Impact of climate change on groundwater-dependent ecosystems

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Outline of presentation

- **Background and classification of wetlands**
- **Wetland hydro-ecology**
- **Impact of climate change on fresh groundwater levels in wetlands**
- **Impact of rising sea level on coastal wetland salinity**
- **Mitigation strategies**
- **Conclusions**

Background

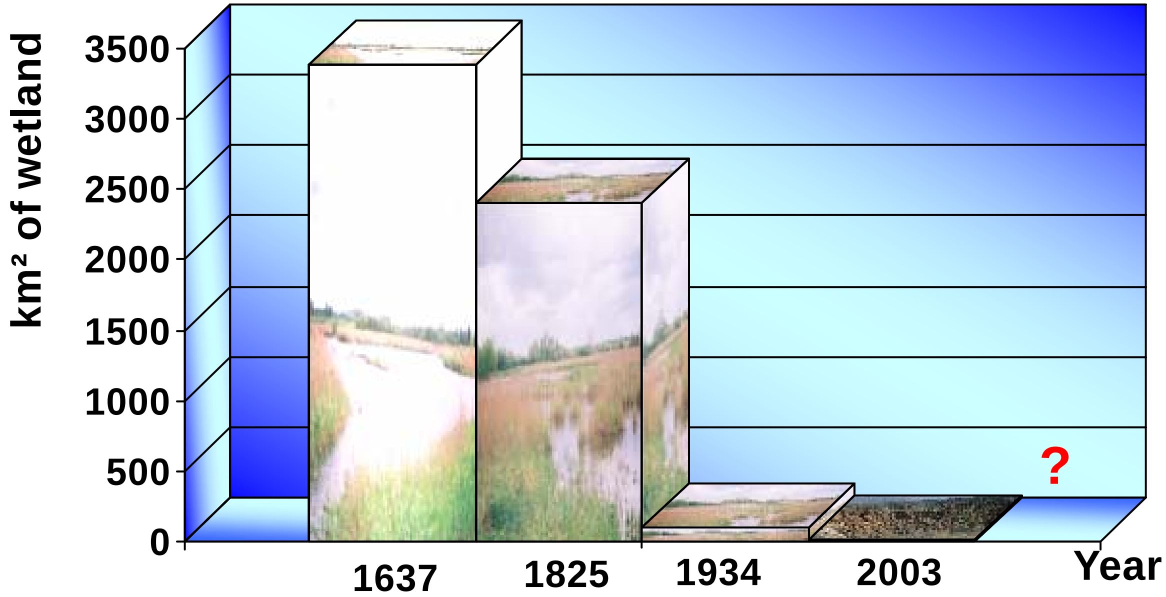
- Wetland ecosystems arise when inundation by water produces soils dominated by anaerobic processes and forces the biota to exhibit adaptations to tolerate flooding (Keddy, 2000)

- Over 3500 species of invertebrates, 650 species of aquatic plant, 22 species of duck and 33 species of wader have been identified in UK wetlands (Acreman, 1998)

Carex elata
(pendulous sedge)

Wetland loss

History of East Anglia fenlands since 1600s



East Anglia contains a significant proportion of the priority wetland sites in Britain

> 80% dependent in part on groundwater

(Wheeler & Shaw 2001)

Wetland classification

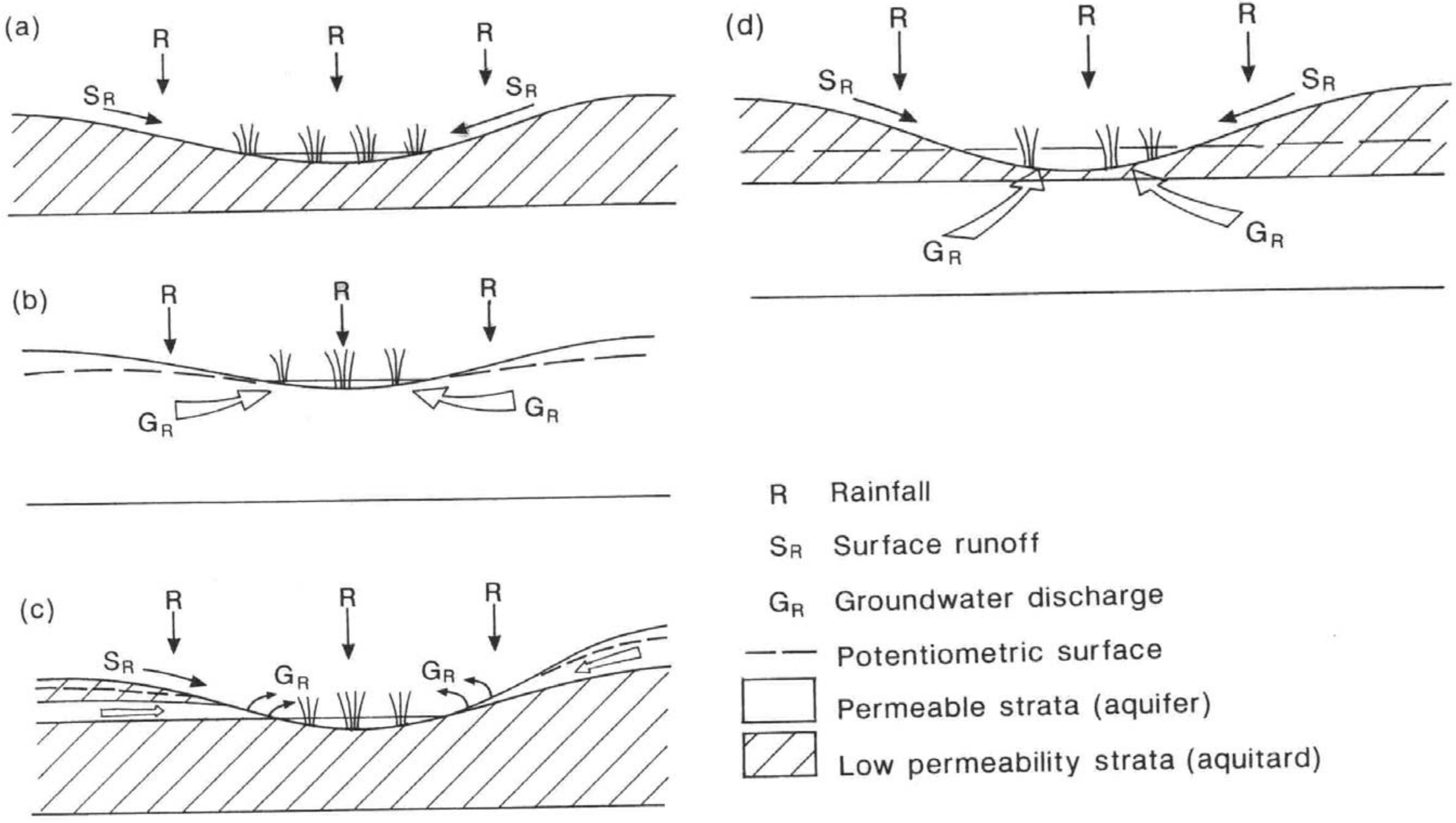
<u>Bogs</u>: acid and nutrient deficient, dominated by *Sphagnum* moss

<u>Fens</u>: peat-producing wetlands supplied by mineral-rich groundwater. Grass and sedge dominated

<u>Marshes</u>: inundated areas fed by groundwater or river water with emergent herbaceous vegetation

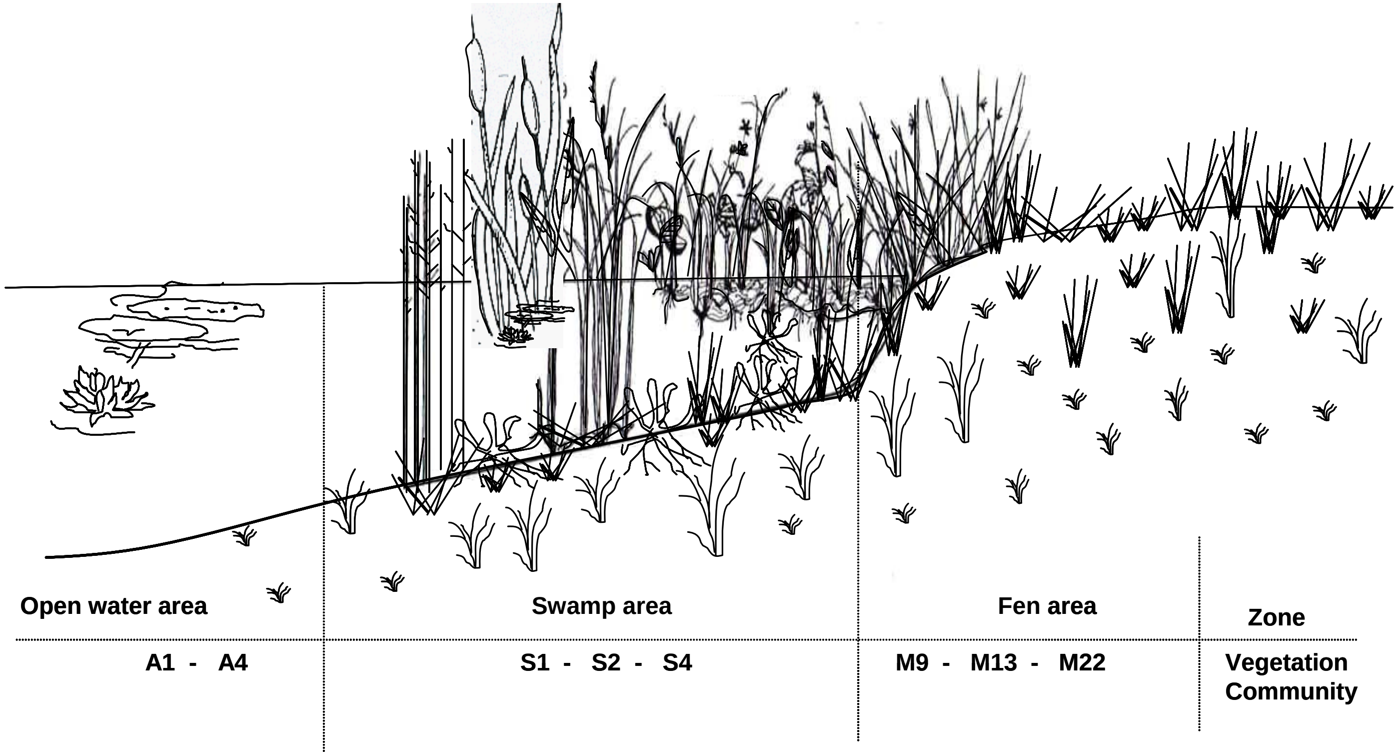
<u>Swamps</u>: forested freshwater wetlands in inundated areas

Hydrogeological classification of wetland types



Lloyd *et al*. (1993)

Generalised zonation of aquatic, swamp and fen vegetation in a typical wetland habitat



Factors affecting plant growth:

- Water level with specific thresholds for both drought and flood (affects morphological and physiological tolerances)
- Soil properties (influence distribution patterns and competitive abilities)
- Hydrochemical conditions (pH, available nutrients, redox potentials, mineralisation and denitrification rates, concentrations of reduced toxins (Fe, Mn, S))
- Site habitat management

Wetland water level requirements

Water table dry/wetness range in cm of some fenland plant species

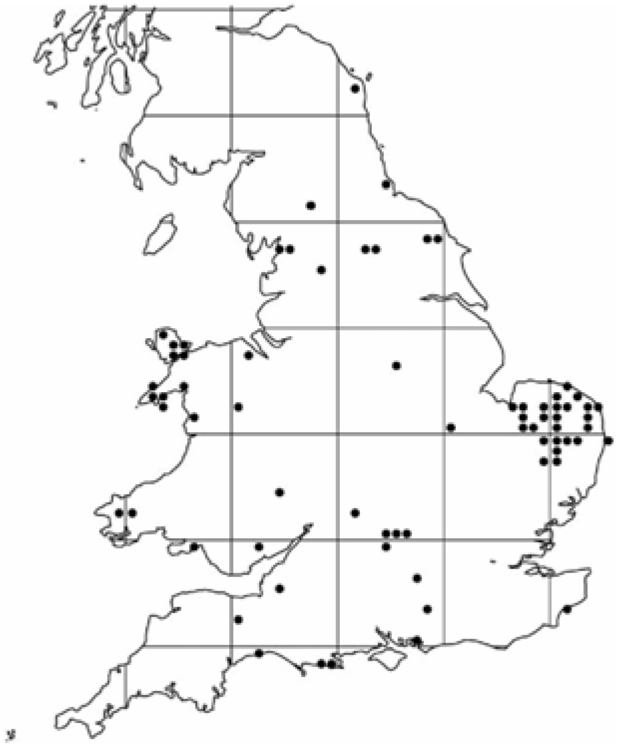
Species	Dry	Preferred	Wet
Phragmites australis (Common Reed)	*-100*	*-20 to 0*	*+50*
Carex rostrata (Bottle sedge)	*-15*	*0 to +30*	*+60*
Phalaris arundinacea (Reed Canary-grass)	*-60*	*-40 to 0*	*+30*
Juncus subnodulosus (Blunt-flowered rush)	*-40*	*-*	*+30*
Molinia caerulea (Purple Moor-grass)	*-100*	*-50 to -25*	*0*

Note: a –ve sign indicates a water table below ground level, a +ve sign indicates a water level above ground level, i.e. depth of water

English Nature (1997)

Environment Agency Ecohydrological Guidelines for Lowland Wetland Plant Communities (Wheeler *et al*., 2004)

Part 3
Fen/Mire Community Guidelines (B.D. Wheeler, S.C. Shaw, R.P. Money)

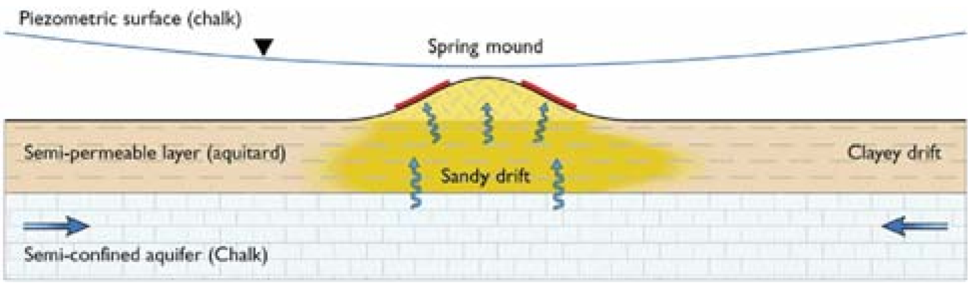


Distribution of M13 *Schoenus nigricans – Juncus subnodulosus* (black bog-rush, blunt-flowered rush) mire

M13 communities occur in calcium-rich, spring water-fed areas on sloping ground in valleyhead fens (occasionally as floodplain margins)

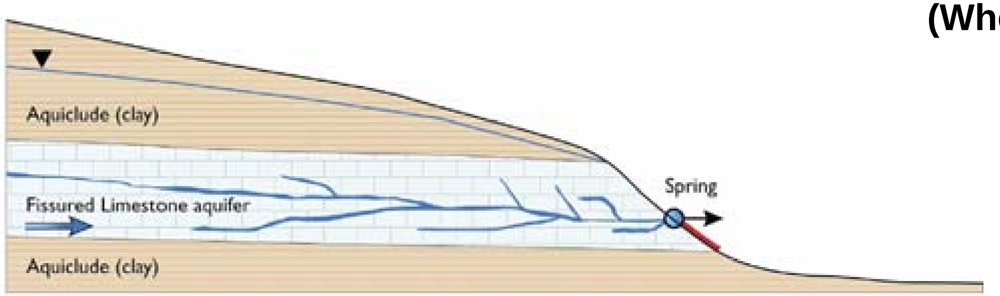
Substratum usually a shallow (<50 cm) organic deposit over permeable strata

Optimal water level condition is for winter water tables at or very close to fen surface (and also in summer for greatest species richness) with ‘flushing’ by oligotrophic base-rich/high pH/calcite-saturated groundwater discharge



Schematic representation of major water supply mechanisms to M13

(Wheeler *et al*., 2004)



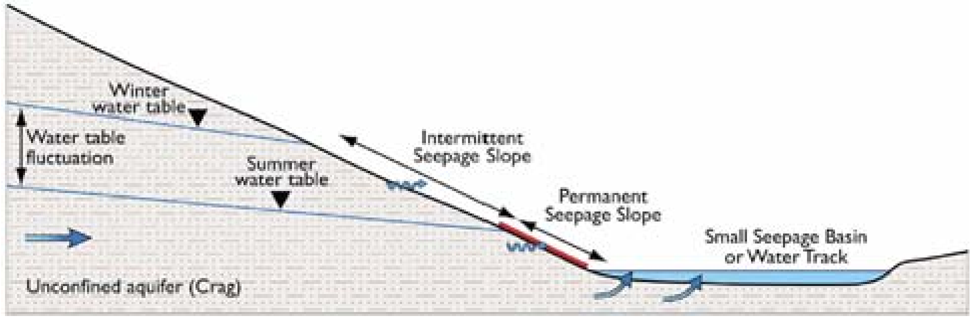
Summer water table for M13 in East Anglia:

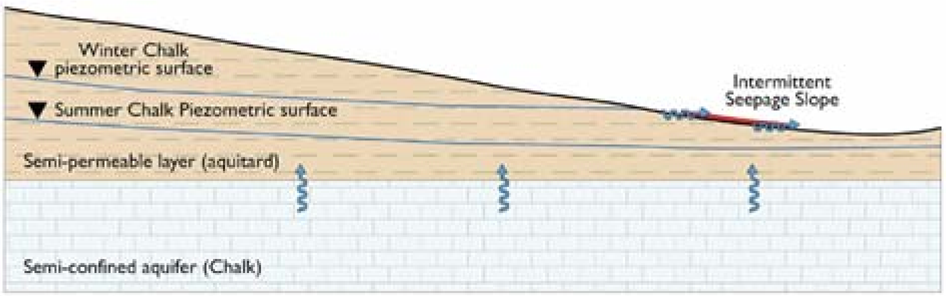
Mean = -9.55 cm (n = 19)

Min. = -38.6 cm

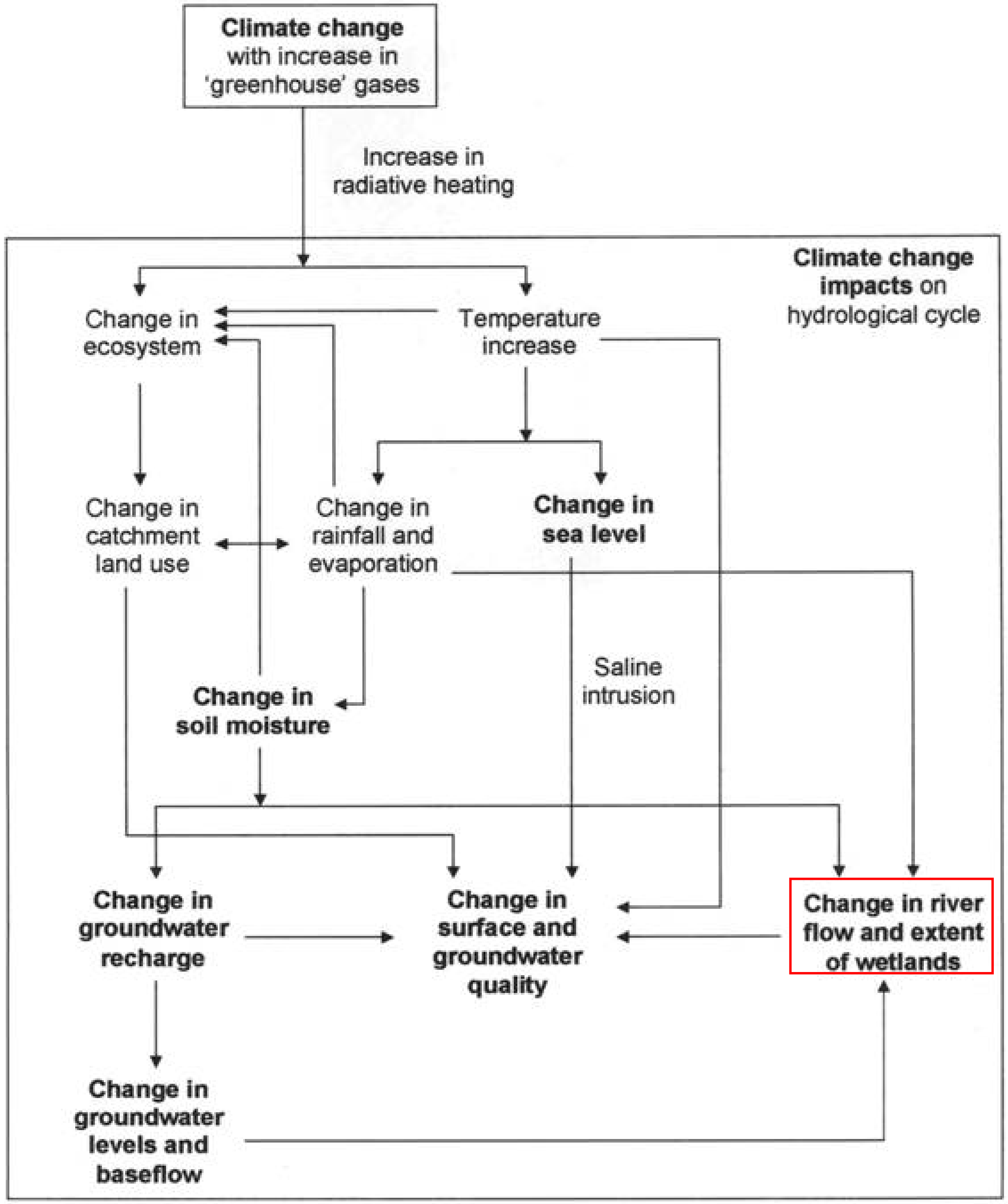
Max. = 5.0 cm

Possible location of NVC M13

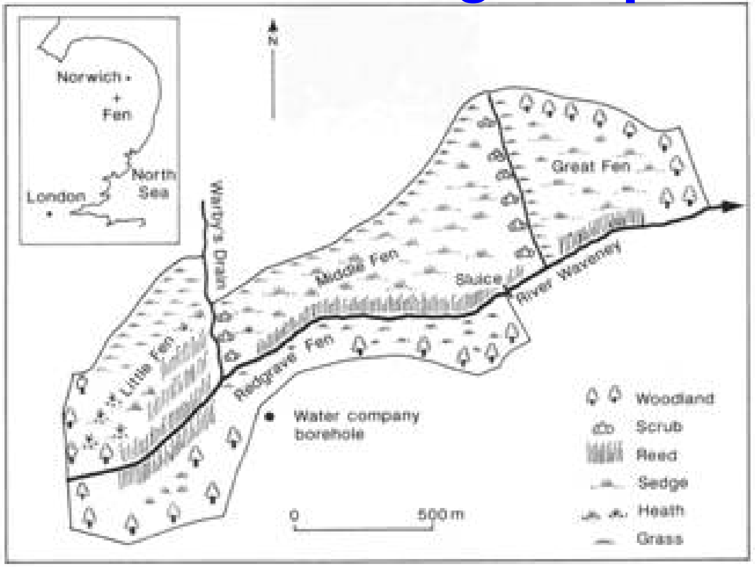




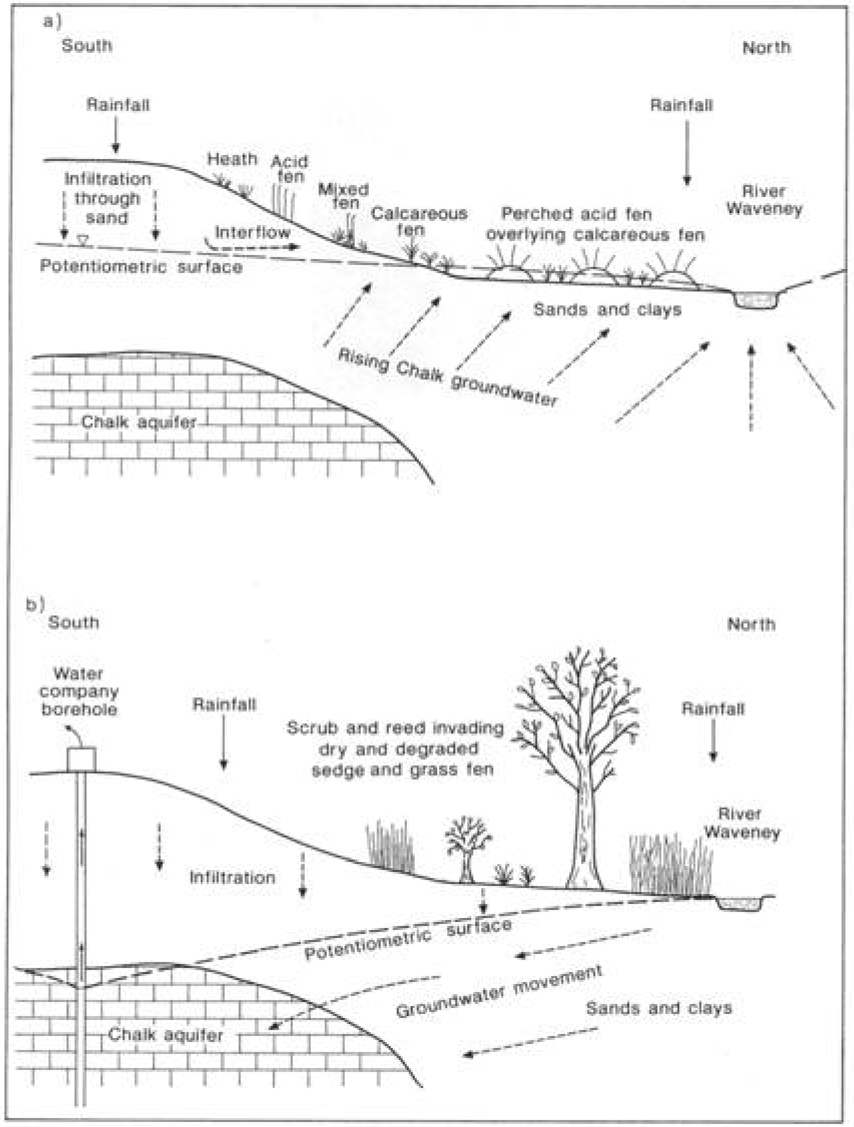
Impacts of increasing 'greenhouse' gas (GHG) concentrations on the natural hydrological cycle (after Arnell 1996) emphasising changes in hydrogeological conditions



Groundwater abstraction and wetlands – an analogue for climate change impacts



Redgrave & Lopham Fen



Modelling climate change impacts on potential groundwater recharge (or hydrological excess, *Hxr*) 2011-2100

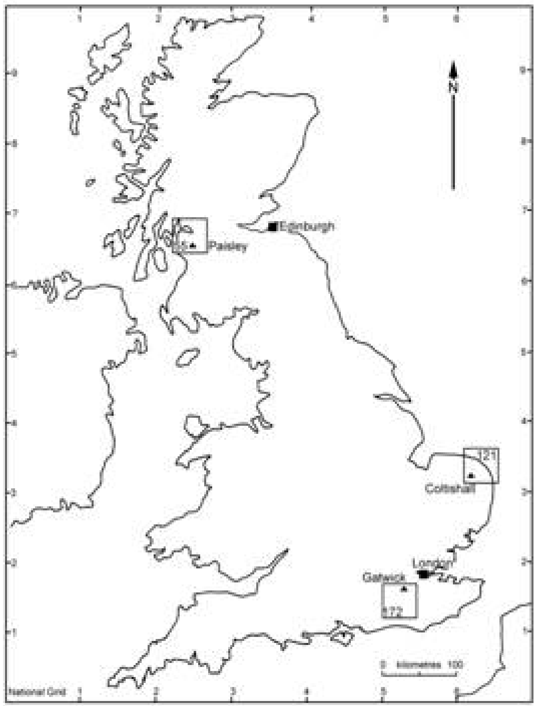
Assessed using the daily weather generator developed by the Climatic Research Unit (CRU) at the University of East Anglia as modified for the BETWIXT project (Built Environment: Weather Scenarios for investigation of Impacts and Extremes)

Methodology based on the incorporation of daily data (*P*, *PE*) from the weather generator in a simple soil moisture balance model and applied to three locations

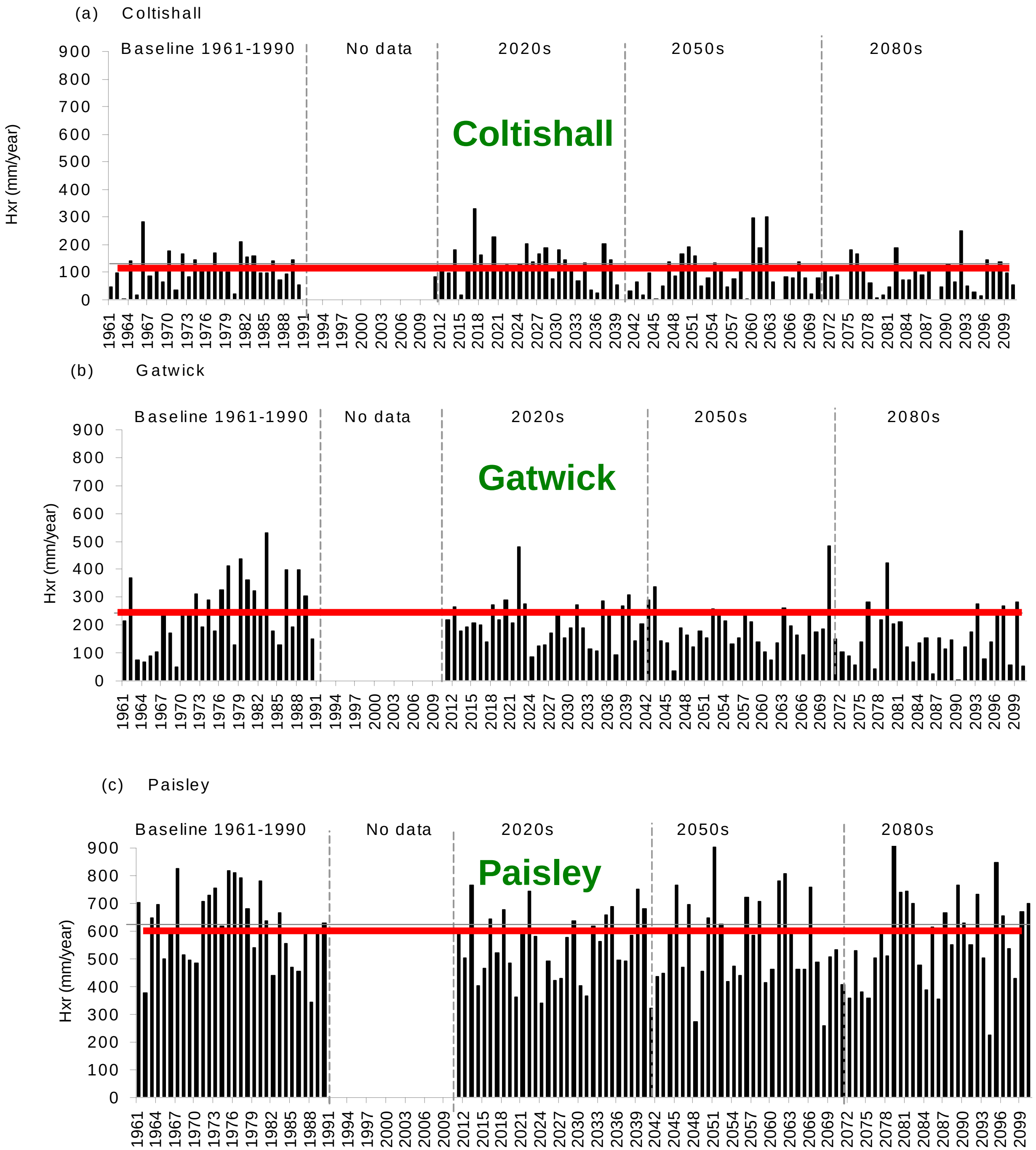
(a) Coltishall in East Anglia

(b) Gatwick in South East England

(c) Paisley in West Scotland



http://www.cru.uea.ac.uk/cru/projects/betwixt/



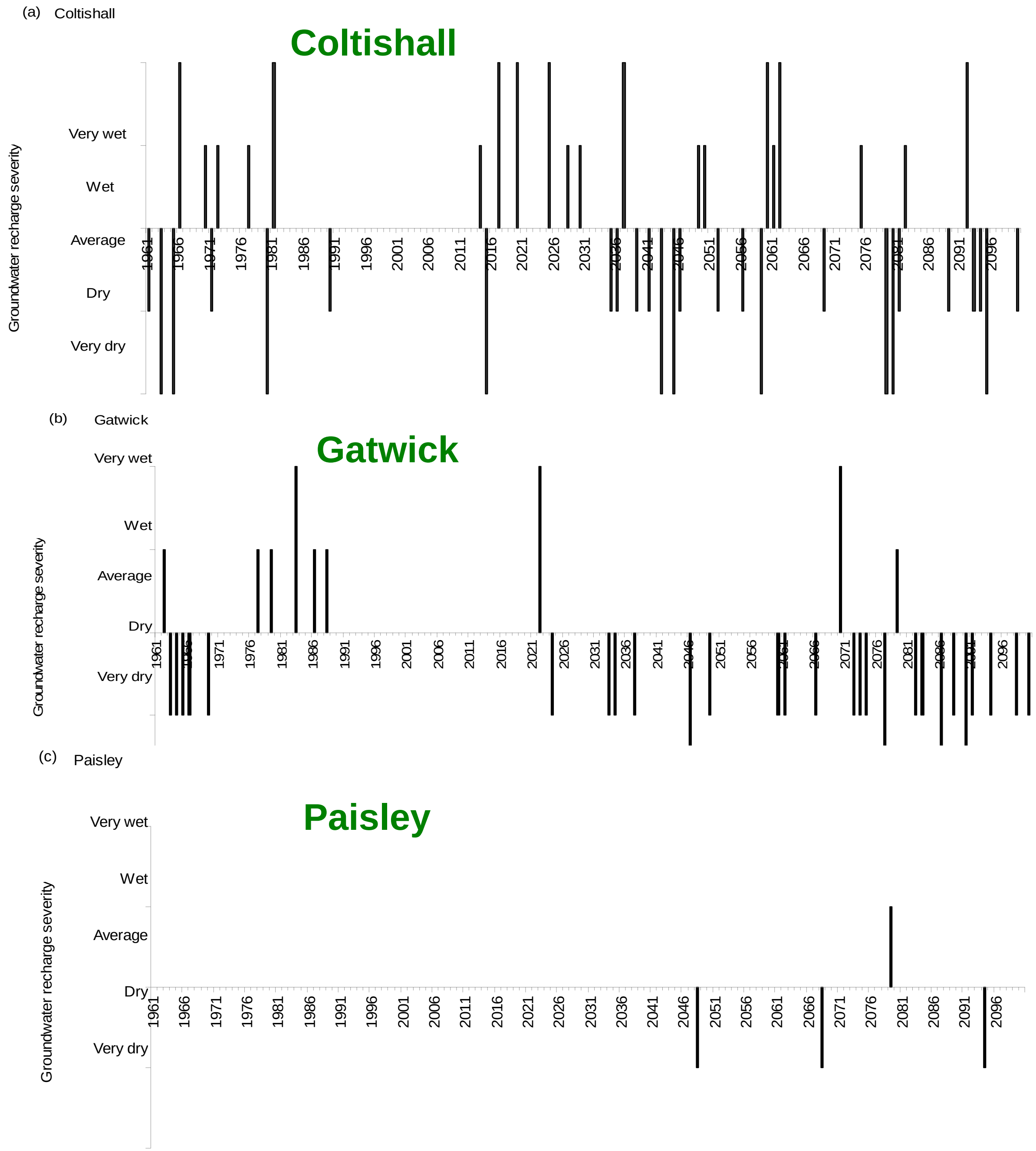
Annual potential groundwater recharge (*Hxr*) values for the baseline period (1961-90) and the three time periods of the High gas emissions scenario (2011-2100)

Horizontal line shows the mean annual groundwater recharge value (*Hxr*) for the baseline

Herrera-Pantoja & Hiscock (2007) *Hydrological Processes*

Mean annual potential groundwater recharge (*Hxr*) and %changes for the baseline period (1961-90) and the three time periods of the High gas emissions scenario (2011-2100)

	Coltishall				Gatwick				Paisley			
	1961-90	2020s	2050s	2080s	1961-90	2020s	2050s	2080s	1961-90	2020s	2050s	2080s
Mean annual *Hxr*	111	126	99	89	246	209	189	151	617	553	551	571
%change		+14	-11	-20		-15	-23	-39		-10	-11	-7



Persistence of *Hxr* periods for the baseline period (1961-90) and the three time periods of the High gas emissions scenario (2011-2100)

The persistence of dry periods increases during the 2050s and 2080s

Gatwick presents the driest conditions

Coltishall presents the largest variability of wet and dry periods

Paisley presents little variability

Change in groundwater levels under future climate (High gas emissions scenario) for the 2020s, 2050s and 2080s for Coltishall, Gatwick and Paisley compared with the baseline (1961-90)

	Baseline	2020s	2050s	2080s
Coltishall				
Mean monthly wet season recharge (mm)	18	20	17	15
Recharge change (mm)	-	+2	-1	-3
Water level change (cm) (S = 0.01)	-	+20	-10	$\boxed{-30}$
Mean monthly dry season recharge (mm)	1	2	0	0
Recharge change (mm)	-	+1	-1	-1
Water level change (cm) (S = 0.01)	-	+10	-10	$\boxed{-10}$
Gatwick				
Mean monthly wet season recharge (mm)	37	32	28	23
Recharge change (mm)	-	-5	-9	-14
Water level change (cm) (S = 0.01)	-	-50	-90	$\boxed{-140}$
Mean monthly dry season recharge (mm)	4	3	2	2
Recharge change (mm)	-	-1	-2	-2
Water level change (cm) (S = 0.01)	-	-10	-10	$\boxed{-20}$
Paisley				
Mean monthly wet season recharge (mm)	89	80	89	91
Recharge change (mm)	-	-9	0	+2
Water level change (cm) (S = 0.25)	-	-4	0	$\boxed{+1}$
Mean monthly dry season recharge (mm)	14	9	4	2
Recharge change (mm)	-	-5	-10	-12
Water level change (cm) (S = 0.25)	-	-2	-4	$\boxed{-5}$

Change in water level

=

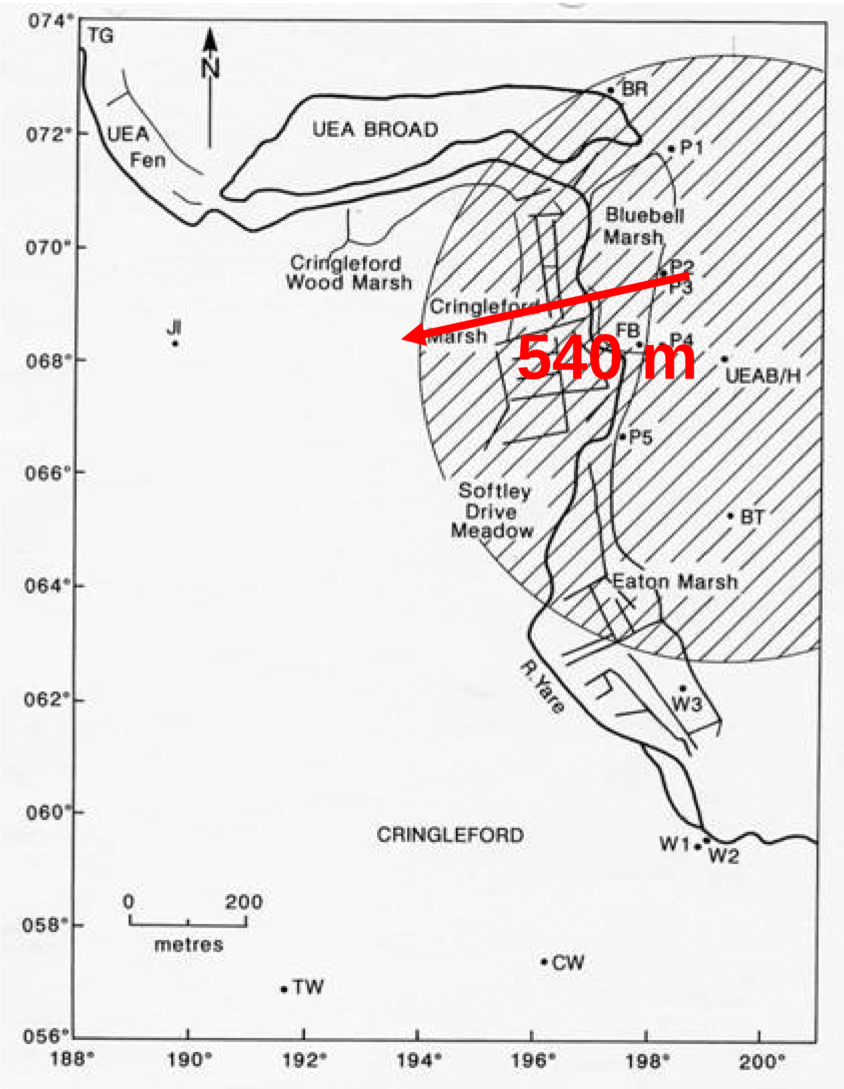
recharge / storativity

$\Delta h = Hxr / S$

Wet season: October - March

Dry season: April - September

UEA Countryside Stewardship Scheme – a possible mitigation strategy for climate change impacts?



<u>Equilibrium condition (Thiem)</u>

Radius of influence of borehole = 540 m (170 m with recharge)

<u>Non-equilibrium condition (Theis)</u>

Drawdown = 56 cm at centre of Bluebell Marsh after 365 days (= 6 cm if Yare treated as a recharge boundary)

Q_{pump} = 16.7 l/s

K = 50 m/day

T = 2100 m^2/day

S = 0.001

Environment Agency Ecohydrological Guidelines for Lowland Wetland Plant Communities (Wheeler *et al*., 2004)

Part 4
Ditch and Swamp Community Guidelines
(J.O. Mountford)

Distribution of the drainage channel habitat

The most important NVC communities that occur in the drainage channels of the Anglian region are:

A3 *Spirodela polyrhiza; Hydrocharis morsus-ranae (duckweed, frogbit) community*

(based on >100 samples, typical values for electrical conductivity (EC_{25}) range from 57 – 943 μS/cm (<250 mg/l Cl^-))

A4 *Hydrocharis morsus-ranae; Stratiotes aloides (frogbit, water-soldier) community*

A9 *Potamogeton natans (pondweed) community*

Ecological considerations of surface drainage salinity

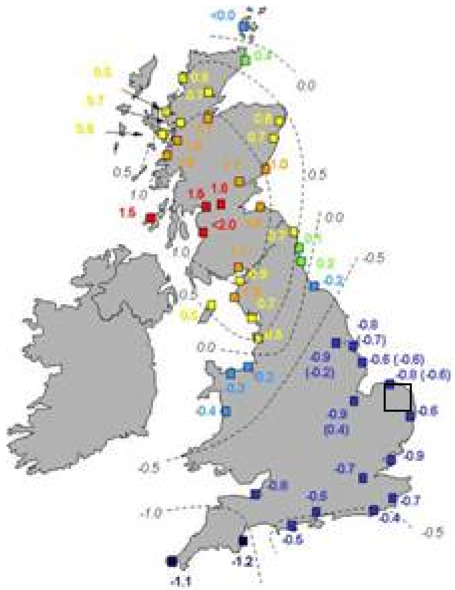
1. **Increased salinity associated with undesirable changes from nationally rare freshwater species to less species-rich brackish communities (Doarks 1984, Driscoll 1985)**

2. **Increased salinity in the Broads has caused algal blooms of *Prymnesium parvum* which produces a toxin that can be fatal to fish and some gill-breathing invertebrates**

3. **Considered that a reduction in salinity of the Broads to around 1000 mg/l will help combat the effects of *P. parvum***

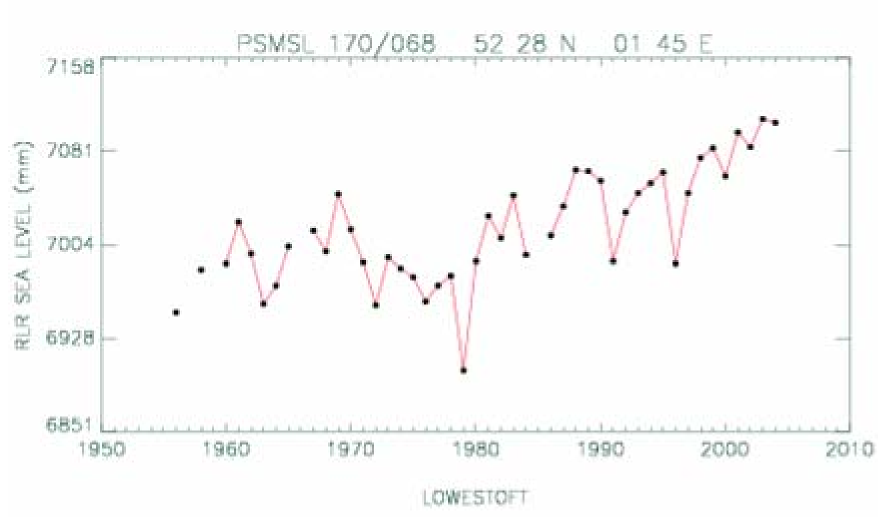
4. **Such benefit might be achieved by raising drainage levels to reduce salinity (George 1992, Bales *et al*. 1993) requiring a change in land use from deeply drained arable land to permanent grassland (wet pasture) under higher drainage water levels**

Upper Thurne catchment, north-east Norfolk



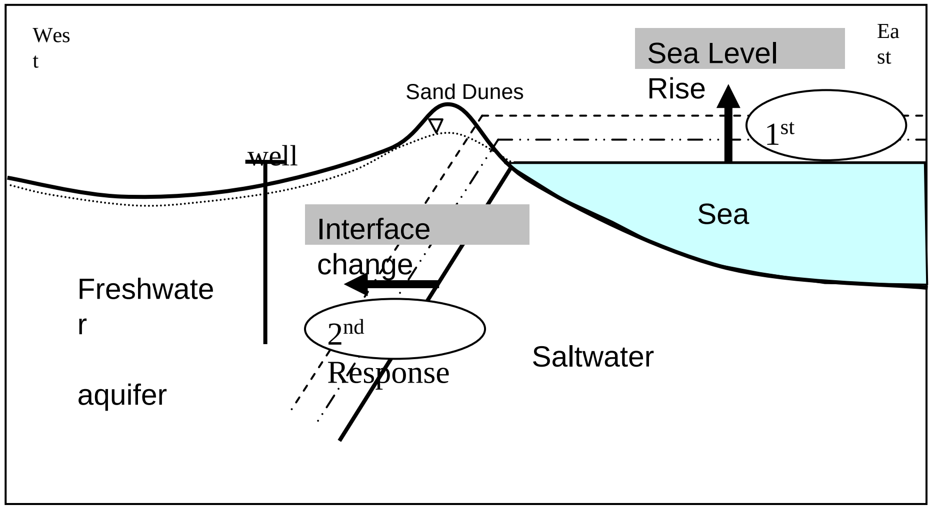
Late Holocene relative land/sea level changes (mm/year) in Great Britain (Shennan and Horton, 2002)

Revised Local Reference (RLR) annual sea level data for Lowestoft



Mean sea level increased by 2.01 (+/- 0.42) mm per year over the period 1960-1996

(Proudman Oceanographic Laboratory, 2005)



Sketch of saltwater intrusion into a coastal aquifer

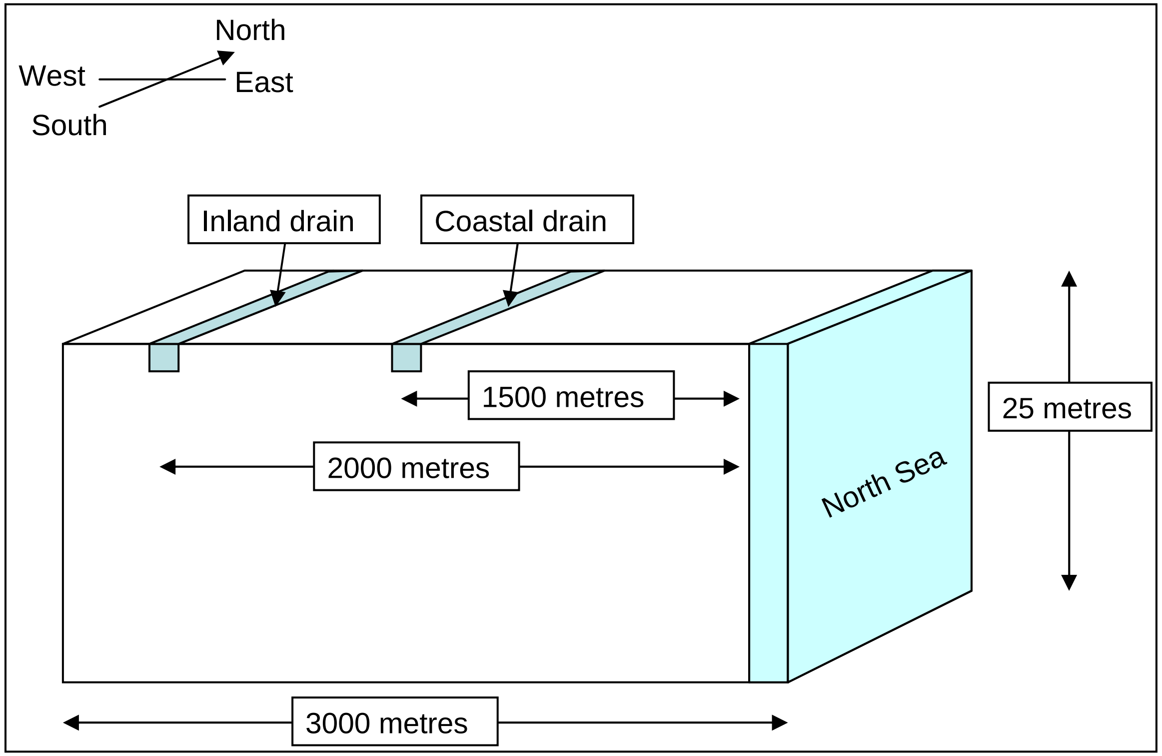
Future net sea level change in eastern England

Net sea level change (cm)						
	Low Emissions			High Emissions		
East of England	2020s	2050s	2080s	2020s	2050s	2080s
	8	13	17	18	42	77

Future net sea level change for 2080s in eastern England

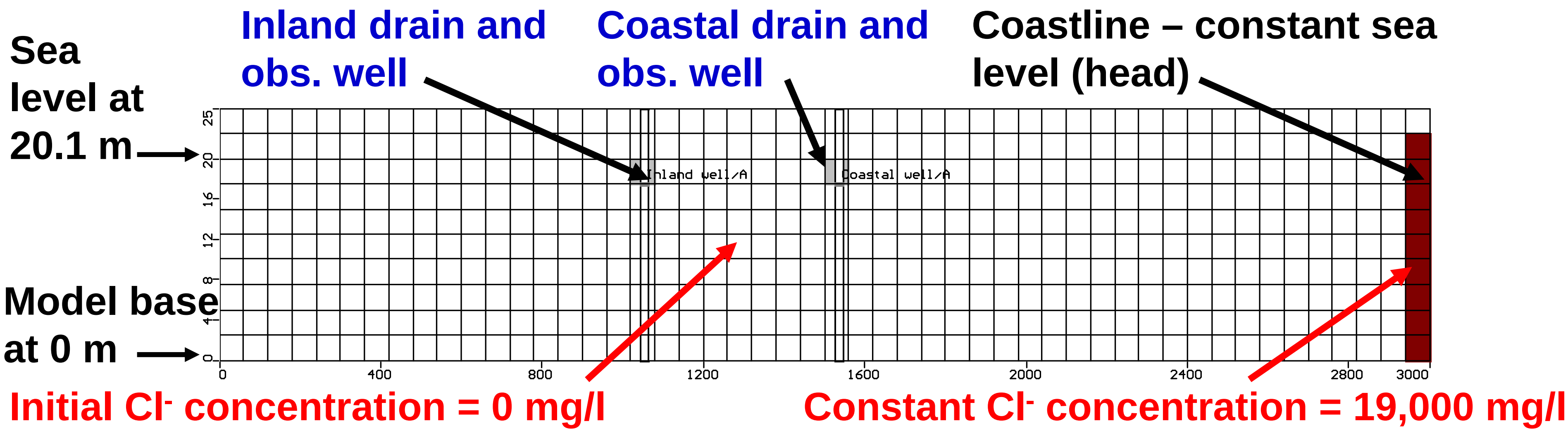
Net sea level change in 2080s (cm)				
East of England	Low	Medium Low	Medium High	High
	17	37	57	77

UKCIP (2005)



Set-up of MT3D solute transport model of the Crag aquifer in the Upper Thurne catchment

(Tanaka 2006)



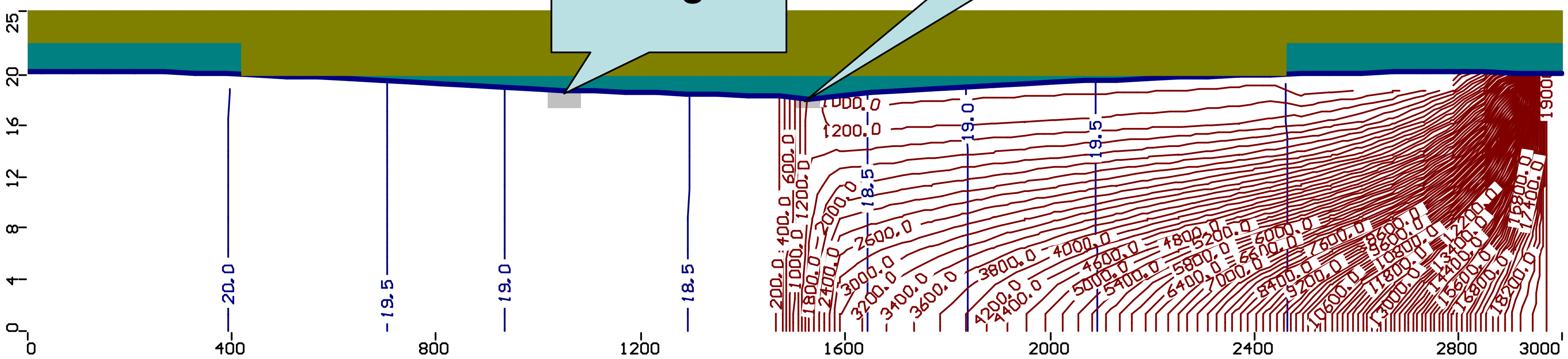
Recharge = 111 mm per year

Simulation time = 100 years

Measured Cl⁻ range of 1150 to 5820 mg/l for Brograve and West Somerton New pumps, 1991-93 (Holman 1994)

Chloride 1327 mg/l

Chloride 0 mg/l



Run 1_Historic (1961-90)

Inland drain level = 18.66 m above model base*

Coastal drain level = 18.07 m above model base**

Sea level = 20.1 m above model base

* Equivalent to Eastfield drainage pump inlet mean water level 1991-93, 2005

**Equivalent to Brograve drainage pump inlet mean water level 1991-93

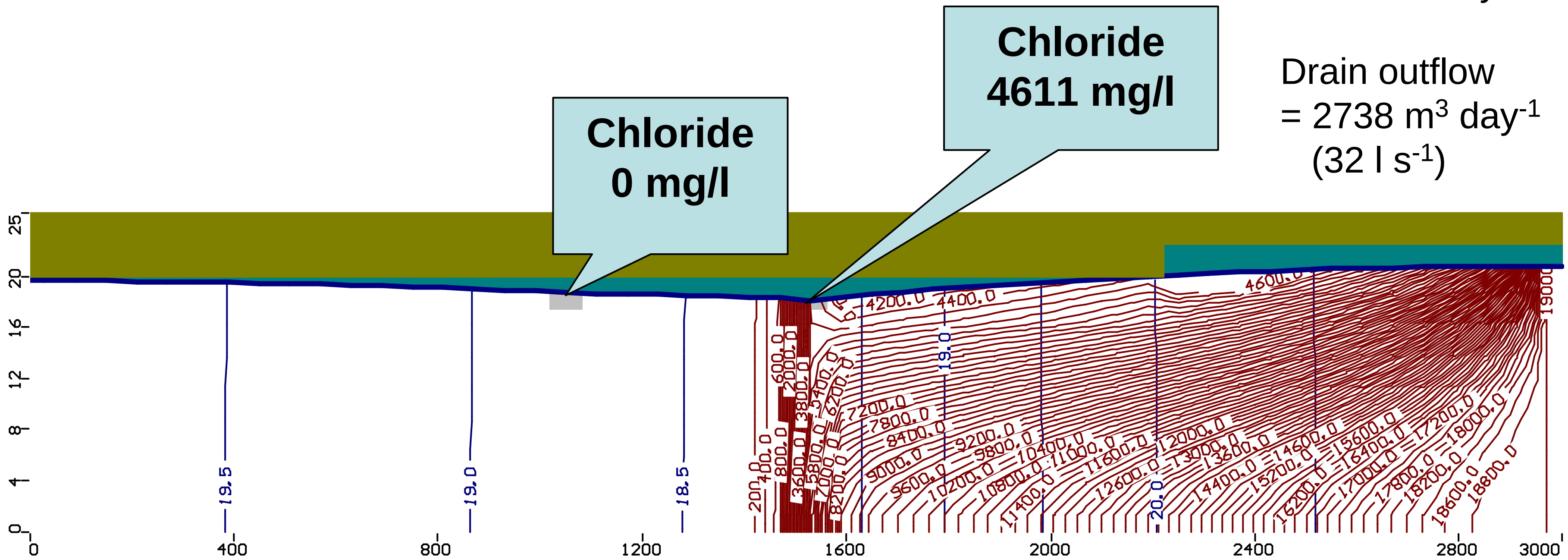
Recharge = 89 mm per year

Simulation time = 100 years

Recharge
= 2151 m^3 day^{-1}

Coastal head input
= 569 m^3 day^{-1}

Drain outflow
= 2738 m^3 day^{-1}
(32 l s^{-1})



Run 3_2080s

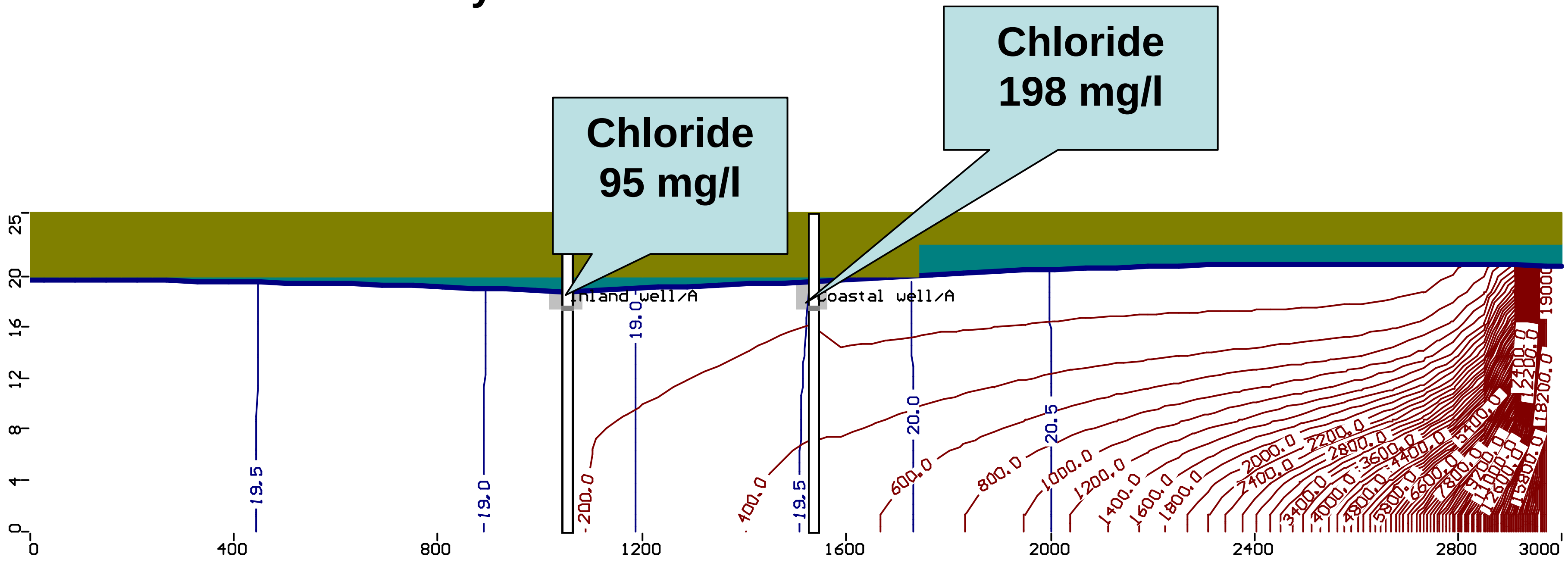
Inland drain level = 18.66 m above model base

Coastal drain level = 18.07 m above model base

Sea level = 20.77 m above model base

Recharge = 89 mm per year

Simulation time = 100 years



Run 6_2080s

Inland drain level = 18.66 m above model base

Coastal drain level = 19.50 m above model base*

Sea level = 20.77 m above model base

*Compare with Horsey drainage pump inlet water level of 19.43 in Nov 2005

Conclusions

- Water regime relationships are imperfect tools, but can aid resource managers to achieve the 'appropriate assessment' of regimes for the maintenance of specific plant species and communities

- Decreases in winter and summer potential groundwater recharge of the order of 10s of centimetres by the end of this century are likely to adversely affect groundwater-fed wetlands with loss of species richness and habitat

- Rising sea level will impact drained coastal wetlands leading to increased surface and ground water salinities

- Mitigation of climate change impacts is possible through management of winter and summer water levels to control drought and flood conditions and to prevent saline intrusion in coastal areas

- Further work is required to predict climate change impacts with respect to the complexities of seasonal fluctuations in water level, soil type, soil moisture saturation and the hydrochemistry governing wetland habitats