Baseline Scotland – Scotland's groundwater quality

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British Geological Survey

With thanks to Alan MacDonald and Pauline Smedley, BGS & Vincent FitzSimons, SEPA

Talk Overview

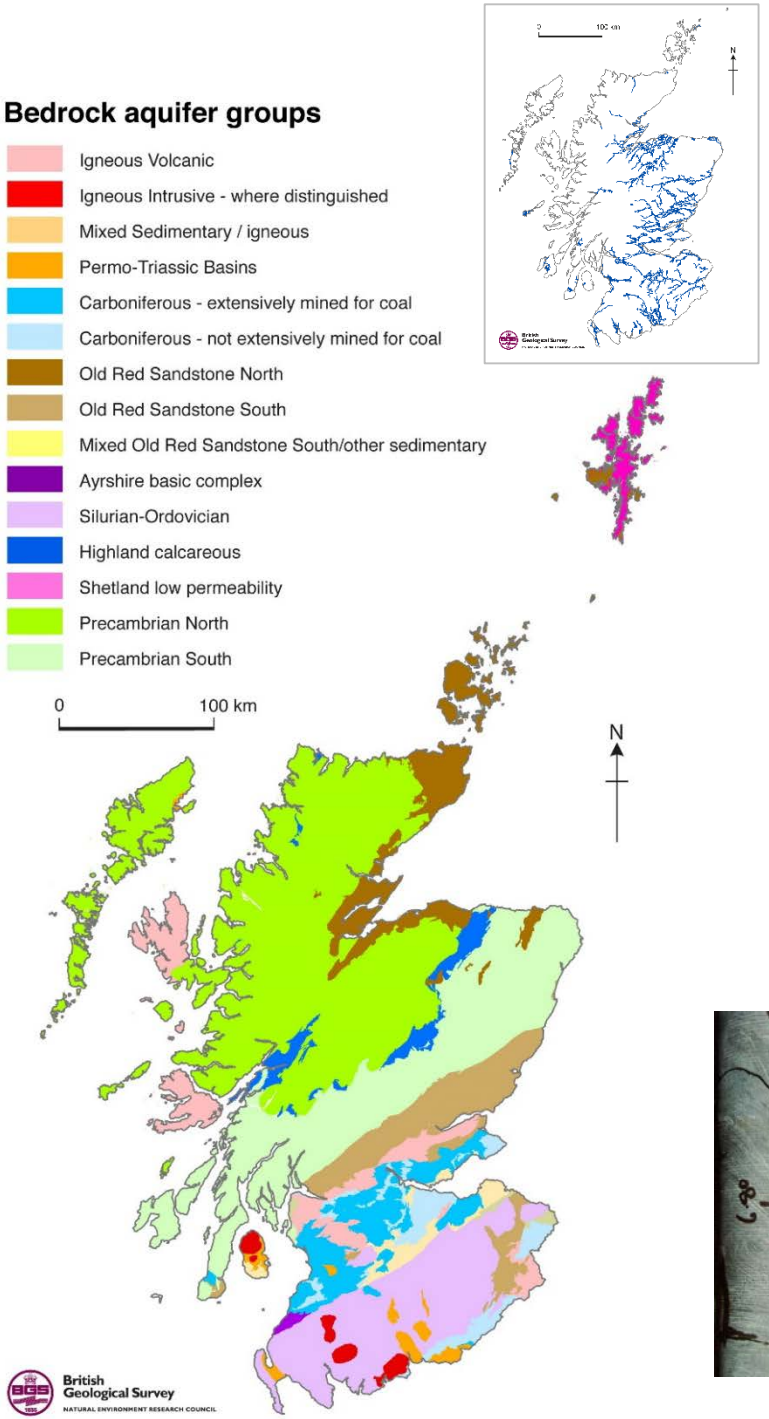
- Groundwater in Scotland
- Introduction to the Baseline Scotland project
- What is baseline groundwater quality?
- Study methodology
- Results

What is groundwater in Scotland used for?

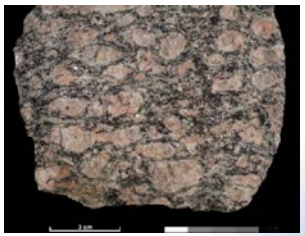
Assimilating waste

Bottled water

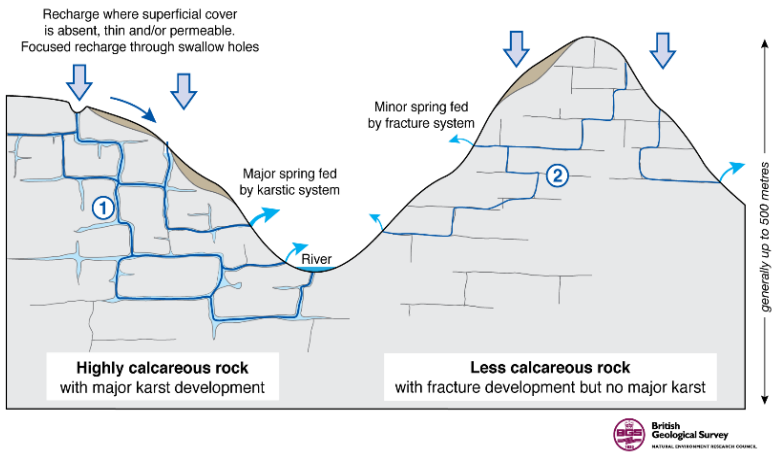
Scotland's Aquifers

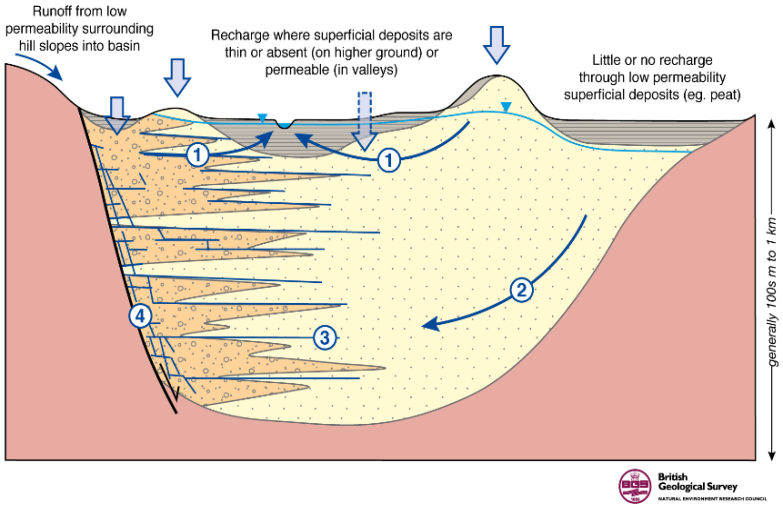


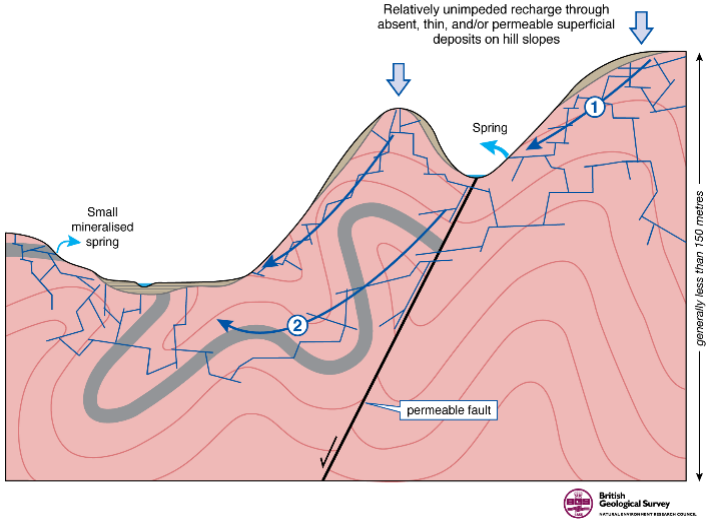
- Different ages, lithologies, geological histories
- Different physical & chemical aquifer properties – permeability & aquifer productivity; groundwater flow type; chemistry
- Occasionally significantly altered by humans – Carboniferous

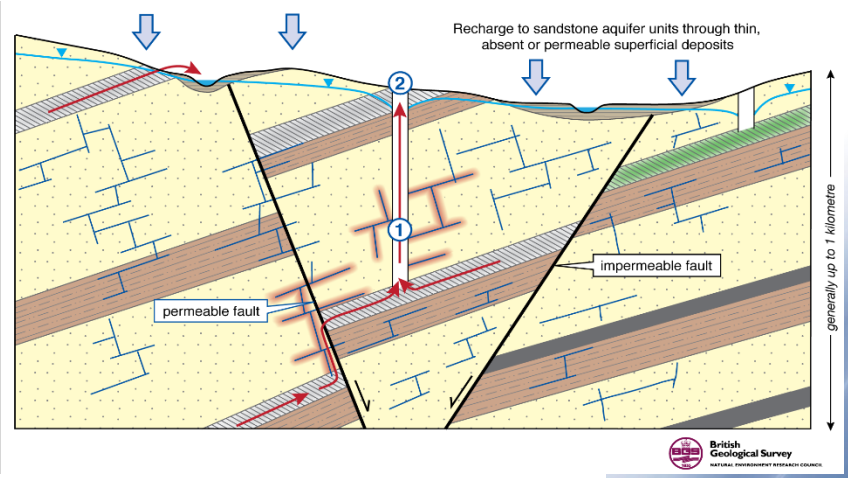


Aquifers are 3D









Find out more about Scotland's aquifers:

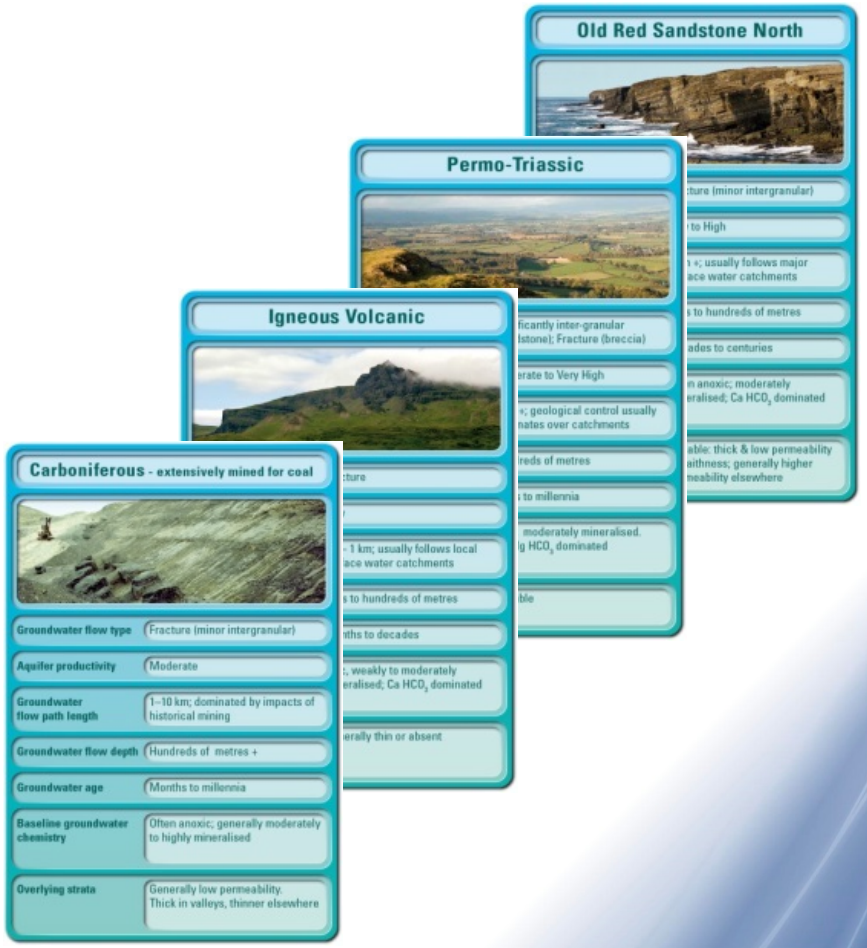
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

SEPA
Scottish Environment Protection Agency

http://nora.nerc.ac.uk/511413/

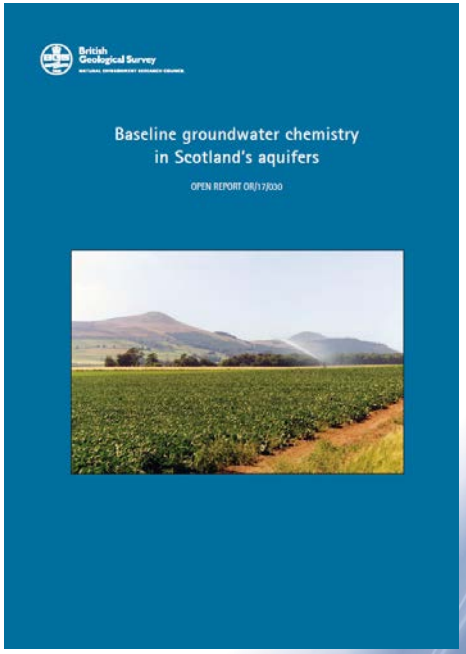
Scotland's aquifers and groundwater bodies

Groundwater Science Programme
OPEN REPORT OR/15/028



The Baseline Scotland project

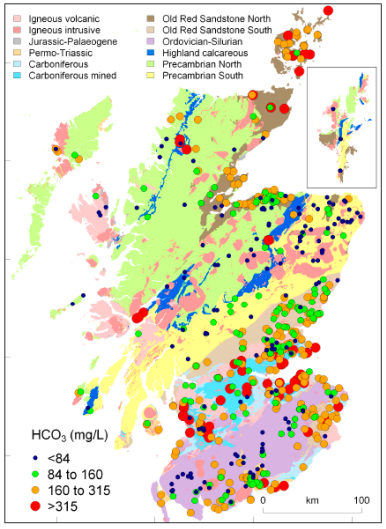
- An overview of the natural ('baseline') chemistry of groundwater in major bedrock aquifers in Scotland
- Project ran 2005 – 2014
- Run by BGS in collaboration with SEPA
- Systematic regional surveys of all major bedrock aquifers
- Several regional / aquifer-specific reports published (e.g. Midland Valley Carboniferous)
- Synthesis report published 2017



Aims of Baseline Scotland

1. To characterise the ranges in natural background groundwater quality in Scotland's main aquifers, by carrying out groundwater sampling surveys that as far as possible are representative of each aquifer.

2. To provide a scientific foundation to underpin Scottish, UK and European water quality guideline policy, notably the Water Framework Directive, with an emphasis on the protection and sustainable development of high quality groundwater.



Baseline Groundwater Quality

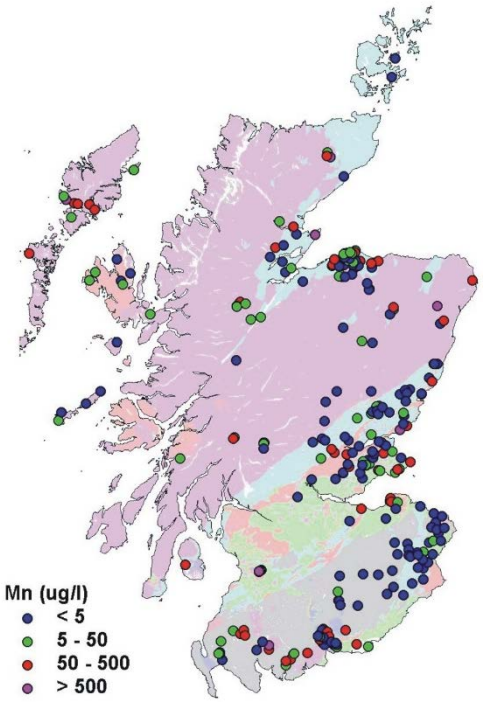
- Groundwater chemistry varies naturally – between & within aquifers
- Many complex & interrelated natural controls, e.g.
  - Rainwater chemistry
  - Evapotranspiration
  - Type & thickness of soil & superficial deposits
  - Geology & geochemistry of an aquifer
  - Chemical evolution of groundwater as it flows through an aquifer (e.g. redox reactions, ion exchange, & sorption)
- A range of chemical values characterises the natural baseline groundwater quality of any one aquifer:
  - **This project used the 10th – 90th percentile range to define a baseline**
- Knowing the baseline allows outliers to be identified – these are more likely to be caused by human pressures than to be natural

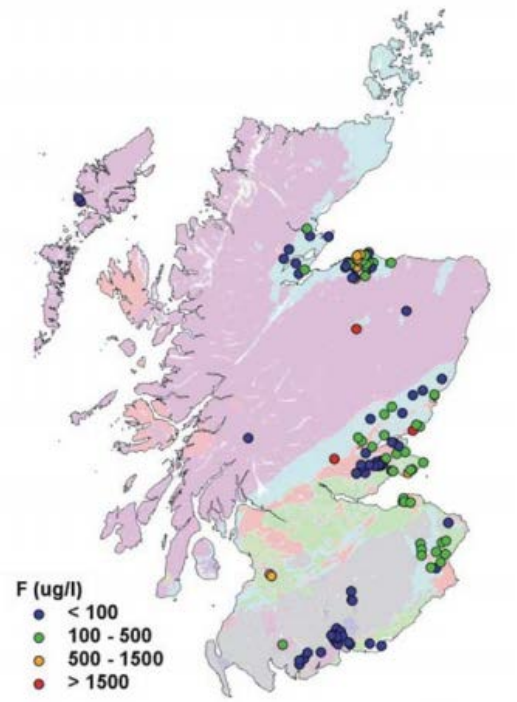
Project Methodology

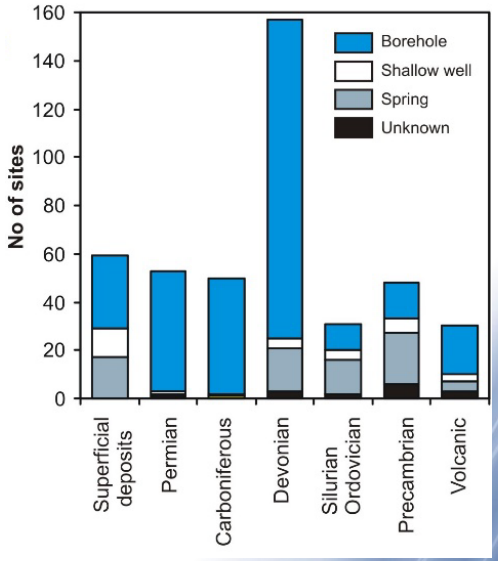
- Review and assess existing data
- New data collection: groundwater sampling
- Sample analysis
- Data interpretation and synthesis

Pre-Baseline Scotland: review & assessment of existing data

- Existing data from previous projects, monitoring, etc
- Variable data distribution, completeness & quality







Groundwater sampling & supporting data collection

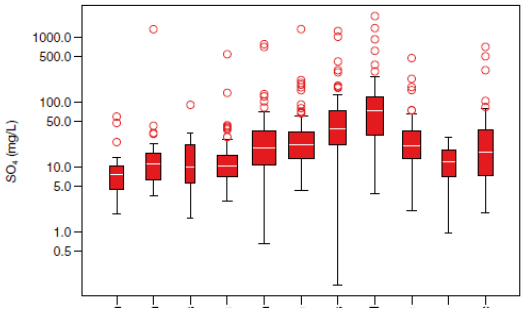
- **Site selection**
  - Representative of aquifer
  - Away from contamination sources
- **Source type**
  - Boreholes 78%
  - Springs 18%
  - Large diameter wells 4%
- **Sampling procedure**
  - Purged/flowing samples, if possible direct from wellhead or spring source.
  - Field measurements – DO, pH, SEC, Eh, temperature, HCO_3
- **Supporting data**
  - Sampling (e.g. date, time, purged status)
  - Source (e.g. depth, construction, condition, pumping rate, use)
  - Surrounding area (e.g. land use)

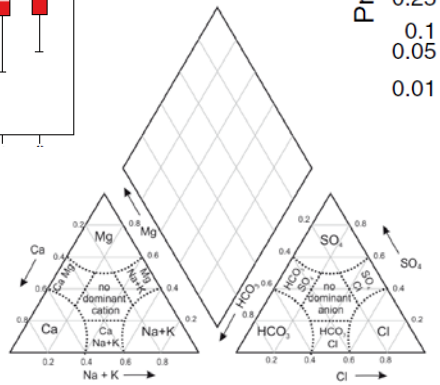
Sample analysis

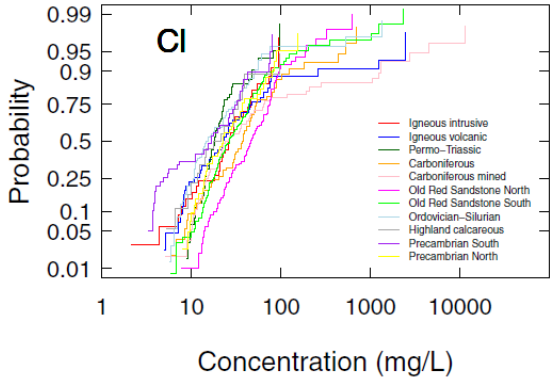
- Samples analysed at BGS laboratories:
  - ICP-OES (major cations, total S, Si)
  - ICP-MS (wide range of trace elements)
  - IC (NO_3, Cl, Br, F)
  - Automated colorimetry (NH_4, I)
  - Carbon analyser (DOC)
- Also analysed for
  - Stable isotopes d^2H, $d^{18}O$ – at most sites
  - Dissolved gases CFC, SF_6, CH_4 – at selected sites
- Rigorous data QA done, including
  - analysis of certified standards
  - exclusion of analyses with high charge imbalances

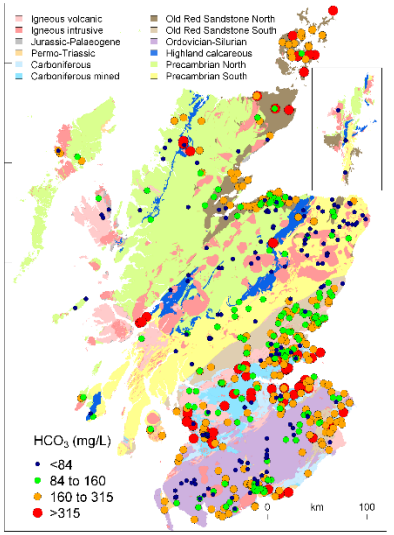
Data interpretation & presentation

- Summary statistics calculated for whole dataset; for each aquifer; & for different land use categories:
  - Minimum, 10th, 25th, 50th, 75th, 90th, 95th percentiles, maximum
  - Median is preferred estimate of central tendency (less affected by extreme concentrations than mean)
- Results presented as Piper diagrams, box plots, cumulative probability plots and maps



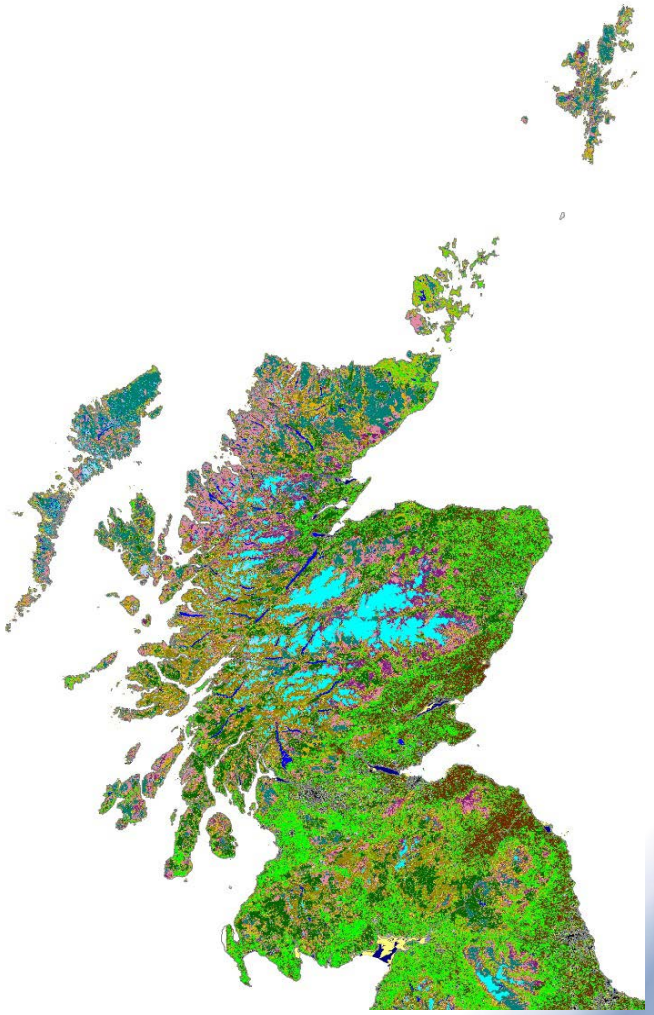






Land use

- Land use is the key influence on anthropogenic impacts on groundwater quality
- National-scale land cover mapping and site-scale land use categorisation used to identify potential diffuse & point source pressures, e.g.
  - Agriculture (e.g. improved pasture grassland; arable; dairy/pigs/poultry)
  - Recreation (e.g. golf courses)
  - Septic tanks
  - Fuel stations
  - Industry



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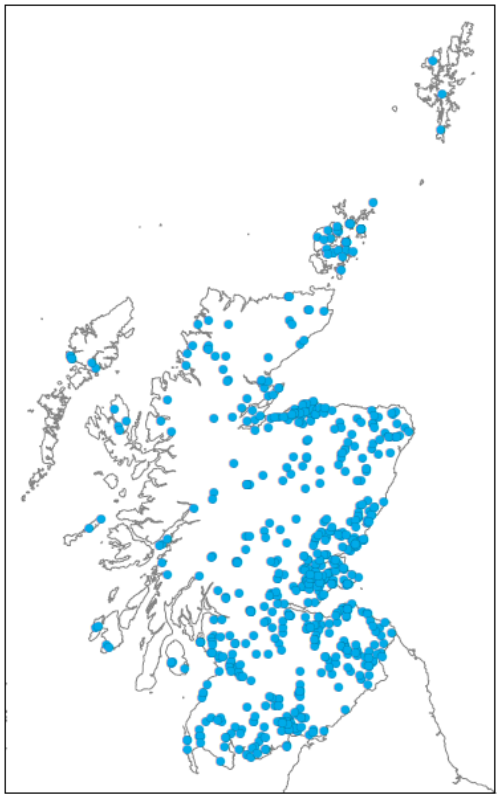
Summary of Results

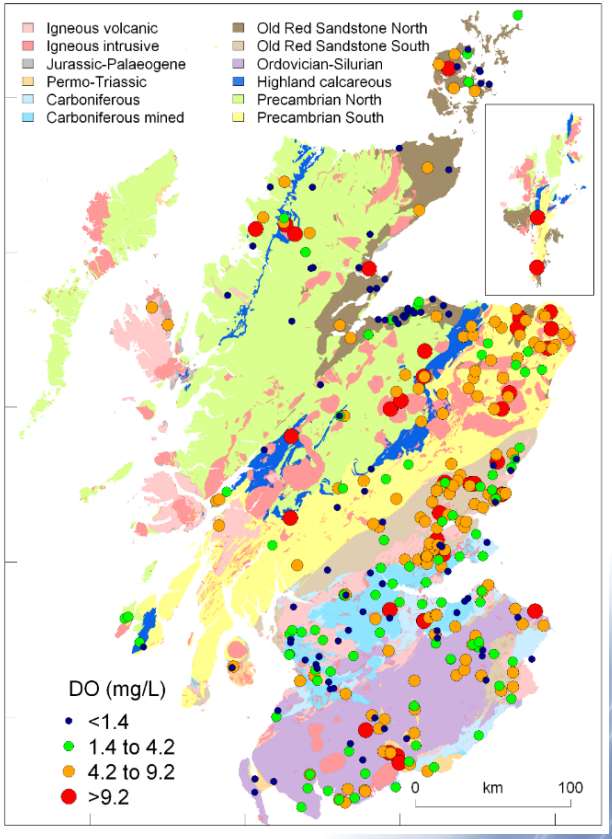
- 646 chemical analyses of groundwater samples
- Distributed across 11 bedrock aquifers & 9 land use categories



Land use	Arable			Improved pasture			Mixed agricultural			Mixed rural land use				Pasture DPP			Recreat-ional			Semi natural				Urban and/ or urban industrial			Woodland			Unknown					Total
Aquifer Group	B	S	W	B	S	W	B	S	W	A	B	S	W	B	S	W	B	S	W	A	B	S	W	B	S	W	B	S	W	A	B	S	W	U	
Permo-Triassic				17			1				5			10							1			5			1				19	2	1		62
Carboniferous	11			4			6				2	1		2	1		5				2	3		2			1				14	1			55
Carboniferous mined	7	1		3			3			1	1			7			1			1	3			9	1					2	16				56
Old Red Sandstone North	9			14	2	1	7		1		6	1		7			4				1			2		1					33	8	2		99
Old Red Sandstone South	23	3	1	8	2		12	1			9	2		3			5					1		3			1	1			44	3	3		125
Silurian-Ordovician	2			14	10	1	1					1		7	1		1				6	5		1				2			9	8	3	1	73
Calcareous				6				2			3	1		1								3										1	1		18
Precambrian North				4			1				4	2					1				8	1					3				7	9	1		41
Precambrian South	2	1		3	4	1		2			7	1		1		1	2					1					1	2			9	1			39
Igneous volcanic	5		1	4	3		4				1			2			2				3	2						1			12	3			43
Igneous intrusive	1			3	2	1	1	1	1		1			4		1					1	3					2	1	1		6	3		1	34
Total	60	5	2	80	23	4	36	6	2	1	39	9	0	44	2	2	21	0	0	1	25	19	0	22	1	1	9	7	1	2	169	39	11	2	
	67			107			44			49				48			21			45				24			17			223					645

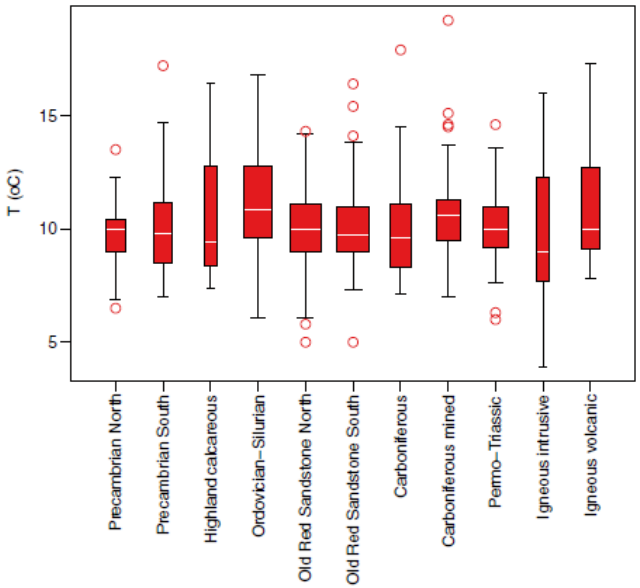
Dissolved oxygen / redox conditions

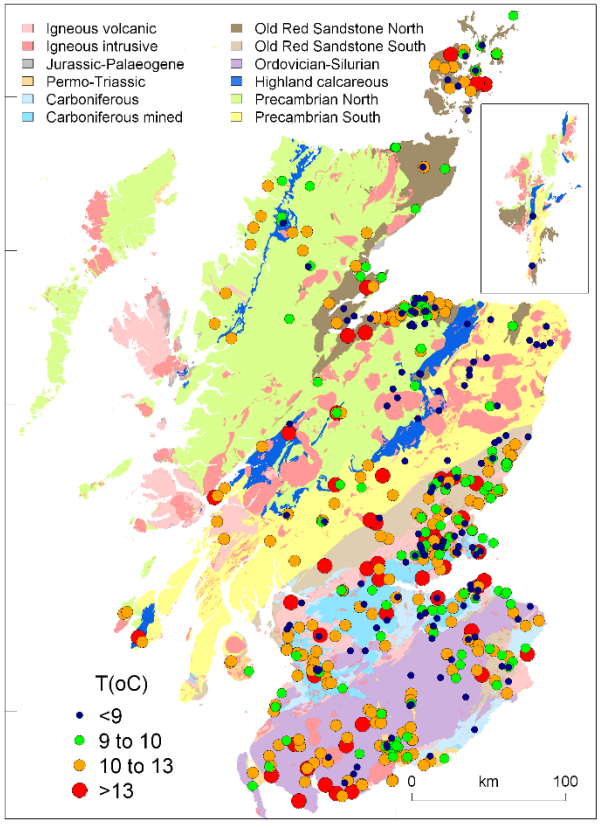
- Oxic conditions dominate – consistent with mainly shallow groundwater flowlines
- Local mildly reducing zones in several aquifers
- Regionally extensive reducing conditions only in Old Red Sandstone North, Moray – reducing NO_3, Fe & Mn
- Locally more strongly reducing conditions in Carboniferous & in mineralised springs in Ordovician-Silurian aquifers – reducing SO_4 & NH_4



Groundwater temperature

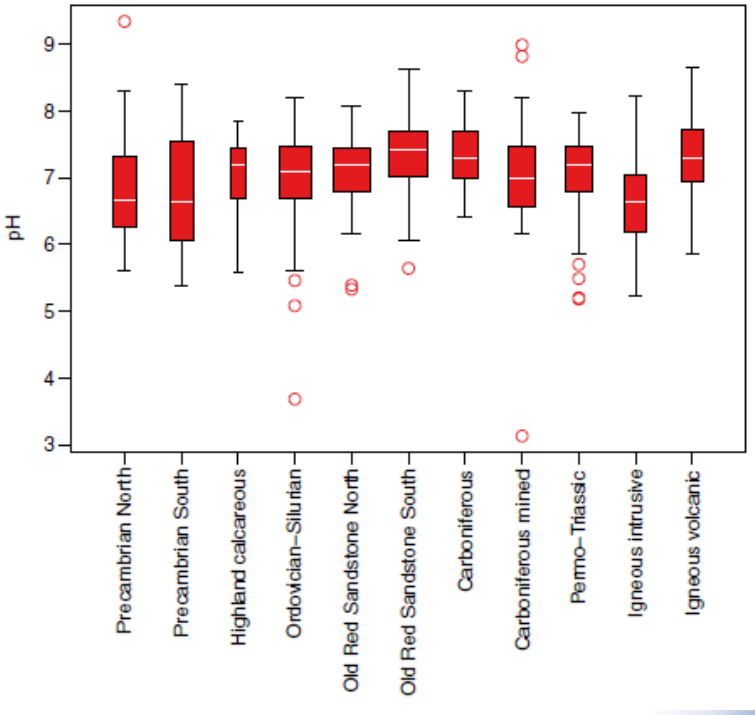
- Average ~10°C
- Lowest in shallow groundwater in uplands
- Highest in deeper groundwater, e.g. from mined zones in Carboniferous (to ~900m)





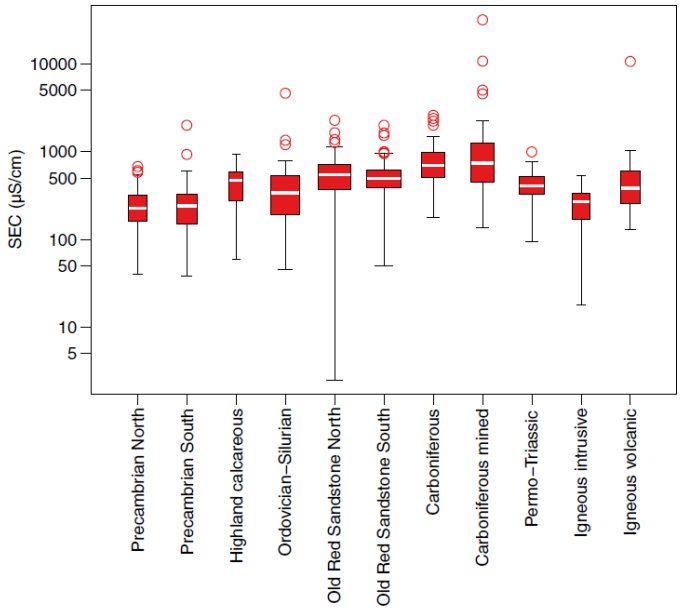
pH

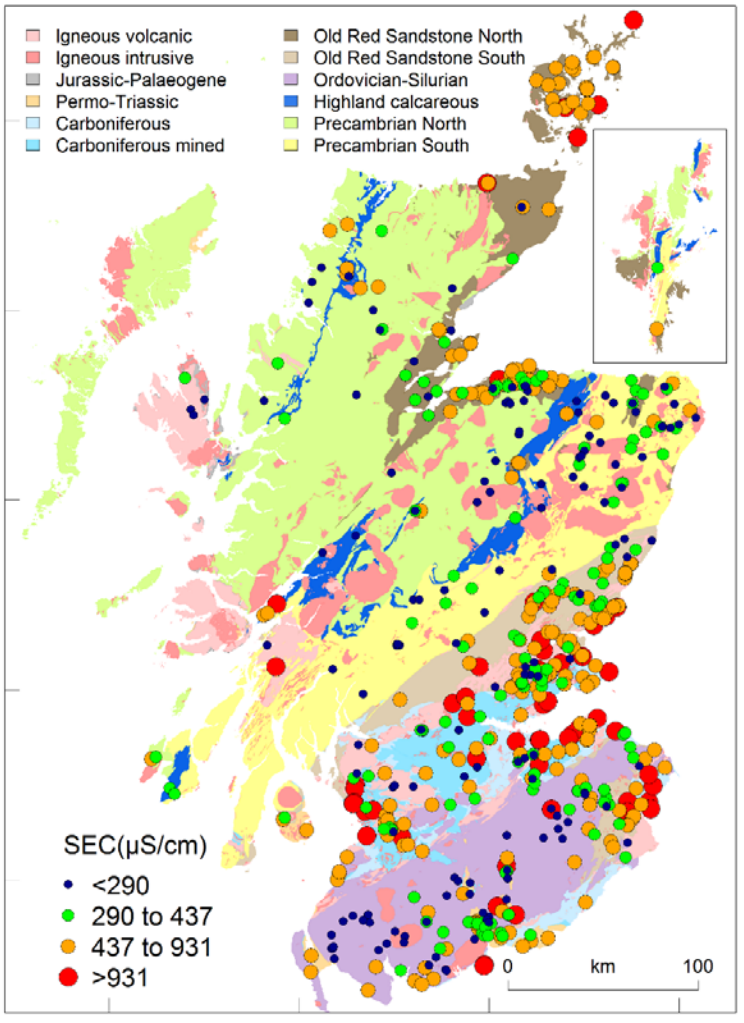
- Median pH for each aquifer is near-neutral, 6.5 – 7.5
- Acidic groundwater (<6) seen in most aquifers – usually reflects an absence of carbonate mineral; in some cases related to oxidation or pyrite & other sulphides
- More strongly acidic conditions locally contribute to higher dissolved Fe, Mn & Al in groundwater



Conductivity (SEC) / Total Dissolved Solids

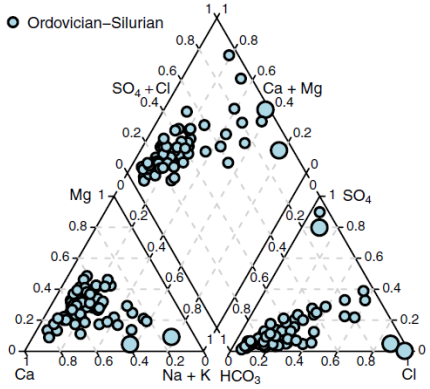
- TDS typically 54 – 520 mg/L
- Highest values in:
  - Mining-impacted groundwaters in Carboniferous
  - Some coastal areas, caused by saline intrusion
  - Rare mineralised springs

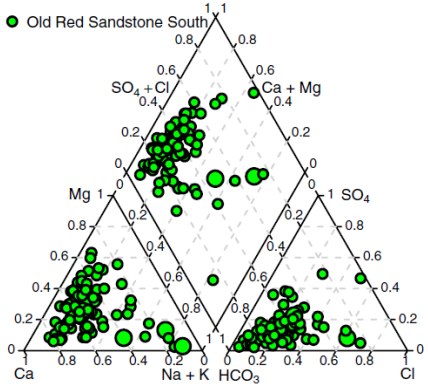


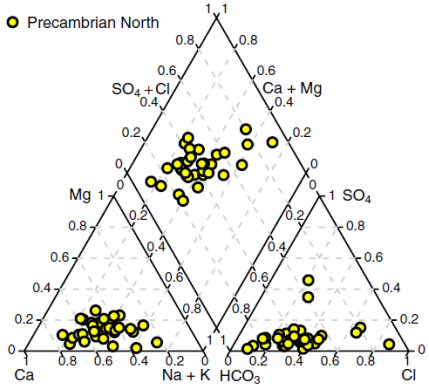


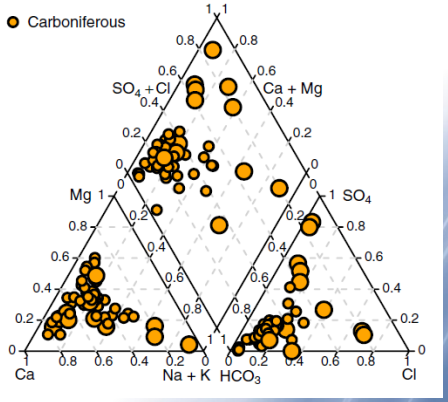
Major ions

- A range of water types – including Ca-HCO_3, Na-HCO_3, Na-HCO_3, Na-SO_4 & Na-Cl
- The highest concentrations of major ions are in Carboniferous (mined & unmined) – reflects presence of carbonate and silicate (e.g. clay) minerals, and acidic conditions related to post-mining effects



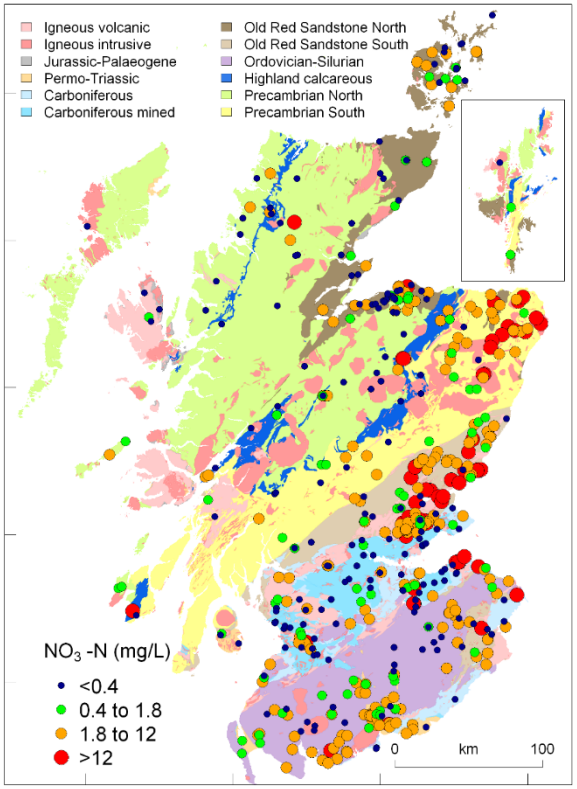


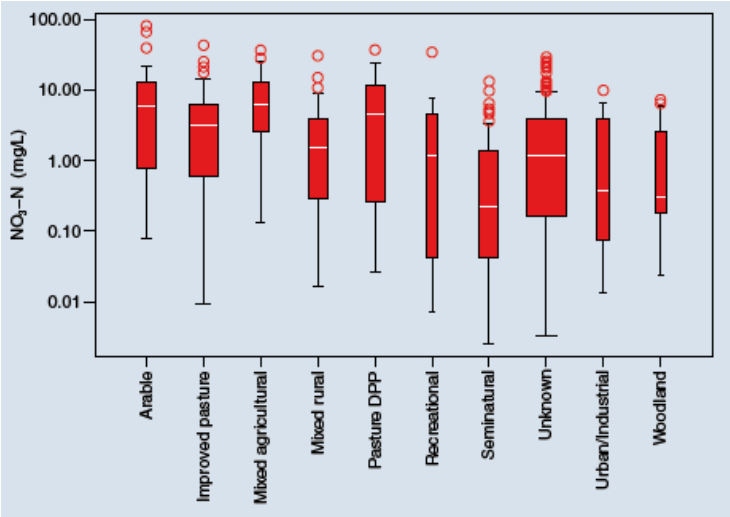




Nitrate (NO_3)

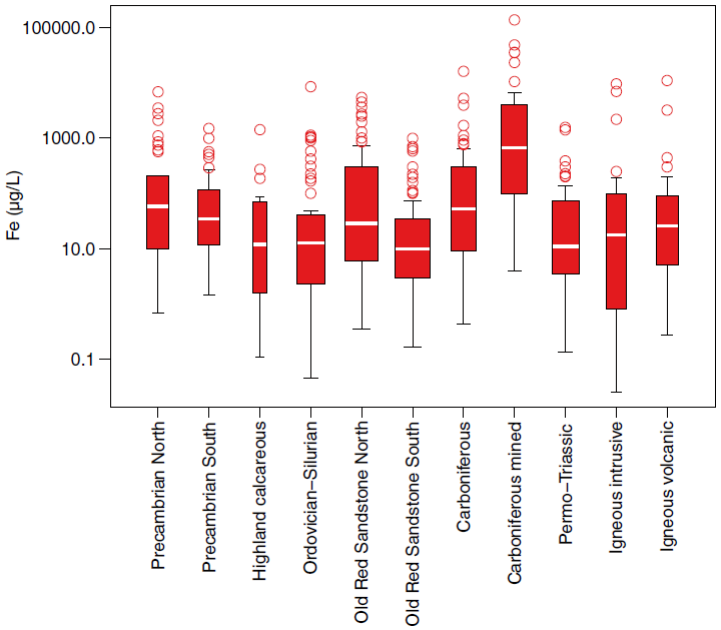
- High nitrate in many aquifers
- Strong link with land use: highest median NO_3 below intensive agricultural land (esp DPP); lowest below seminatural, woodland & urban / industrial
- Clear spatial trend – highest NO_3 in east in areas of greatest agricultural activity

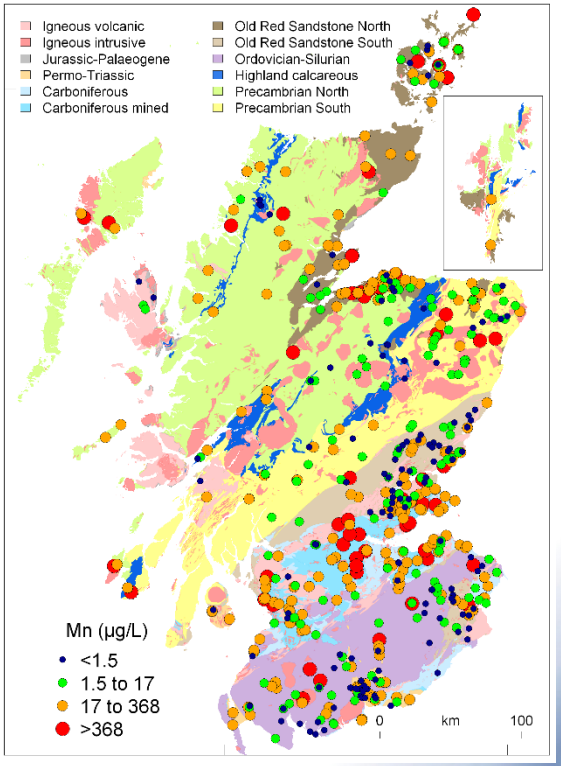




Iron and Manganese

- Low in most bedrock groundwaters, related to the generally oxic conditions
- Can be high where groundwater is reducing, e.g. Old Red Sandstone North & Carboniferous (especially mined – where Fe from pyrite is also possible)

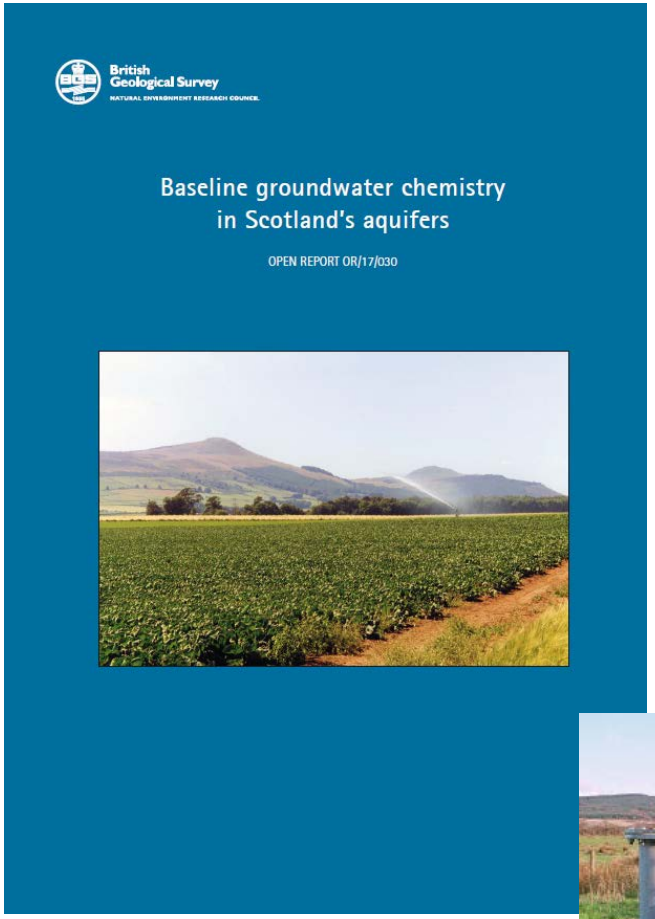




Summary

- Scotland’s groundwater chemistry is naturally highly variable
- Natural groundwater chemistry reflects:
  - Host aquifer lithology
  - Mineral reactions (e.g. silicate & carbonate dissolution, sulphide oxidation & ion exchange)
  - Redox conditions
  - Residence time
- Groundwater chemistry also reflects human influences, especially:
  - Land use
  - Groundwater abstraction (e.g. saline intrusion)

Much more detail in this report!



http://nora.nerc.ac.uk/id/eprint/519084/

Thankyou