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Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



Applied geoscience for our  
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# Statistical approaches to analysing trends in groundwater quality

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Groundwater Science Programme

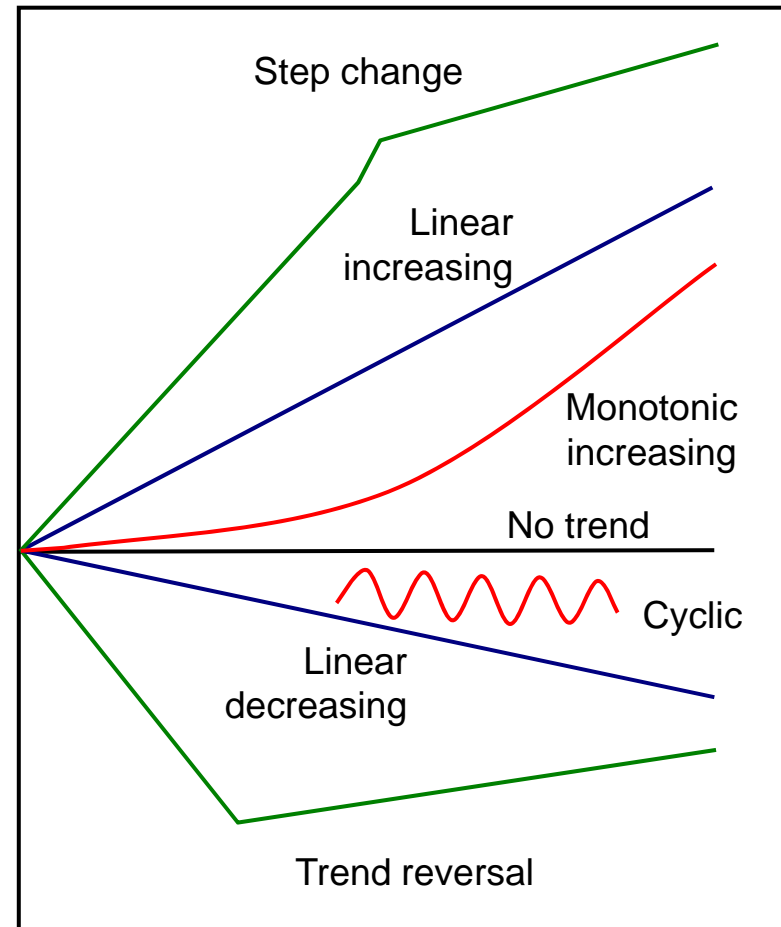
BGS Wallingford

Isonitrate Conference

10/11 December 2009 – Paris - UNESCO

# Trends

- Underlying long-term rate of change
- Estimation complicated by:
  - Cyclic and autocorrelated behaviour (diurnal or seasonal)
  - Short-term fluctuations
  - Step changes and reversals
  - Data censoring



# Importance

- Water Framework Directive
  - Achievement of 'good status'
  - Reversal of significant and sustained trends by 2015
- Water supply utilities
  - Operational expenditure and capital investment to meet drinking water regulations
- Environment
  - Climate change
  - Environmental impact assessments



# Trend assessment

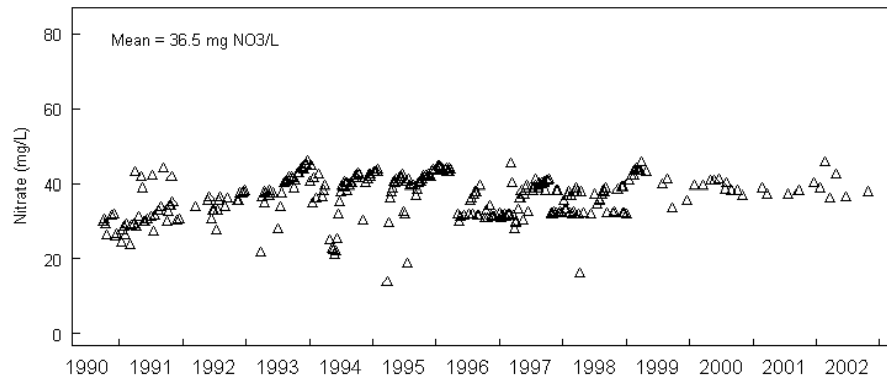
- Depends on dataset characteristics:
  - Sampling frequency
  - Length of monitoring period
  - Missing data / irregularity of sampling
- Descriptive data exploration
- Statistical data exploration
  - Trend test
  - Autocorrelation
  - Cyclical behaviour
  - Trend test on residuals
  - Correlation with covariates



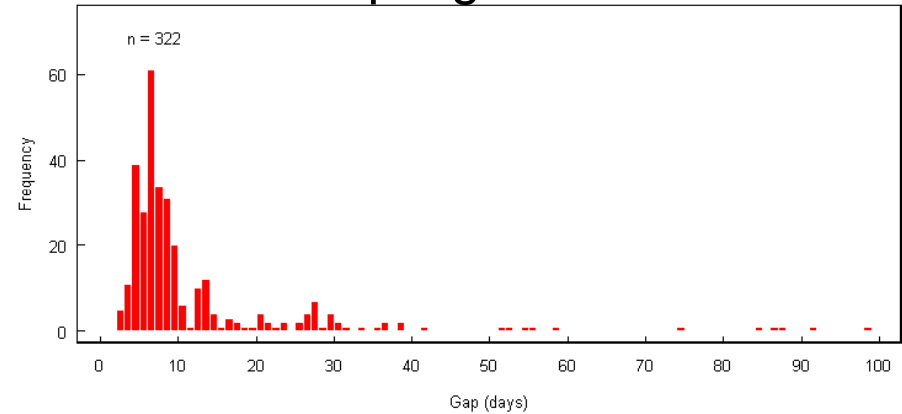
Increasing  
quality of  
dataset

# Descriptive tests

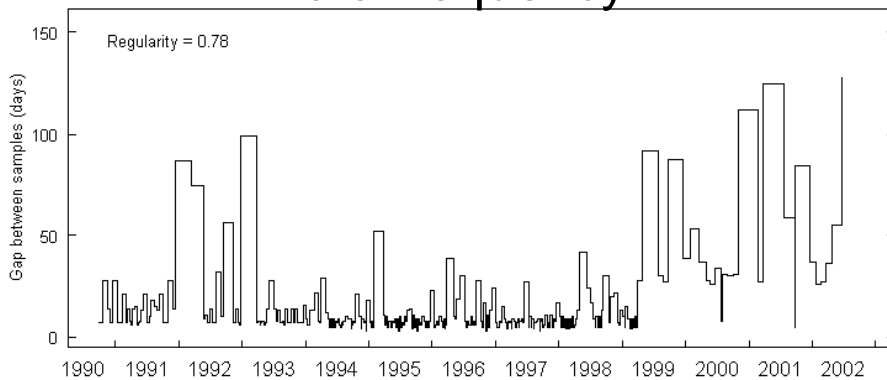
## Raw data



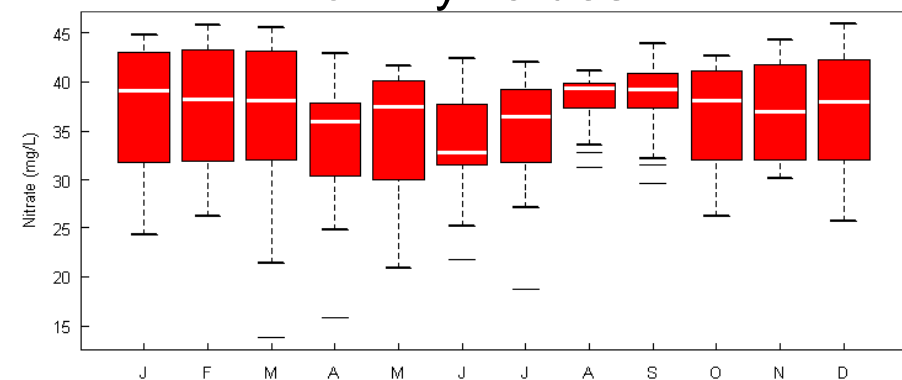
## Sampling interval



## Data frequency

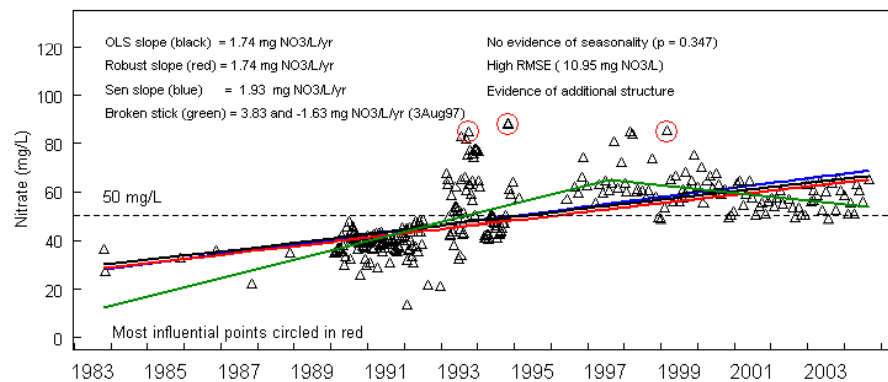
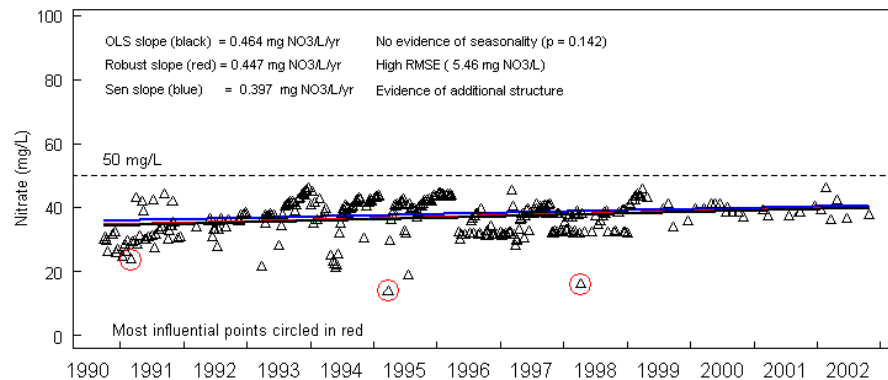


## Monthly values

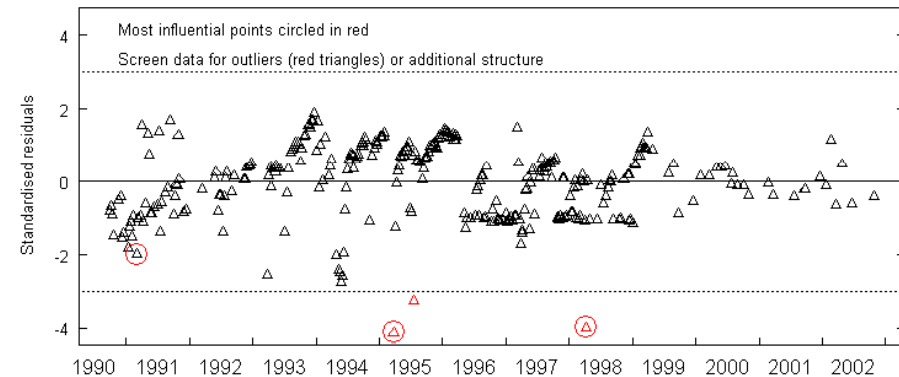


# Statistical tests

## Trend and seasonality

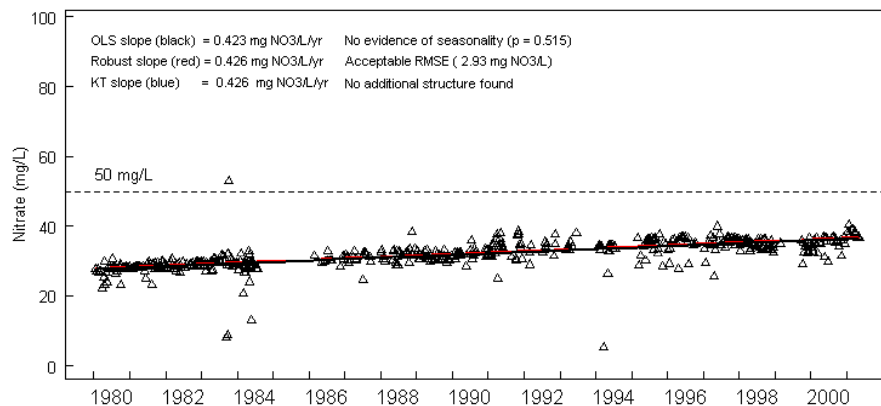
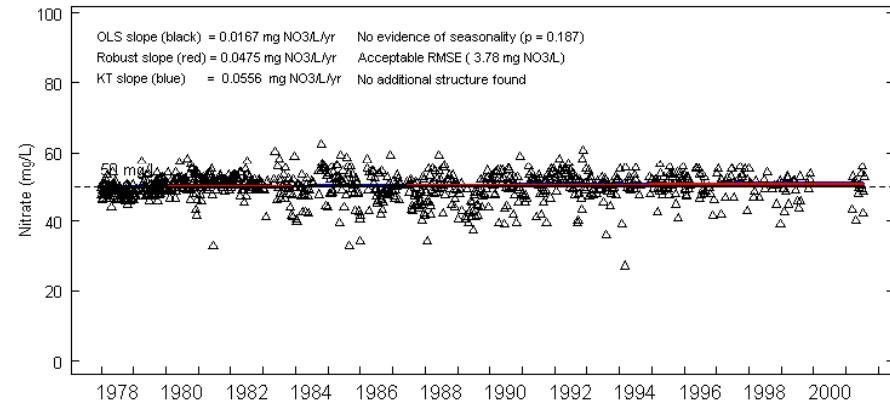
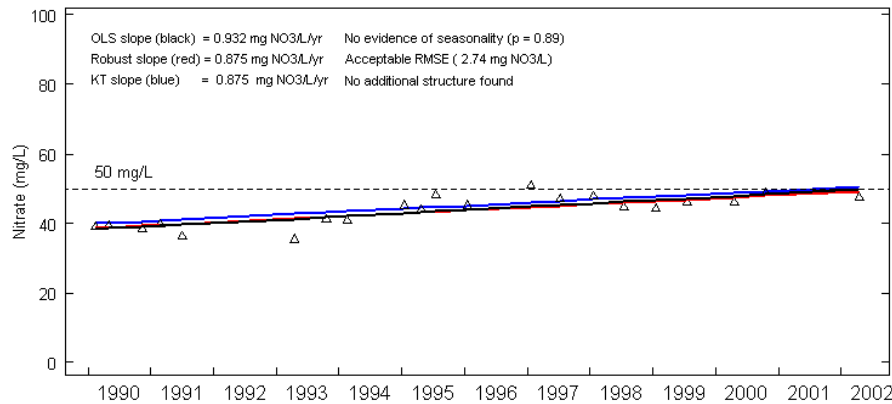


## Standardised residuals



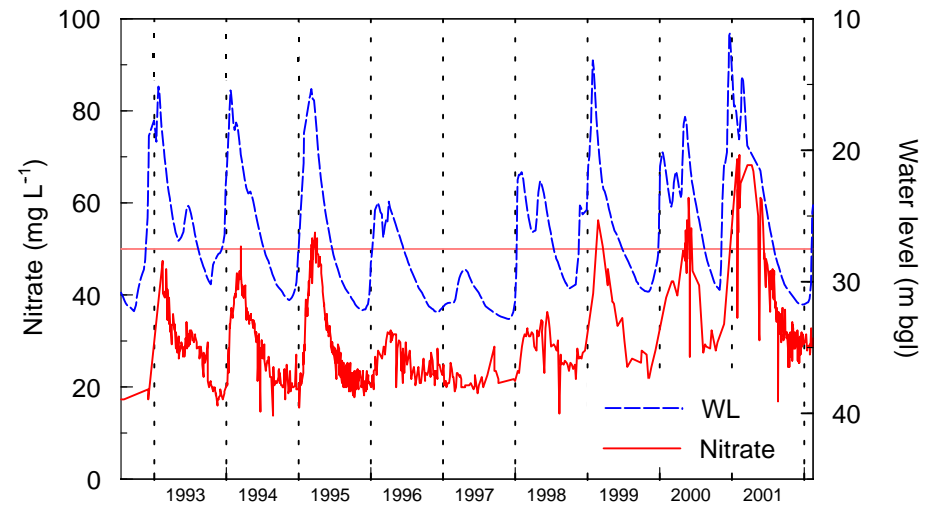
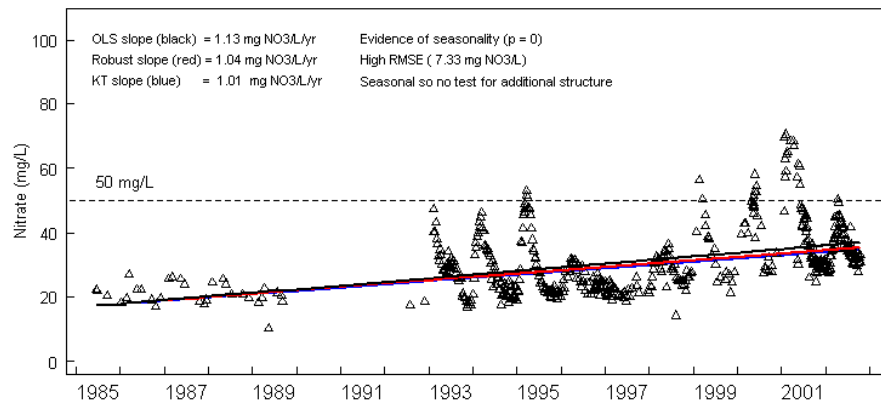
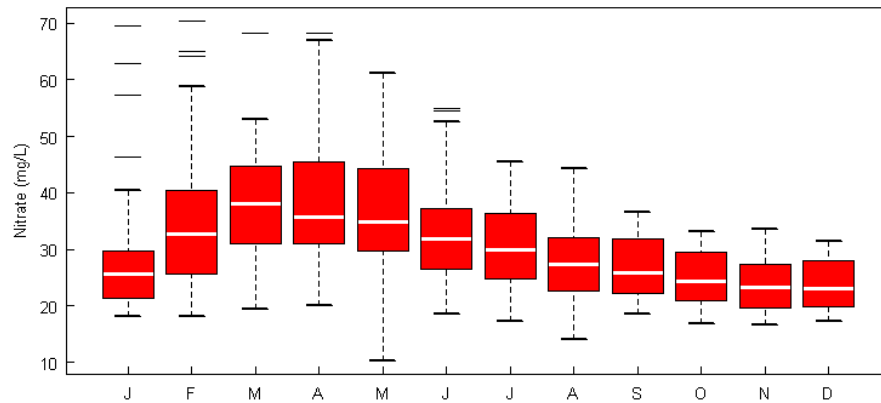
- OLS-ordinary least squares
- Robust linear regression
- K-T & Sen slope
- Step change - Broken stick
- Seasonality – AIC and F-test
- RMSE residual error
- Additional structure
- Influential points

# Non-seasonal



- 10 - 20 years of data
- Trends well-constrained even with low data frequency

# Seasonal

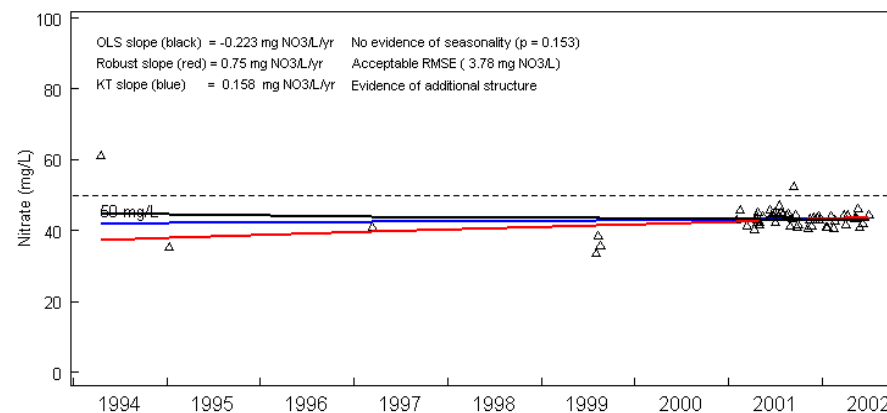
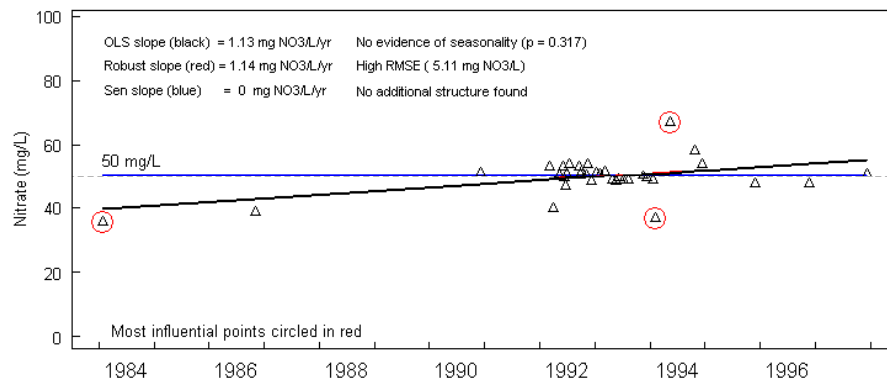


- Chalk borehole
- Seasonality significant
- Mainly accounted for by water level fluctuations

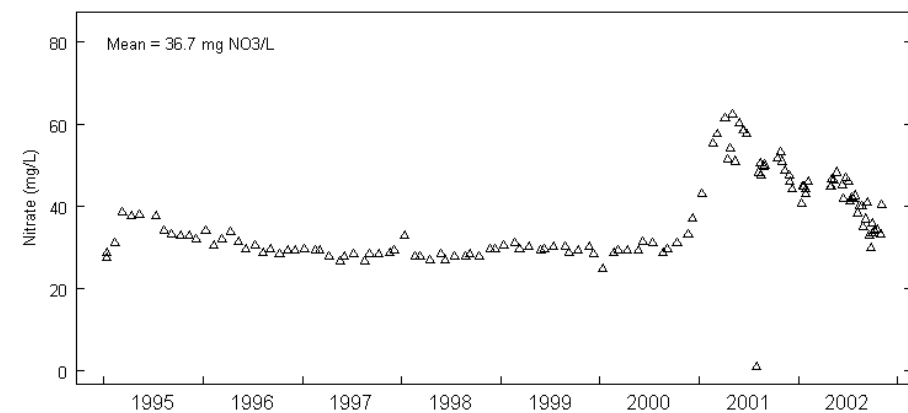
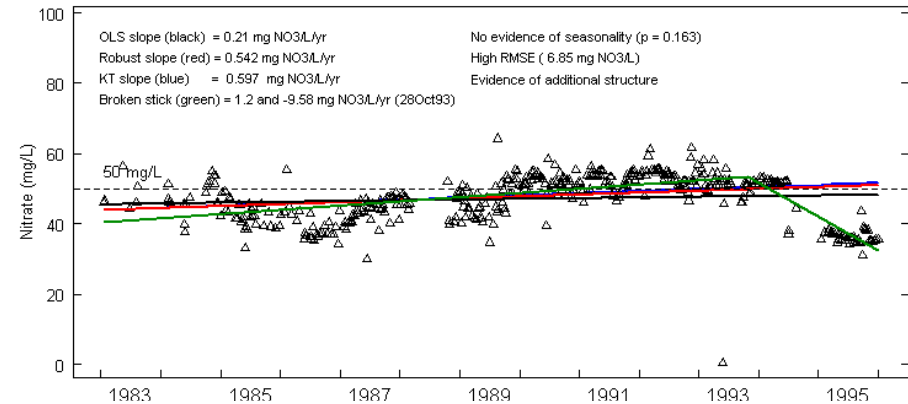


# Irregular data

## Clustering and outliers



## Step changes and excursions

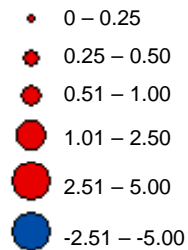


# Summary of trends

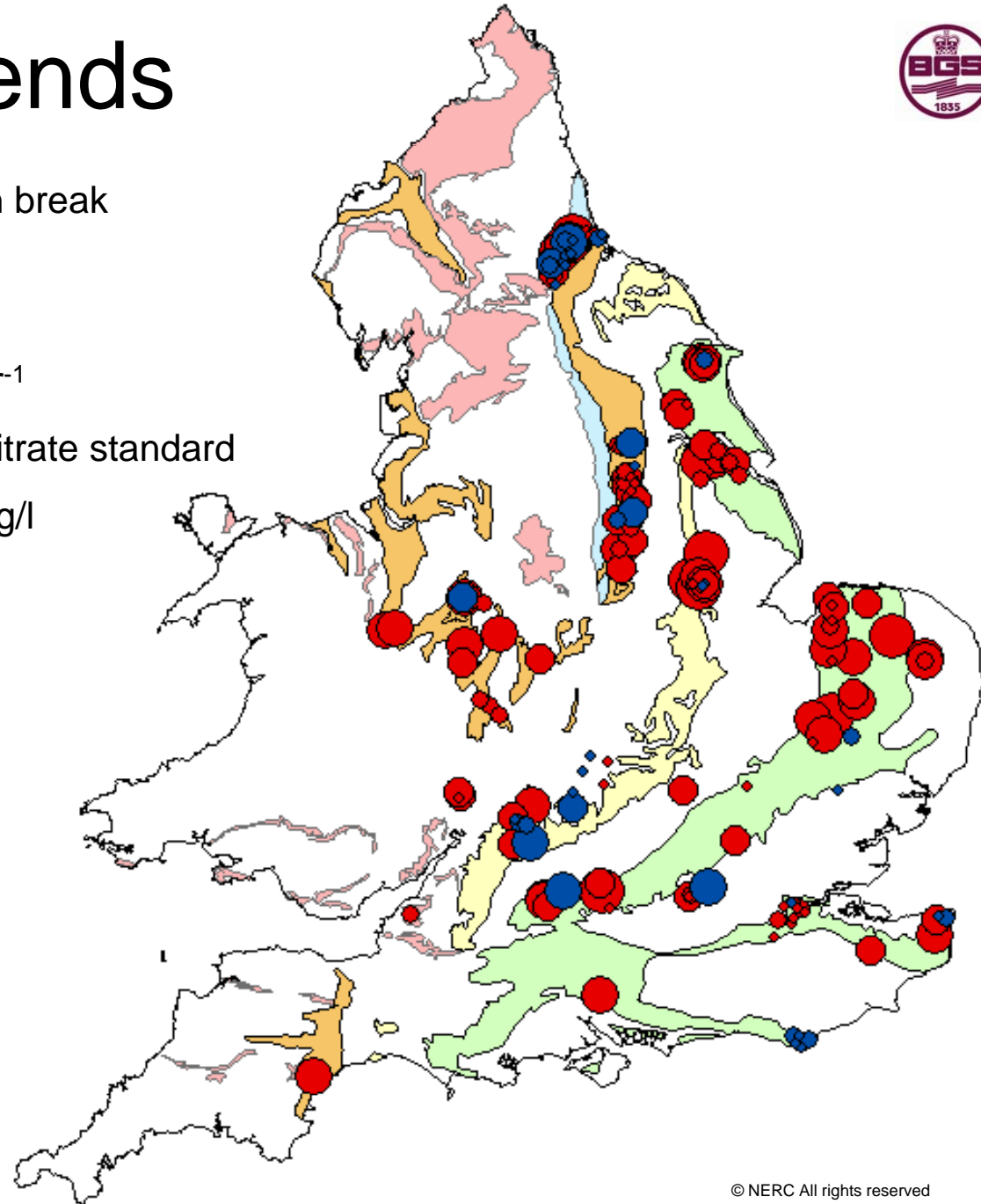
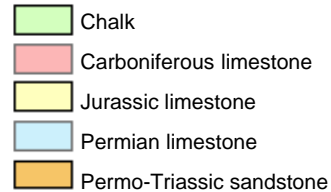


- 21% showed better trend fit when break included
- 33% were seasonal
- Average trend  $0.34 \text{ mg NO}_3 \text{ L}^{-1} \text{ yr}^{-1}$
- In 2001 34% exceeded 50 mg/l nitrate standard
- By 2015 41% could exceed 50 mg/l

## Trend ( $\text{mg NO}_3 \text{ L}^{-1} \text{ year}^{-1}$ )

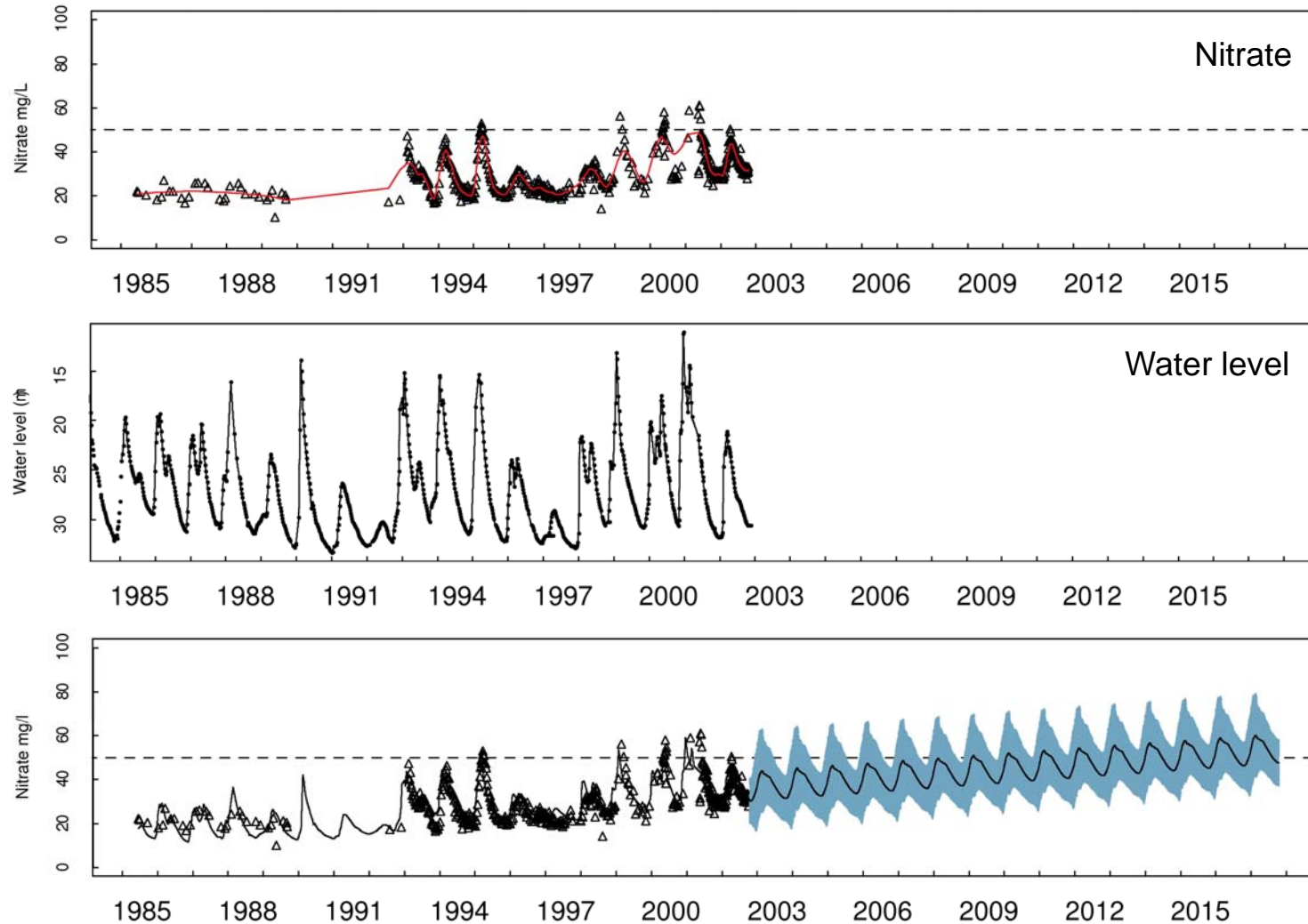


## Aquifer



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# Predictions



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# Conclusions

- Method unhelpful for step changes and excursions caused by external factors
- Cannot predict impact of changes
- Regression to covariables helps to make prediction of trends and peak concentrations
- **Long-term, regular monitoring is the key**

Acknowledgement to colleagues at Wallingford

Reference - Stuart ME, Chilton PJ, Kinniburgh DG and Cooper DM. 2007. Screening for long-term trends in groundwater nitrate monitoring data, Quart. J. Eng. Geol. Hydrogeol, 40, 361-376

