



**British
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Applied geoscience for our
changing Earth

Statistical approaches to analysing trends in groundwater quality

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Groundwater Science Programme

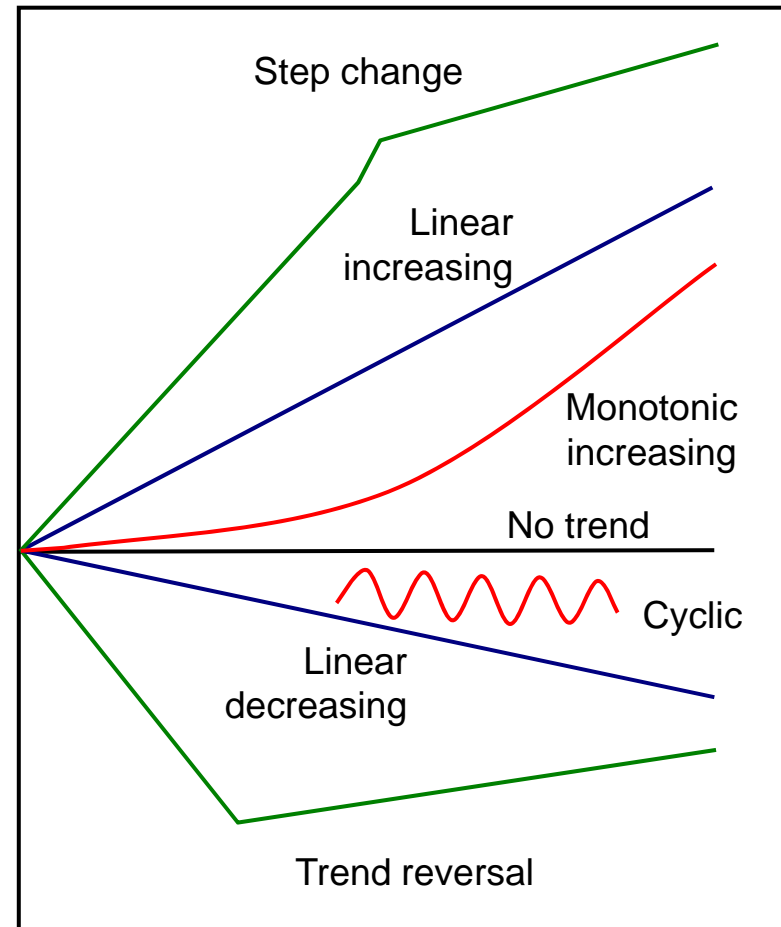
BGS Wallingford

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

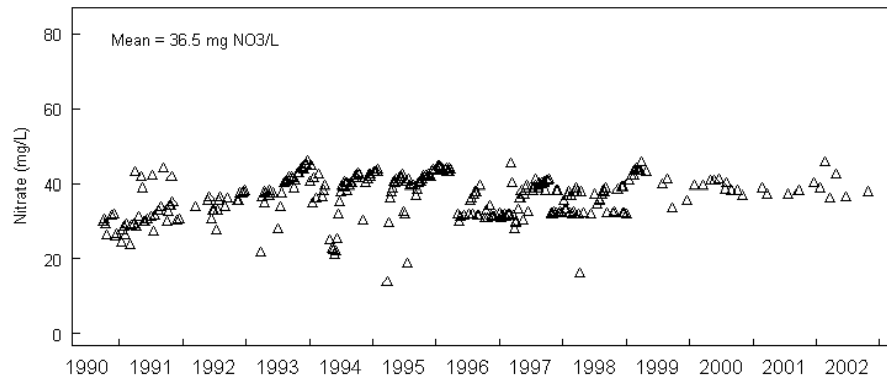
- Depends on dataset characteristics:
 - Sampling frequency
 - Length of monitoring period
 - Missing data / irregularity of sampling
- Descriptive data exploration
- Statistical data exploration
 - Trend test
 - Autocorrelation
 - Cyclical behaviour
 - Trend test on residuals
 - Correlation with covariates



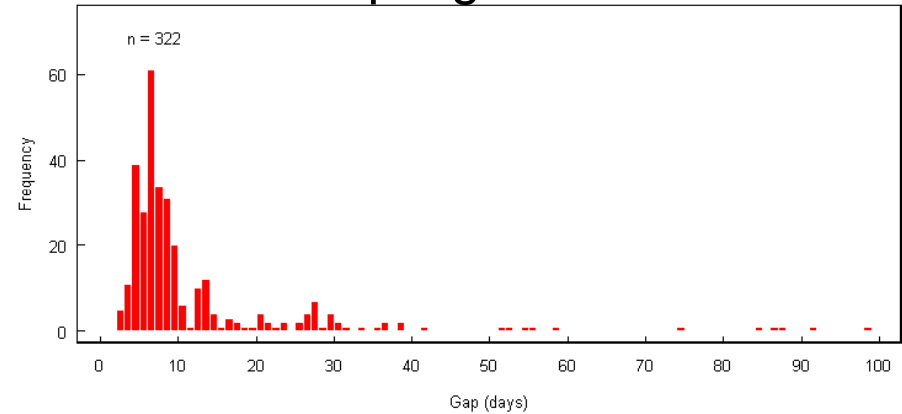
Increasing
quality of
dataset

Descriptive tests

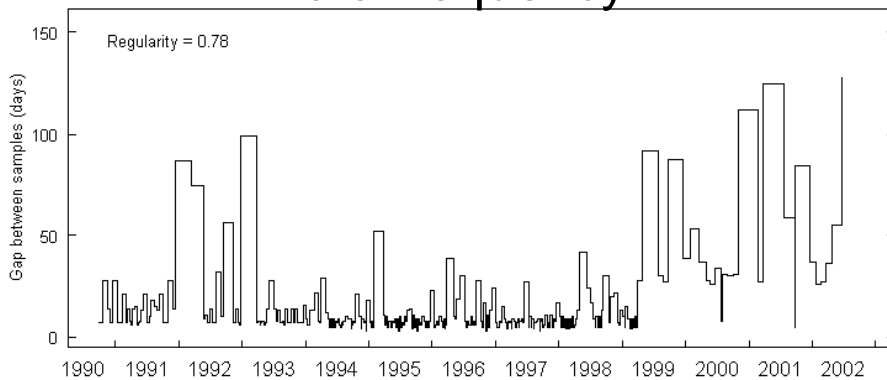
Raw data



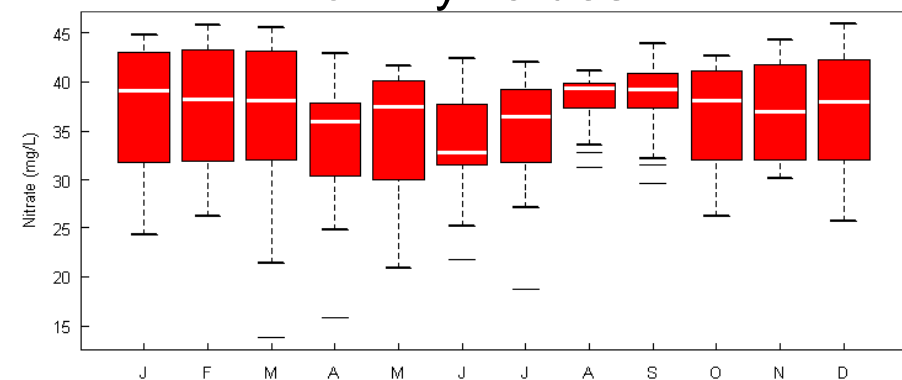
Sampling interval



Data frequency

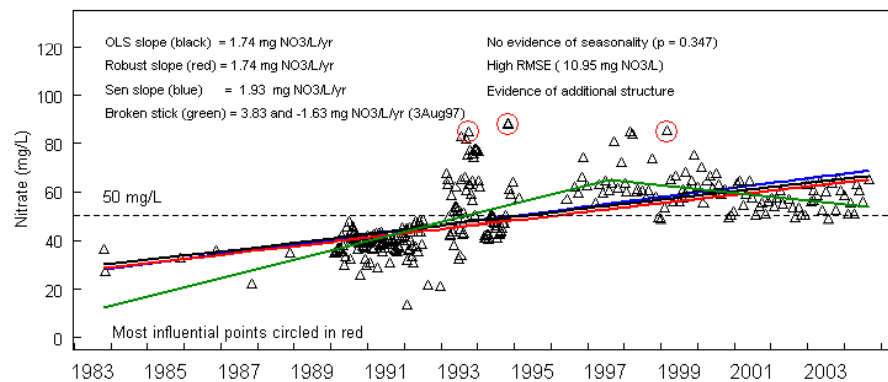
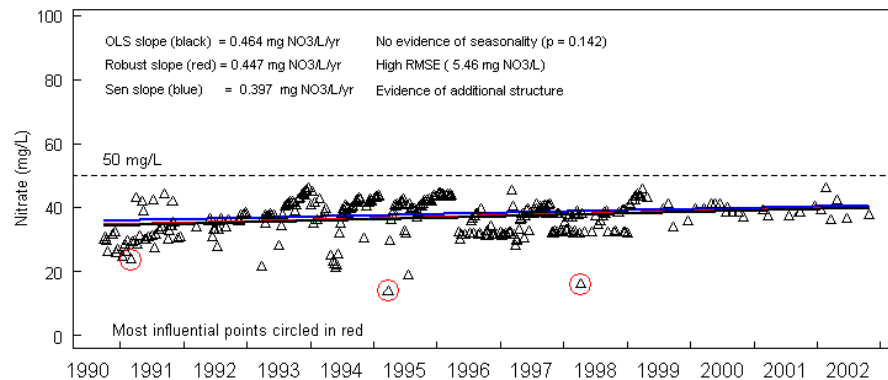


Monthly values

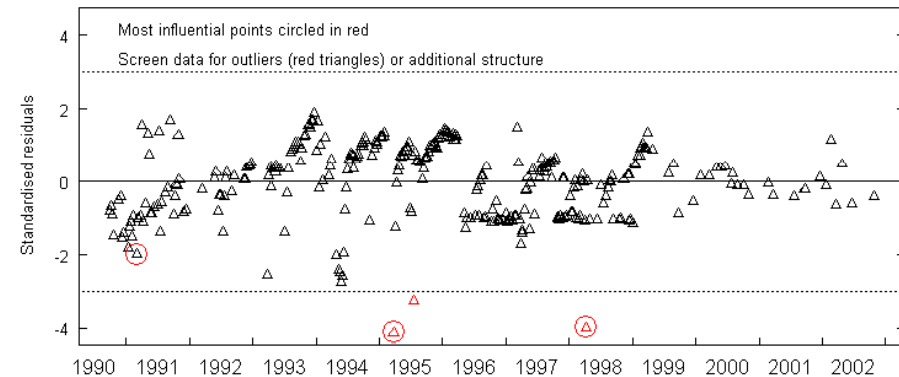


Statistical tests

Trend and seasonality

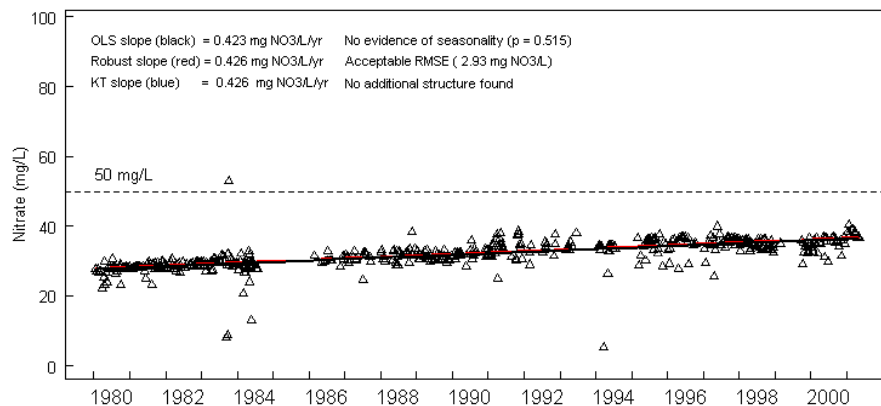
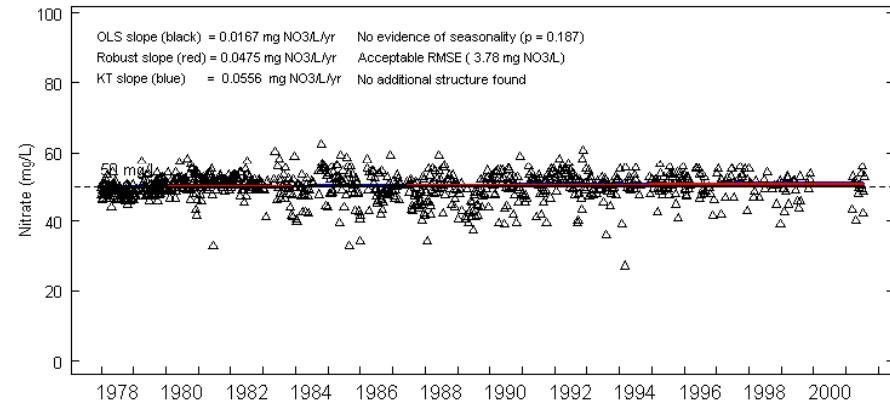
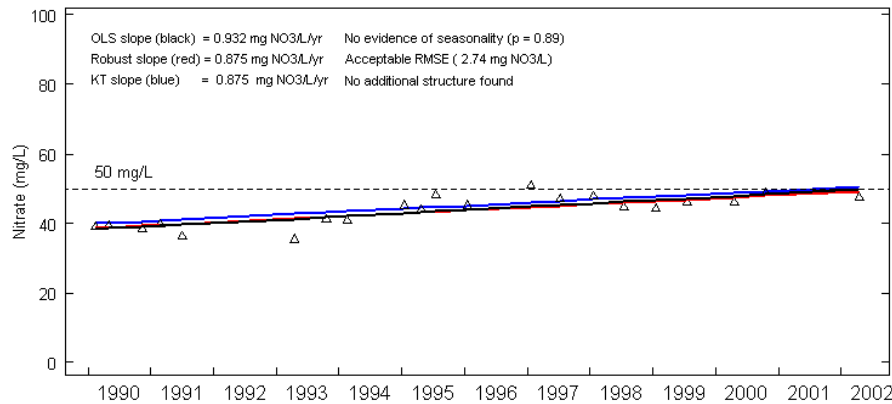


Standardised residuals



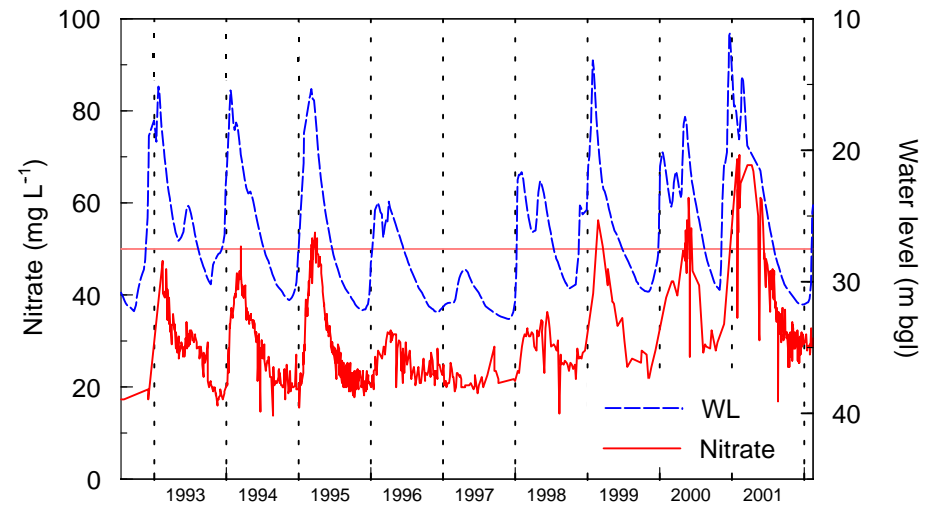
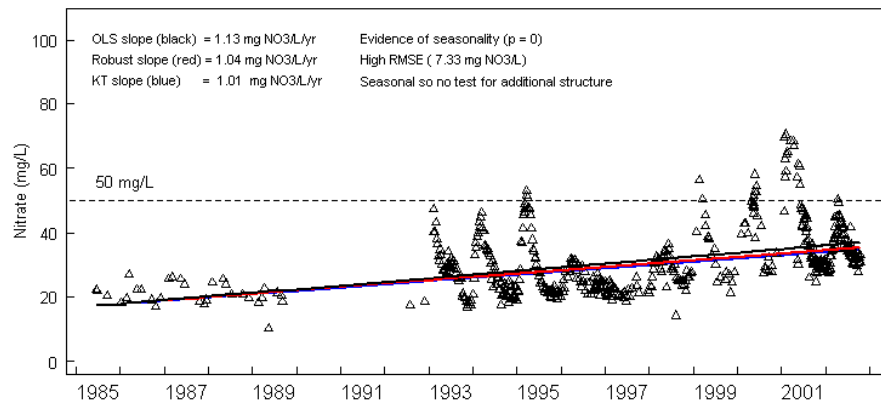
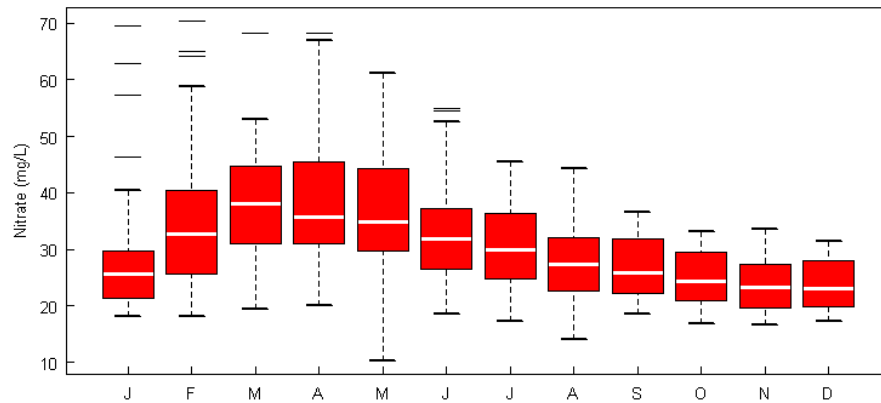
- OLS-ordinary least squares
- Robust linear regression
- K-T & Sen slope
- Step change - Broken stick
- Seasonality – AIC and F-test
- RMSE residual error
- Additional structure
- Influential points

Non-seasonal



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

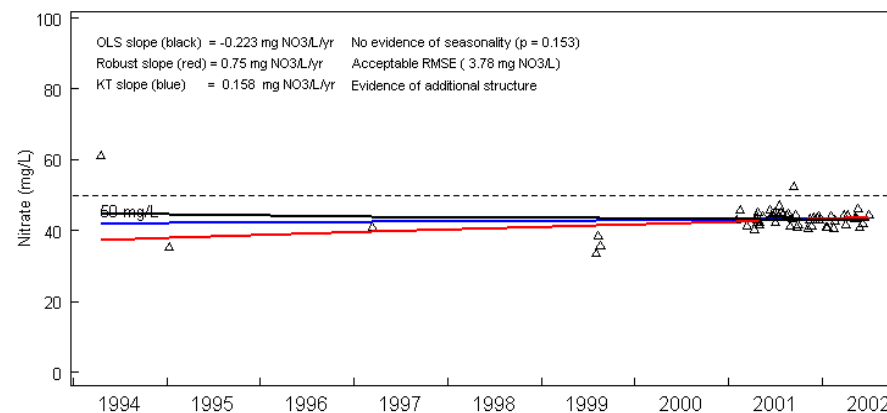
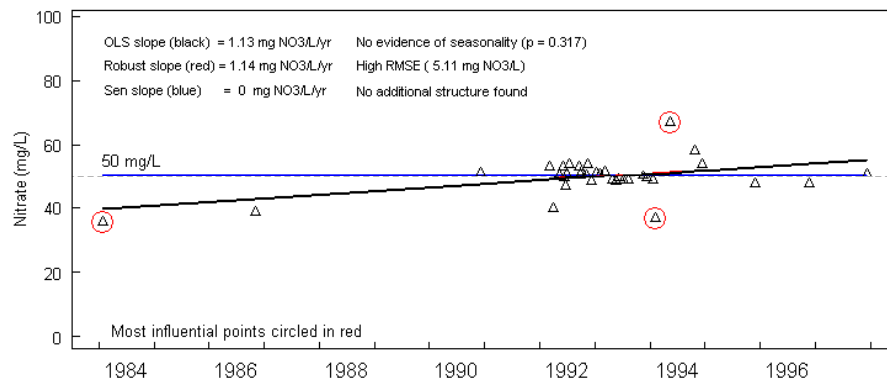
Seasonal



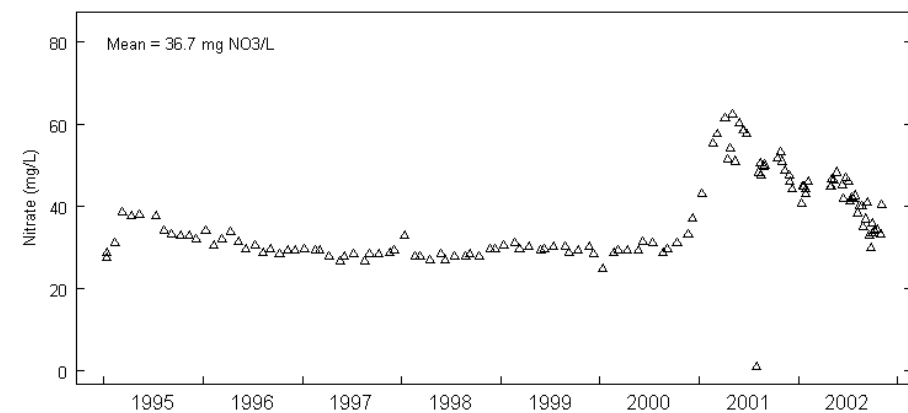
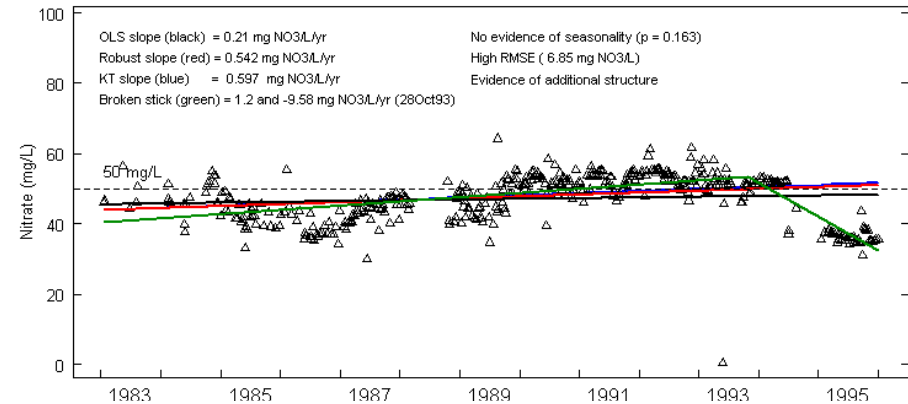
- Chalk borehole
- Seasonality significant
- Mainly accounted for by water level fluctuations

Irregular data

Clustering and outliers



Step changes and excursions

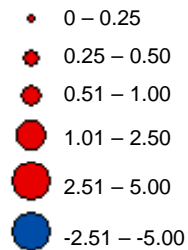


Summary of trends

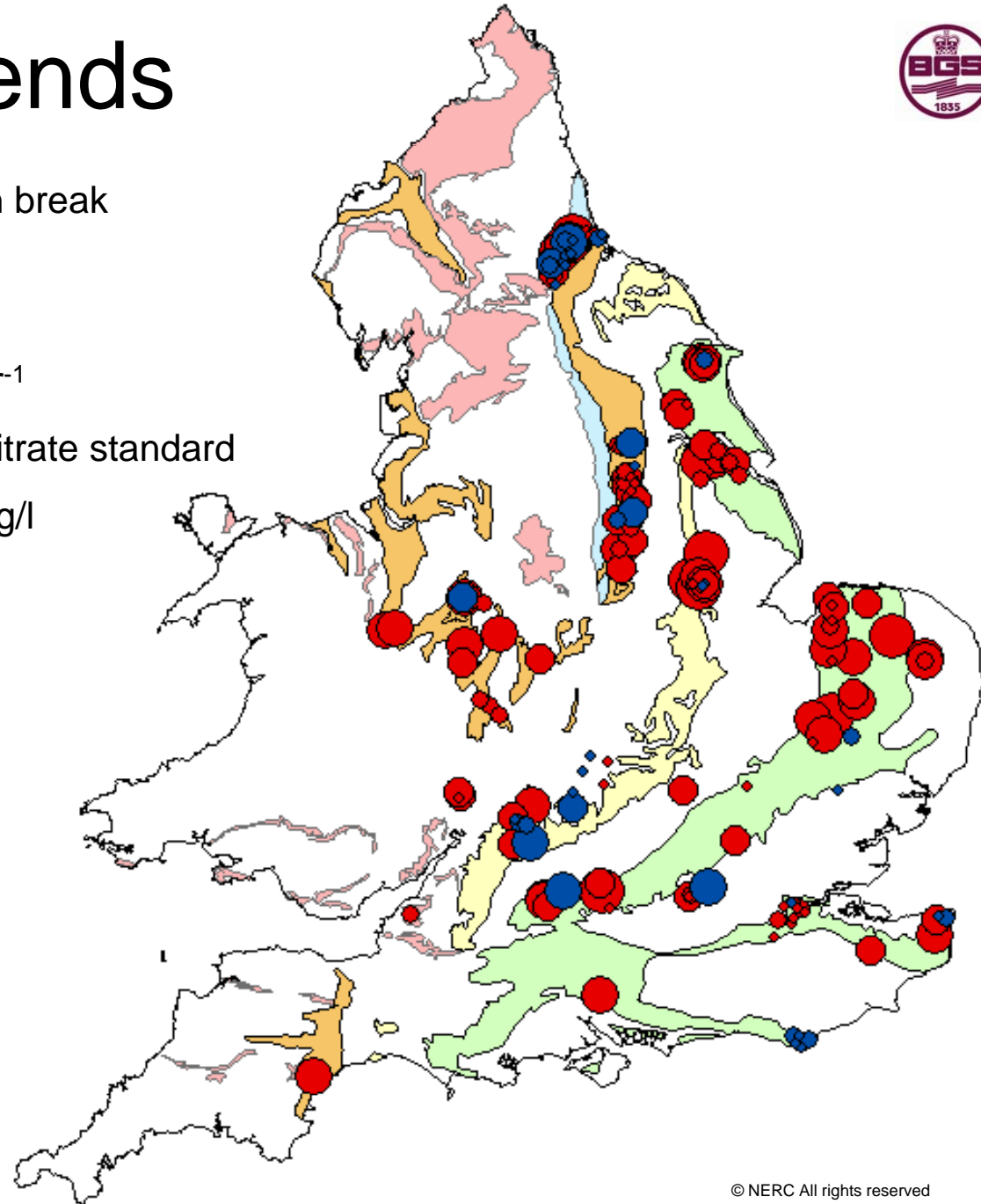
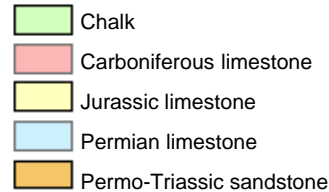


- 21% showed better trend fit when break included
- 33% were seasonal
- Average trend $0.34 \text{ mg NO}_3 \text{ L}^{-1} \text{ yr}^{-1}$
- In 2001 34% exceeded 50 mg/l nitrate standard
- By 2015 41% could exceed 50 mg/l

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

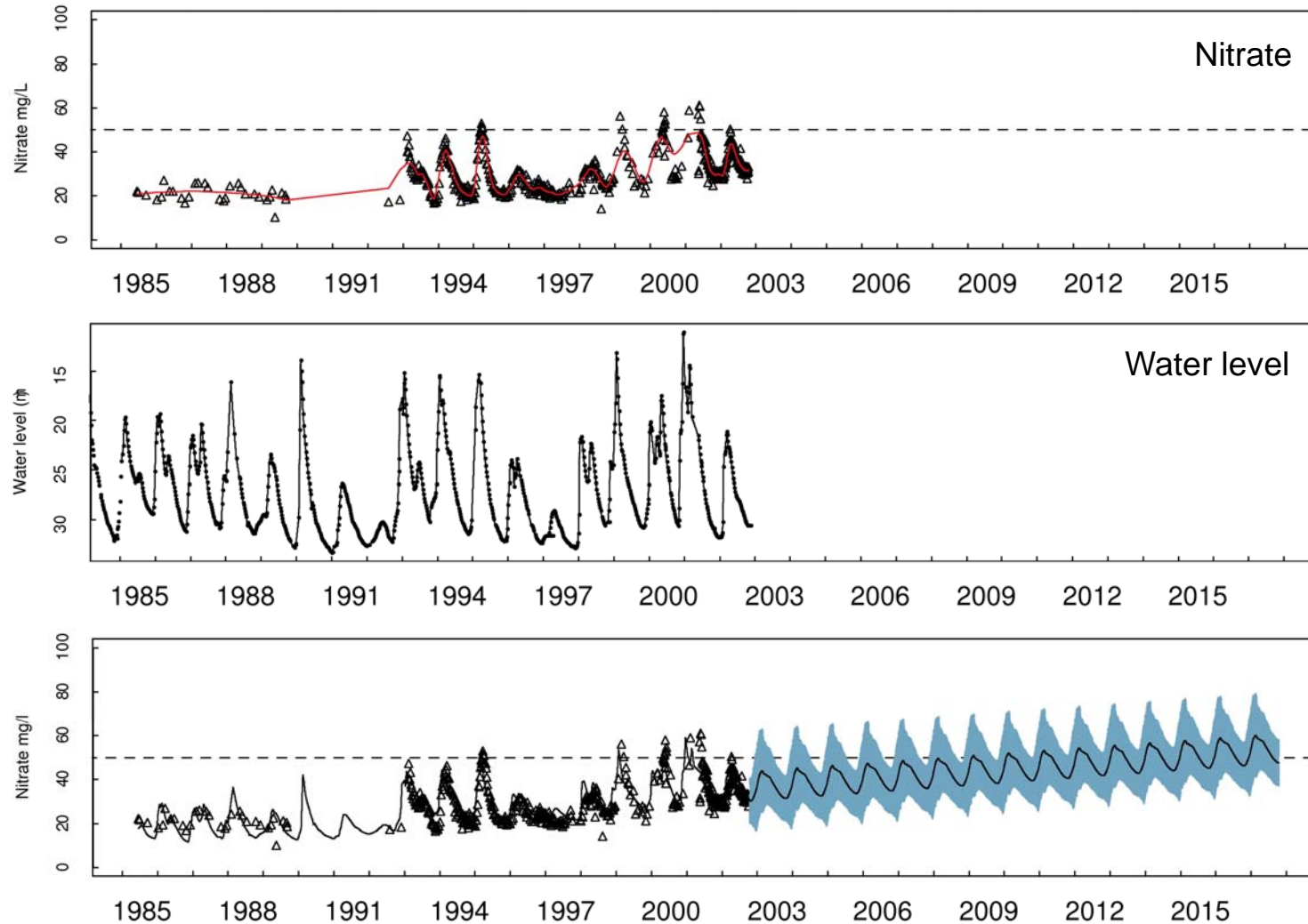


Aquifer



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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

