Climate impacts on groundwater in a UK coastal wetland

Dr Derek Clarke
Faculty Engineering and the Environment
University of Southampton

UNIVERSITY OF Southampton

Overview

- Groundwater levels fundamentally control wetland environments
- In sand dune systems groundwater, levels are driven by the dynamics of seasonal, inter annual and longer term climatic conditions.
- Inter annual variations in these systems can be large and are often incorrectly attributed to climatic change.
- In this paper we present a 40 year record of groundwater levels in north west England and compare observed inter annual variation with estimates of the effects of anticipated climate change.

Humid dune slack environments in North West England

- There are only 1200 ha of humid dune slacks in the UK and these account for 4.3% of the area reported in Natura 2000 for Europe. (Houston, 2008).

- These are manly confined to relatively few dune systems on the west coast of England and Wales.

- Important species occurring in dune slacks include Petalophyllum ralfsii (petalwort), stonewort, orchid and species of Bryum (thread-mosses).

- Seasonally flooded pools within the slacks provide a vital breeding site for the Natterjack toad (Bufo calamita).

- Ranwell, (1959) started to make the links between hydrological regime and vegetation communities.
- Ranwell divided slacks into “wet", "transitional” and “dry”, and assigned maximum and minimum summer and winter water table levels to each category.

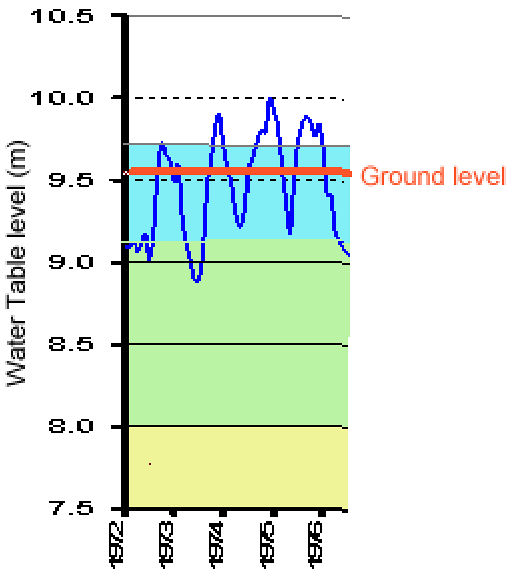
Range of observed depth-to-water table values for each of the three phases of the annual cycle grouped by plant community type. (After Ranwell, 1959).

	Depth to water table (cm) (+ve = above ground, -ve = below ground)		
Slack Type	*November to April*	*April to to August*	*August to November*
Wet	+20 to –60	+20 to –90	–10 to –90
Transitional	0 to –90	–10 to –120	–50 to –120
Dry	–35 to –120	–35 to –160	–90 to –170

- Ranwell, (1959) started to make the links between hydrological regime and vegetation communities.

- Ranwell divided slacks into “wet", "transitional” and “dry”, and assigned maximum and minimum summer and winter water table levels to each category.

“wet”



Range of observed depth-to-water table values for each of the three phases of the annual cycle grouped by plant community type. (After Ranwell,1959).

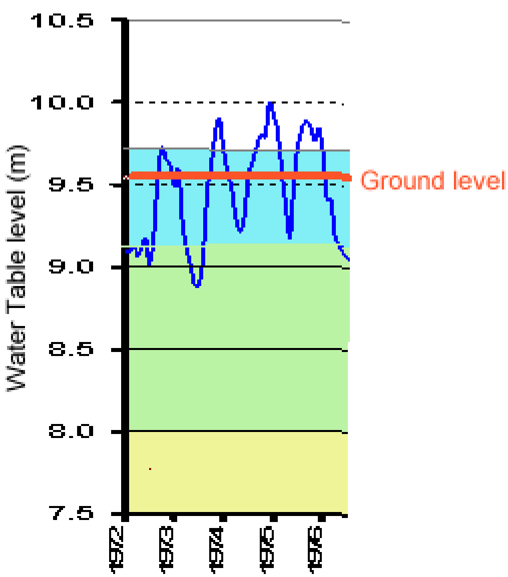
	Depth to water table (cm) (+ve = above ground, -ve = below ground)		
Slack Type	*November to April*	*April to to August*	*August to November*
Wet	+20 to –60	+20 to –90	–10 to –90
Transitional	0 to –90	–10 to –120	–50 to –120
Dry	–35 to –120	–35 to –160	–90 to –170

- Ranwell, (1959) started to make the links between hydrological regime and vegetation communities.
- Ranwell divided slacks into “wet", "transitional” and “dry”, and assigned maximum and minimum summer and winter water table levels to each category.

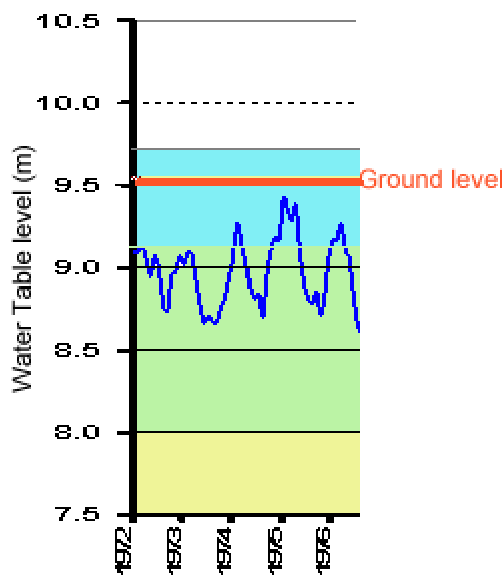
Range of observed depth-to-water table values for each of the three phases of the annual cycle grouped by plant community type. (After Ranwell,1959).

	Depth to water table (cm) (+ve = above ground, -ve = below ground)		
Slack Type	*November to April*	*April to to August*	*August to November*
Wet	+20 to –60	+20 to –90	–10 to –90
Transitional	0 to –90	–10 to –120	–50 to –120
Dry	–35 to –120	–35 to –160	–90 to –170

“wet”



“transitional”

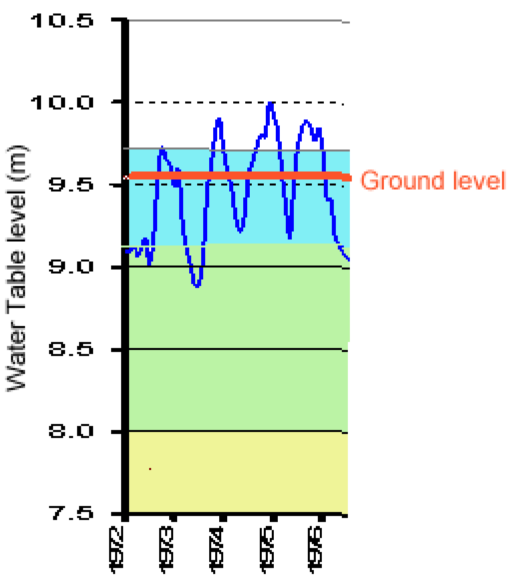


- Ranwell, (1959) started to make the links between hydrological regime and vegetation communities.
- Ranwell divided slacks into "wet", "transitional" and "dry", and assigned maximum and minimum summer and winter water table levels to each category.

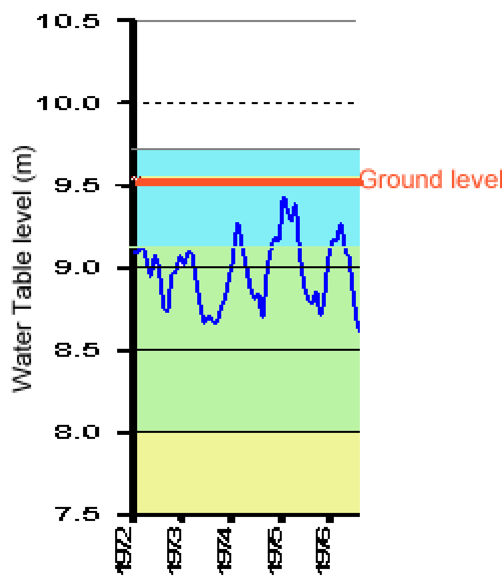
Range of observed depth-to-water table values for each of the three phases of the annual cycle grouped by plant community type. (After Ranwell,1959).

	Depth to water table (cm) (+ve = above ground, -ve = below ground)		
Slack Type	*November to April*	*April to August*	*August to November*
Wet	+20 to –60	+20 to –90	–10 to –90
Transitional	0 to –90	–10 to –120	–50 to –120
Dry	–35 to –120	–35 to –160	–90 to –170

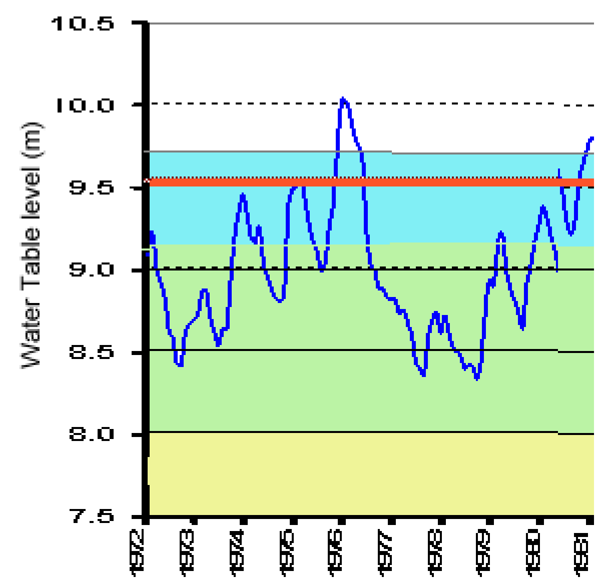
"wet"



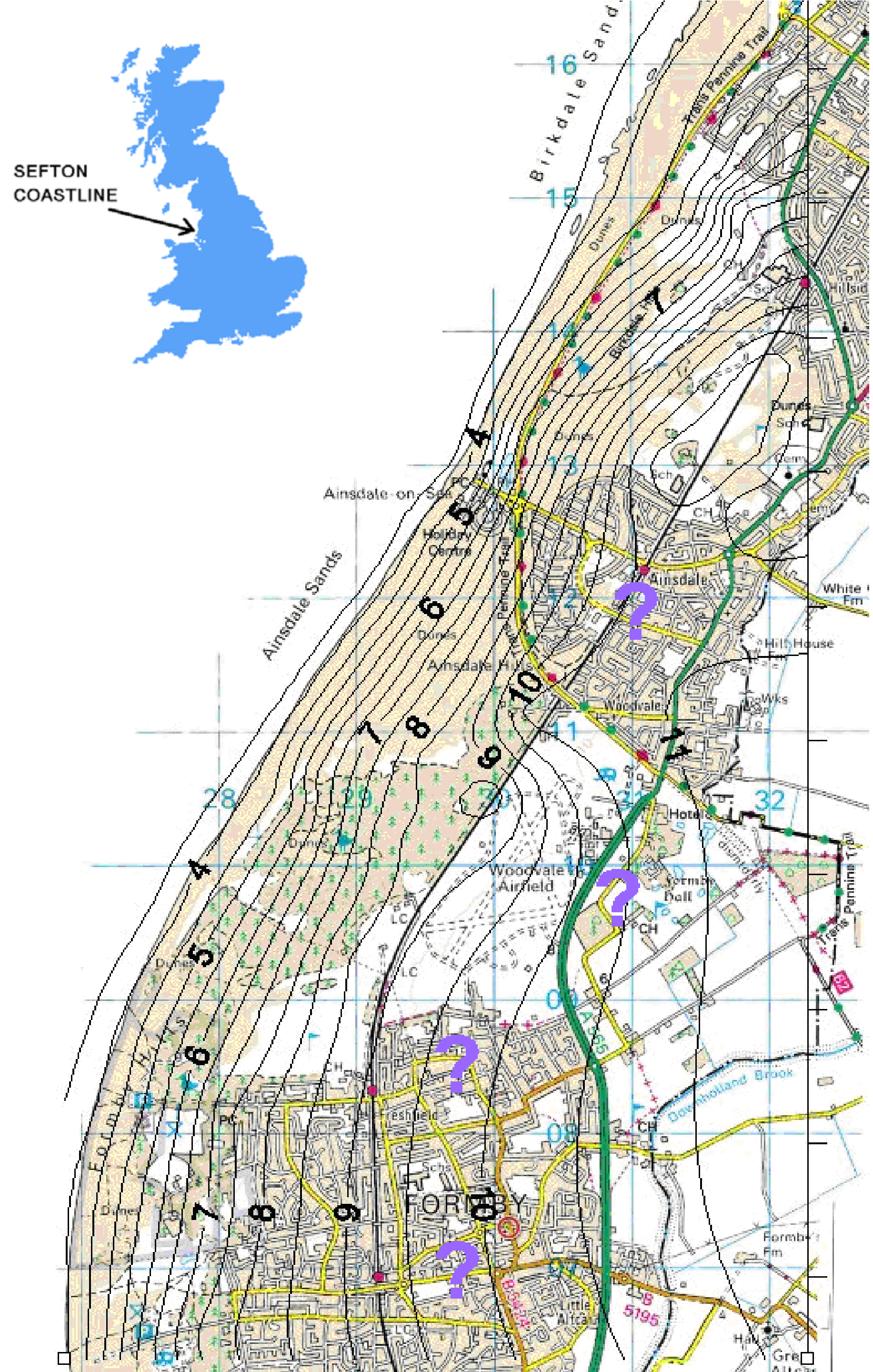
"transitional"



????



Groundwater contours in the Sefton Coastline

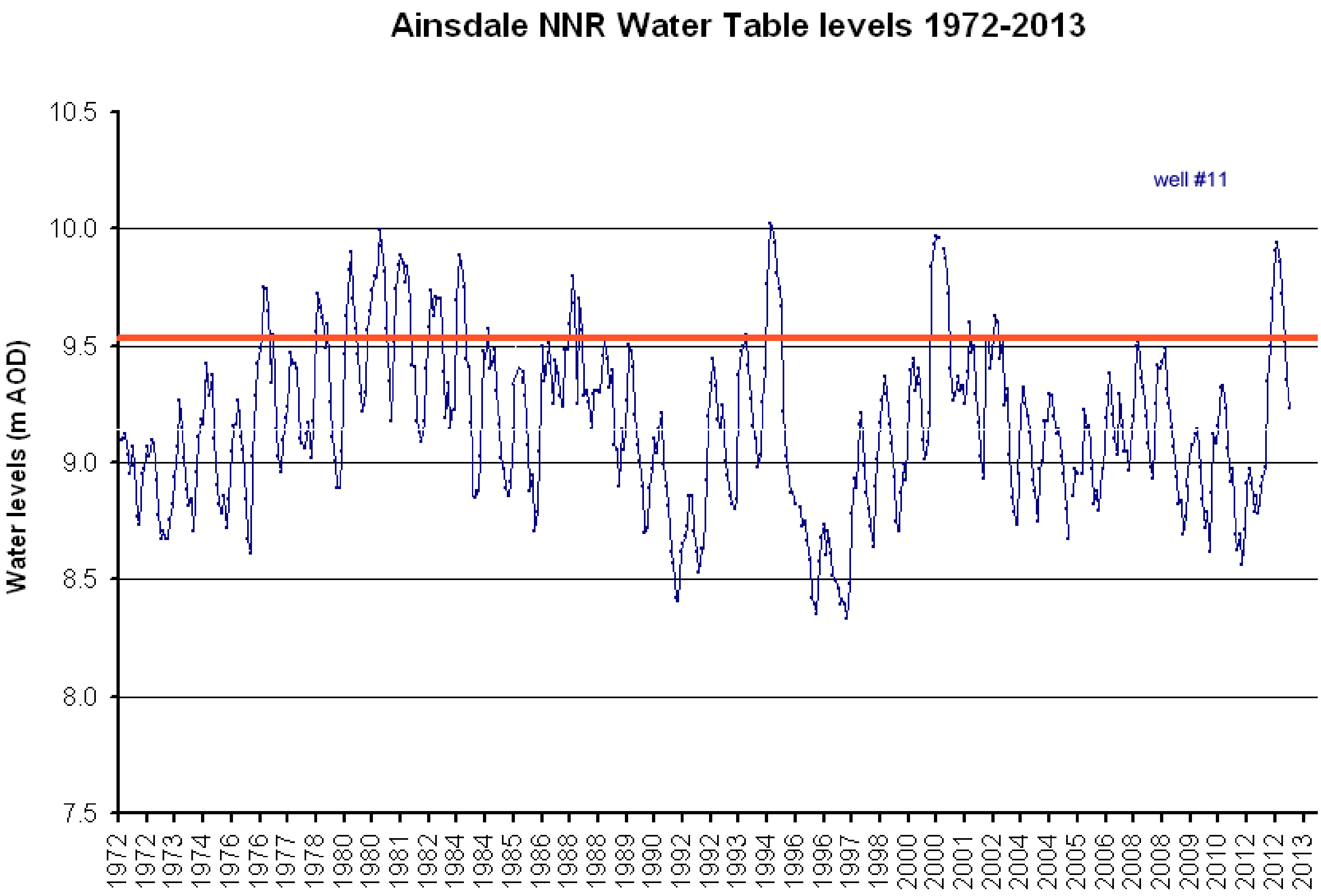


1km

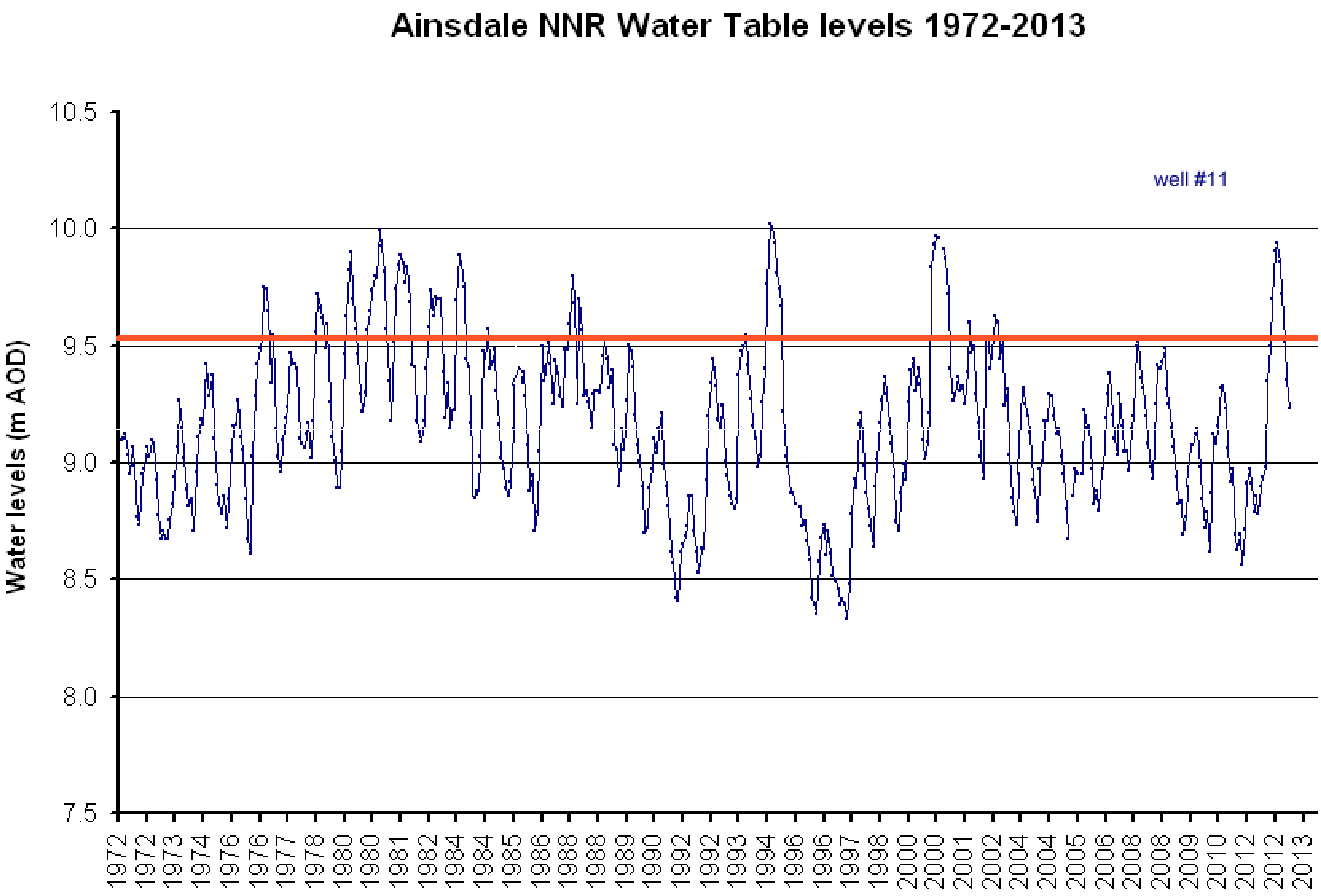
courtesy of:

- Sefton District Council/ IMCORE project
- Environment Agency
- Natural England
- Formby Golf Club
- Southport & Ainsdale Golf Club

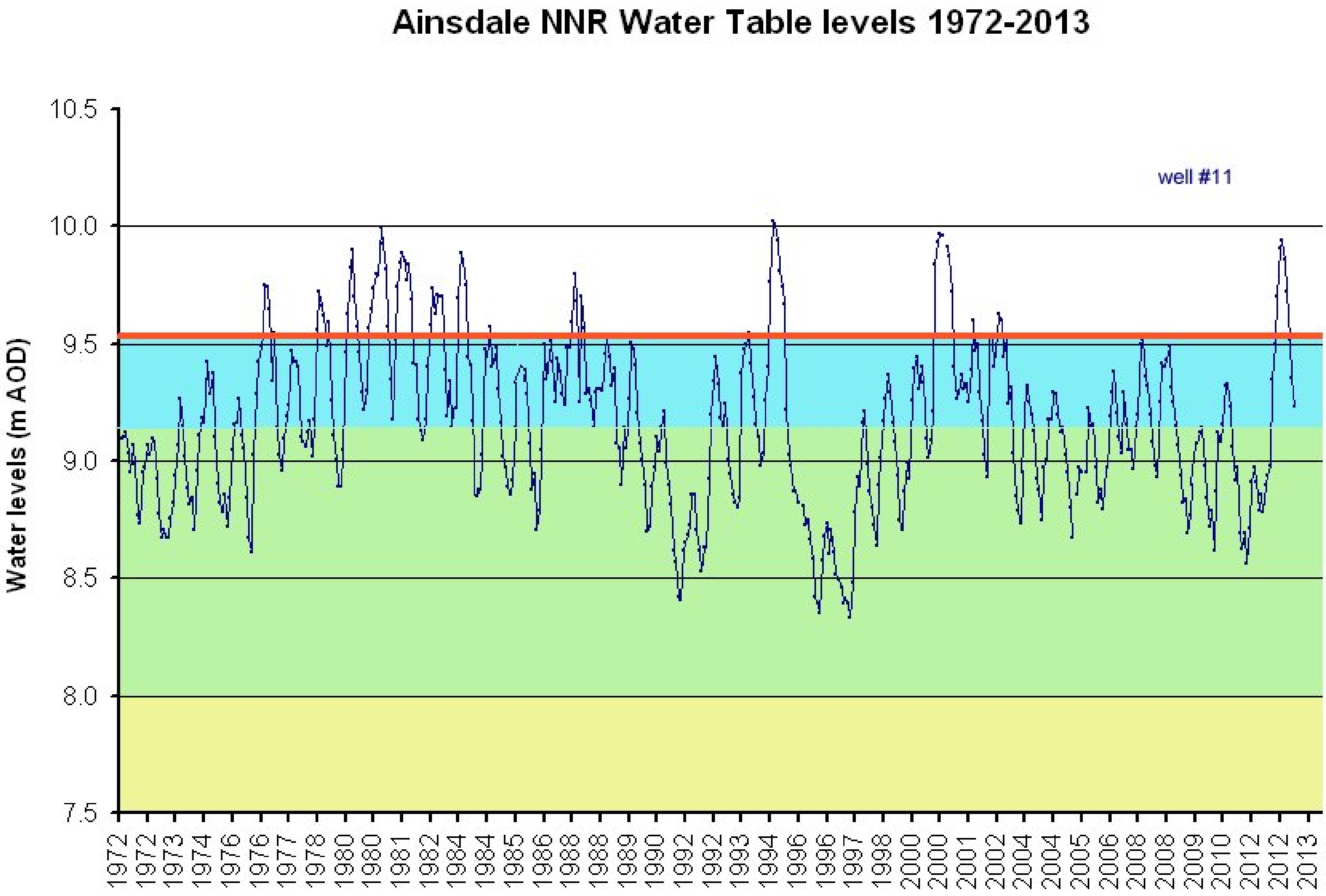
- The longest continuous record of water levels in coastal dunes in the UK is at Ainsdale, near Liverpool. Regular monitoring of water levels began in 1972 and are a record where groundwater levels were only affected by natural processes i.e. drainage, land use changes or other interventions were absent.



- Figure shows water level measurements at a “humid” slack site. The annual amplitude of water level change is +/-0.5m. Wet winters, where water levels are above ground (+9.54m above sea level) occur in approximately 50% of the years

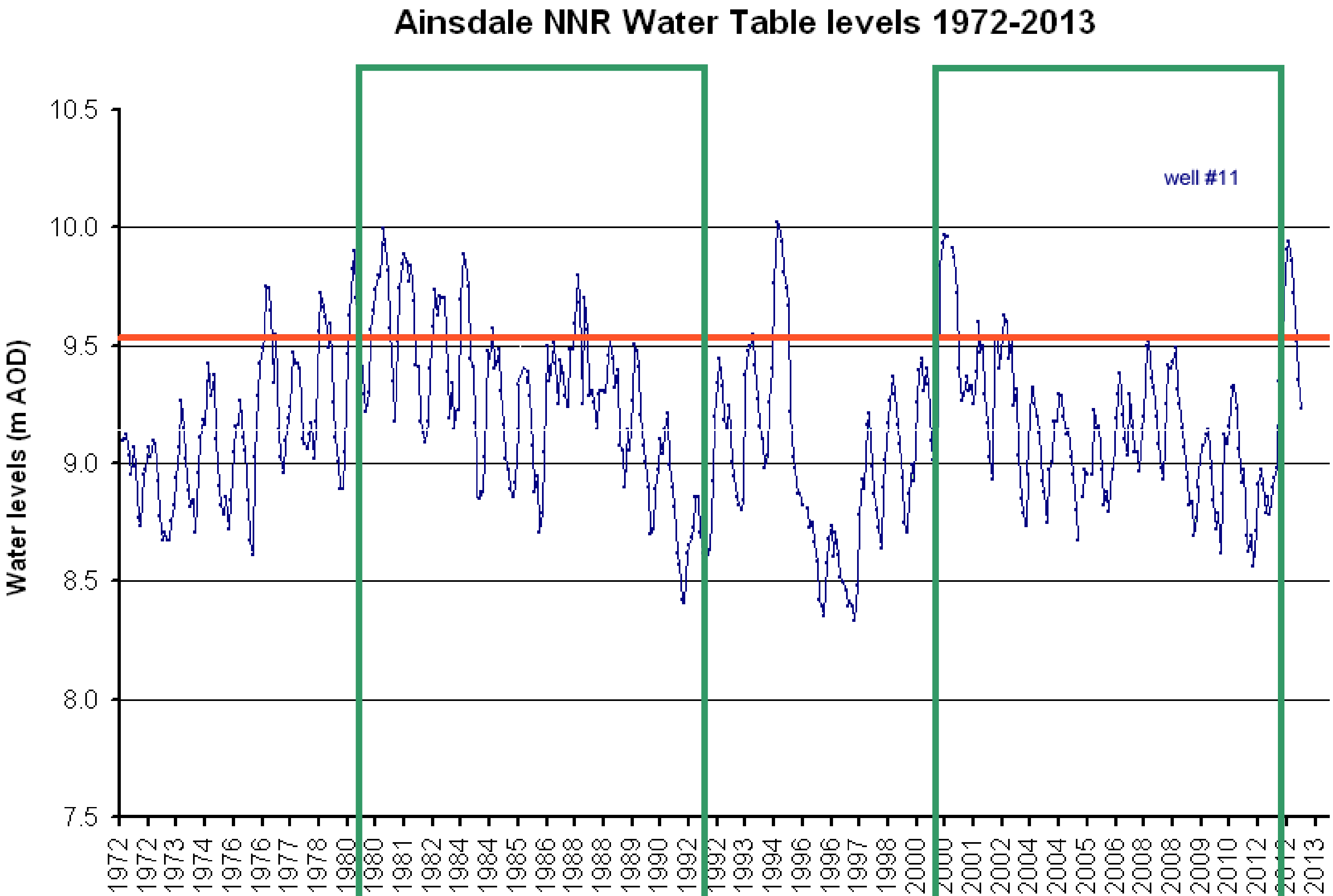


- Figure shows water level measurements at a “humid” slack site. The annual amplitude of water level change is +/-0.5m. Wet winters, where water levels are above ground (+9.54m above sea level) occur in approximately 50% of the years.

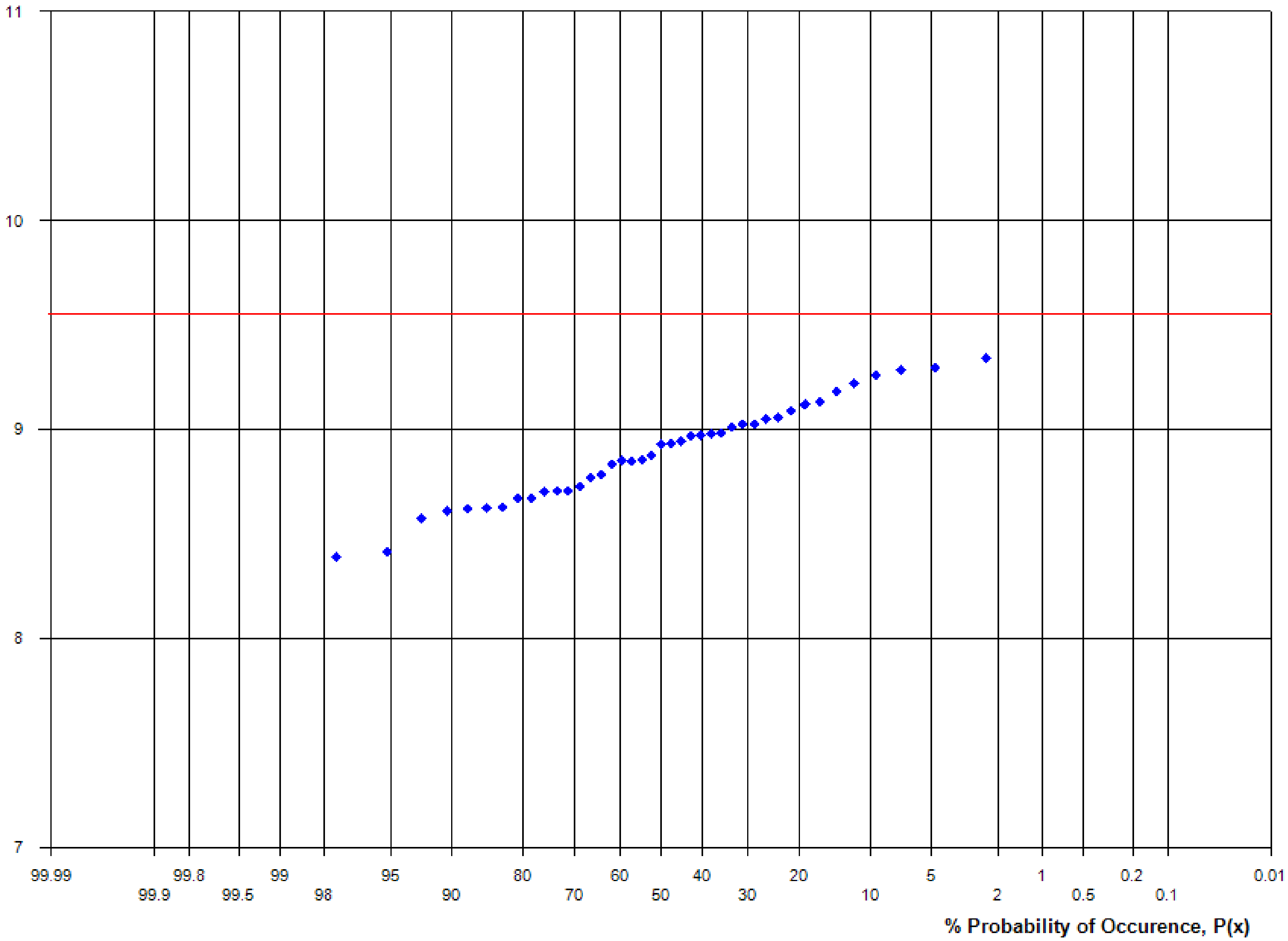


Record length and assertions of "climatic change" :

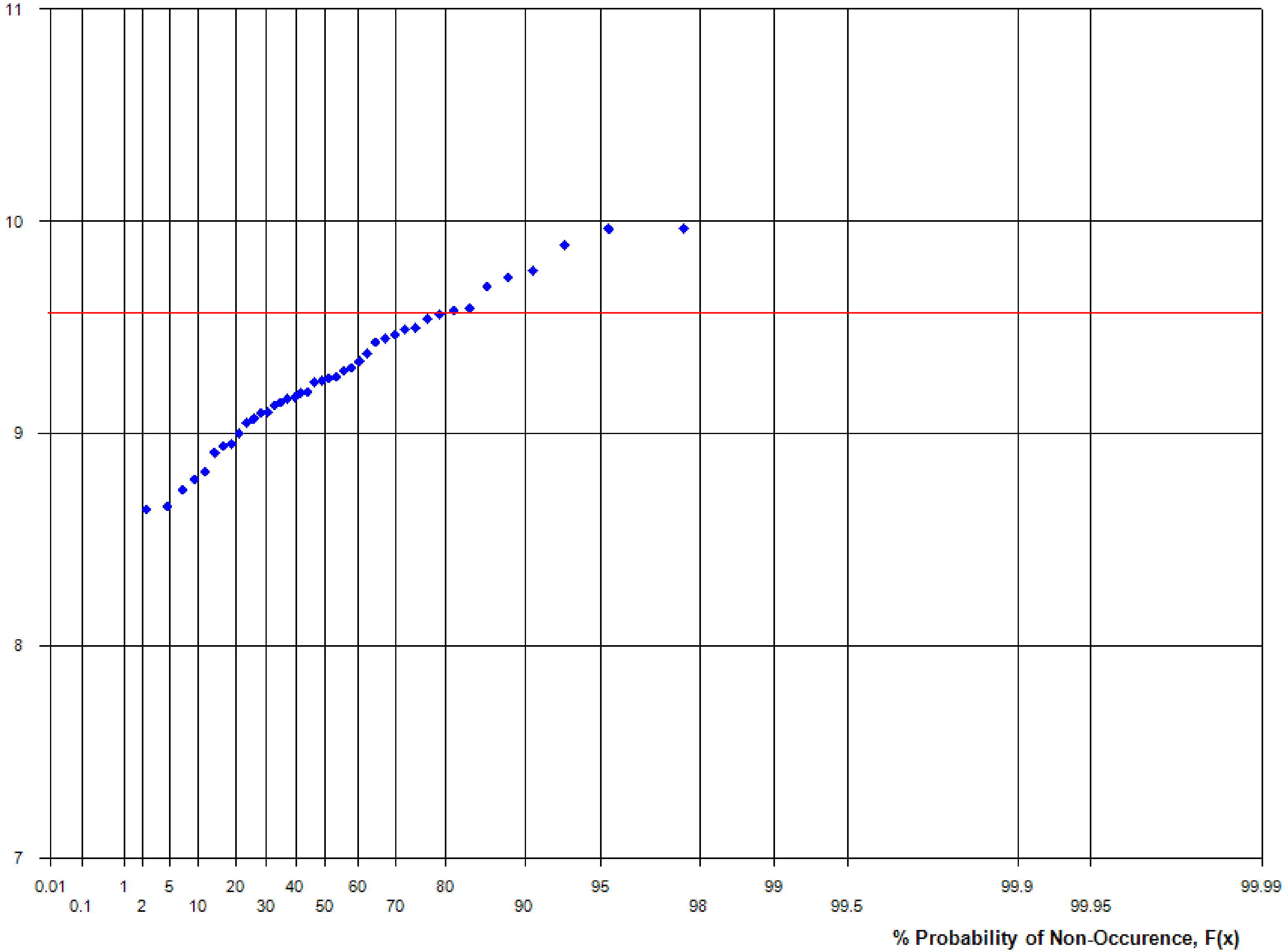
- Long term monitoring data sets are rare.
- Boxes shows two 12 year sequences of continual water table decline.
- If a study were undertaken in these periods, what would the conclusions be ?



Frequency distribution of summer water table levels : 1972-2012

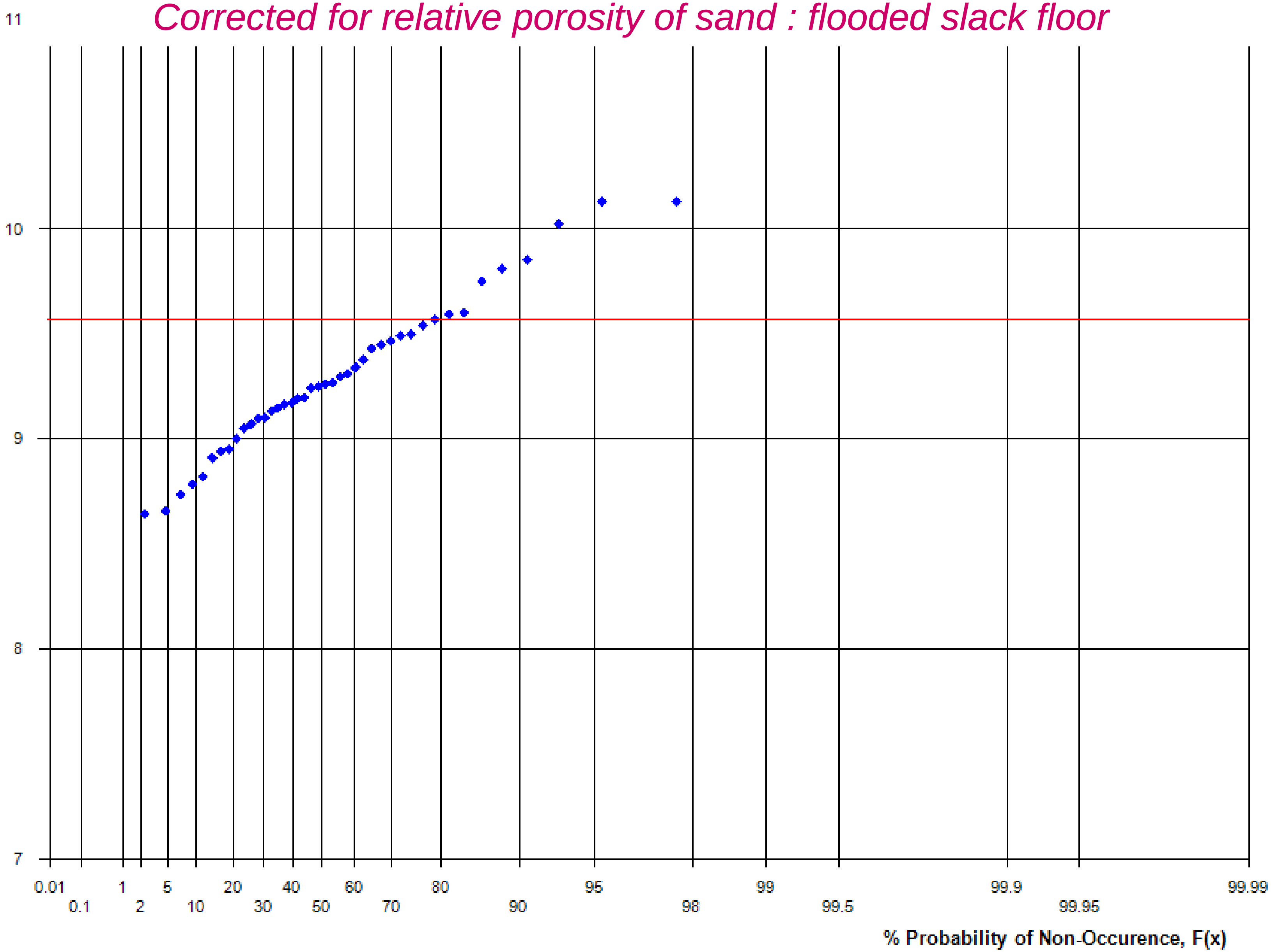


Frequency distribution of winter water table levels : 1972-2013



Frequency distribution of winter water table levels : 1972-2013;

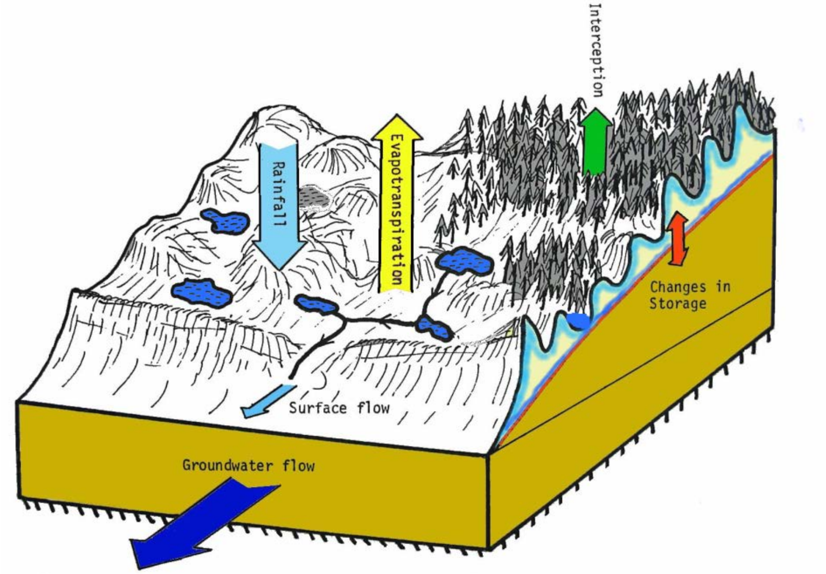
Corrected for relative porosity of sand : flooded slack floor



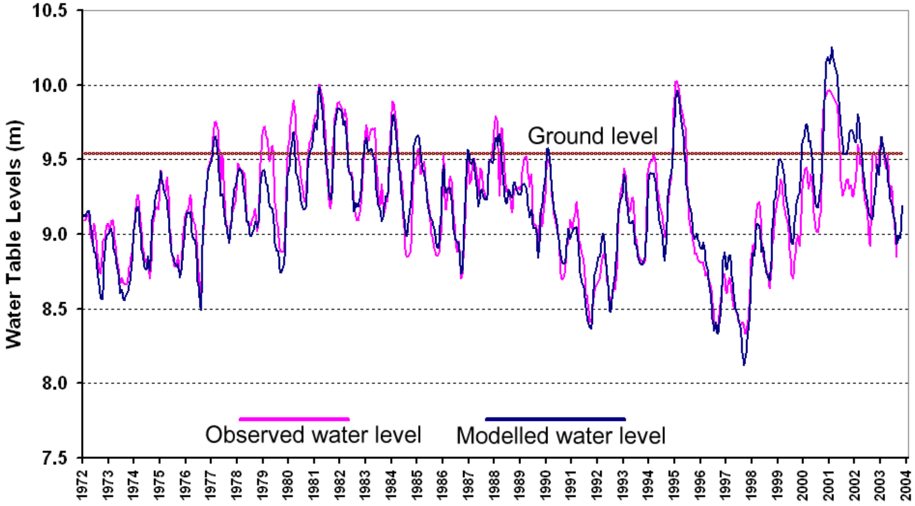
Groundwater recharge model

- We developed a 1-Dimensional recharge model linked to groundwater flow and soil moisture deficit model to simulate the observed changes in water levels (Clarke and Sanitwong, 2010).

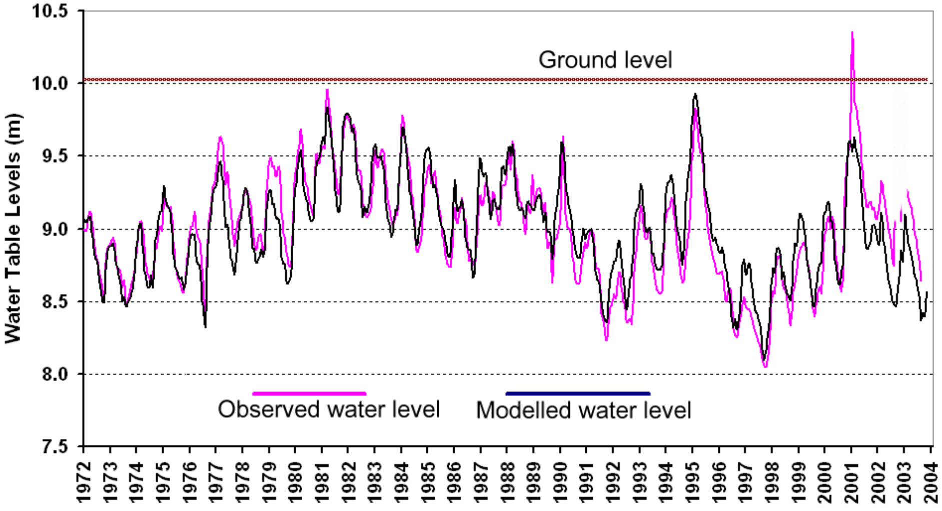
- The model was validated for dune slacks with and without tree cover



Simulation in open dune slacks



Simulation under pine trees

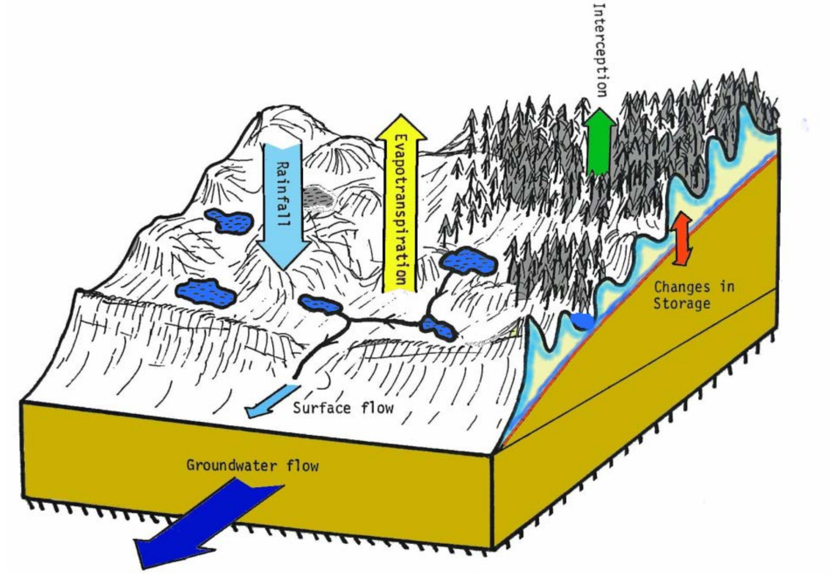


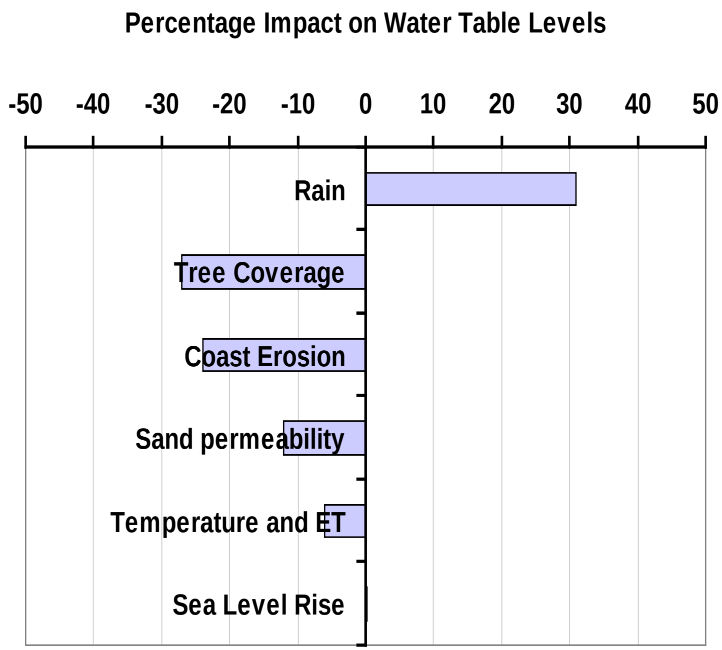
Groundwater recharge model

- The key drivers affecting groundwater levels were found to be rainfall, vegetation cover, coastal erosion (0-20% depending on distance from the sea over a range of 0-3km) and sand permeability.

- Factors directly associated with **climatic change had a lower effect** on the model : evapotranspiration, temperature and sea level rise (again depending on distance from the sea).

- However the **seasonal distribution of rain** will significantly affect the amount of recharge, and it is expected that summers will become drier and winters will become wetter.

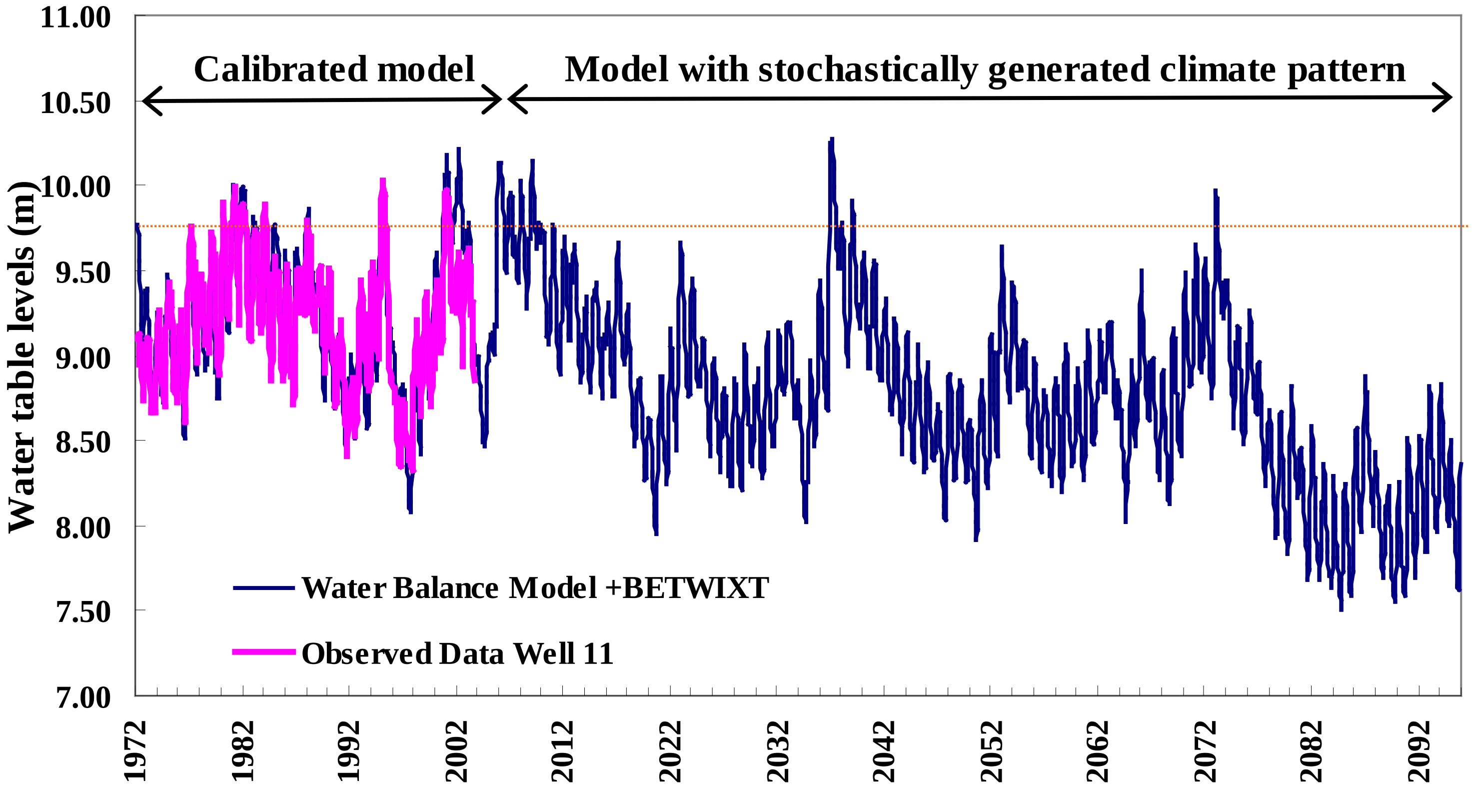




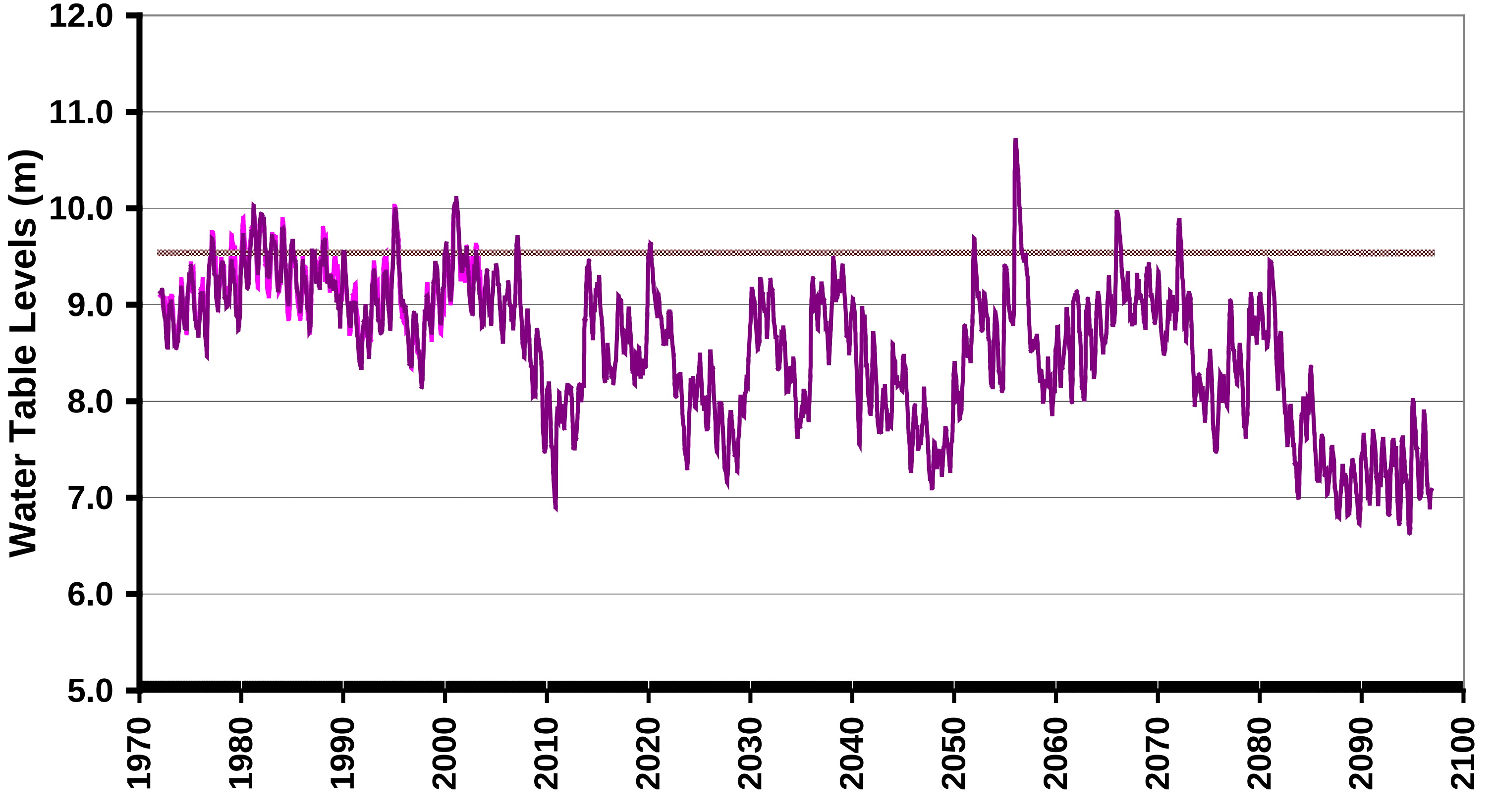
Simulating climate change and inter annual variability of rainfall on groundwater levels

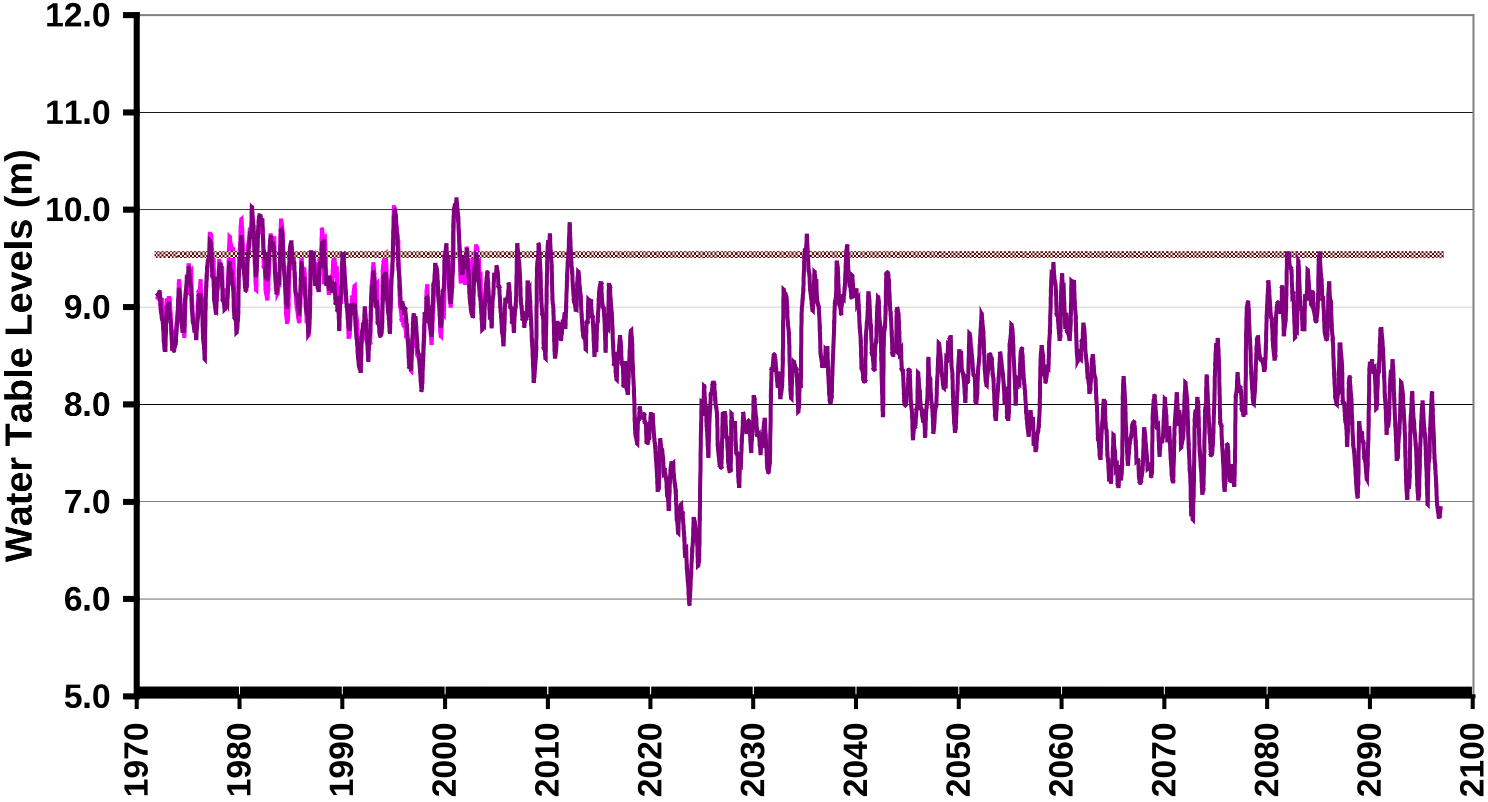
- The calibrated groundwater model was used to investigate the impacts of future climate under a Medium High $C0_2$ emissions scenario.
- 3 representative time periods, the 2030’s 2050’s and 2080’s
- 1000 sets of stochastically generated weather data obtained from the UK Climate Impacts Programme (UKCIP02).
- In each run the total amount of rainfall remained the same but the sequences of wet/dry days and wet/dry months were modified within anticipated ranges.
- The effects of a) climate change and b) inter-annual variability are identified

The BETWIXT daily precipitation sequence combined with PE estimated using UKCIP’02 medium high emissions climate data.

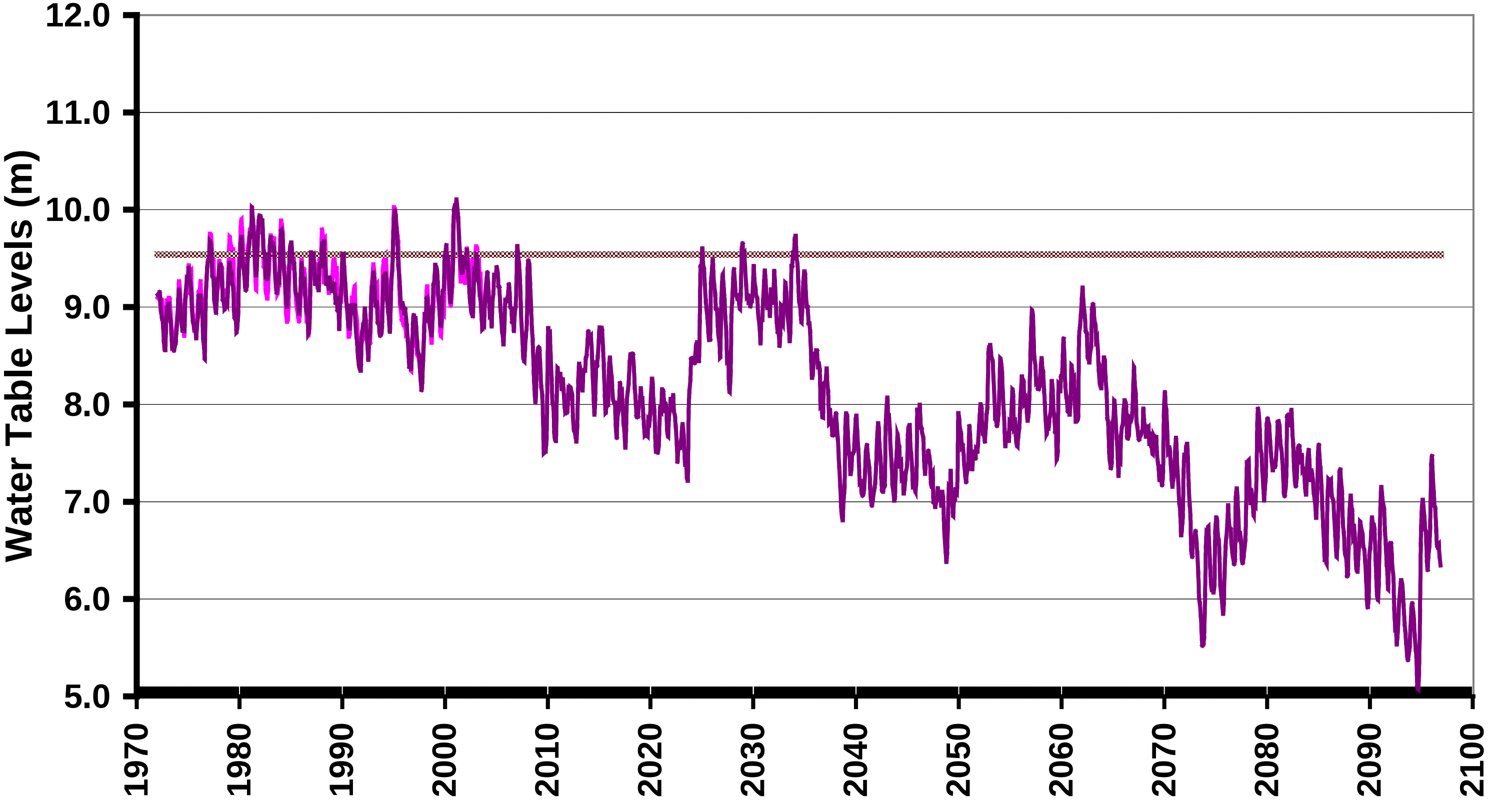


Multiple future scenarios of aquifer recharge were generated by re-sequencing the time series of daily precipitation data

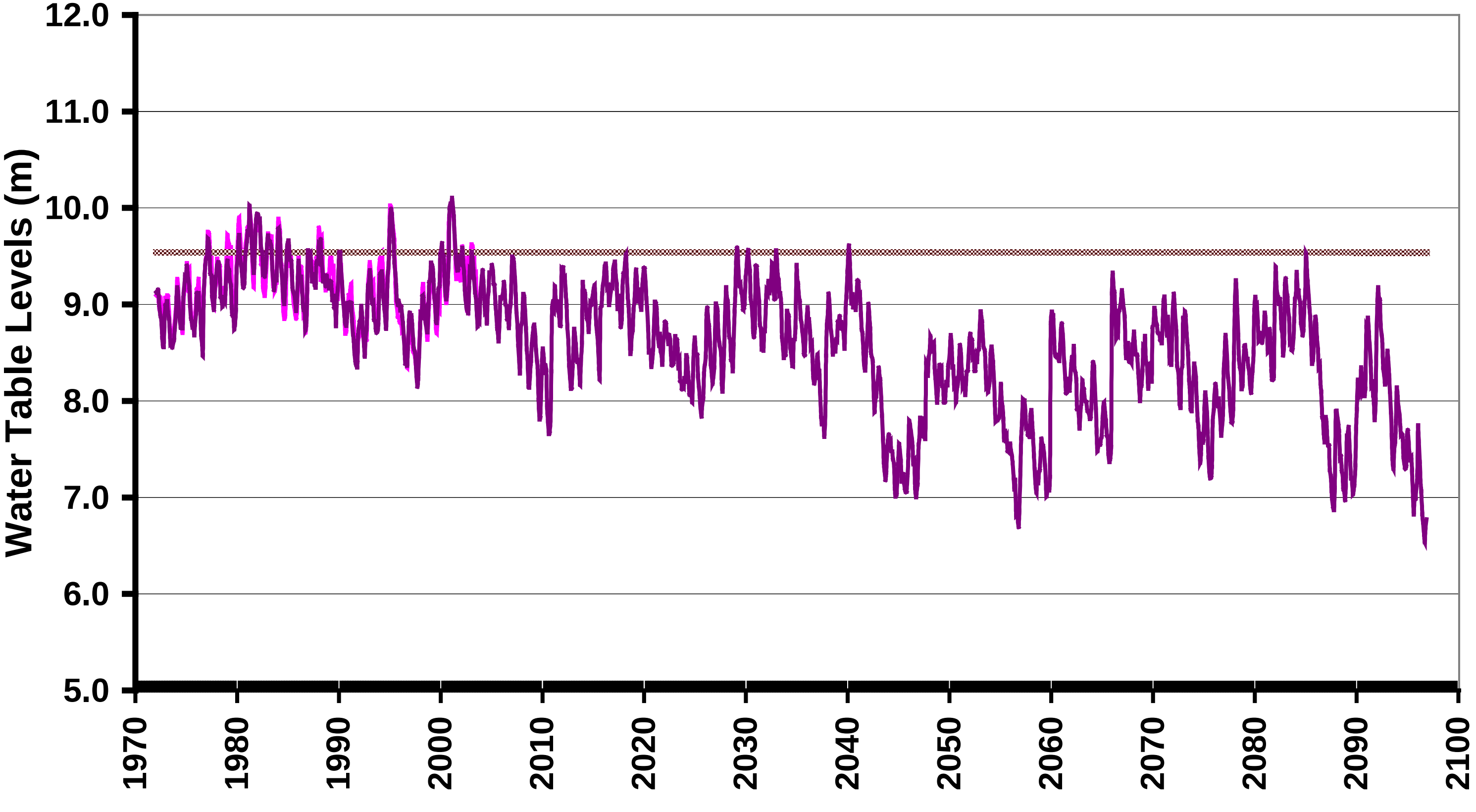




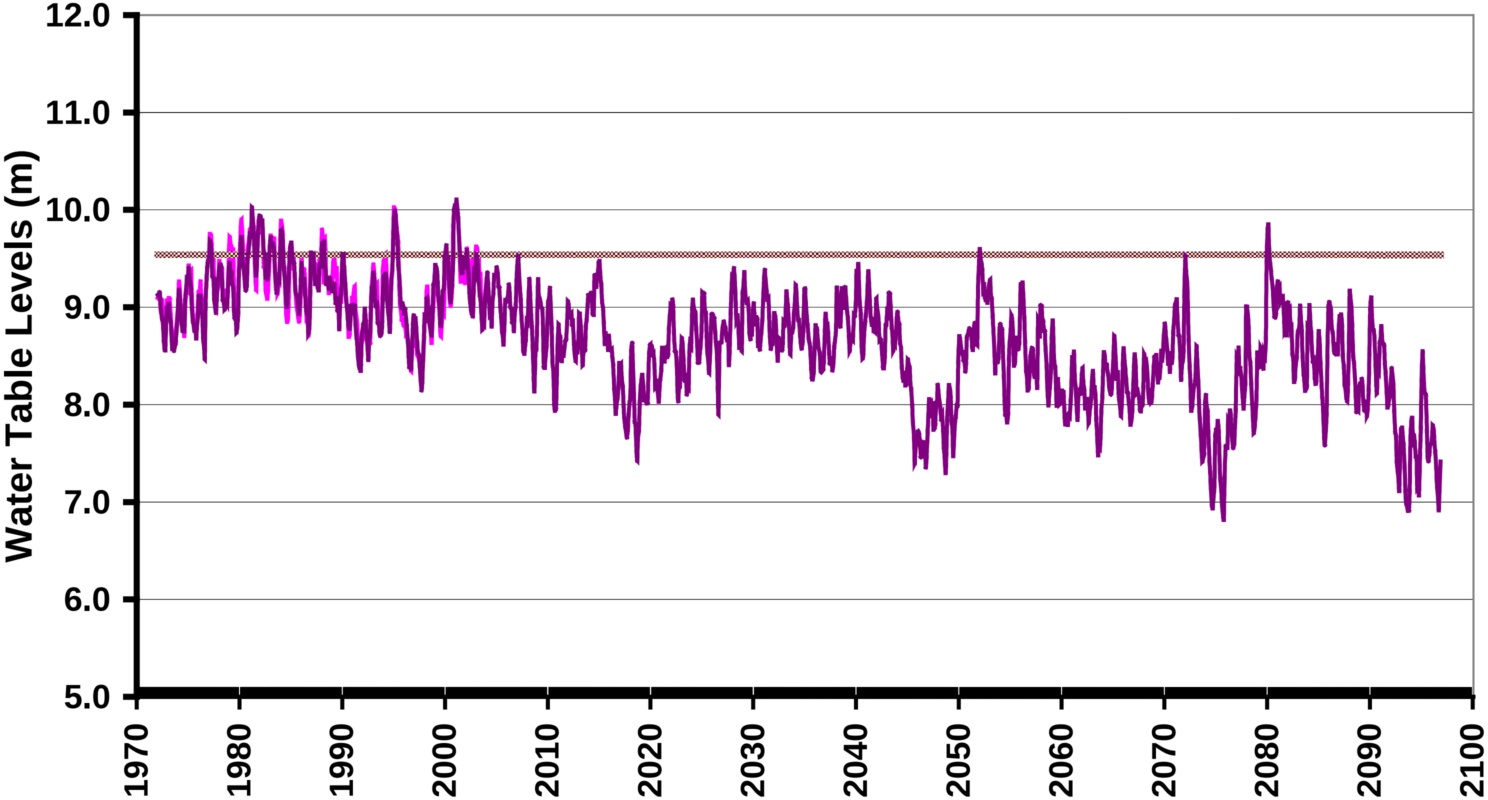
Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100



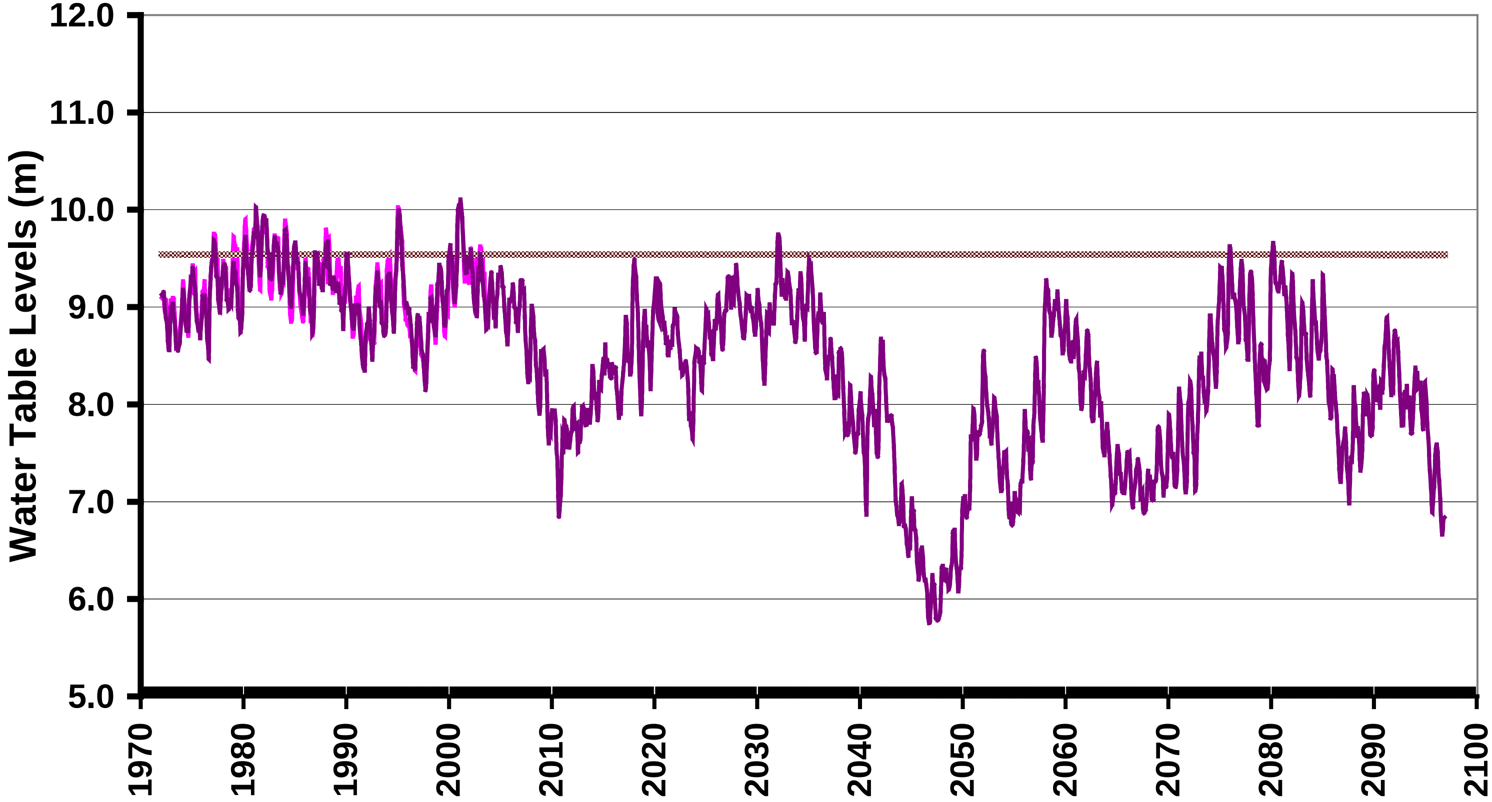
Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100



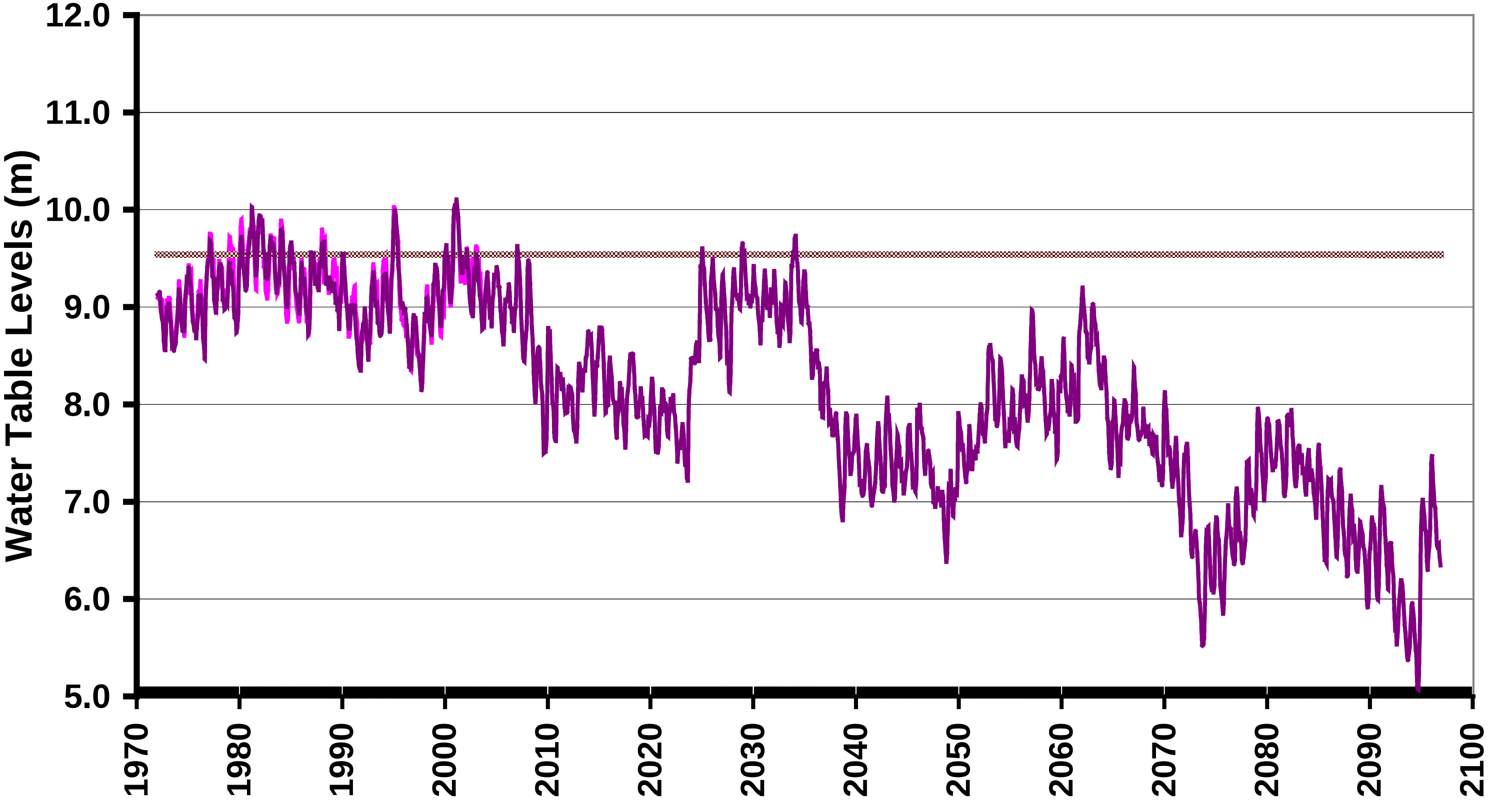
Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

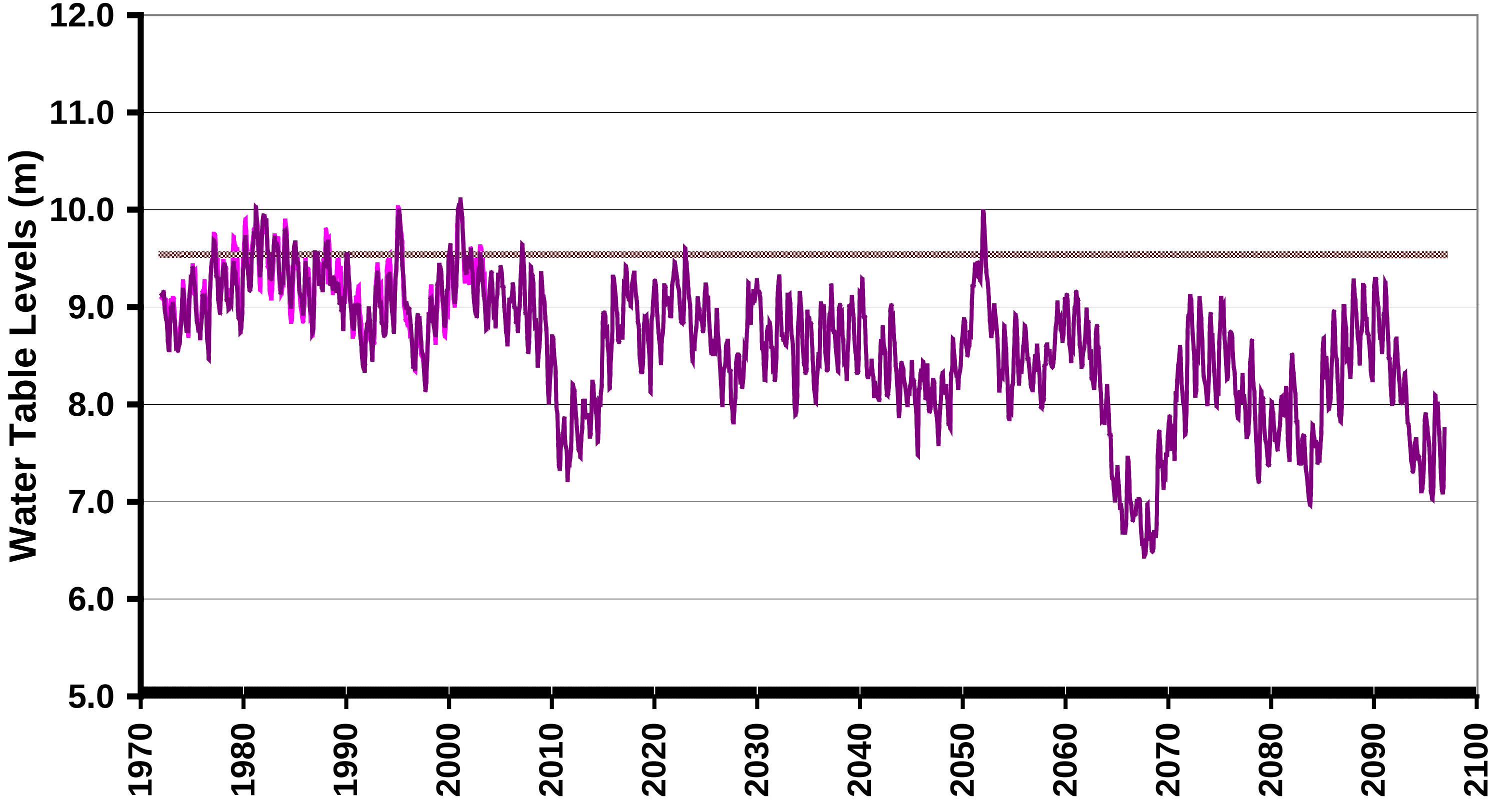


Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

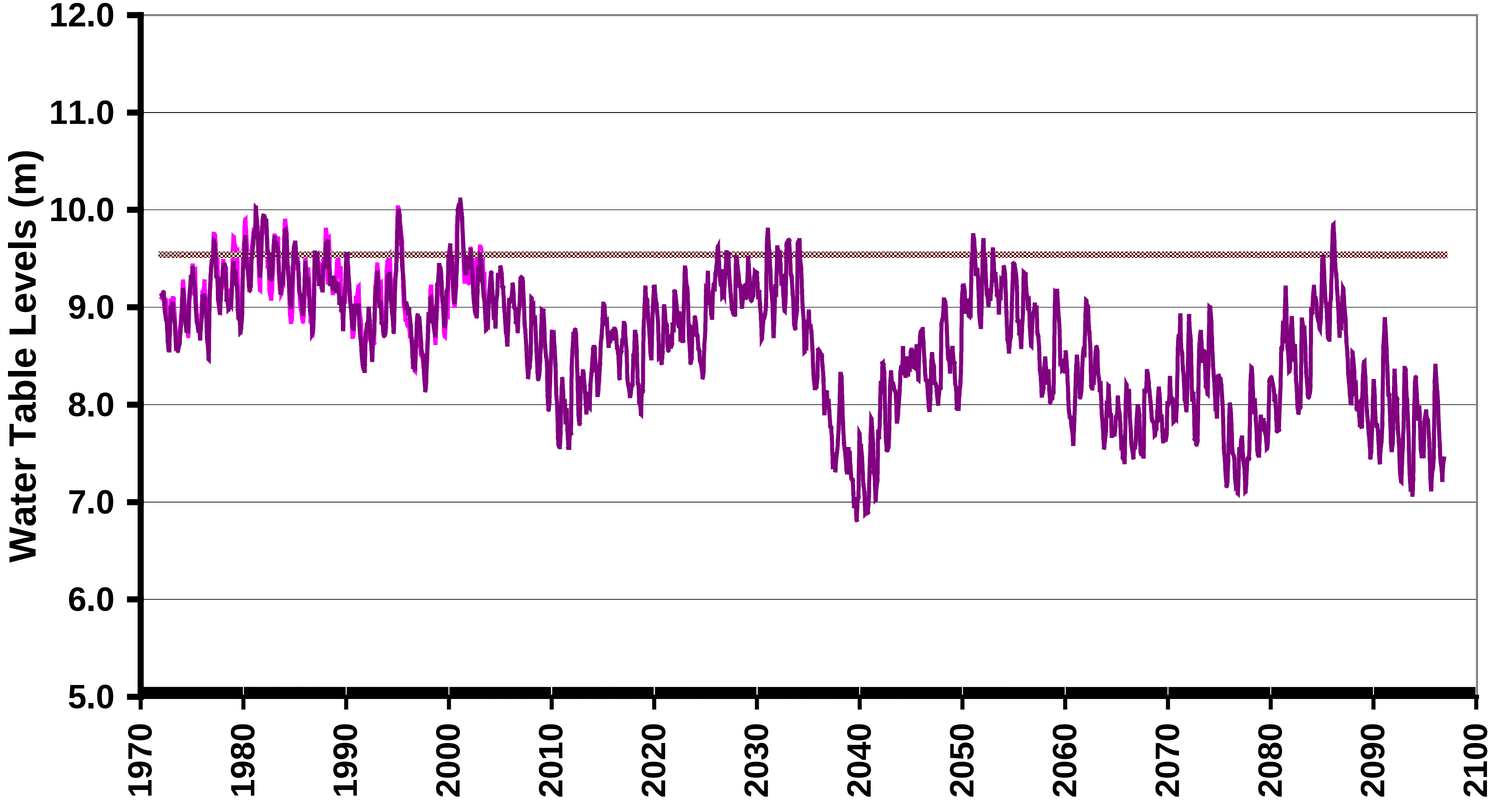


Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

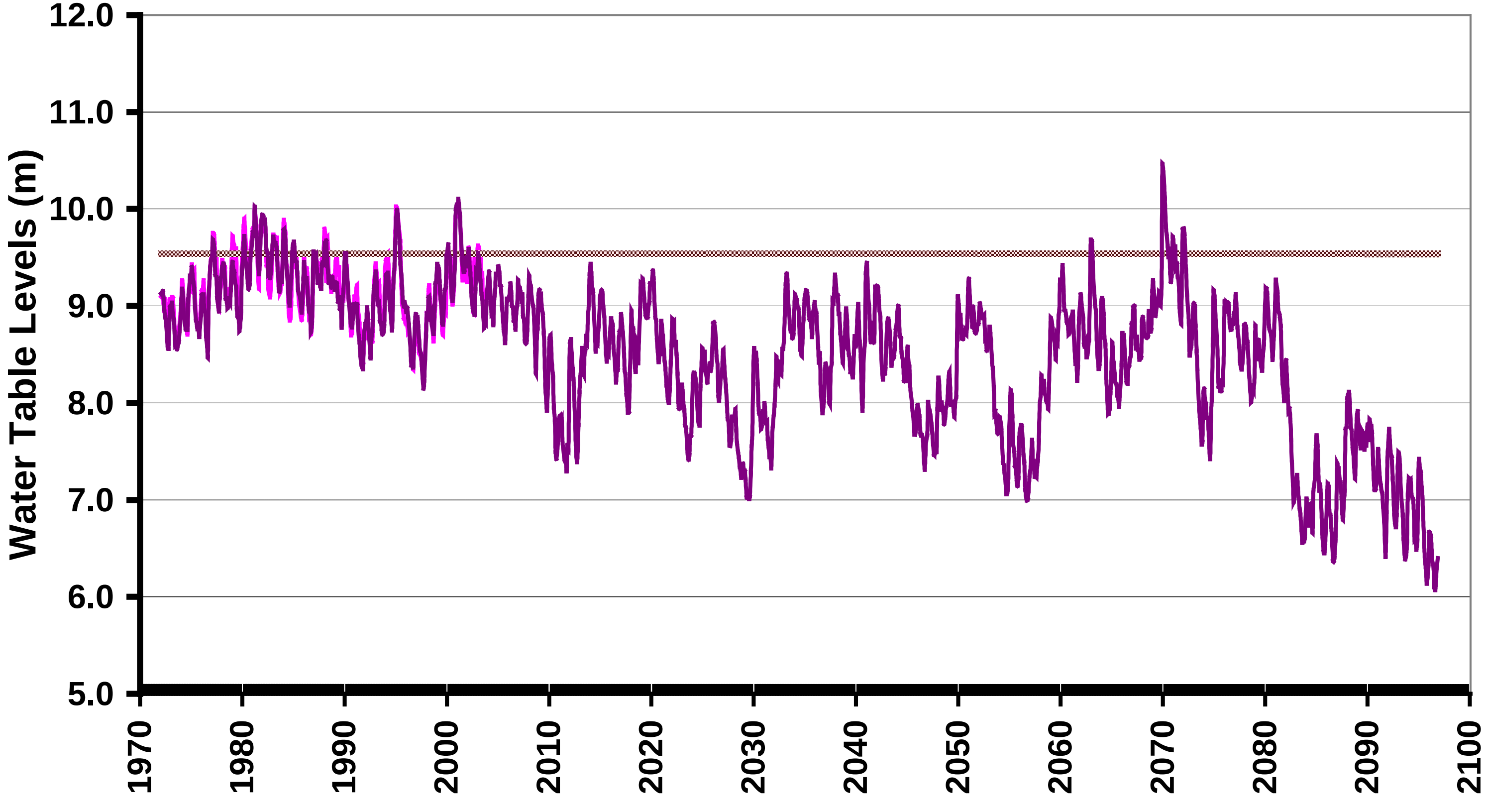

Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100



Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

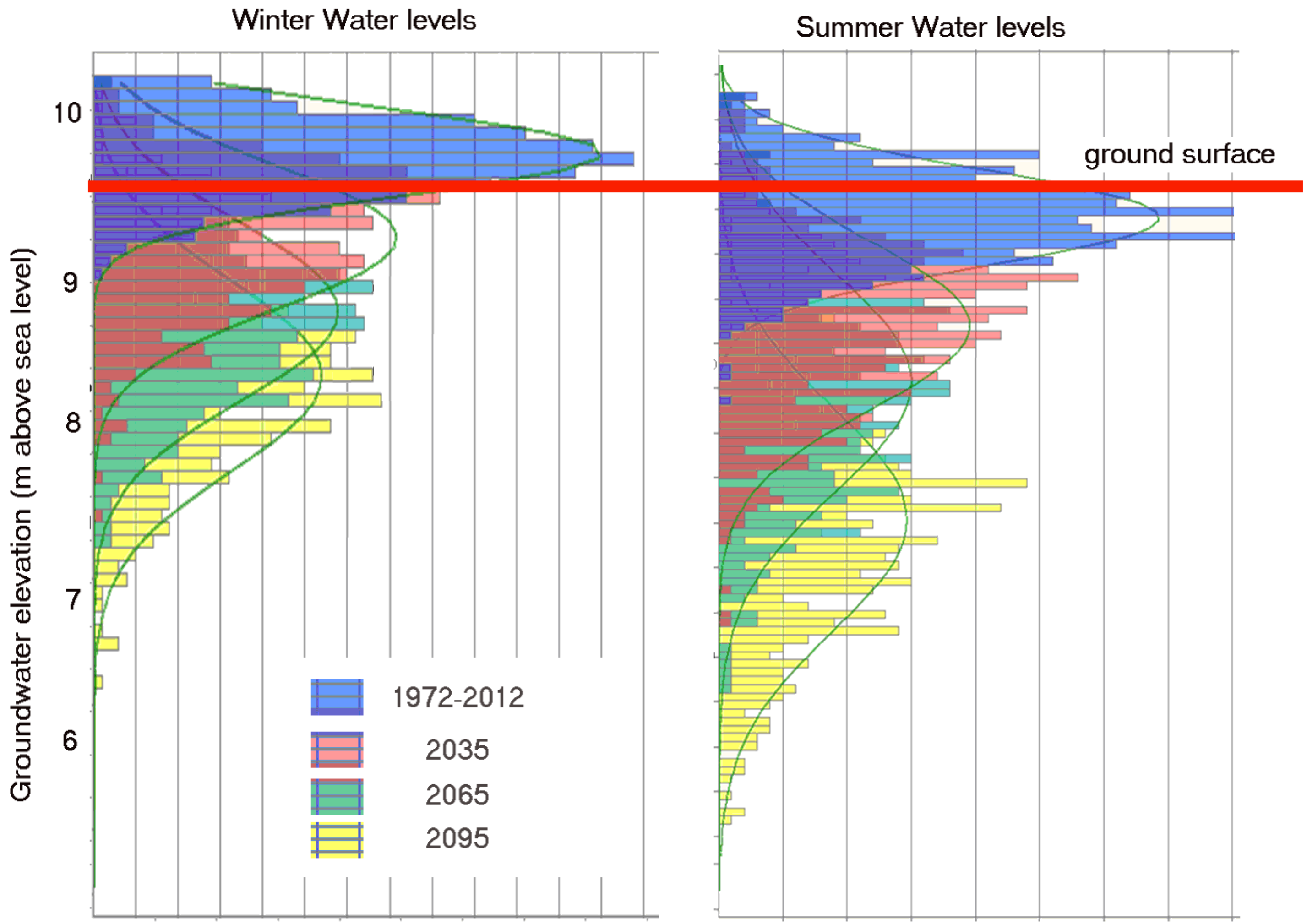


Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

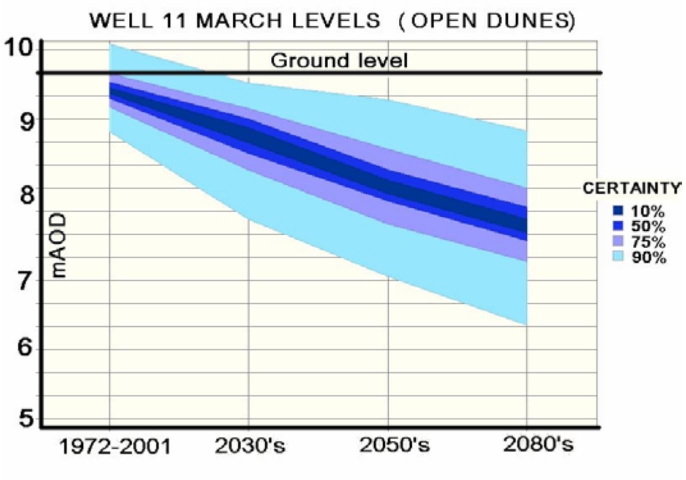

Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

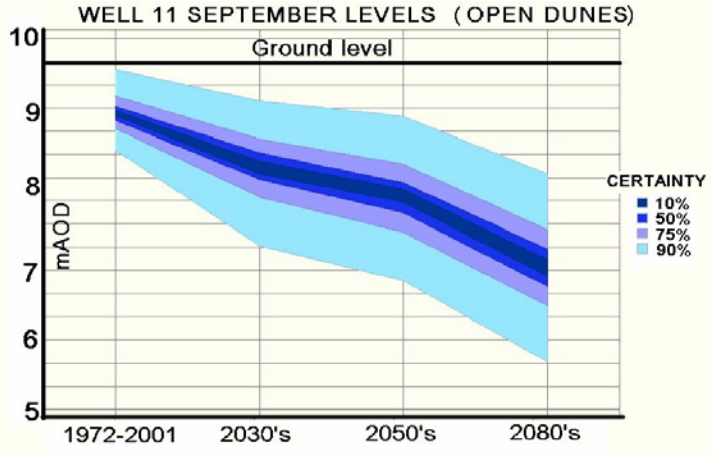
Summary of 1000 simulations of rainfall sequences on predicted groundwater levels.

Each 30 year time period has the same amount of rainfall, but rainy days are spaced differently to simulate inter-annual variability.

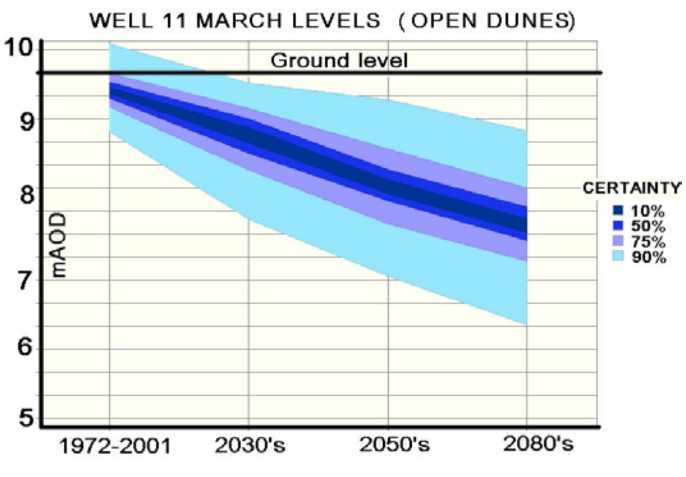


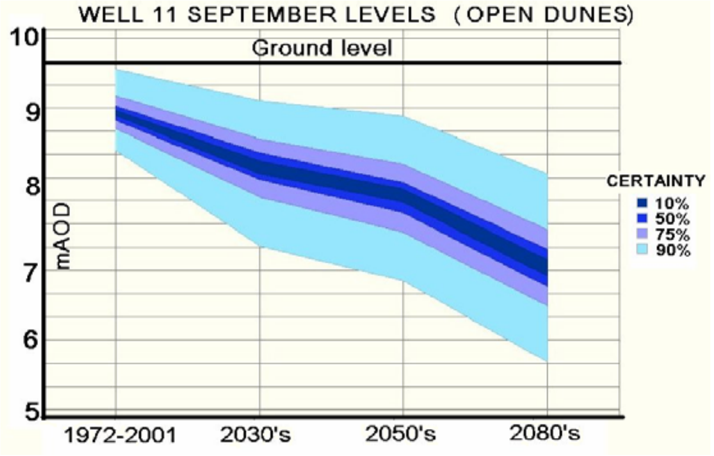
Expected water table levels at the end of winter



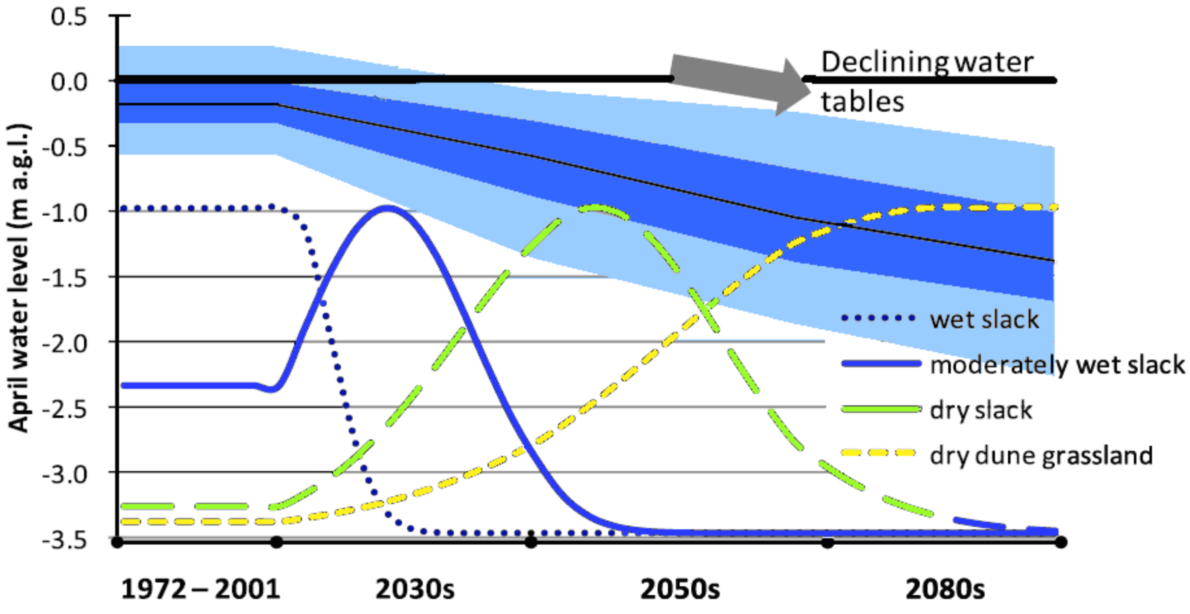


Expected water table levels at the end of winter and summer seasons





Curelli et at (2013) mapped characteristic dune slack environments on to trends in ground water levels.



Flooded Slack conditions suitable for a sustainable Natterjack toad population

- ***Timing and duration of flooding***

  Flooded slacks are used by Natterjack Toads. For adequate breeding opportunity at Ainsdale flooded slacks are required in March, April, May and June.

Flooded Slack conditions suitable for a sustainable Natterjack toad population

- ***Timing and duration of flooding***

  Flooded slacks are used by Natterjack Toads. For adequate breeding opportunity at Ainsdale flooded slacks are required in March, April, May and June.

- ***Area of flooding***

  The minimum flooded slack area has not been formally defined in the literature. Beebee et al. (1996) found that adult Natterjack population is directly related to breeding pond density and pool availability is a limiting factor in population size. A minimum acceptable flooded slack area of $0.3km^2$ was chosen as the area which can support a population of a size satisfactory to BAP requirements.

Flooded Slack conditions suitable for a sustainable Natterjack toad population

- ***Timing and duration of flooding***

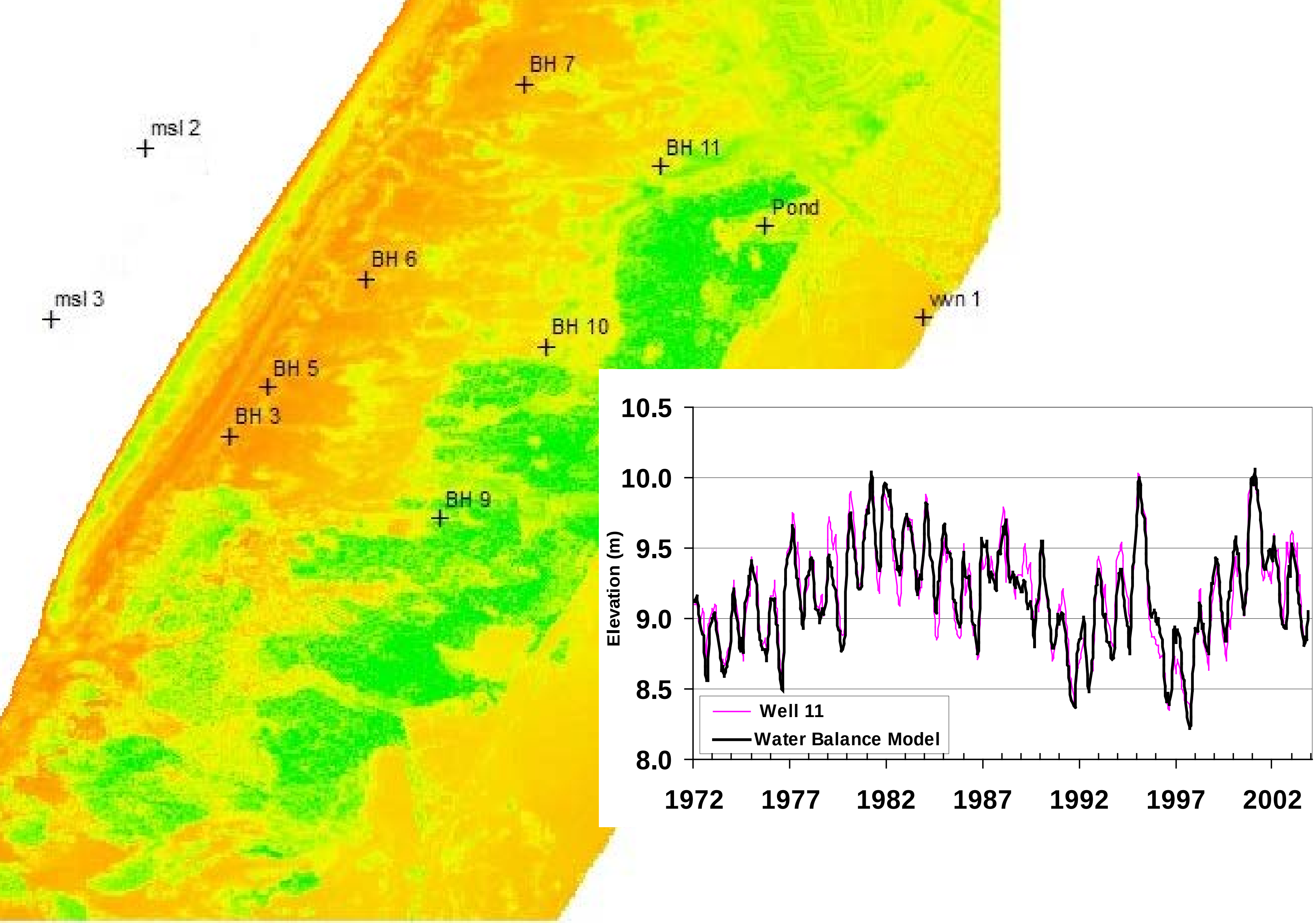
  Flooded slacks are used by Natterjack Toads. For adequate breeding opportunity at Ainsdale flooded slacks are required in March, April, May and June.

- ***Area of flooding***

  The minimum flooded slack area has not been formally defined in the literature. Beebee et al. (1996) found that adult Natterjack population is directly related to breeding pond density and pool availability is a limiting factor in population size. A minimum acceptable flooded slack area of $0.3km^2$ was chosen as the area which can support a population of a size satisfactory to BAP requirements.

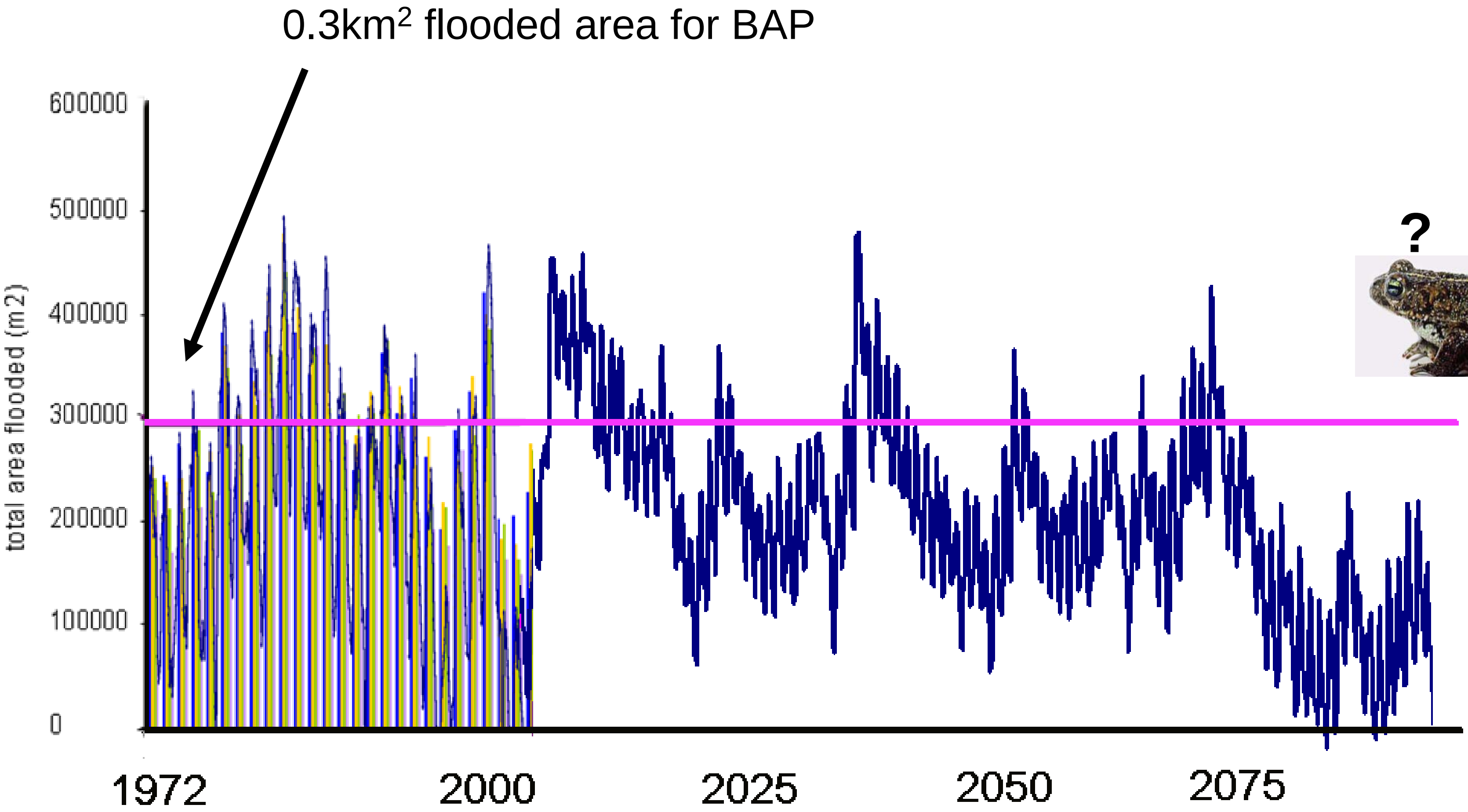
- ***Depth of water***

  Flooded areas that are too deep are cooler, vegetated and harbour predators. These conditions are unfavourable for Natterjack breeding, so a maximum water depth of 1m was chosen.

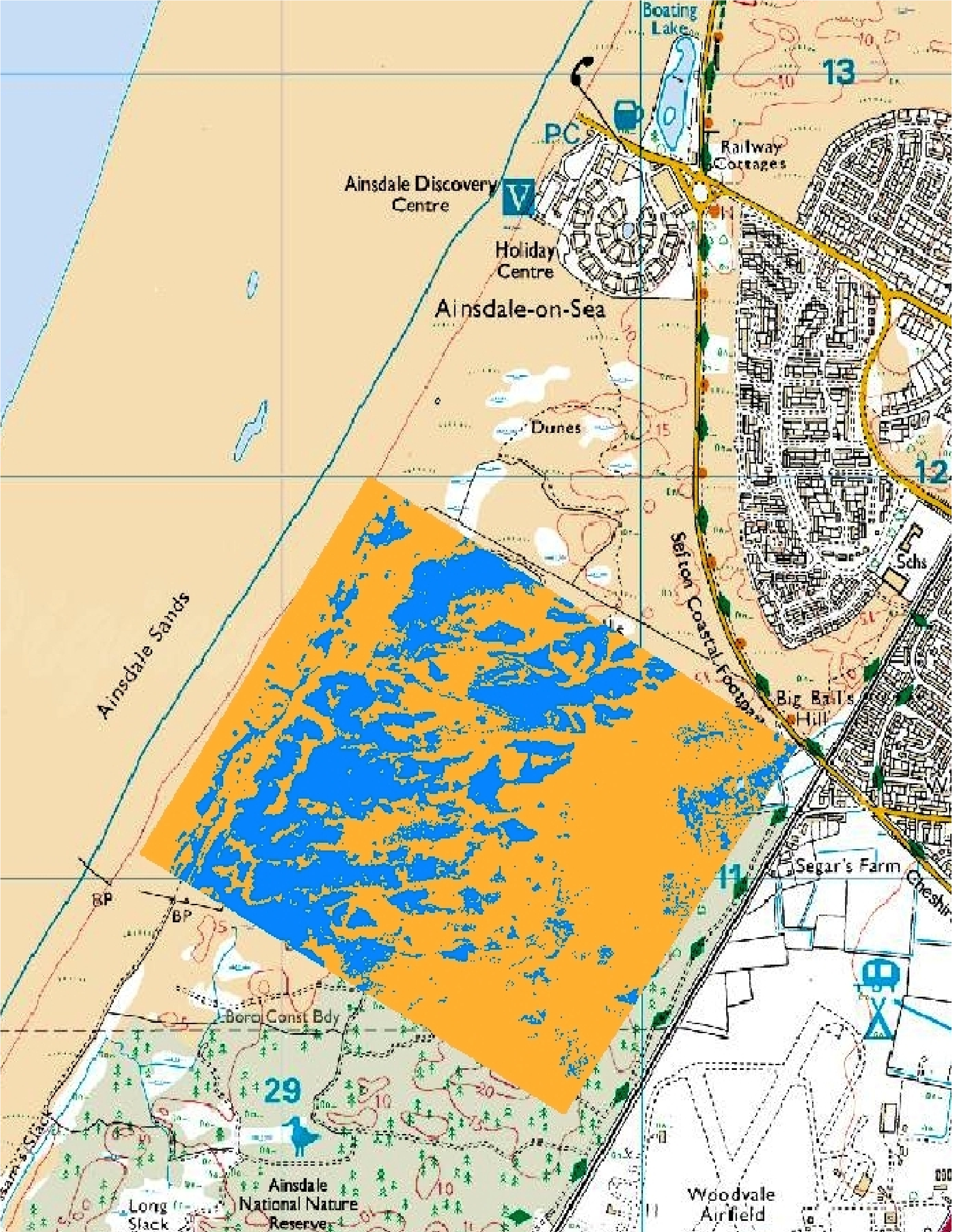


Interception of LIDAR DEM surface + water balance model

Modelled flooded slack area 1972-2090

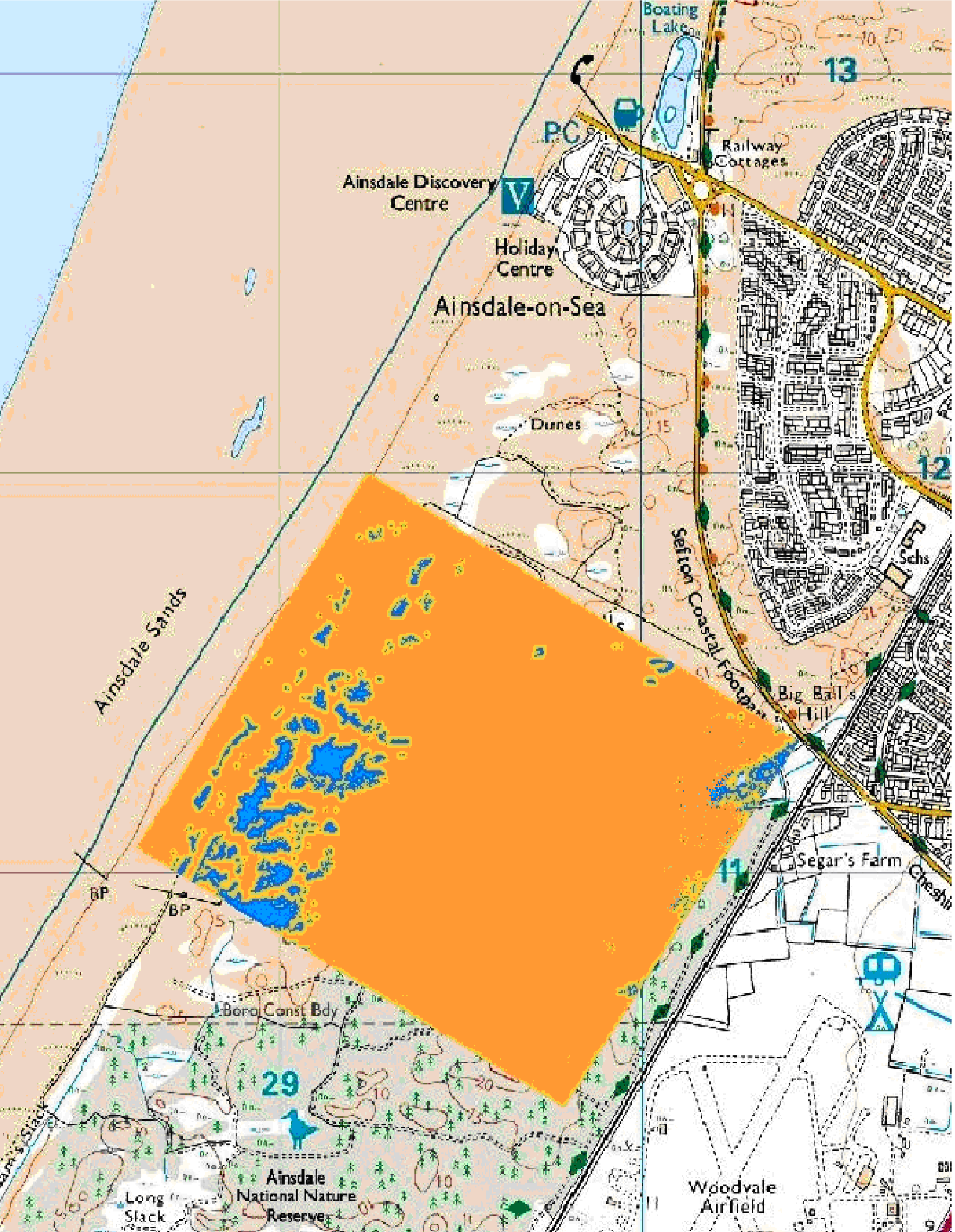


?



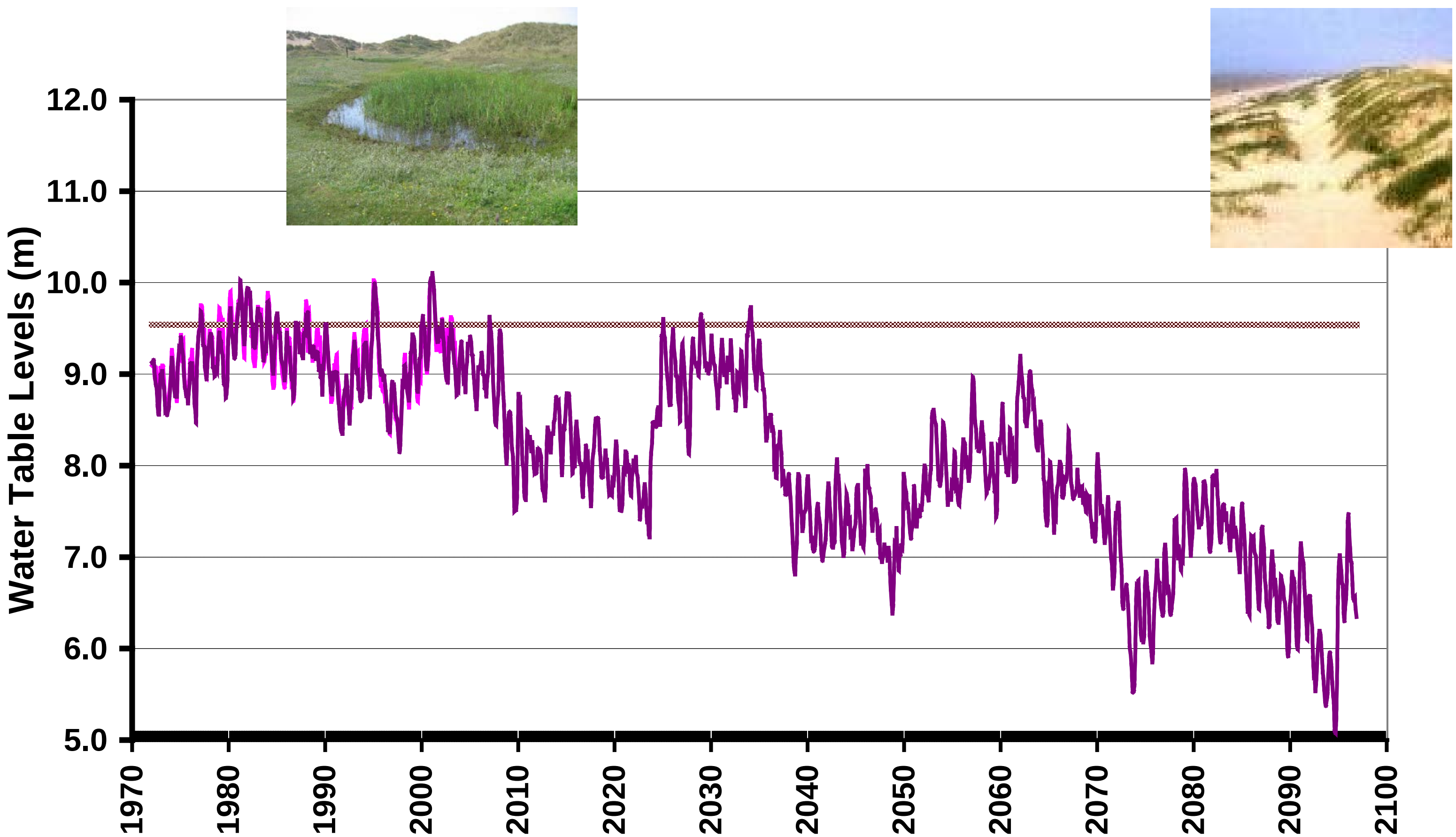
Intersection of Lidar ground elevation data and water table levels. Very wet conditions, 1981

Blue areas = potentially flooded slacks

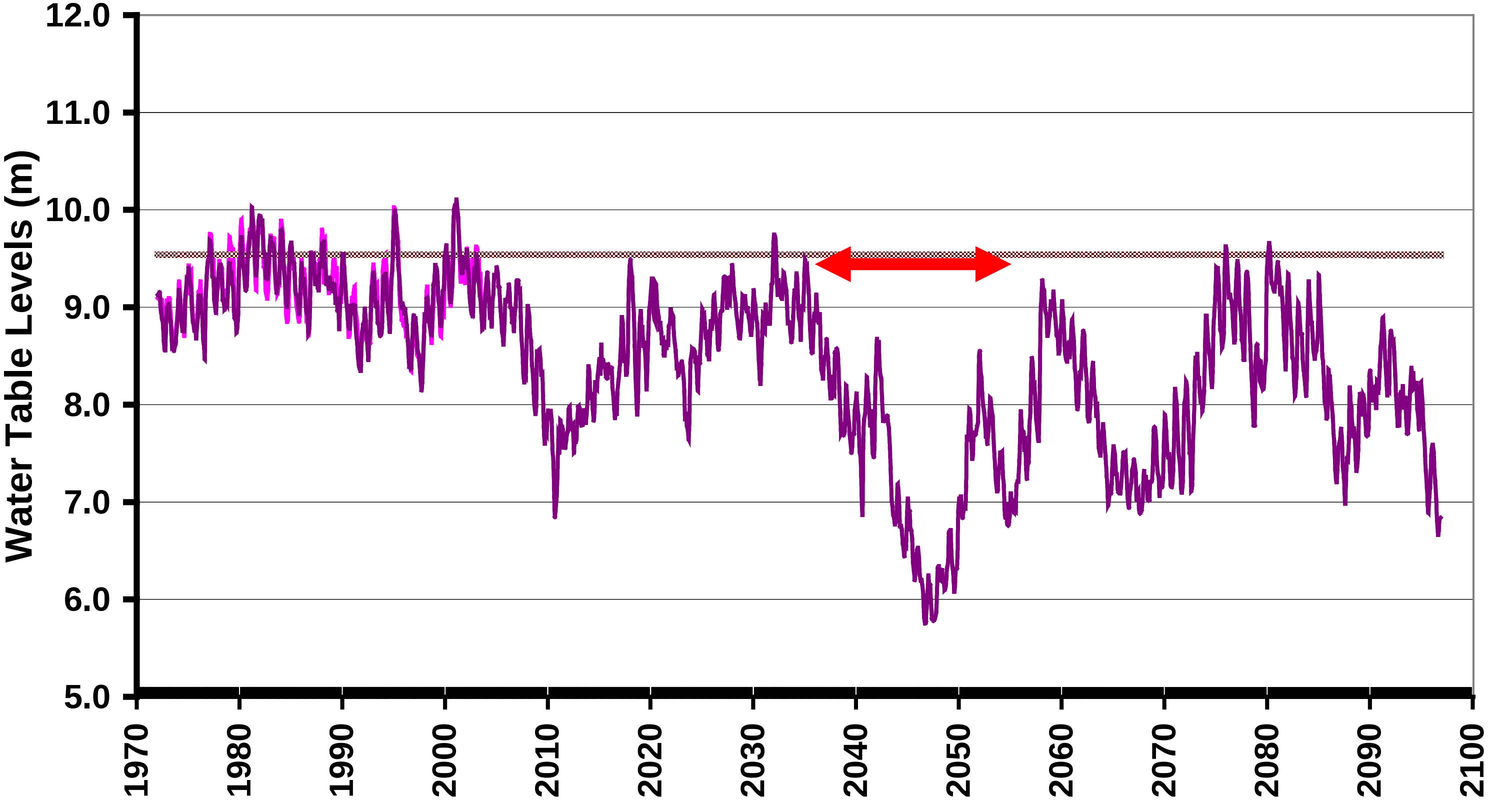


Predicted extent of potentially flooded slacks, 2080's

Blue areas = potentially flooded slacks

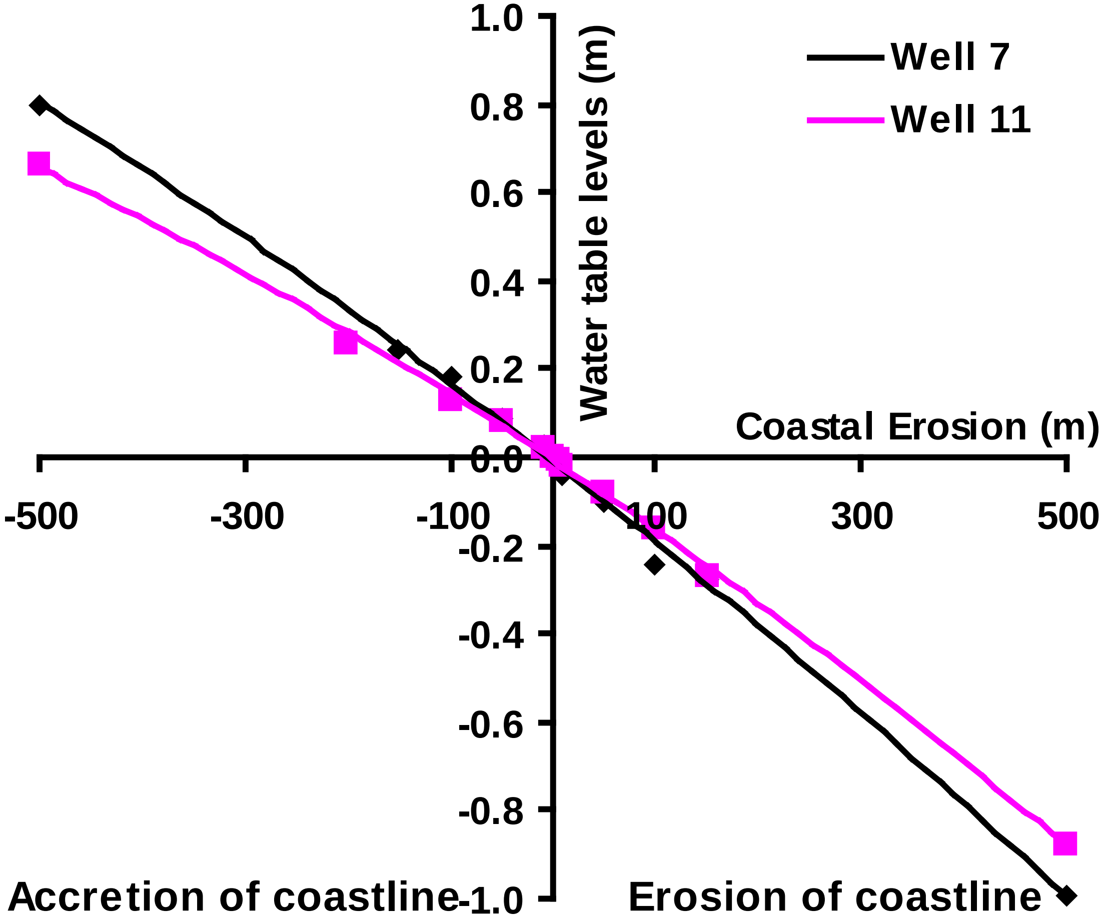

Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

?


Water Table Levels (m)
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
1970
1980
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100

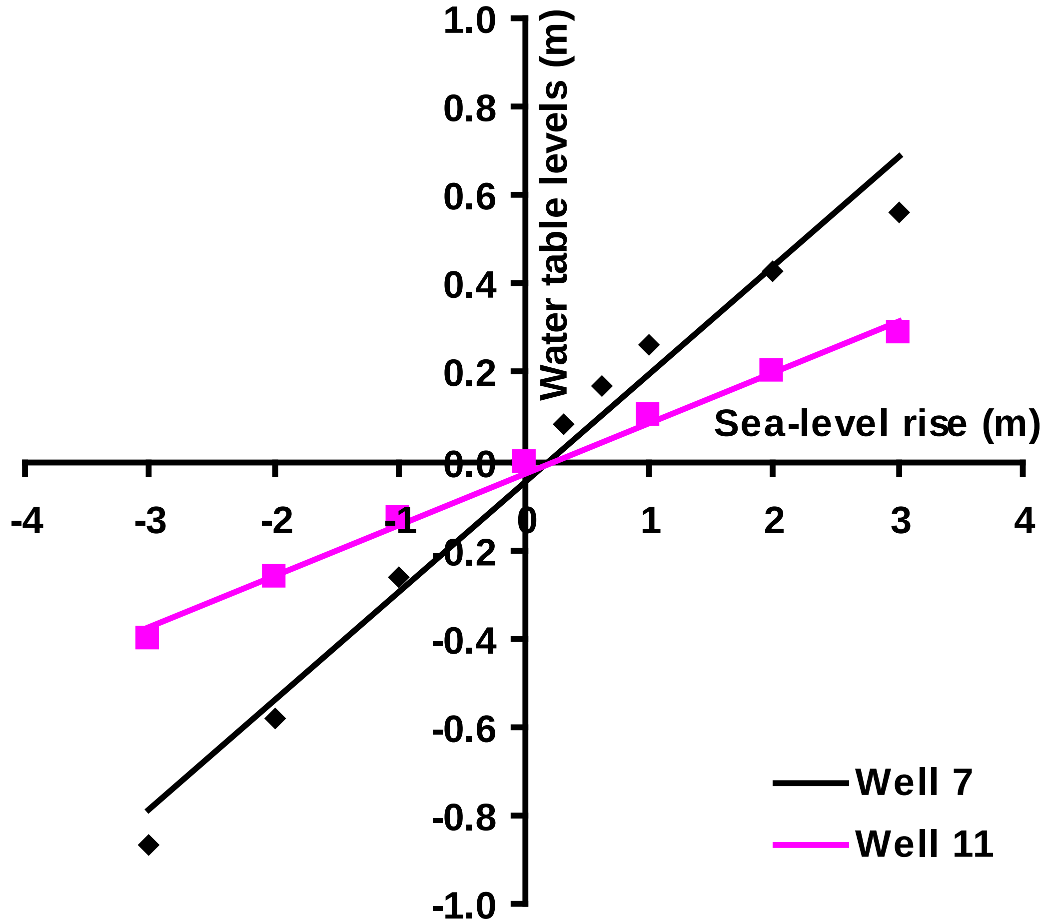
Other impacts

Sea level rise will change the hydraulic gradient between the fresh water in the dunes and the sea. This will initially reduce groundwater flow out of the dunes. Sea level rise in this region is expected to be of the order of +1 to +3 mm/year



Other impacts

Coastal Erosion and deposition. The dune coastline at Sefton is currently being eroded at up to 4.5m/year, in the south and it is accreting in the north.



Conclusions

The expected changes are

- Average water table levels in the study areas are expected to fall by about 1.0m.
- This will dry out the inland slack floors and reduce the biodiversity.
- In areas of coastal accretion, new areas will develop that offer wet slack conditions that will provide a suitable environment for threatened species.

Conclusions

The expected changes are

- Average water table levels in the study areas are expected to fall by about 1.0m.
- This will dry out the inland slack floors and reduce the biodiversity.
- In areas of coastal accretion, new areas will develop that offer wet slack conditions that will provide a suitable environment for threatened species.

Responses should consider that

- Sites which are best suited to given ecosystems will change location.
- In the long term may it be necessary to re-locate areas of nature conservation?
- Management should adopt proactive land management to minimise impacts in the short term and identify future sites of conservation in the dune system.

Acknowledgements

- Natural England
- Staff of Ainsdale Sand Dunes National Nature Reserve
- UK Climate Impacts Programme
- Research students, University of Southampton :-
  - Sarinya Sanitwong-Na-Ayutthaya
  - Ruth Abbott

Contact details

Dr Derek Clarke
School of Civil Engineering & the Environment
University of Southampton, SO17 1BJ

Email **DC@soton.ac.uk**
Phone 02380 593 573
Web www.civil.soton.ac.uk/staff

Useful paper :

Clarke D., Sanitwong Na Ayuttaya S, (2009).

"Predicted effects of climate change, vegetation and tree cover on dune slack habitats at Ainsdale on the Sefton Coast, UK."

Journal of Coastal Conservation DOI: 10.1007/s11852-009-0066-7

UNIVERSITY OF Southampton