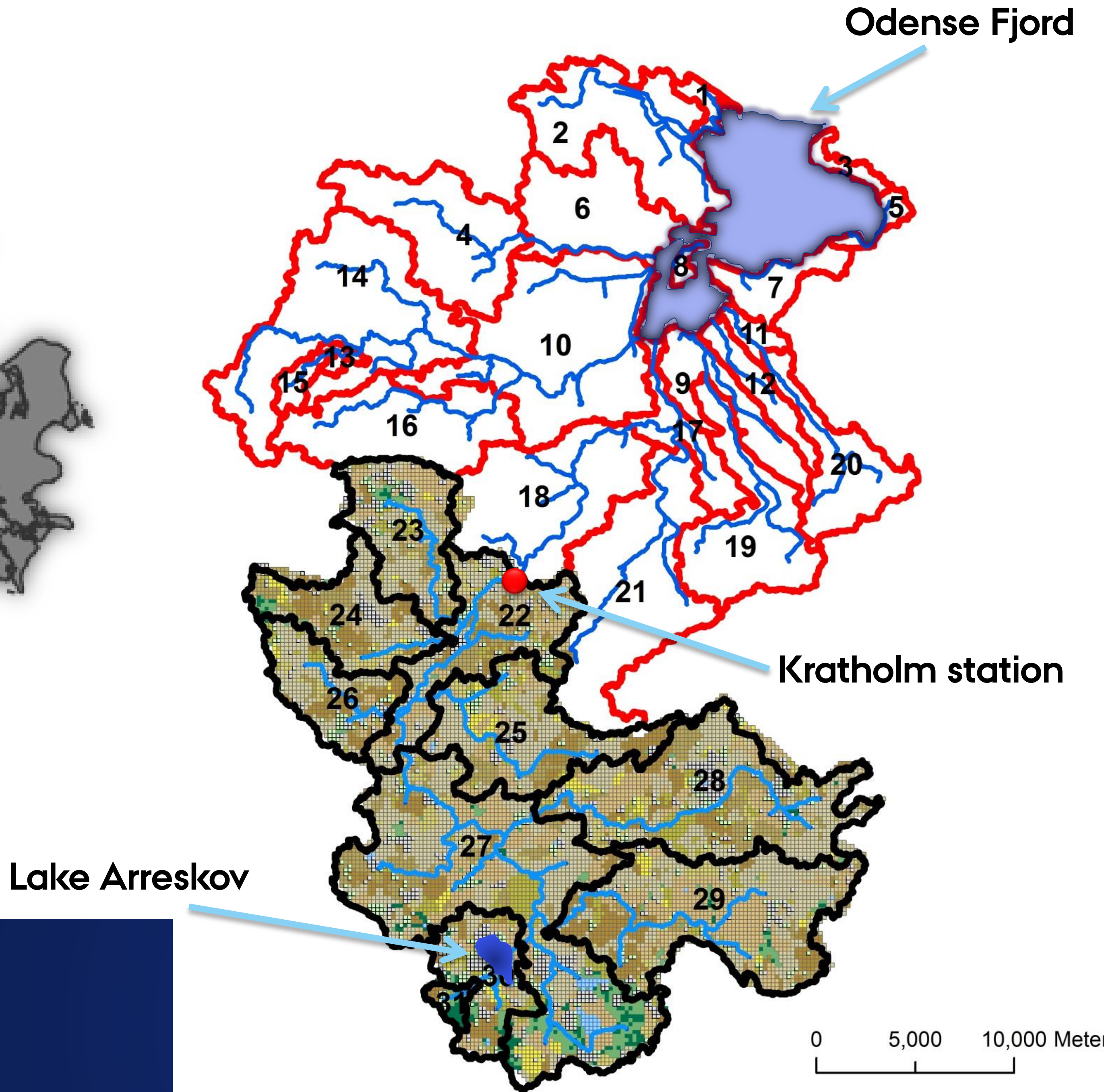
Output:

- stream flow
- nutrient concentrations in streams (and lakes)
- Crop yield (etc....)

OUTLINE

- Baseline model set up
- Climate and land use scenarios
- Focus on the effects and uncertainty of future projections on
    - Hydrological properties
    - Agricultural production
    - Nutrient losses to (and effects on) surface waters

Study site


Odense Fjord
Kratholm station
Lake Arreskov
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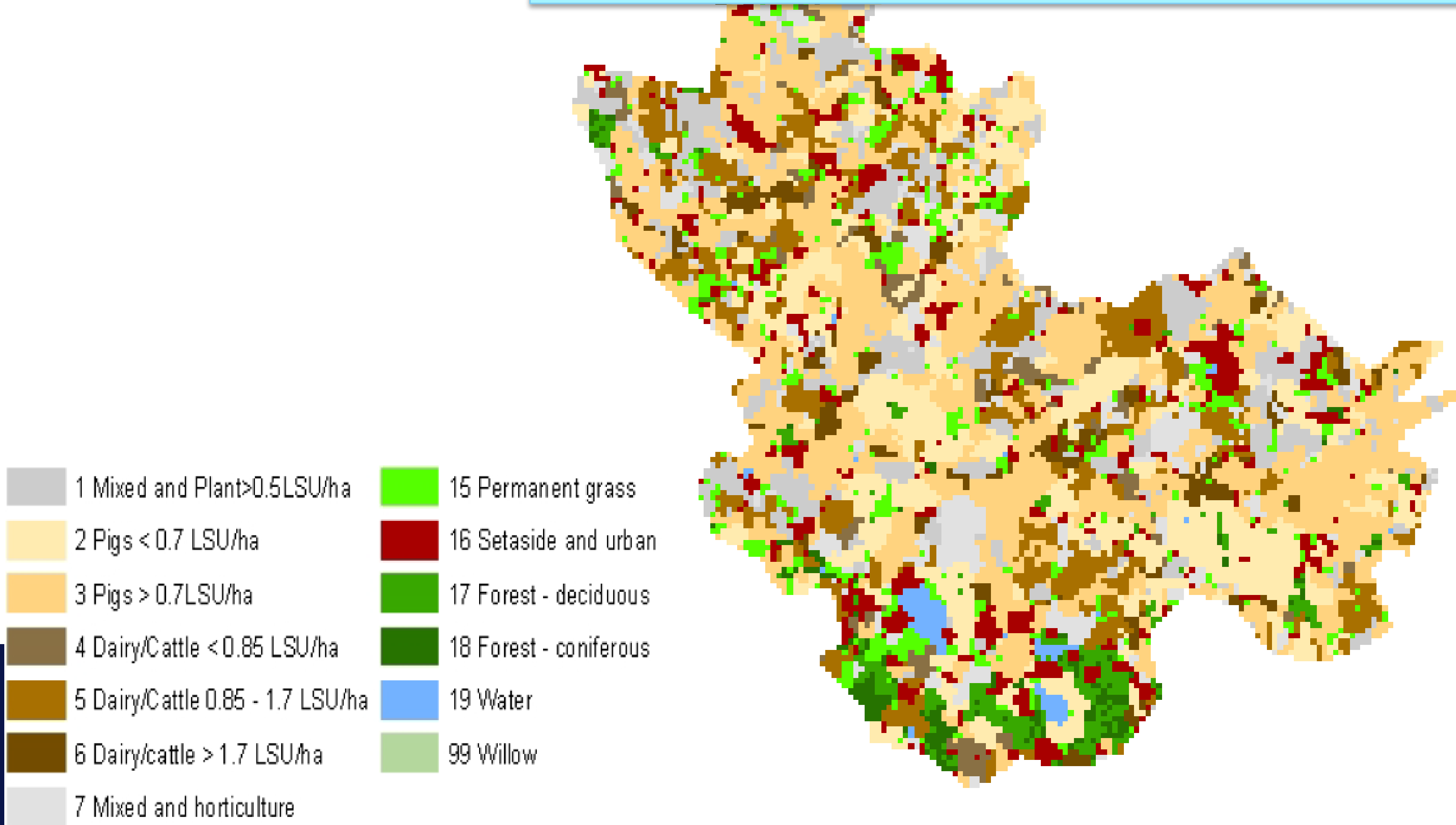
Baseline land use

Agriculture:	80%
Setaside and urban:	8%
Forest:	5%
Permanent grass:	5%
Water surfaces:	2%

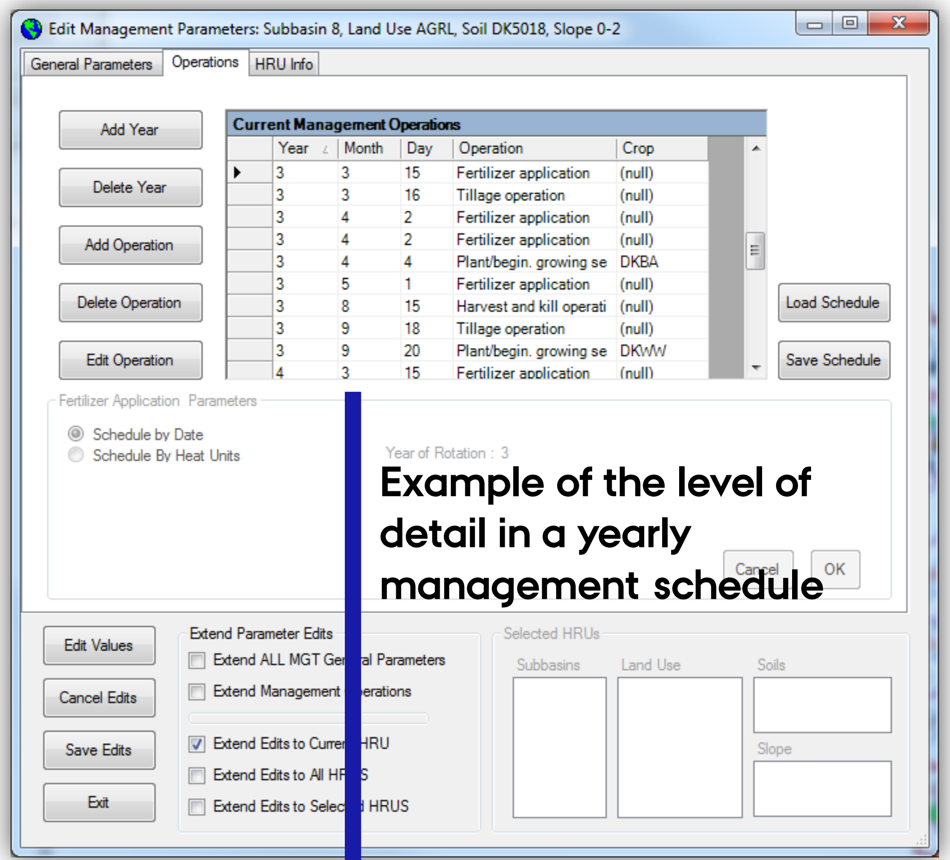
SWAT input:
- DEM of 32m resolution (resampled from 1.6m lidar DEM)
- 3-layer national soil map of 250m resolution
- Danish land use map in vectorized format
- Daily precipitation in 10 km grid (other inputs in 20 km grid)
- Detailed agricultural practices from reported data/statistics



Agricultural management

In total 7 farm types; each with two 5-year crop rotation schedules (totaling 14 different crop rotation schedules in the SWAT baseline set up)

Farm type	Manure N ($kg\ N\ ha^{-1}$)	Crop rotation				
Plant	<50	W. cereal	W. cereal	S. cereal	W. cereal	W. cereal
		Seed grass	S. cereal	Grass	Grass	W. cereal
	>50	Sugar beet	S. cereal*	S. cereal	Seed grass	W. cereal
		Grass	S. cereal	W. cereal	W. cereal*	S. cereal
Pig	<70	W. cereal	W. cereal	W. cereal	S. cereal	W. rape
		W. cereal*	Sugar beet	S. cereal	Seed grass	S. cereal
	>70	W. rape	W. cereal	W. cereal	W. cereal	S. cereal
		S. cereal	Seed grass	S. cereal	W. cereal	W. cereal
Cattle	<85	W. cereal	W. cereal	Sil. maize	S. cereal	Seed grass
		S. cereal	W. cereal	W. cereal*	S. cereal	Grass
	85-170	Sil. maize	Sil. maize	S. cereal*	Sugar beet	S. cereal
		W. cereal	S. cereal	Grass	S. cereal	Sil. maize
	>170	S. cereal	Sil. maize	Sil. Maize	Sil. maize	Sil. maize
		S. cereal	Sil. maize	S. cereal	Grass	Grass



Year	Month	Day	Operation	Crop
3	3	15	Fertilizer application	(null)
3	3	16	Tillage operation	(null)
3	4	2	Fertilizer application	(null)
3	4	2	Fertilizer application	(null)
3	4	4	Plant/begin. growing se	DKBA
3	5	1	Fertilizer application	(null)
3	8	15	Harvest and kill operati	(null)
3	9	18	Tillage operation	(null)
3	9	20	Plant/begin. growing se	DKWW
4	3	15	Fertilizer application	(null)

Example of the level of detail in a yearly management schedule

Spring Barley

Winter Wheat

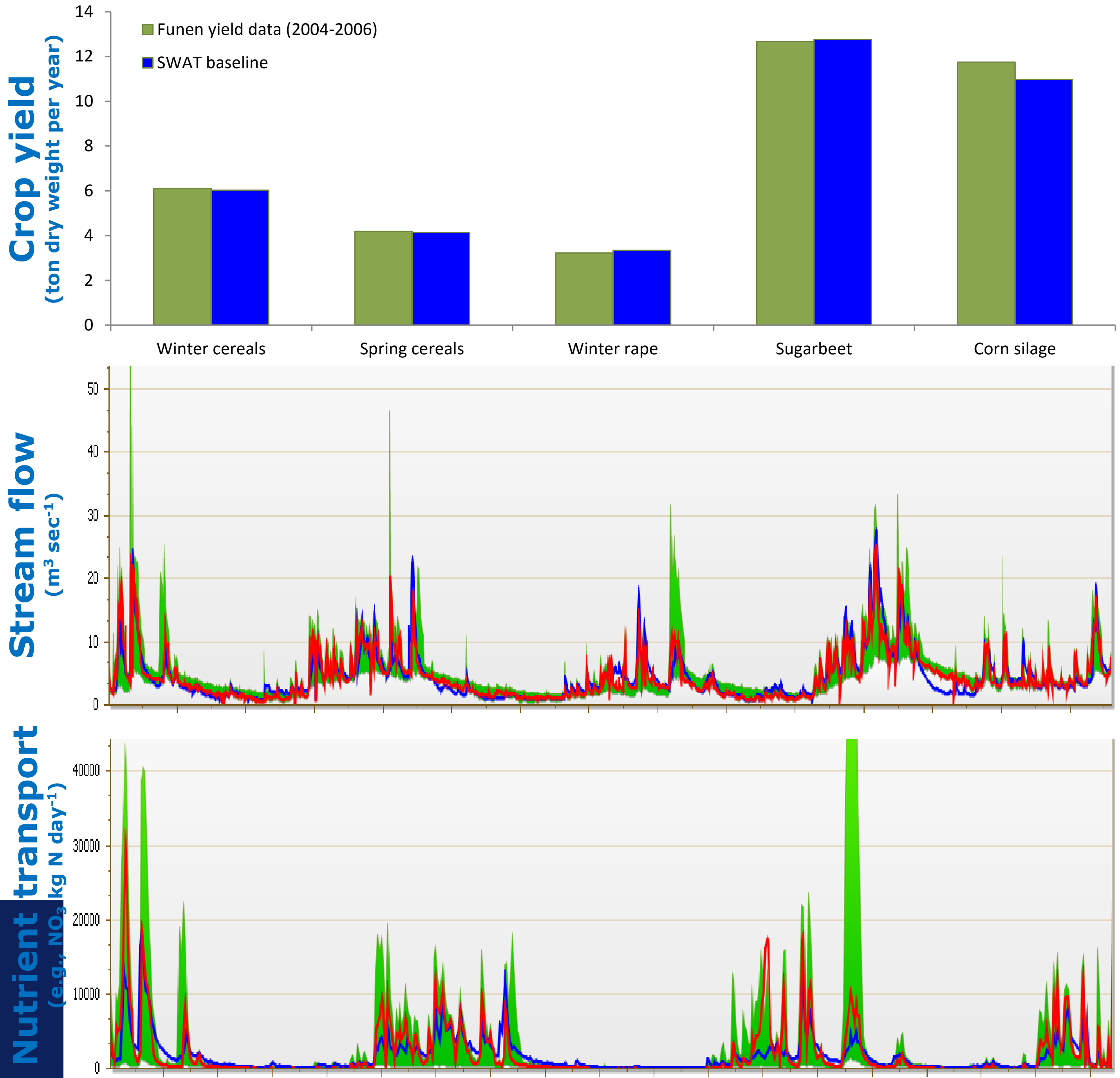
3 Step calibration process

We used SUFI2

Simulation period: 1990-2009

Daily calibration (2004-2007) NS ~ 0.8

Daily validation (2000-2003, 2008-2009) NS ~ 0.8



AARHUS UNIVERSITY

Using 4 different GCM-RCM coupled models from ENSEMBLES, and the IPCC A1B emission scenario

ENSEMBLES

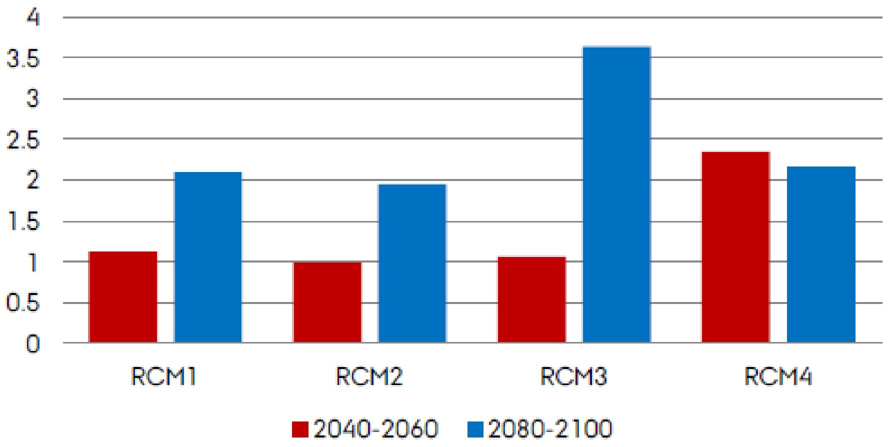
- GCM-RCM1 (Wet): (DMI) **ECHAM5–HIRHAM5**
- GCM-RCM2 (Median): (SMHI) **ECHAM5–RCA3**
- GCM-RCM3 (Dry): (CNRM) **ARPEGE–RM5.1**
- GCM-RCM4 (Warm): (METO) **HadCM3–HadRM3**

Baseline: 1990-2009
Near future: 2040-2059
Far future: 2080-2099

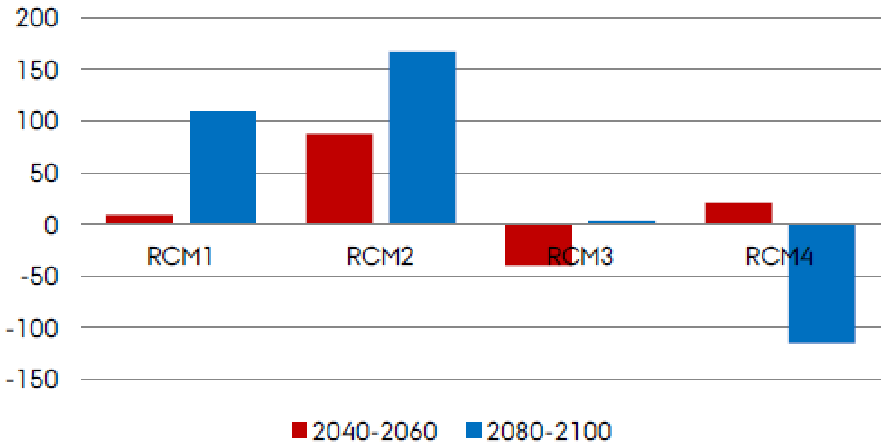
In all cases: model warm-up for 10 years prior to scenario periods

OVERVIEW OF CLIMATIC PROJECTIONS

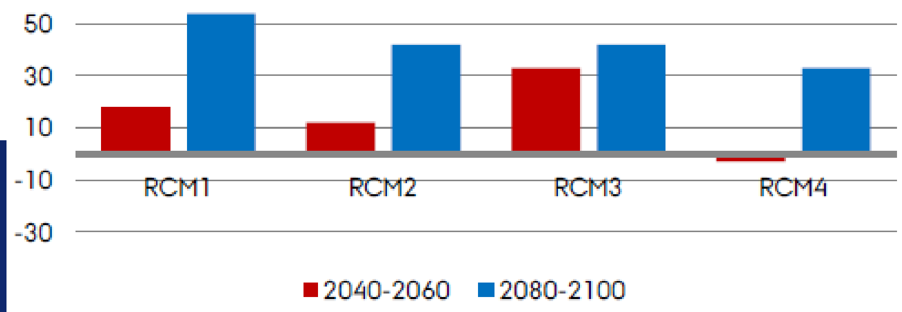
Changes in annual mean air temperature (°C)



Changes in precipitation (mm/year)



Changes in winter precipitation (mm/year)



Land use change scenarios

Non-market values

High

Agriculture for nature

<u>Scenario 1</u>

- Decrease in agricultural area (and changes towards forest and also less intensive farming types)
- Slight decrease in artificial fertilizer application rates

High-tech agriculture

<u>Scenario 3</u>

- Agricultural area remain similar to today, but with some conversion to permanent grass and willow
- Slight increase in livestock density
- Slight decrease in artificial fertilizer application rates

Market prices

Low *High*

Extensive agriculture

<u>Scenario 2</u>

- Decrease in agricultural area (but not as much as in scenario 1) and changes towards less intensive farming types
- Decrease in livestock density
- Slight decrease in artificial fertilizer application rates

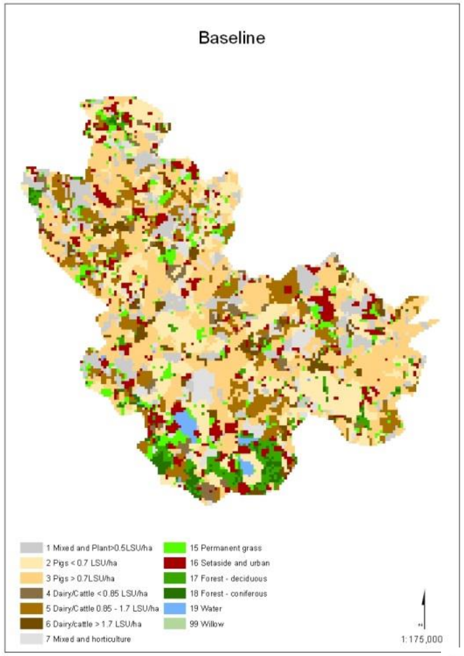
Market driven agriculture

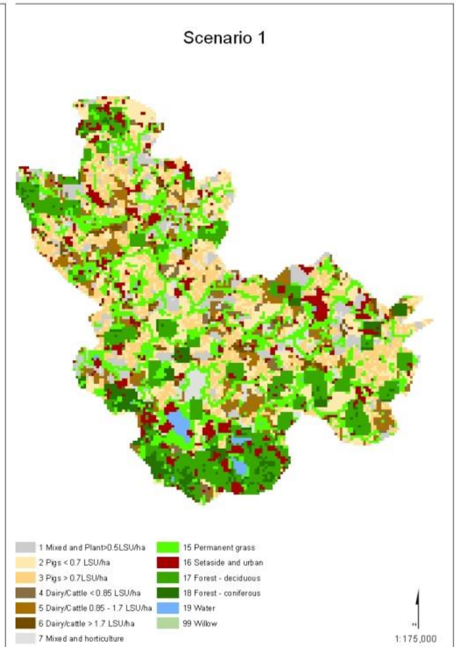
<u>Scenario 4</u>

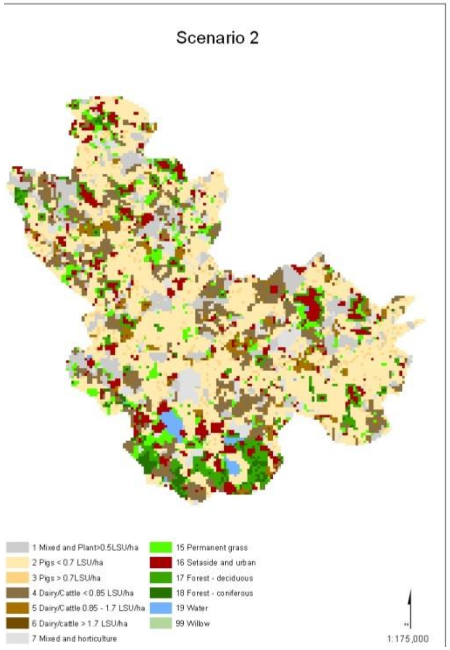
- Increase in agricultural area (also at the expense of forest) and changes towards intensive pig and dairy farm types
- Increase in livestock density
- Increases in fertilizer application rates for optimal production
- Introduction of grain maize in future scenarios

Low

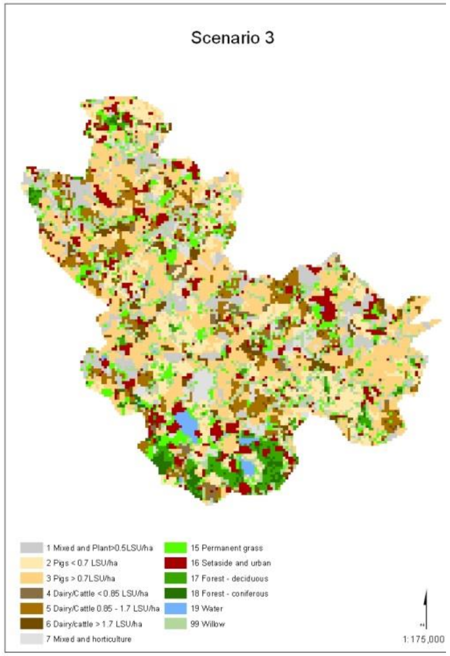
Land use change scenarios

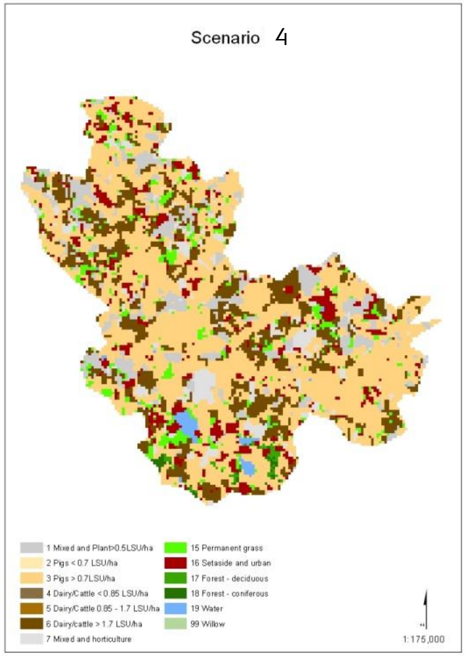


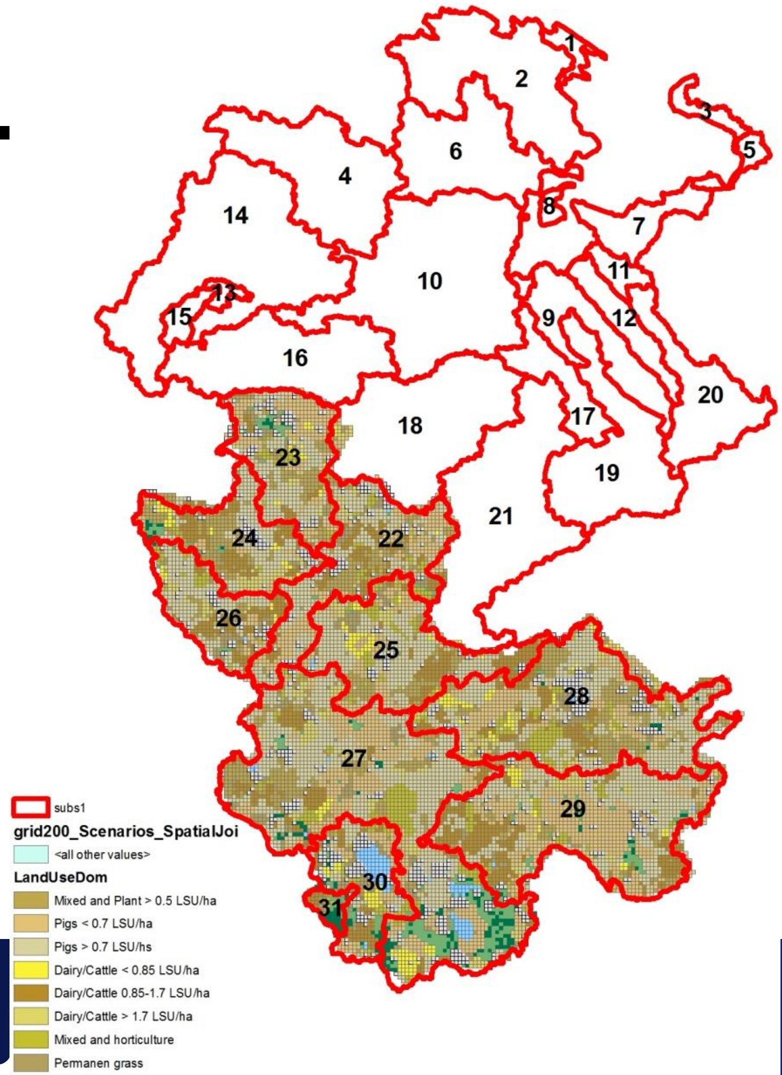




- 1 Mixed and Plant>0.5LSU/ha
- 2 Pigs < 0.7 LSU/ha
- 3 Pigs > 0.7LSU/ha
- 4 Dairy/Cattle < 0.85 LSU/ha
- 5 Dairy/Cattle 0.85 - 1.7 LSU/ha
- 6 Dairy/cattle > 1.7 LSU/ha
- 7 Mixed and horticulture
- 15 Permanent grass
- 16 Setaside and urban
- 17 Forest - deciduous
- 18 Forest - coniferous
- 19 Water
- 99 Willow







The changes in area-proportion of land use types (and individual farm types) where differentiated between subbasins (derived from a GIS overlay of the subbasin polygons on top of the scenario maps) for the scenarios

Changes in agricultural management

Crop management under current and future (2050 and 2090) conditions following approaches by Olesen et al. (2012), Henriksen et al. (2013) and Doltra et al. (2014).

Crop	Period	Ploughing	Sowing	Manure	Fertiliser	Harvest
W. cereal	Current	18/9	20/9	15/3	1/4, 1/5	20/8
	2050	24/9	27/9	11/3	26/3, 25/4	12/8
	2090	2/10	5/10	6/3	18/3, 17/4	26/7
S. cereal	Current	15/3	4/4	15/3	2/4	15/8
	2050	7/3	22/3	7/3	20/3	6/8
	2090	28/2	6/3	18/2	4/3	25/7
W. rape	Current	20/8	22/8	15/3	1/4	20/7
	2050	26/8	26/8	5/3	20/3	15/7
	2090	2/9	4/9	22/2	8/3	8/7
Sugar beet	Current	15/3	12/4	15/3	10/4	15/10
	2050	5/3	1/4	5/3	30/3	25/10
	2090	20/2	13/3	20/2	11/3	5/11
Silage maize	Current	1/4	27/4	1/4	25/4	20/10
	2050	25/3	17/4	25/3	15/4	10/10
	2090	20/3	7/4	20/3	5/4	30/9
Grain maize	2050	25/3	17/4	25/3	15/4	20/10
	2090	20/3	7/4	20/3	5/4	10/10
Seed grass	Current			15/3	1/4	15/8
	2050			7/3	19/3	6/8
	2090			18/2	3/3	257
Grass (clover)	Current			15/3	15/3, 1/6, 5/7	25/5, 1/7, 10/8, 10/10
	2050			5/3	5/3, 1/6, 10/7	25/5, 5/7, 15/8, 20/10
	2090			25/2	25/2, 1/6, 20/7	25/5, 10/7, 20/8, 1/11

- Winter cereals are sowed later and harvested earlier in the future
- Spring cereals are sowed and harvested earlier in the future

Climate and land use change combinations

\ Land use Climate	Baseline	Land use SC 1	Land use SC 2	Land use SC 3	Land use SC 4
GCM-RCM 1 (baseline)	1a	1b	1c	1d	1e
GCM-RCM 2 (baseline)	1f	1g	1h	1i	1j
GCM-RCM 3 (baseline)	1k	1l	1m	1n	1o
GCM-RCM 4 (baseline)	1p	1q	1r	1s	1t
Baseline (observed climate)	**1**	**2**	**3**	**4**	**5**
GCM-RCM 1 (near future)	**6**	**7**	**8**	**9**	**10**
GCM-RCM 2 (near future)	**11**	**12**	**13**	**14**	**15**
GCM-RCM 3 (near future)	**16**	**17**	**18**	**19**	**20**
GCM-RCM 4 (near future)	**21**	**22**	**23**	**24**	**25**
GCM-RCM 1 (far future)	**26**	**27**	**28**	**29**	**30**
GCM-RCM 2 (far future)	**31**	**32**	**33**	**34**	**35**
GCM-RCM 3 (far future)	**36**	**37**	**38**	**39**	**40**
GCM-RCM 4 (far future)	**41**	**42**	**43**	**44**	**45**

A total of 65 combinations of baseline and scenario simulations

Baseline: 1990-2009 (model warm-up: 1990-1999, note: this periode is also included (repeated) in baseline)
Near future: 2040-2059 (model warm-up: 2030-2039), SWAT note: 2030 has 365 days
Far future: 2080-2099 (model warm-up: 2070-2079), SWAT note: 2070 has 365 days

Climate variables used as scenario forcing data in SWAT:

	SWAT specifics:
Air temperature	tmp1.tmp
Precipitation	pcp1.pcp
Radiation	slr.slr
Reference ET	ref_et.pet
Changes in the average atmospheric CO_2 concentration	CO_2 conc. in *.sub

Implementation of land use change scenarios in SWAT

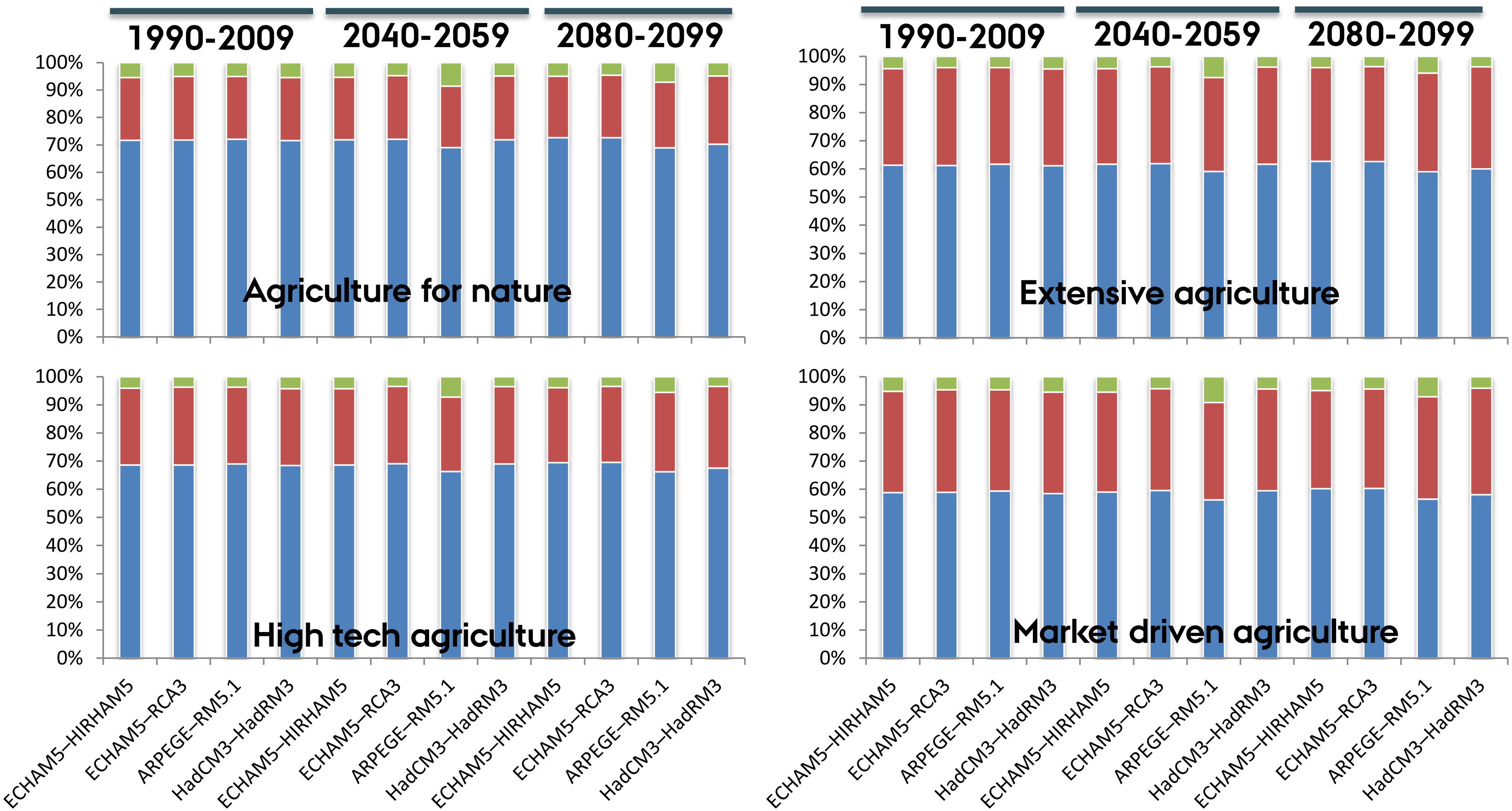
Land use changes applied in scenarios:

Change	SWAT specifics:
Changes in the proportion of land use types (including individual farm types)	HRU_FR in *.hru
Changes in fertilizer application rates for individual farm types	FRT_KG in mgt2 (*.mgt)
Changes in the timing of crop management (ploughing, sowing, manure and chemical fertilizer application and harvest) for future scenarios	Year, Month, Day values in mgt2 (*.mgt)
Introduction of willow and grain maize (the latter only in future scenarios)	Complete adaptation of rotation schedules in mgt2 (*.mgt)

Effects of land use and climate on hydrology

Flow components

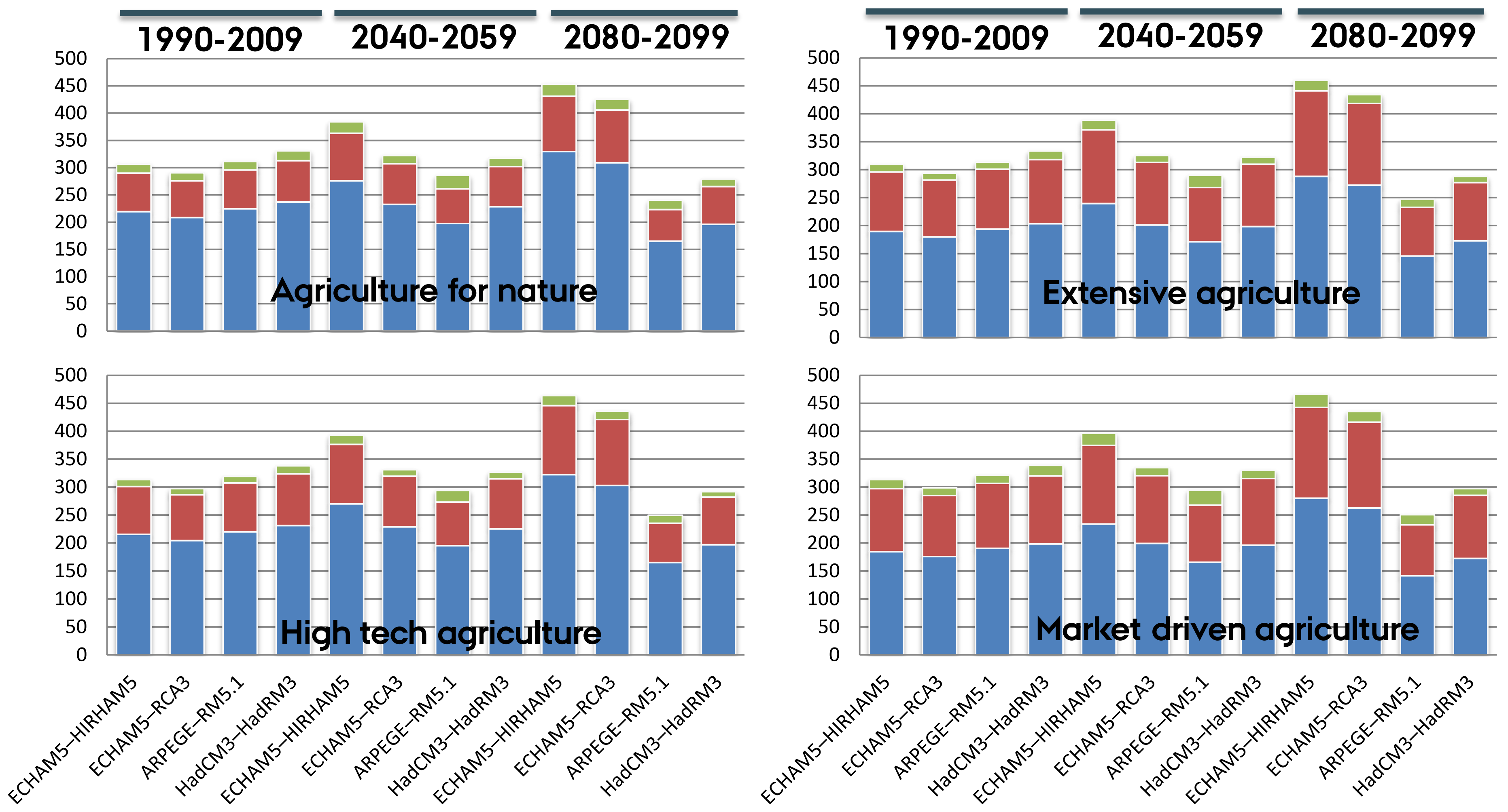
(relative distribution)



Effects of land use and climate on hydrology

Flow components

(actual flow contribution [mm/year])

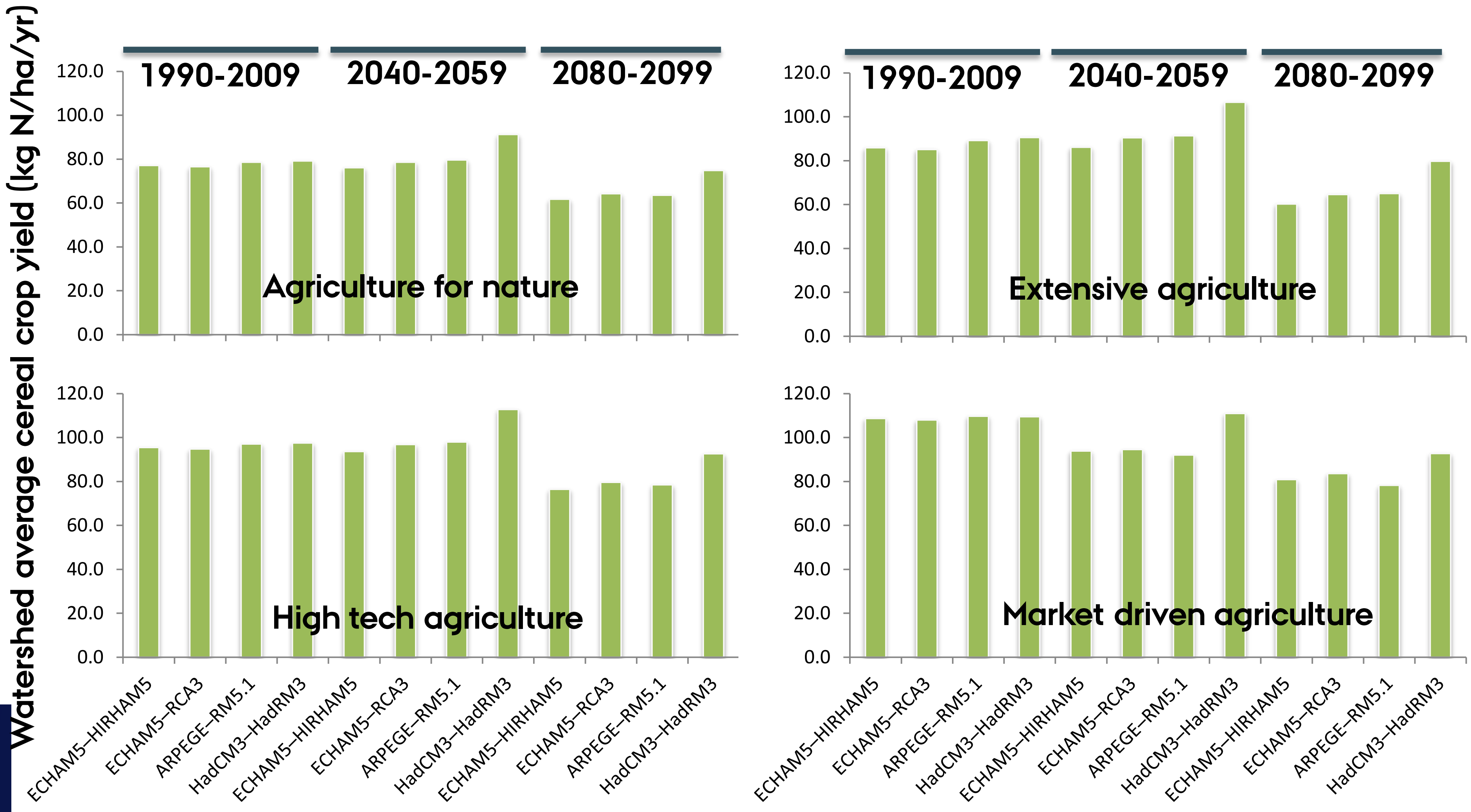


Where are the uncertainties for hydrological projections?

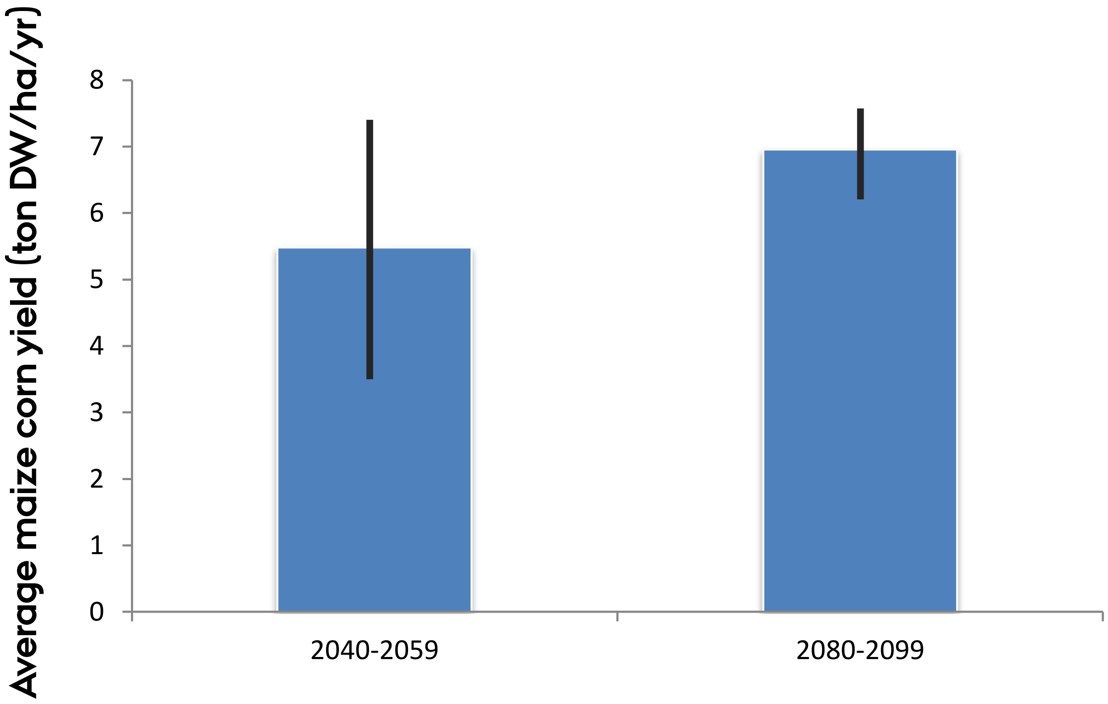
Decomposition of variance

Source of uncertainty	Mean discharge	Max. discharge (99 percentile)	Min. discharge (1 percentile)
Climate models	99%	83%	90%
Hydrological models	8%	41%	15%
Land use change	1%	36%	3%

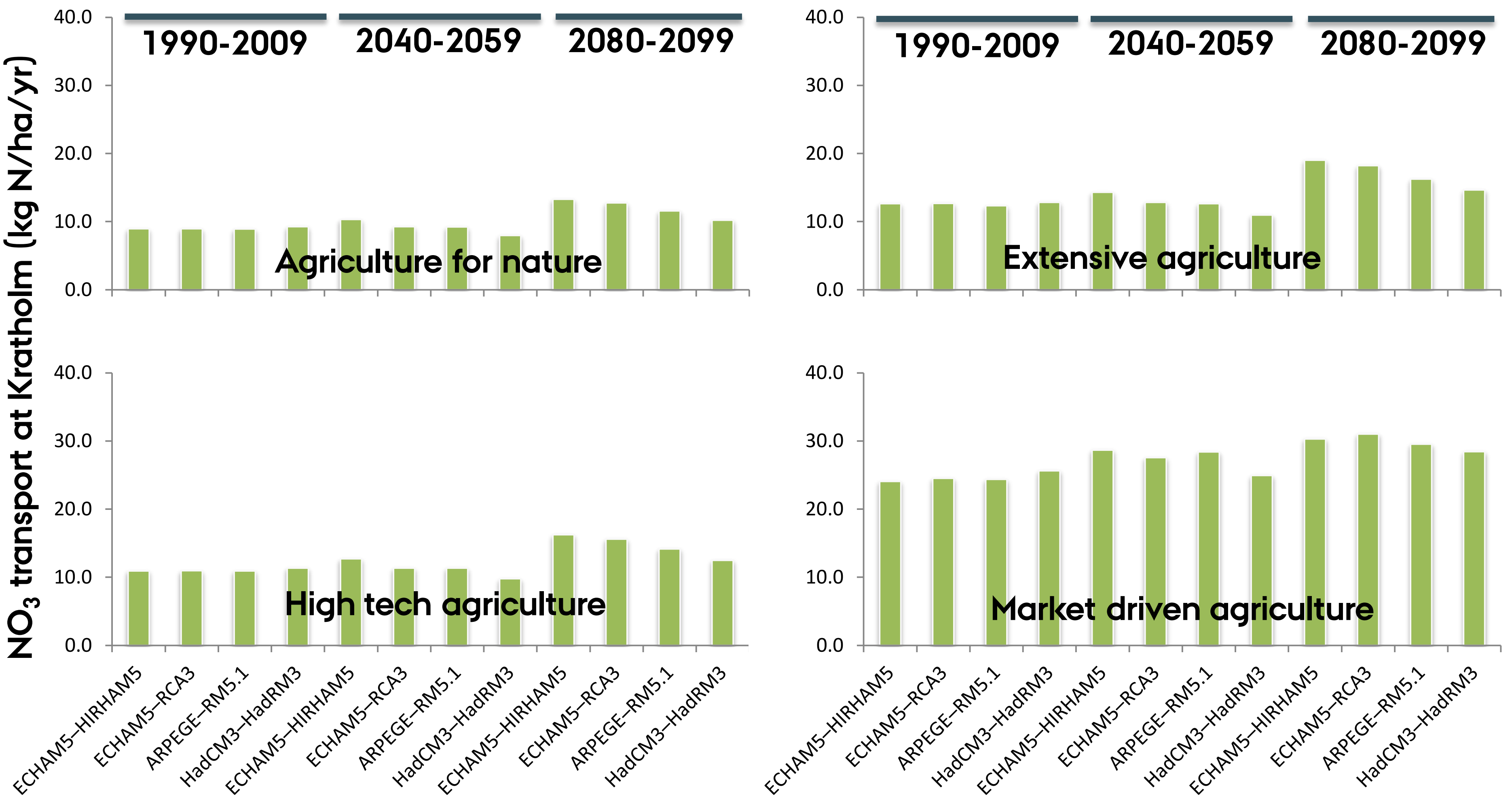
Effects of land use and climate on crop yields



THE MAIZE STORY…



Effects of land use and climate on nitrate transport



Where are the uncertainties for nitrate transport projections?

Decomposition of variance

Source of uncertainty	Leaching from rootzone	Transport out of watershed
Climate models	11%	8%
Hydrological models	15%	18%
Land use change	91%	85%

SCENARIOS FOR THE FUTURE IN THE ODENSE FJORD WATERSHED – SUMMARY

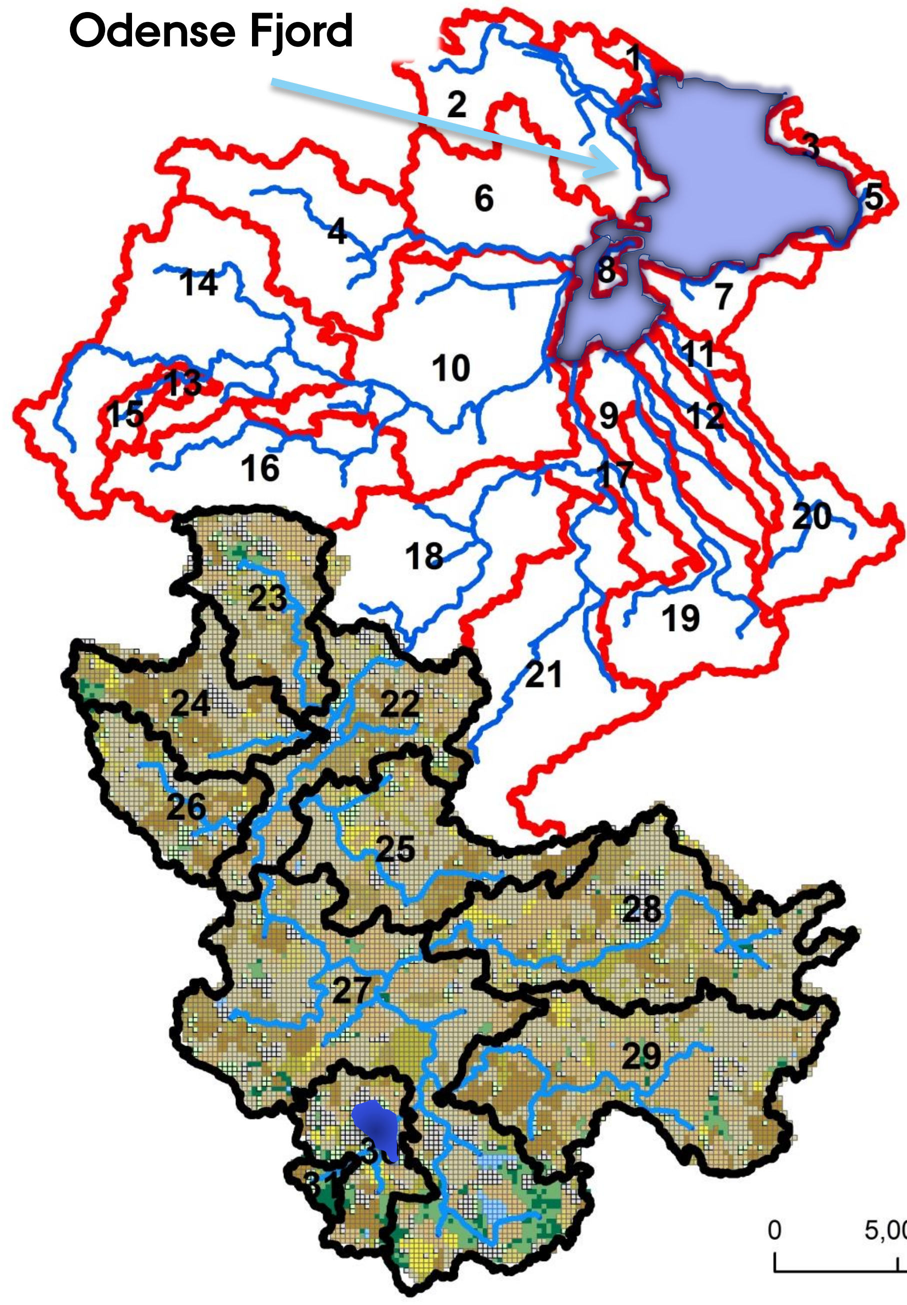
CLIMATE:

- Near future climate (2050):
- Far future climate (2090):
- ”Extreme” future climate (~2200):

LAND USE SENARIOS:

- Status quo
- Nature:

- Extensive agriculture:
- High-tech agriculture:
- Market agriculture:

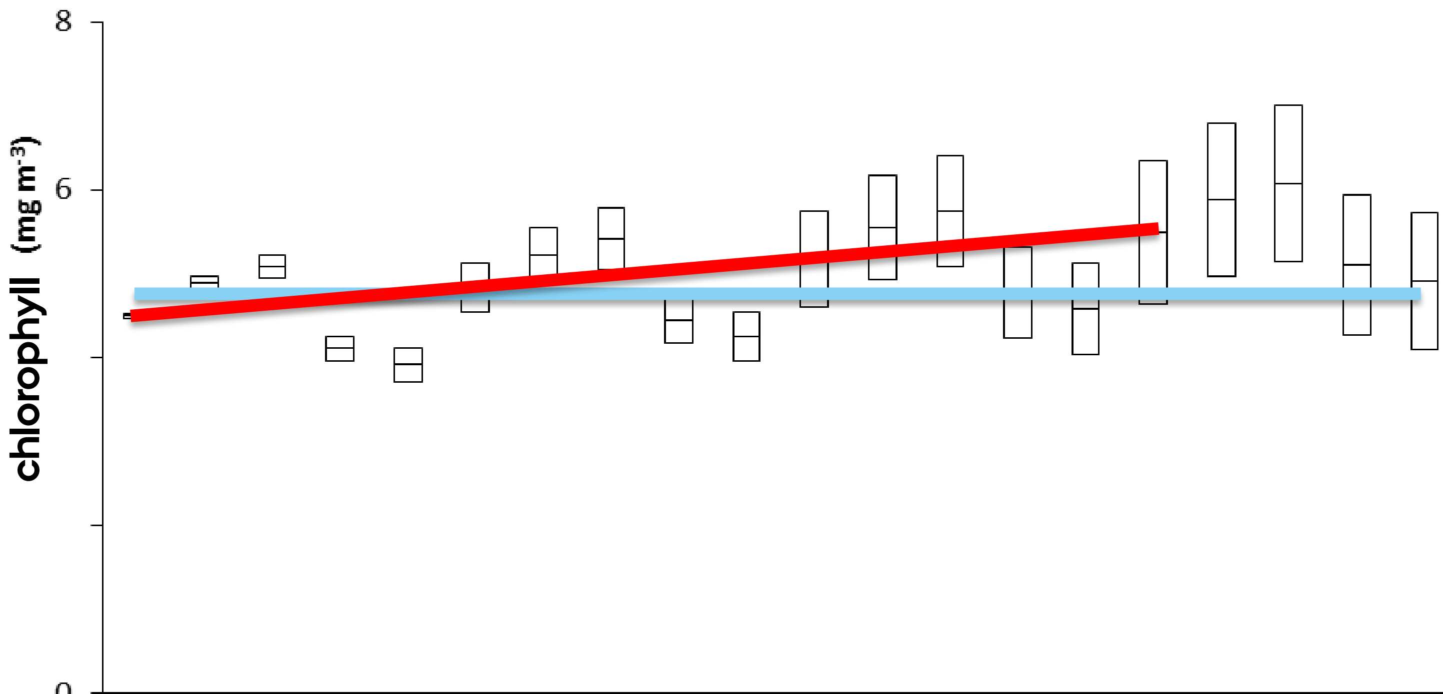


Statistical model for Odense Fjord

- Empirical relations between Nitrogen conc, algae biomass, temperature and nutrient load

EFFECTS OF SCENARIOS ON ALGAE BIOMASS IN ODENSE FJORD

- Scenario results: 2, 4, 6°C warming, changed N-loads, and combinations (chlorophyll in Jul-Sep)



Temperature change:	0	0	0	0	0	2	2	2	2	2	4	4	4	4	4	6	6	6	6	6
N-load change (%):	0	50	75	-50	-75	0	50	75	-50	-75	0	50	75	-50	-75	0	50	75	-50	-75

CONCLUSIONS

- Higher temperatures speeds up the maturing of crops
  - **Crop yields will generally be reduced in the future projections**
  - Harvest dates occur earlier in the future, potentially leaving the soil surfaces exposed for a longer period of time (cover crops may partly reduce this effect)
  - Precipitation during winter will increase
  - **Nitrate leaching and transport to surface waters increase in the future projections**
- The variability caused by the land use scenarios are more important for determining nitrate losses relative to variability due to both hydrological models and climate model projections
- **Warming and increased nutrient transport to waterways will lead to degradation of surface water quality in both fresh and marine ecosystems – but effects of warming can be reduced by reduced nutrient loads**

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