Overview of current drought research and its relevance to the challenges we face

Kevin Hiscock

School of Environmental Sciences

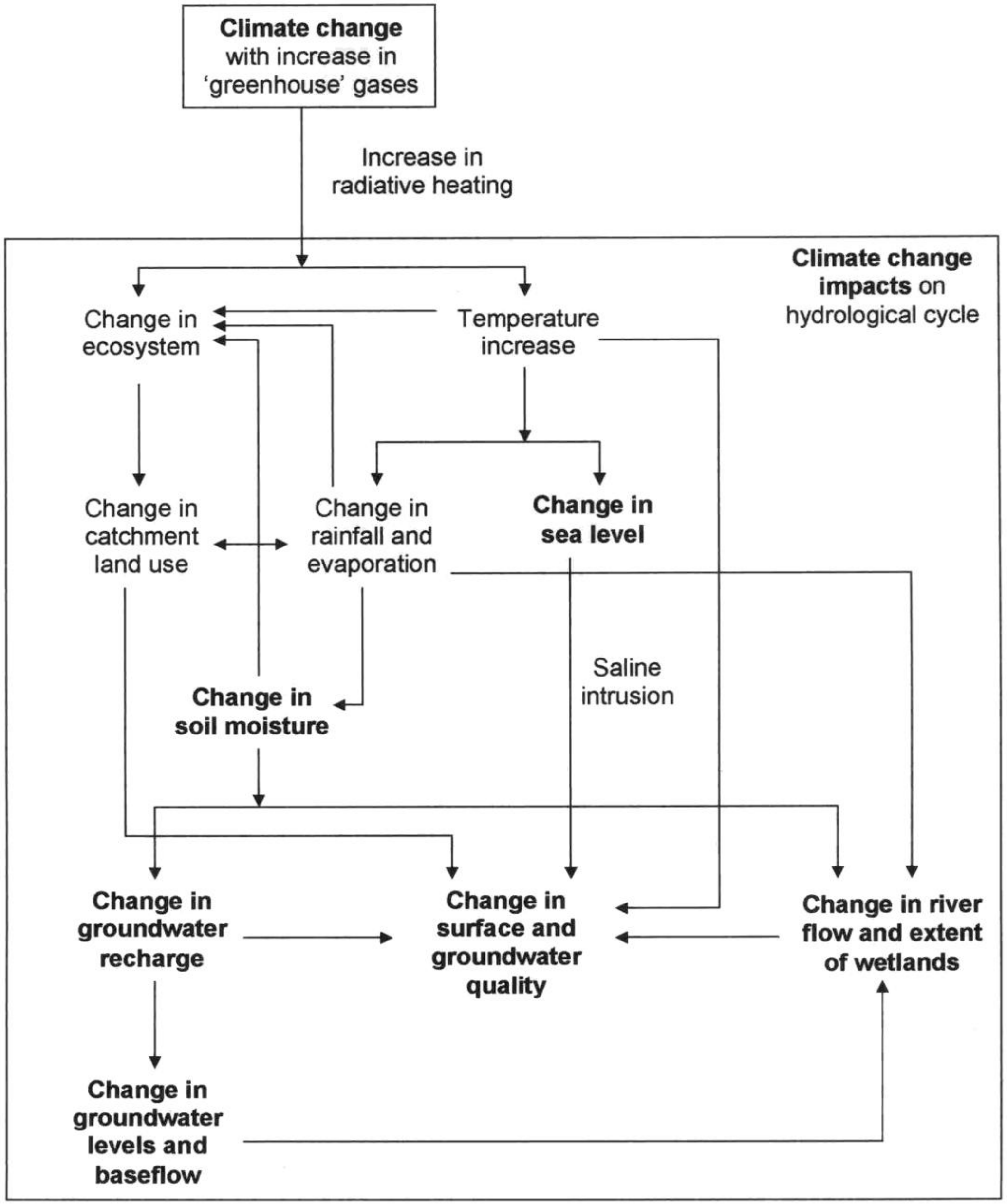
University of East Anglia, Norwich

E-mail: k.hiscock@uea.ac.uk

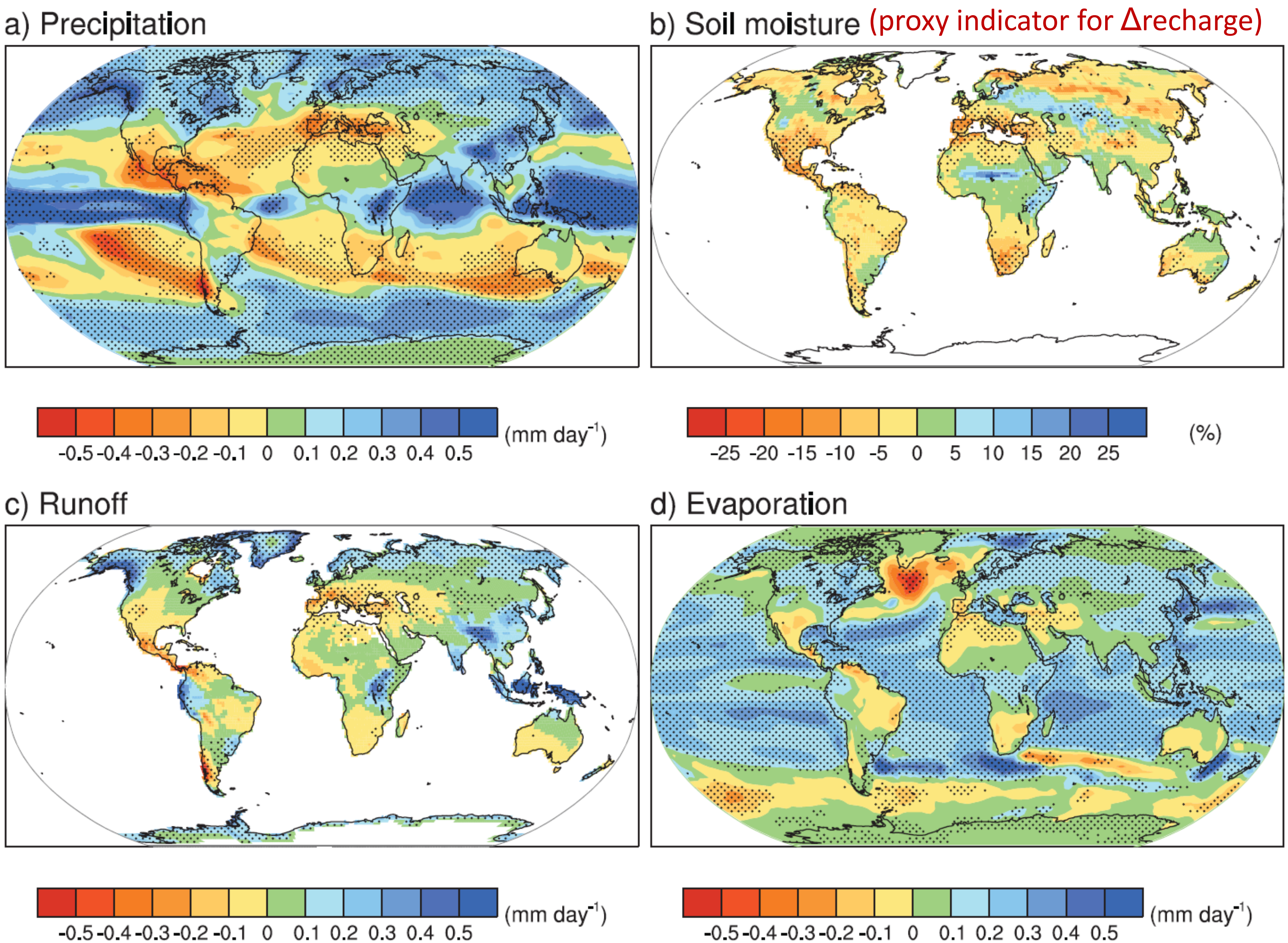
Outline of presentation

- Coupled climate change and groundwater modelling (local scale)
- Climate change impacts on groundwater quality
- Integrated modelling for multi-objective decision-making
- Global-scale modelling of climate change impacts on groundwater
- Further research recommendations

Impacts of increasing GHG concentrations on the natural hydrological cycle emphasising changes in hydrogeological conditions



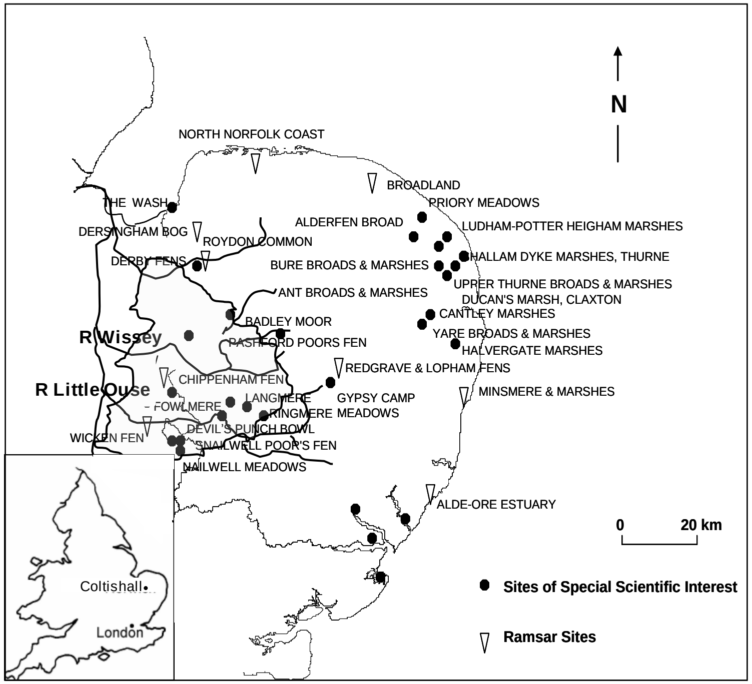
Multi-model mean changes in: (a) precipitation (mm/day), (b) soil moisture content (%), (c) runoff (mm/day) and (d) evaporation (mm/day)

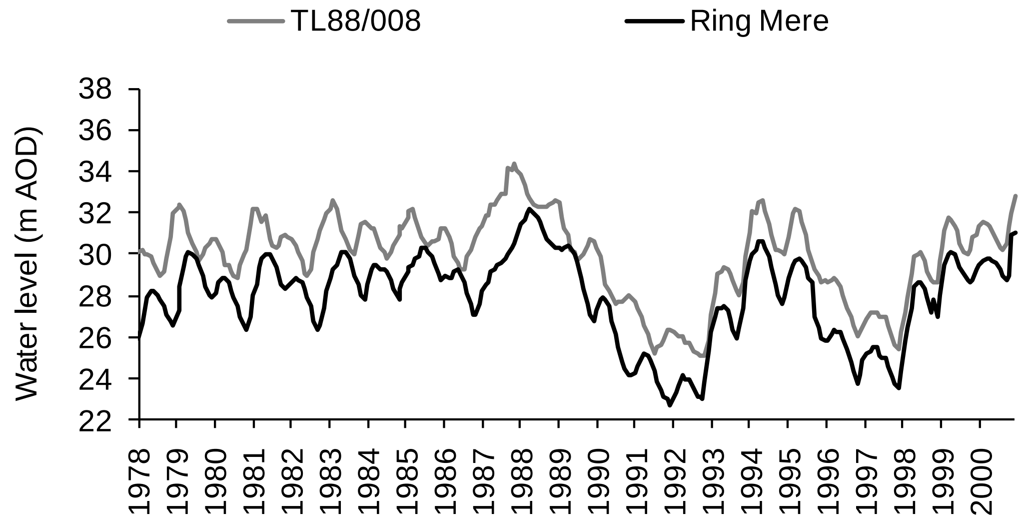


To indicate consistency in the sign of change, regions are stippled where at least 80% of models agree on the sign of the mean change. Changes are annual means for the medium, A1B scenario 'greenhouse gas' emissions scenario for the period 2080-2099 relative to 1980-1999. Soil moisture and runoff changes are shown at land points with valid data from at least 10 models.

(Collins *et al*. 2007 IPCC AR4 WG1)

Climate change impacts on groundwater-fed wetlands

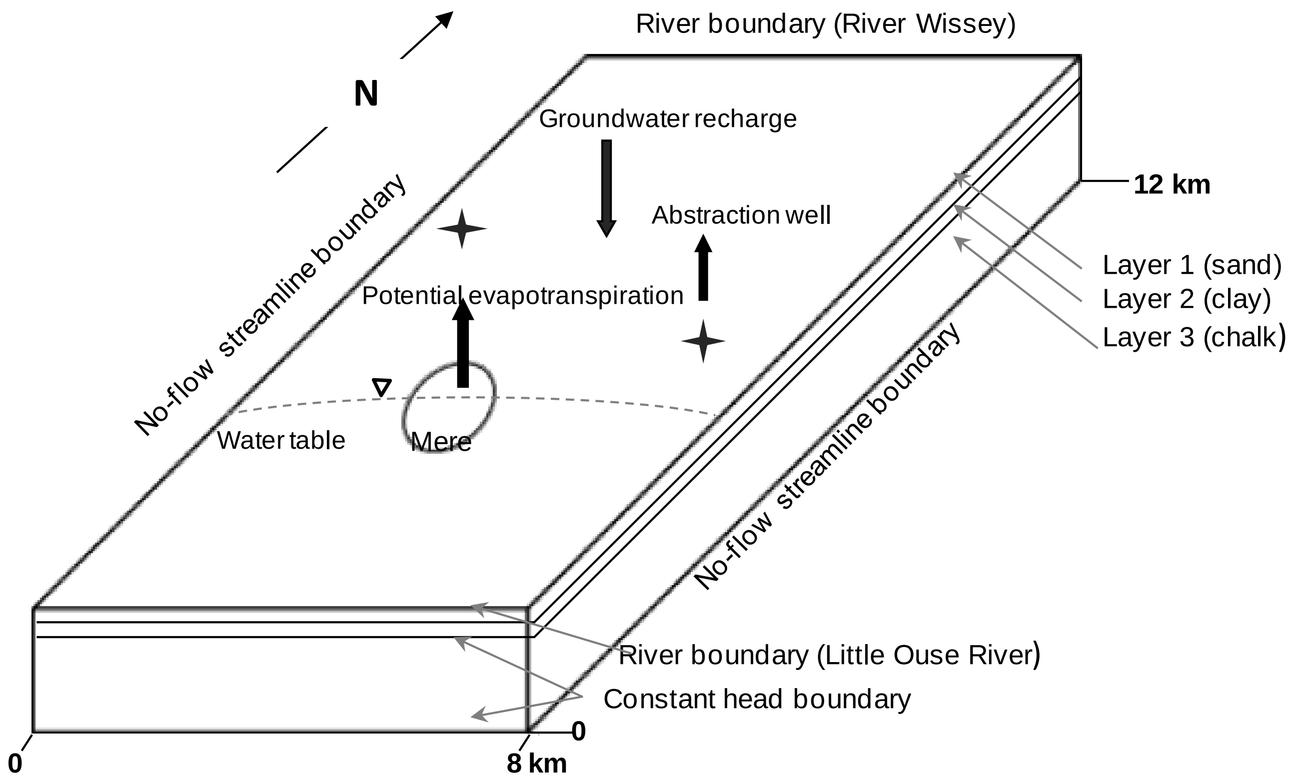




Comparison of Chalk groundwater levels at observation borehole TL88/008 and water levels at Ringmere
(Environment Agency data)

Water level thresholds of wetland plants typical of East Anglia (after Newbold and Mountford, 1997). Negative numbers indicate water levels below ground level

Species	Common name	Dry water level (cm)	Wet water level (cm)
Carex nigra	Common sedge	-65	0
Schoenus nigricans	Black bog-rush	-20	0
Carex elata	Tufted sedge	-30	40
Phragmites australis	Common reed	-100	50
Carex rostrata	Bottle sedge	-15	100

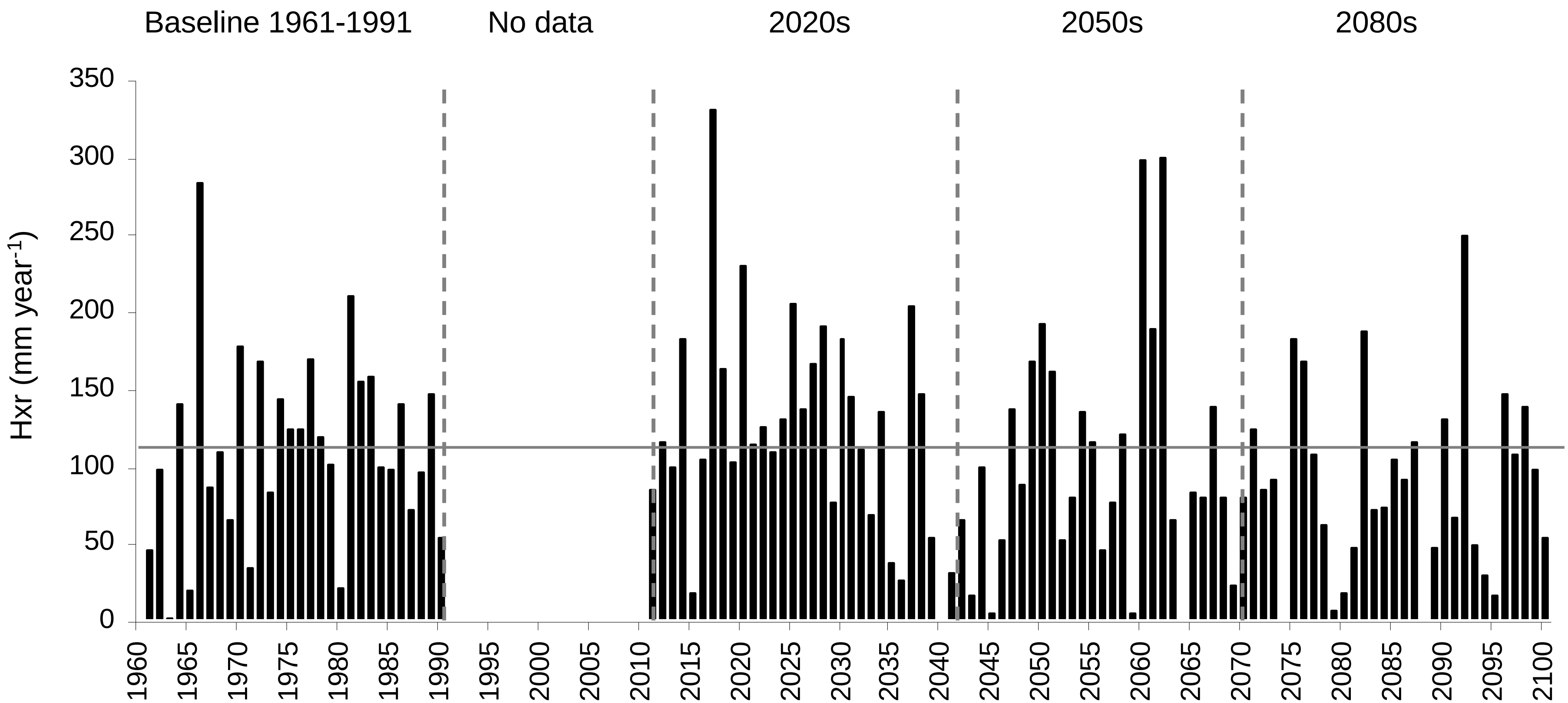


Conceptual groundwater model for a wetland fed by an unconfined Chalk aquifer in East Anglia

Herrera-Pantoja *et al*. *Ecohydrology* (In Press)

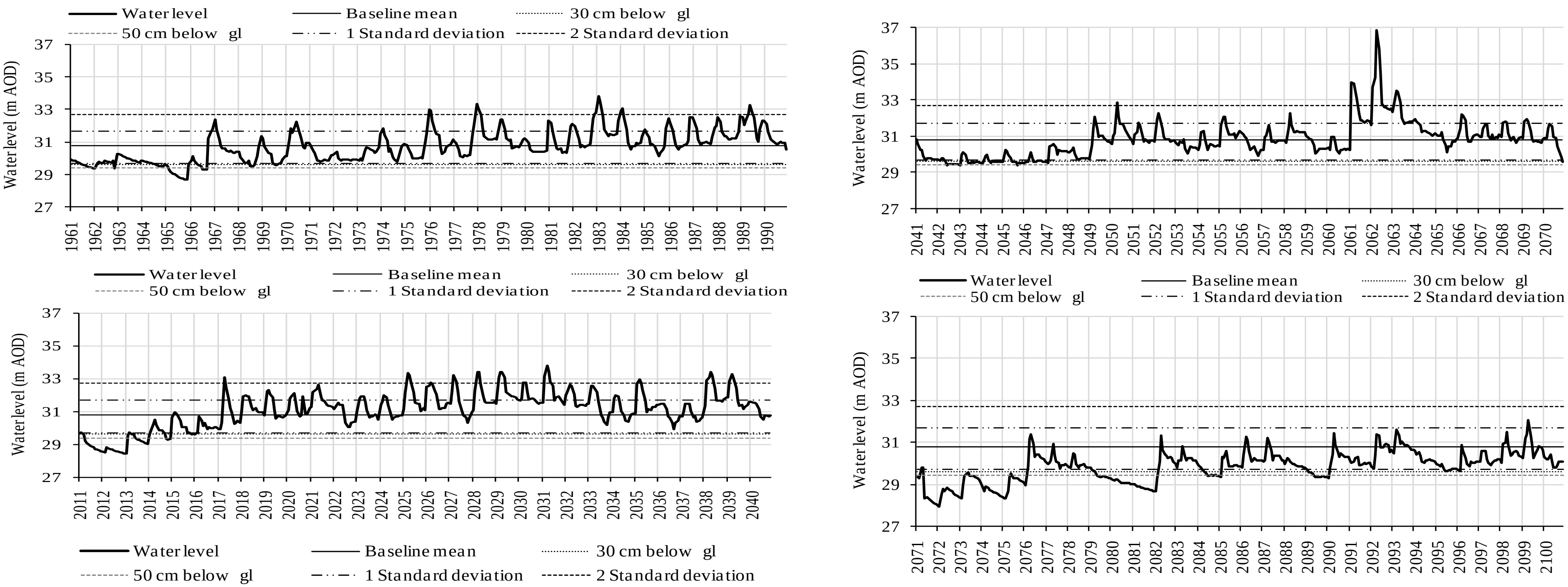
Calibrated hydraulic values

Kx ($m\ d^{-1}$)	Ky ($m\ d^{-1}$)	Kz ($m\ d^{-1}$)	Specific storage	Specific yield
7.55	7.55	0.77	0.005	0.05
3.0	3.0	3.0	0.02	0.25
1.5	1.5	0.015	0.001	0.01



Annual potential groundwater recharge (*Hxr*) values for the baseline period (1961–1990) and three time periods for a 'high' gas emissions scenario (2020s, 2050s and 2080s) for northern East Anglia. The horizontal line shows the mean annual value for the baseline period

Herrera-Pantoja *et al*. *Ecohydrology* (In Press)



Time series of water levels for a wetland fed by an unconfined Chalk aquifer for the baseline period 1961–1990 and for the 2020s, 2050s and 2080s periods of the ‘high’ gas emissions scenario

The series present the baseline mean, one and two standard deviations about the mean above ground level (gl) and two dry water level thresholds

Herrera-Pantoja *et al*. *Ecohydrology* (In Press)

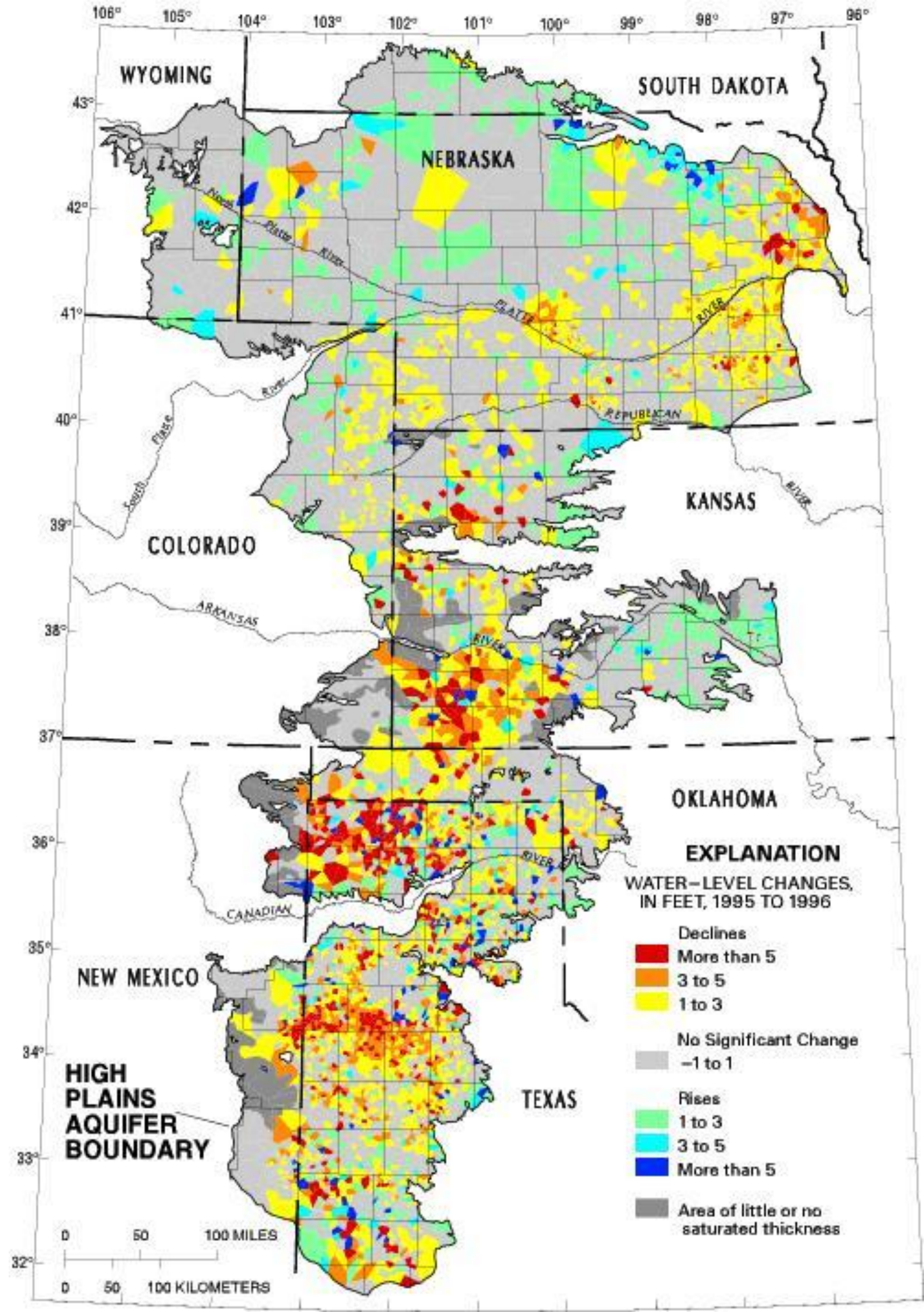
Simulated water levels in a wetland fed by an unconfined Chalk aquifer during the baseline period (1961–1990) and the 2020s, 2050s and 2080s future periods of the 'high' gas emissions scenario and their likely impacts on groundwater-fed wetland communities

	Mean water table (m AOD)	**Minimum water table (m AOD)**	**Duration of low water table (months)**	**Maximum water table (m AOD)**	**Duration of hight water table (months)**	**Likely impact on wetland communities**
Baseline	30.74	28.68	12	33.85	3	
2020s	31.06	27.98	24	33.76	2	Changes towards swamp-like stands
2050s	30.79	29.35	9	36.85	6	Recovery of rare and local plant species
2080s	29.84	27.91	61	32.03	0	Loss of wetlands communities

Herrera-Pantoja *et al*. *Ecohydrology* (In Press)

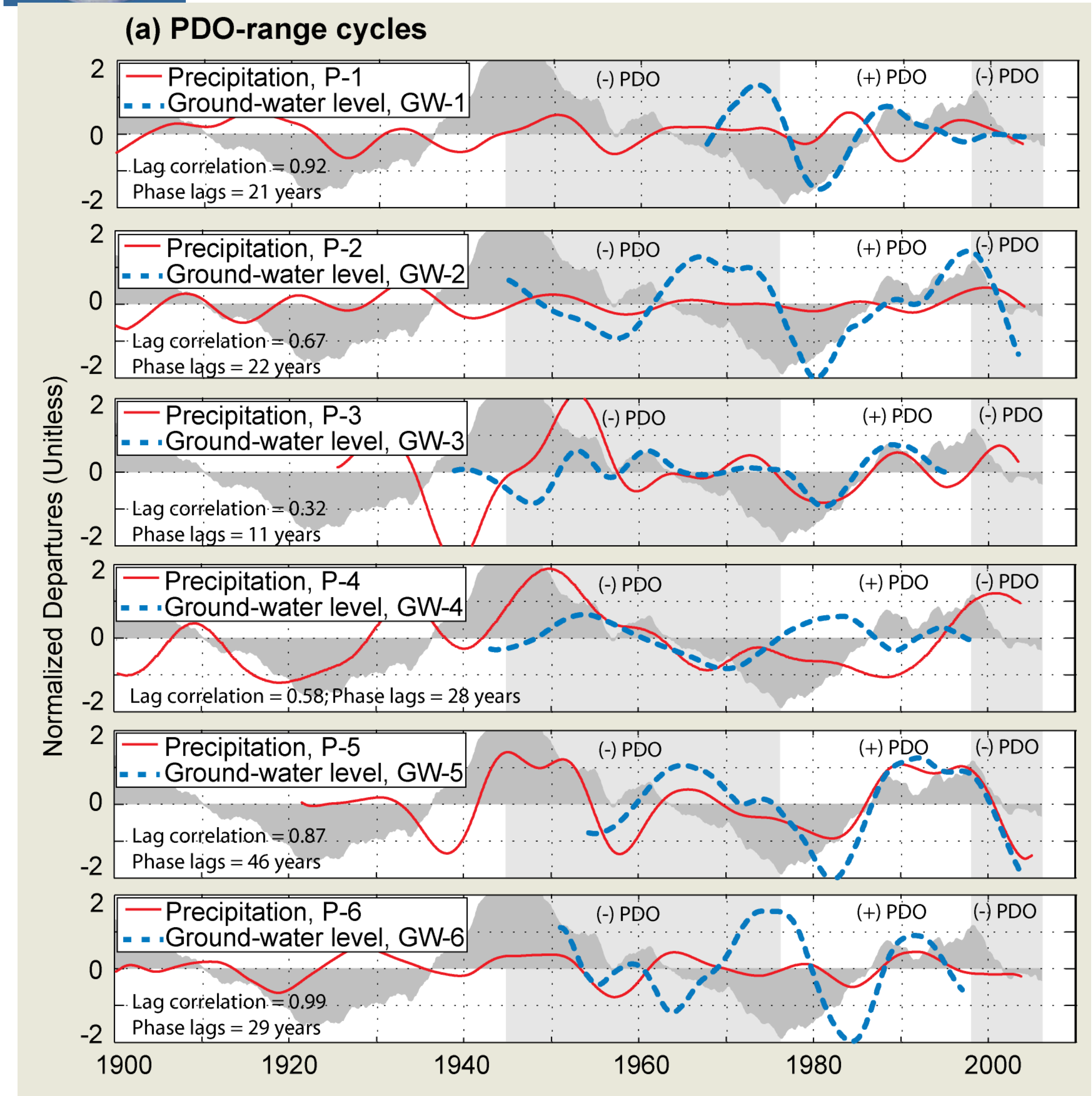
Over-abstraction in the High Plains Aquifer

- ➢In 1990, 2.2 million people were supplied by groundwater from the High Plains Aquifer with total public supply abstractions of 1.26 million m^3 per day
- ➢In general, water levels in this important aquifer and dropping (>30 m in some areas)



Strong Correlations: PDO, precip., gw.

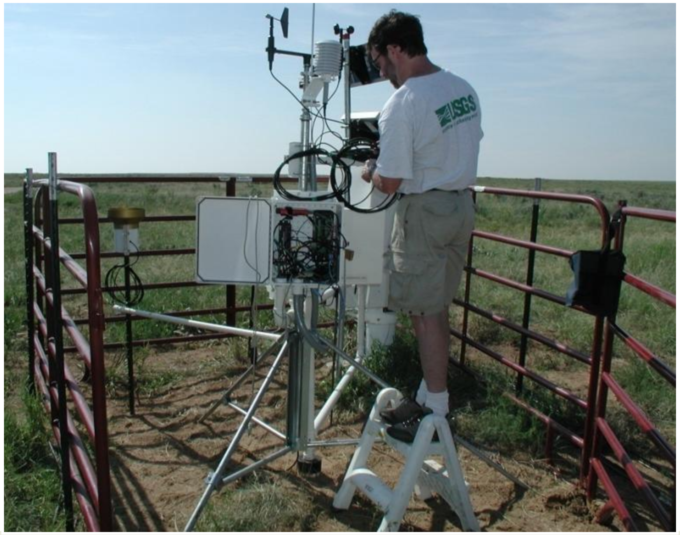
Courtesy J. Gurdak, USGS

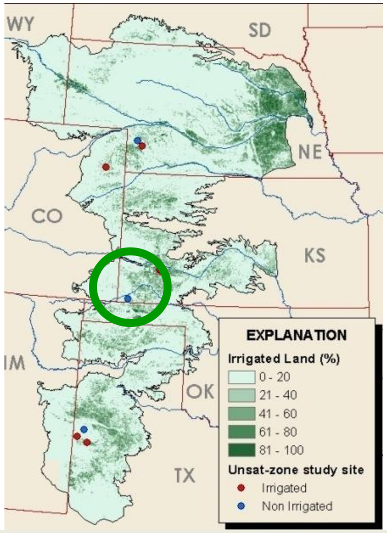


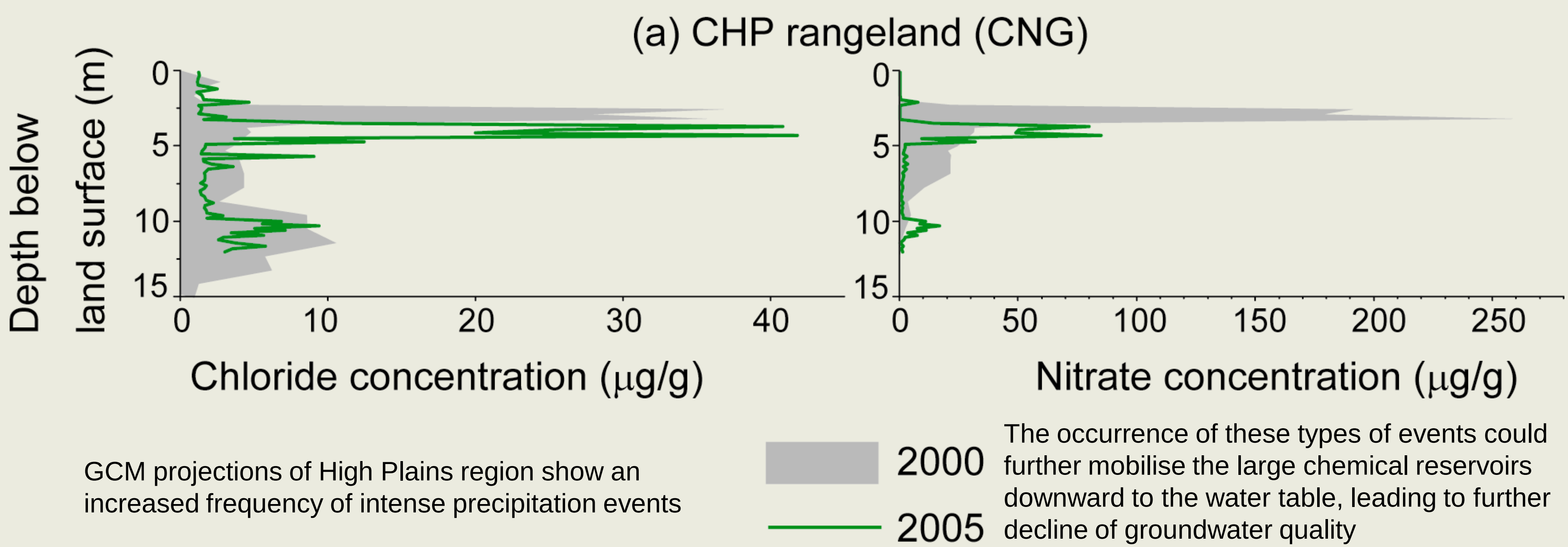
Pacific Decadal Oscillation (PDO, every 10-25 years) appears to have strongest correlations with groundwater level fluctuations and is a dominant control on climate varying recharge to this aquifer

Mobilisation of chemical reservoir by climate

Courtesy J.Gurdak, UGSG







GCM projections of High Plains region show an increased frequency of intense precipitation events

The occurrence of these types of events could further mobilise the large chemical reservoirs downward to the water table, leading to further decline of groundwater quality

Integrated modelling

Social, Economic and Environmental Research (SEER) Project

Multi-objective land use decision making

Natural environment

Water environment

nt

CSERGE

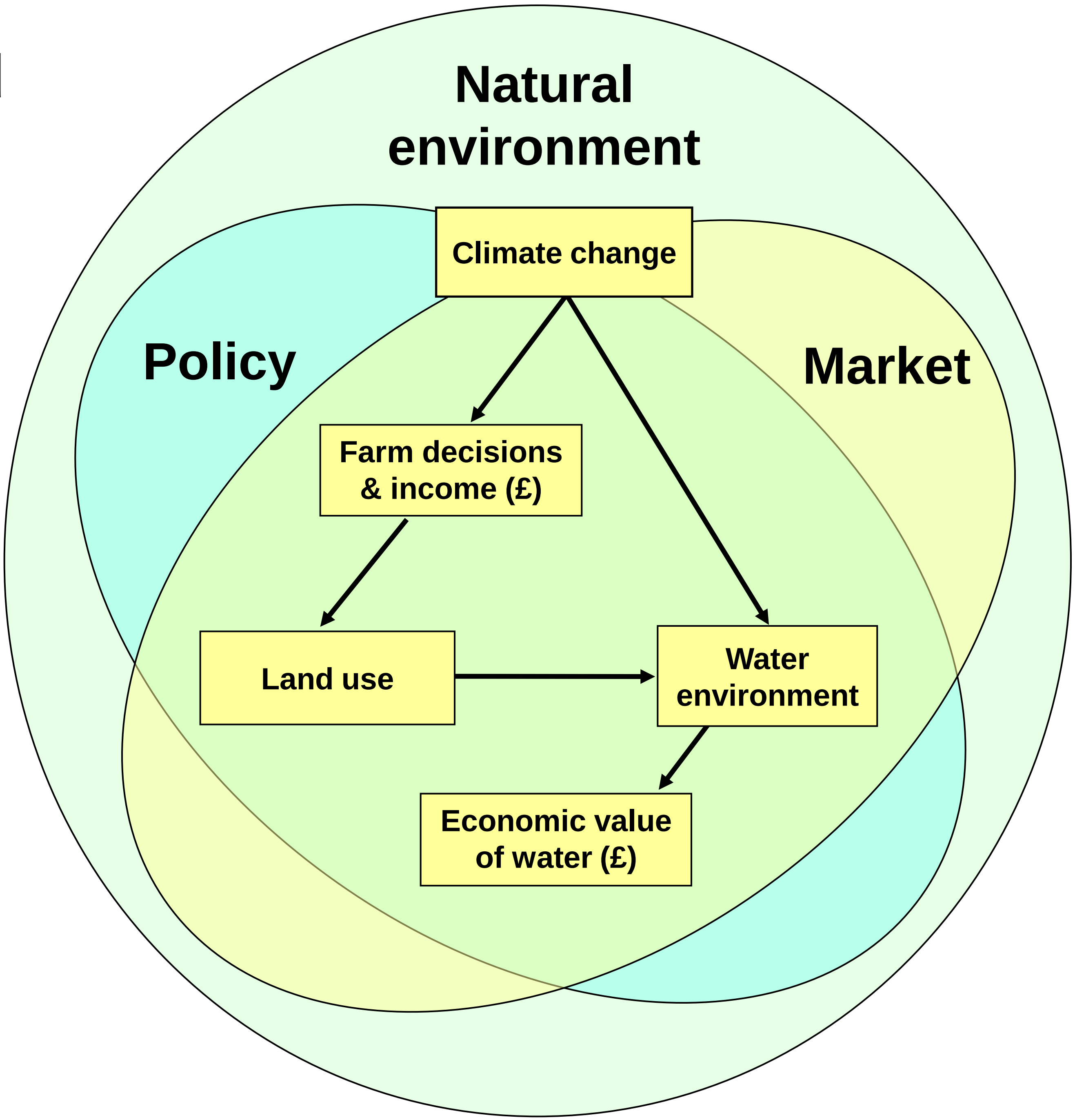
University of East Anglia

RURAL ECONOMY AND LAND USE

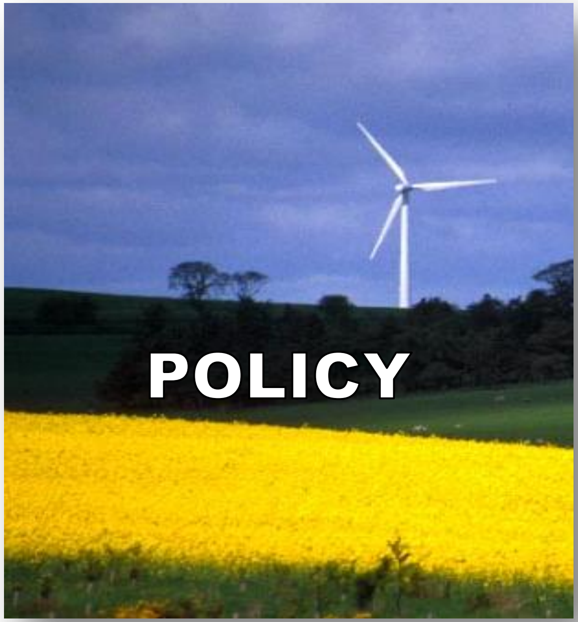
E·S·R·C ECONOMIC & SOCIAL RESEARCH COUNCIL

S E E R

Integrated modelling



If land use in part drives water quality what drives land use?



Set aside rate	Output prices	Soils
NVZ, ESA, Parks, etc.	Input costs	Temperature
Milk quota	Technology	Rainfall

Data and analysis

Agricultural Census data for **every 2km grid square of GB from 1969** plus **50,000 farm years** of Farm Business Survey data:

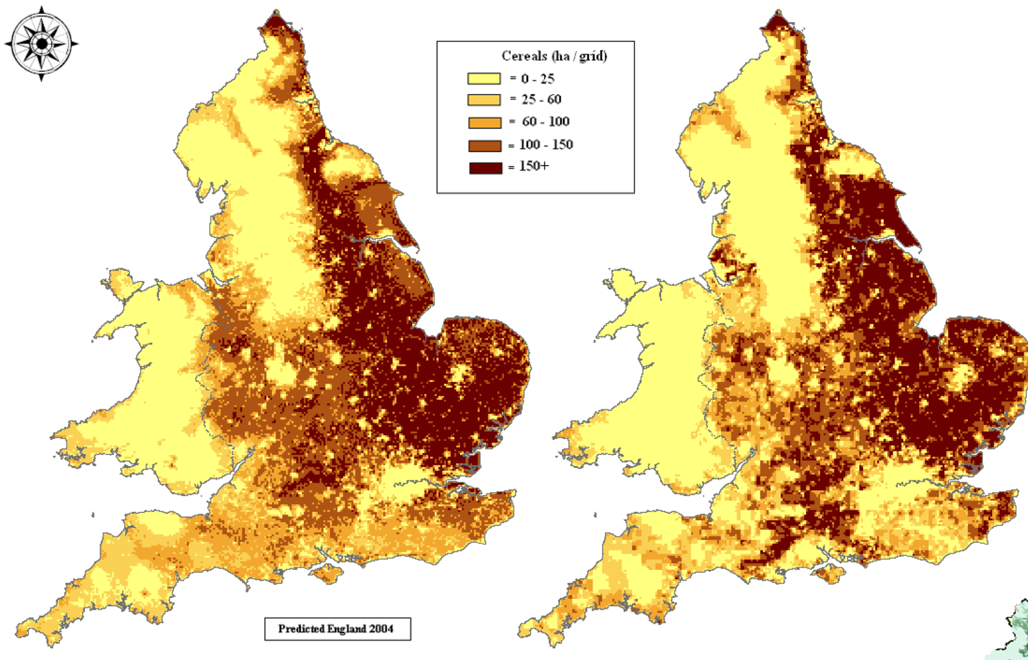
- Agricultural **land use** hectares (wheat, barley, grass, etc.);
- **Livestock** numbers (dairy, beef, sheep, etc)
- **Time trends** (response times, new crops, etc.)

We then add

- **Environmental & climatic data** (rainfall, temperature, etc.)
- **Policy** determinants (CAP reform etc.)
- **Input** and **output prices** for the period

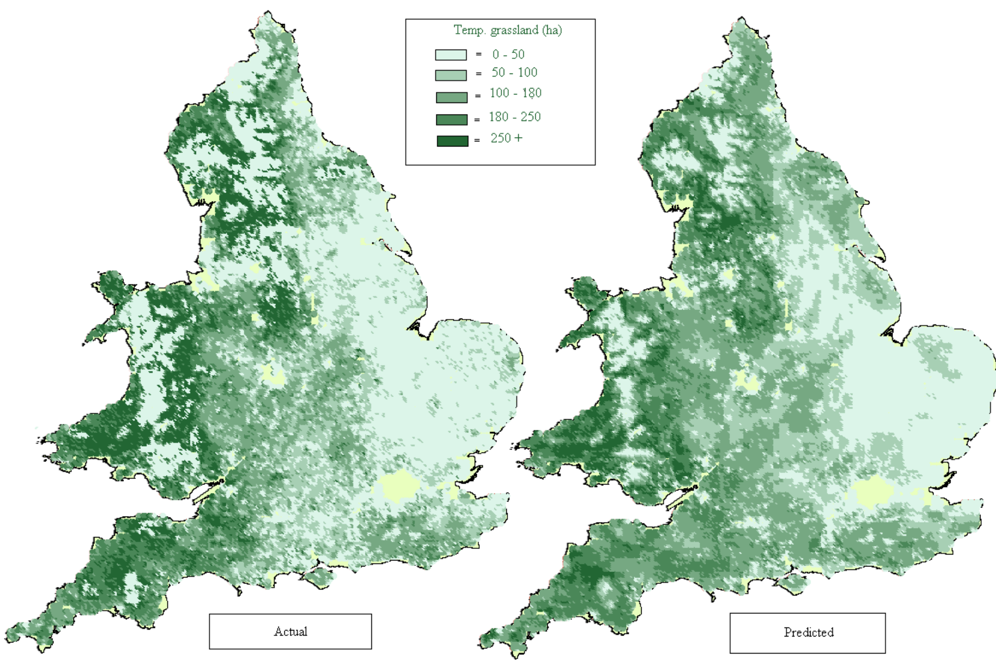
Resulting models tested by comparing predictions with actual land use

Validation: Actual versus predicted tests

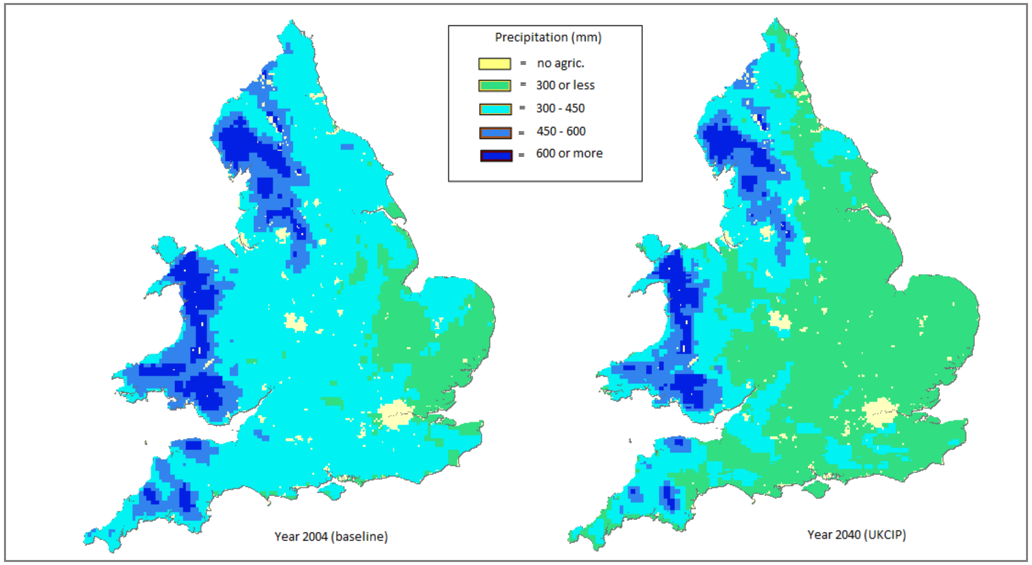


Cereals

Temporary grassland

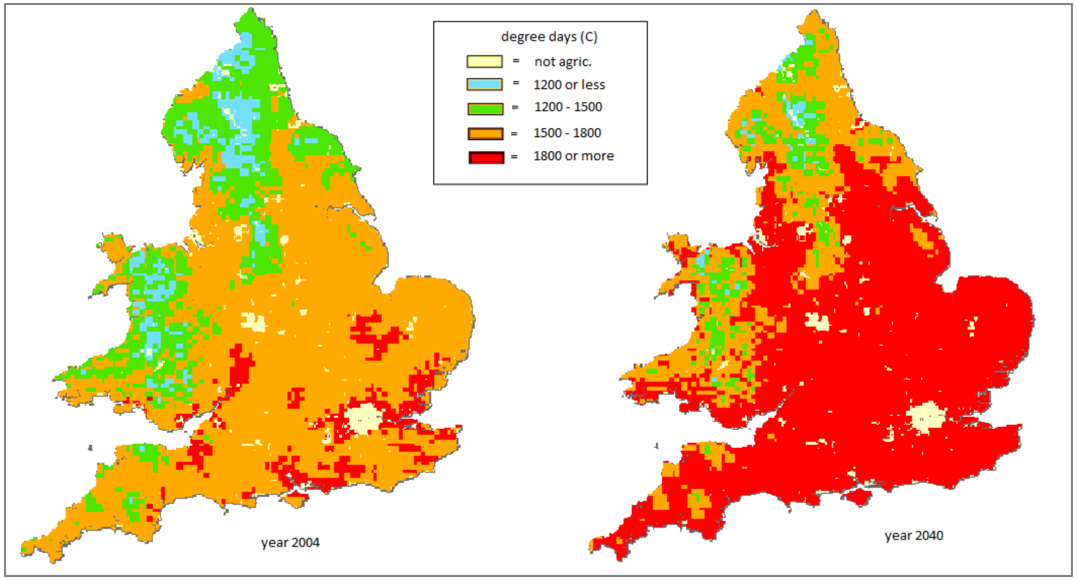


Climate change impacts



Rainfall: 2004 - 2040

Temperature: 2004 - 2040



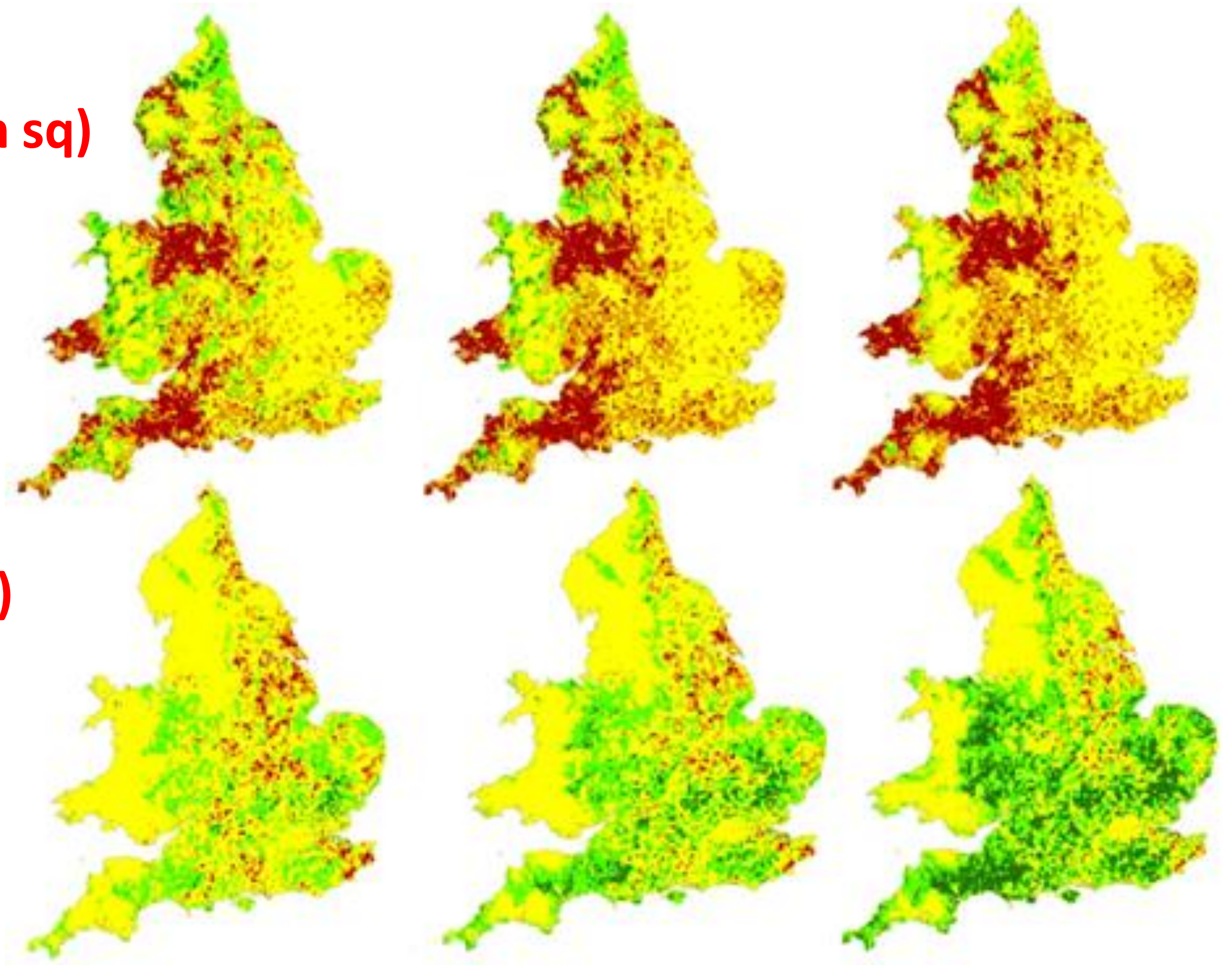
Predicted climate change impacts on land use

Dairy (Δcows/2km sq)

- < -100
- -100 to -20
- -20 to 20
- 20 to 80
- 80 to 200

Oilseed rape (Δha/2km sq)

- < -30
- -30 to -12
- -12 to 12
- 12 to 30
- 30 to 70

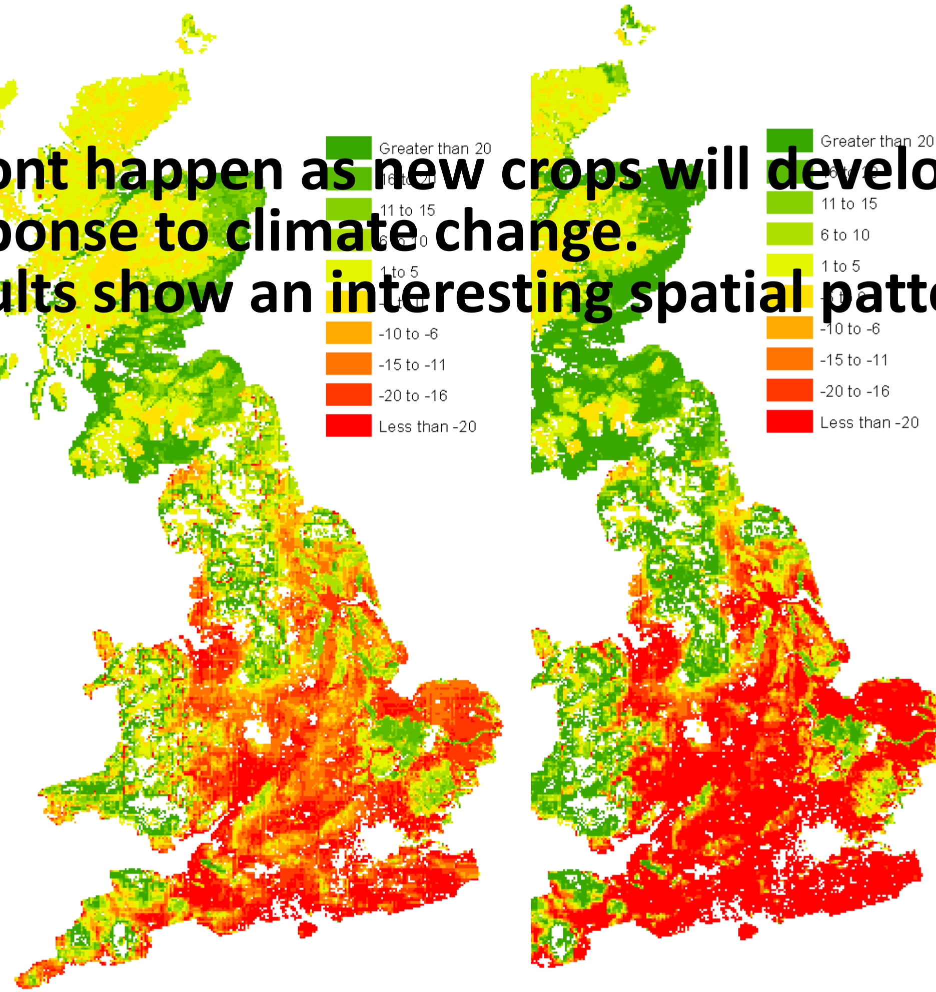


2004-2020 **2004-2040** **2004-2060**

Holding all else constant* - what is the impact of climate change on farm incomes by 2050?

UKCIP low emissions scenario

UKCIP high emissions scenario



***this, of course, wont happen as new crops will develop in response to climate change.**

Nevertheless, results show an interesting spatial pattern

Land use change & water quality

Land use change

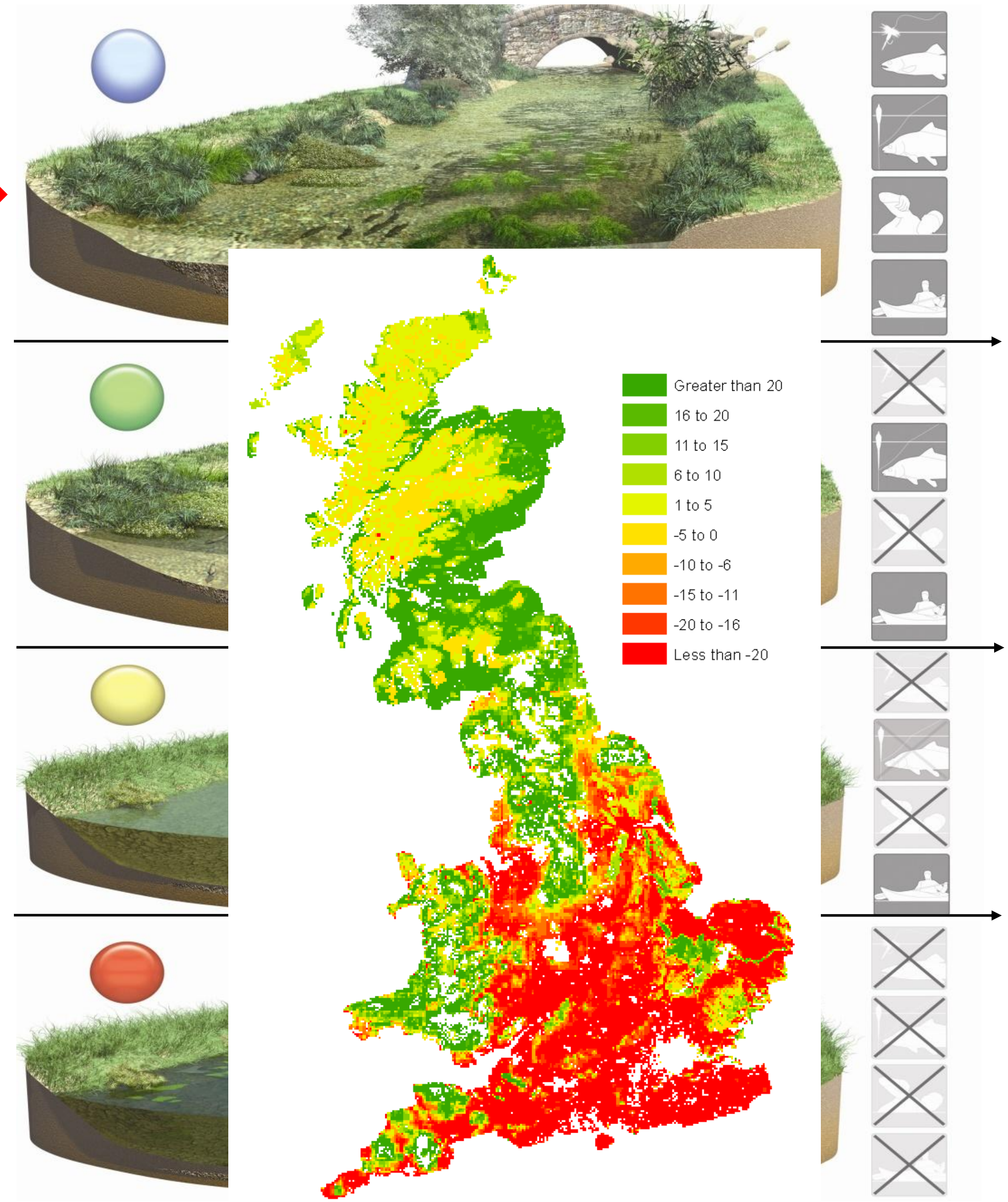
Modelling land use change as a result of:

- climate change;
- new policy;
- market shifts;
- etc.

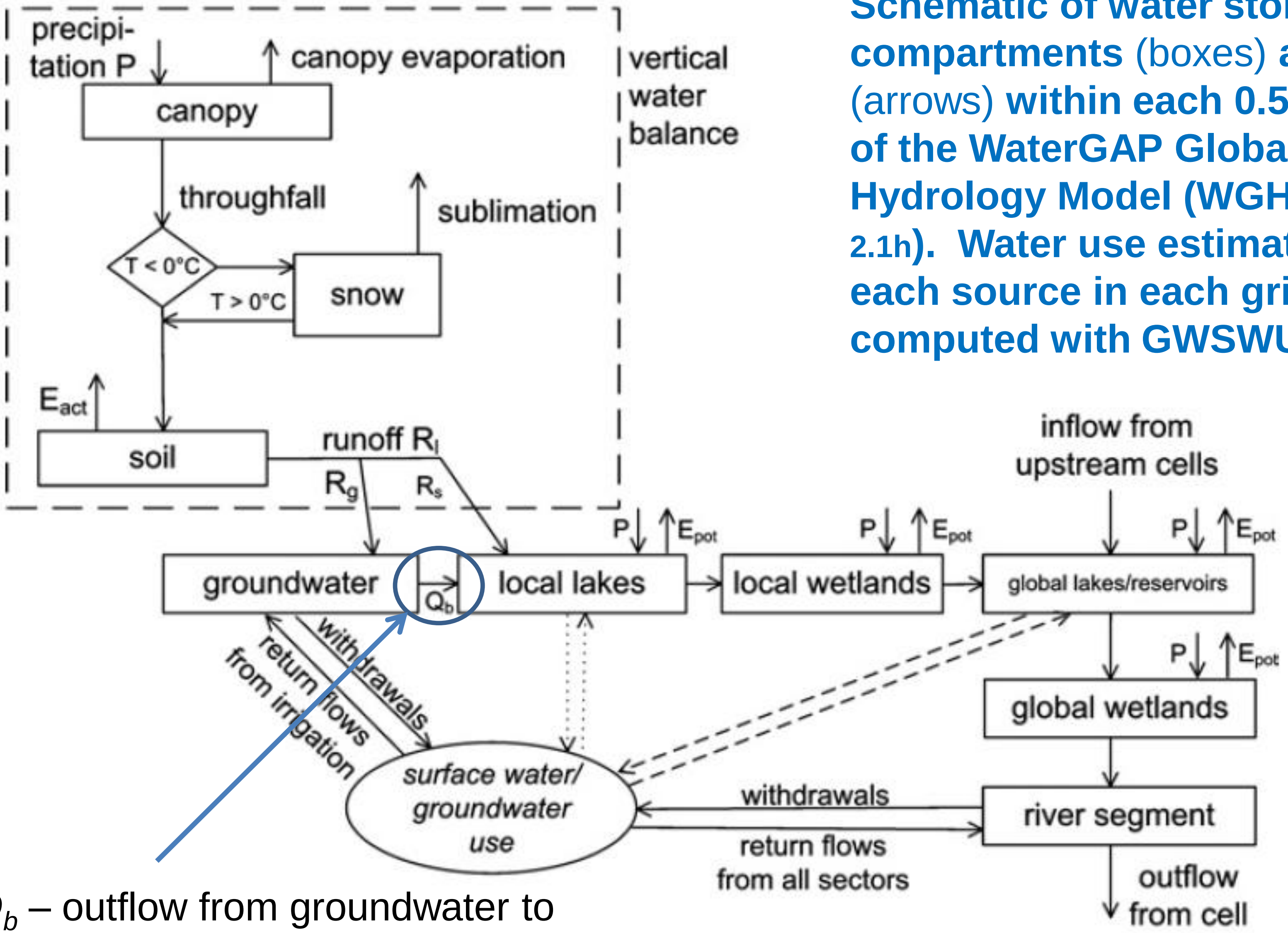
Modelling the impacts of land use change on river water quality and diffuse water pollution

Integrated modelling: Linking land use with ecosystems services

Also estimating resultant farm incomes and how water policies like WFD forces land use to change



Schematic of water storage compartments (boxes) **and flows** (arrows) **within each 0.5º grid cell of the WaterGAP Global Hydrology Model (WGHM version 2.1h). Water use estimates for each source in each grid cell computed with GWSWUSE**

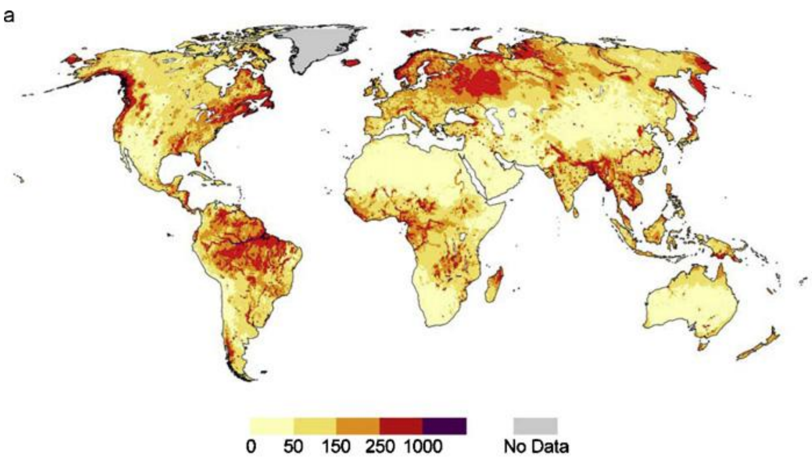


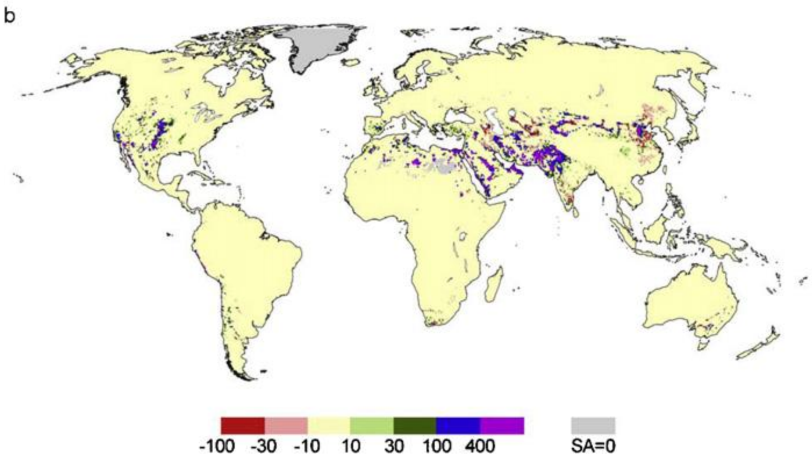
Q_b – outflow from groundwater to surface water; controlled by an outflow coefficient, k_g, set globally at 0.01 day^{-1}

Döll *et al*. *Journal of Geodynamics* (In Press)

Global water use during the period 1998-2002, including groundwater fractions

Water use sector	Withdrawals *WU* [km^3/year]	Groundwater fraction of *WU* [%]	Consumptive use *CU* [km^3/year]	Groundwater fraction of *CU* [%]
Irrigation	3185	42	1231	43
Thermal power	534	0	13	0
Domestic	330	36	53	37
Manufacturing	264	27	110	24
Livestock	27	0	27	0
All sectors	4340	35	1436	40





Impact of human water use on seasonal amplitude (*SA*) of total water storage (*TWS*).

(a) *SA* computed as the grid-cell specific value of maximum mean monthly *TWS* minus minimum mean monthly *TWS*, averaged over 1998-2002, taking account of water withdrawals, in mm.

(b) Change of *SA* with water withdrawals relative to *SA* without withdrawals, in percent of *SA* without water withdrawals (positive values indicate that water withdrawals increase *SA*s of *TWS*)

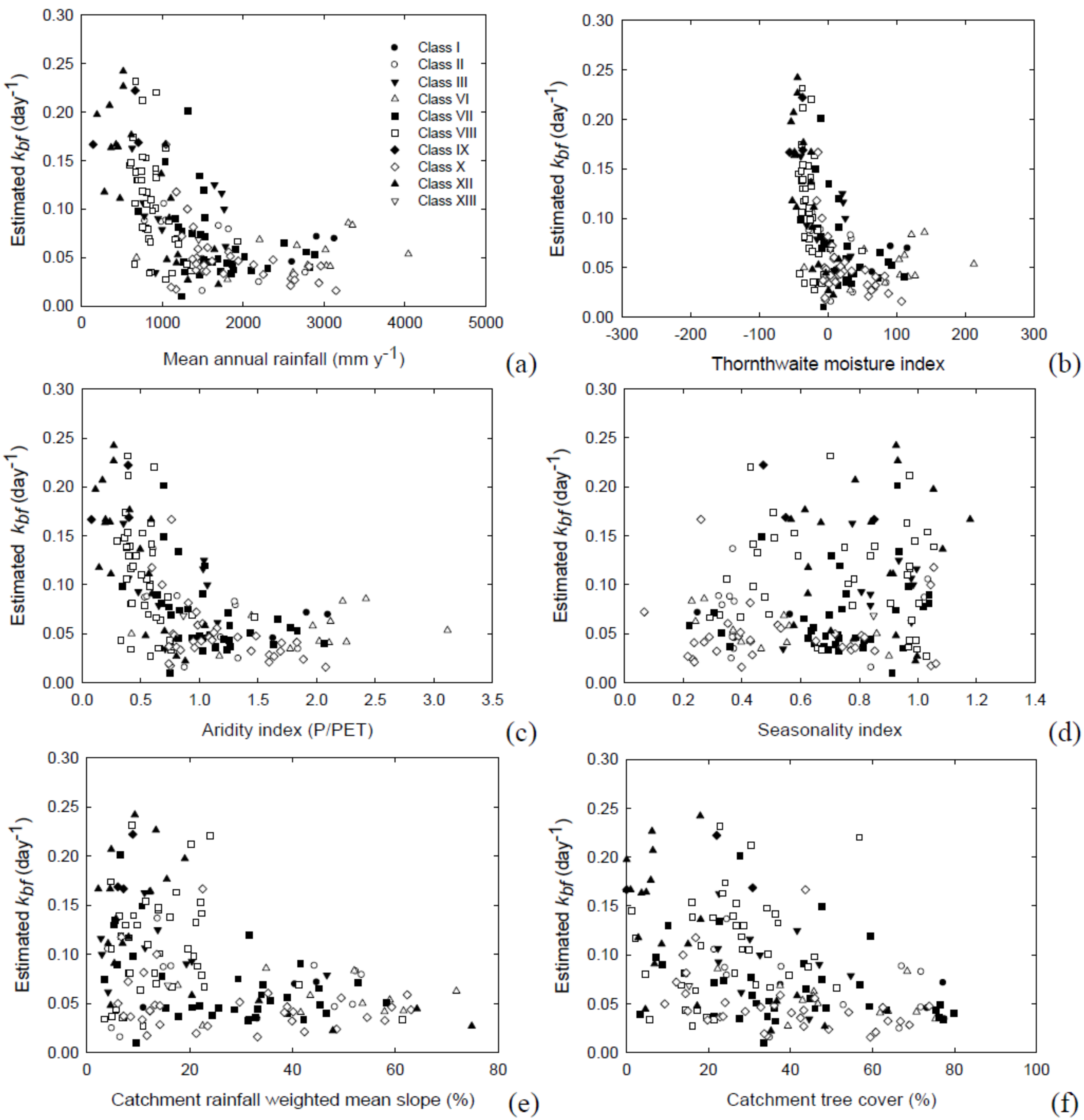
Döll *et al*. *Journal of Geodynamics* (In Press)

Scatter plots of recession coefficient, k_{bf} *vs.* various catchment parameters and WHYMAP (2010) hydrogeological classes

$$Q_t = Q_o e^{-k_{bf} t}$$

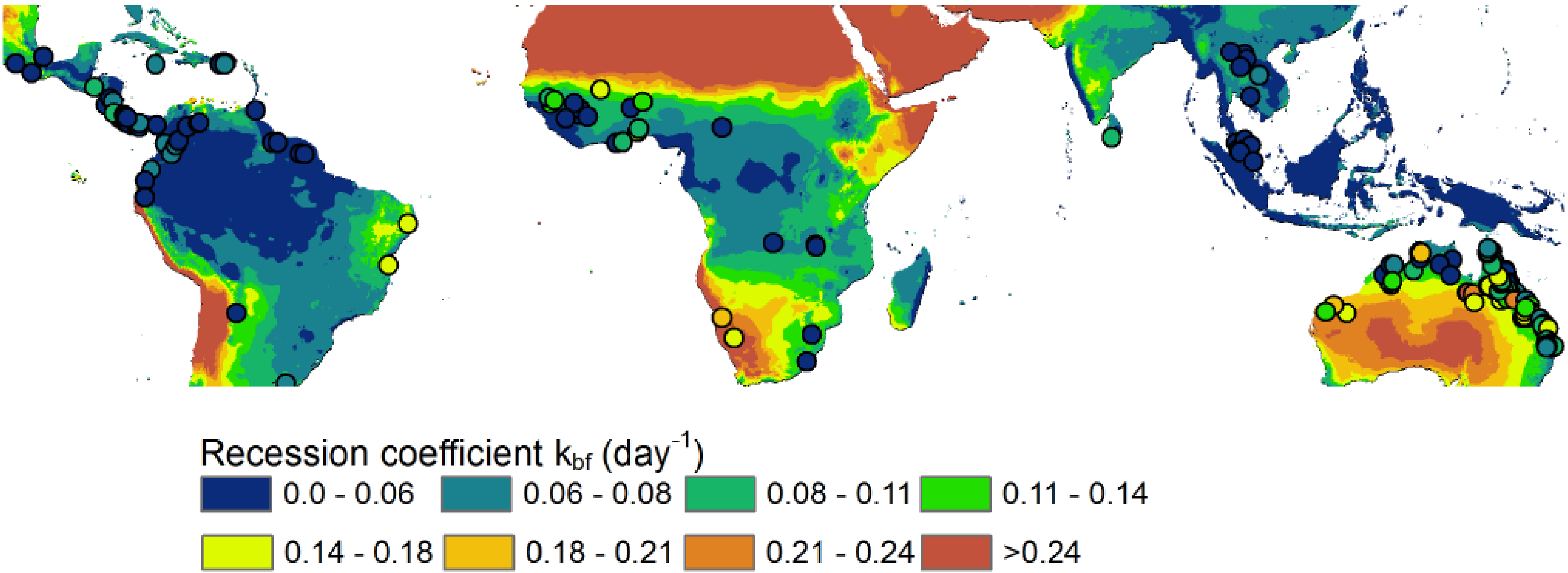
Q_o - discharge at the start of baseflow recession
Q_t - discharge at later time, t
k_{bf} - aquifer or recession coefficient

Q data from the Global Runoff Database from the GRDC



Peña-Arancibia *et al*. *Hydrology and Earth System Sciences* (2010)

Pan-tropical map of baseflow recession coefficient using the exponential regression equation and mean annual rainfall (MAR)



Peña-Arancibia *et al*. *Hydrology and Earth System Sciences* (2010)

Climate impacts modelling

ERMITAGE:

Enhancing Robustness and Model Integration for the Assessment of Global Environmental Change

The ERMITAGE project aims to link several key component models into a common framework in order to better understand how management of land, water and the Earth's climate system can best be understood. Key component models represent: the climate system (**MAGICC6**, **GENIE; ClimGEN**); climate change and land use change impacts upon water resources, agricultural and ecological systems (**LPJmL**); the agricultural/agro-economic system (**MAgPIE**); and the world economy and energy technologies (**TIAM**, **REMIND**, **GEMINI-E3**)

École Polytechnique Fédérale de Lausanne · PIK · Manchester 1824 The University of Manchester · The Open University · ORDECSYS · ENERIS Environment Energy Consultants · University of East Anglia

Results of pattern-scaled climate scenario data (provided by ClimGEN) used to drive the LPJmL land use model, providing a global-scale impact scenario assessment

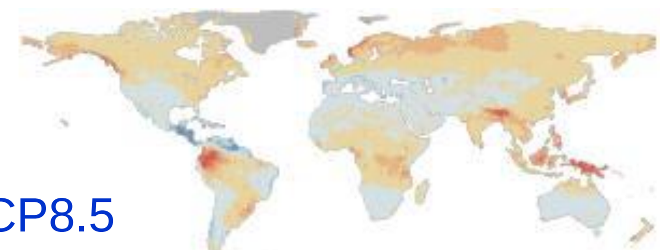
RCP2.6

RCP4.5

Simulated impacts shown as ensemble median changes for each of four RCPs and each of 18 GCMs, showing 30-yr average changes (2071–2100) relative to the observed period 1971–2000

Note that impacts tend to strongly increase for the higher RCPs, suggesting significant decreases in runoff (as a proxy for water availability) in many regions

RCP6.0



RCP8.5

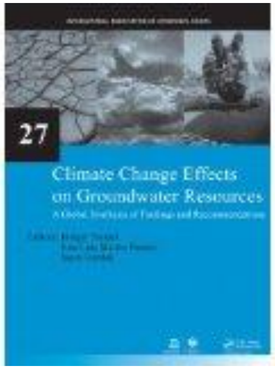
Representative concentration pathways (RCPs)

	Radiative forcing (W/m^2)	CO_2 equivalent concentration (ppm)	Rate of change in radiative forcing
RCP8.5	8.5	1350	Rising
RCP6.0	6.0	850	Stabilizing
RCP4.5	4.5	650	Stabilizing
RCP2.6	2.6	450	Declining

Ensemble median changes in simulated average annual (sub)surface runoff

< –300 | –200 – –100 | 0 – 100 | 200 – 300
–300 – –200 | –100 – 0 | 100 – 200 | > 300

(mm)



Climate Change Effects on Groundwater Resources: A Global Synthesis of Findings and Recommendations

Treidel, H, Martin-Bordes, M. Gurdak, J. (eds).
IAH/CRC Press, 2012

Recommendations for further research

1. Integrate climate change and variability to improve conceptual hydrological models
2. Institute a comprehensive strategy to monitor global groundwater resources
3. Give greater attention to groundwater quality
4. Study mechanisms of snowmelt runoff and recharge
5. Continue interdisciplinary and multidisciplinary collaboration
6. Make groundwater research usable by (ground)water managers