Nutrient Use Efficiency and Biosolids

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Background

- Project is funded by SARIC (Sustainable Agriculture Research and Innovation Club) and NERC (Natural Environment Research Council) as an innovation not research project.
- An attempt to make better use of academic knowledge in a practical, environmentally benign and economically useful way.

Our aims and objectives

- Identify key environmental factors that influence Nutrient Use Efficiency,
- Synthesise existing knowledge to generate spatially explicit data
- Consult with stakeholders to determine the **best use** of biosolids
- Disseminate knowledge through a “Data Hub” such as LandIS.

- “Best” for SARIC ≈ efficient, resilient, sustainable?
- “Best” for water companies ≈ trouble free, simple?
- “Best” of EA ≈ material disaggregated in pure chemicals?
- “Best” for environment ≈ BATNEEC (best available technology not entailing excessive costs) or BPEO (best practical environmental option)?

Nutrient Use Efficiency and Biosolids

- Data mostly from experimental farms.
- Data mostly small-scale and short-term (some exceptions)
- Data mostly ignores management skill
- Most experiments NUE of N
- Most reports end by stressing importance of P
- Crop uptake for at least 3 years after application of biosolids (complicates estimating the “Fertiliser Replacement Value”).
- Tens of thousands of farmers have been using biosolids for decades, *theoretically*, there is large amounts of information on agronomic, economic and environmental effects, but …

Importance of Phosphate

- Phosphate is a strategically important, non-renewable, heterogeneously distributed resource
- Conventional agriculture depends on imported rock Phosphate (mostly from Morocco which has >80% of economically exploitable resource)
- Biosolids contain usable concentrations of Phosphate
- NUE of P is generally less than N, BUT, P uptake is very dependent on:
  - Soil concentration
  - Chemical form of the P compound
  - Whether plant growth is limited by other nutrients
  - Time period over which uptake is measured (years)
- Phosphate can pollute, but, leaching from biosolids can be LESS than from conventional fertilisers.

Where's the best place for biosolids?

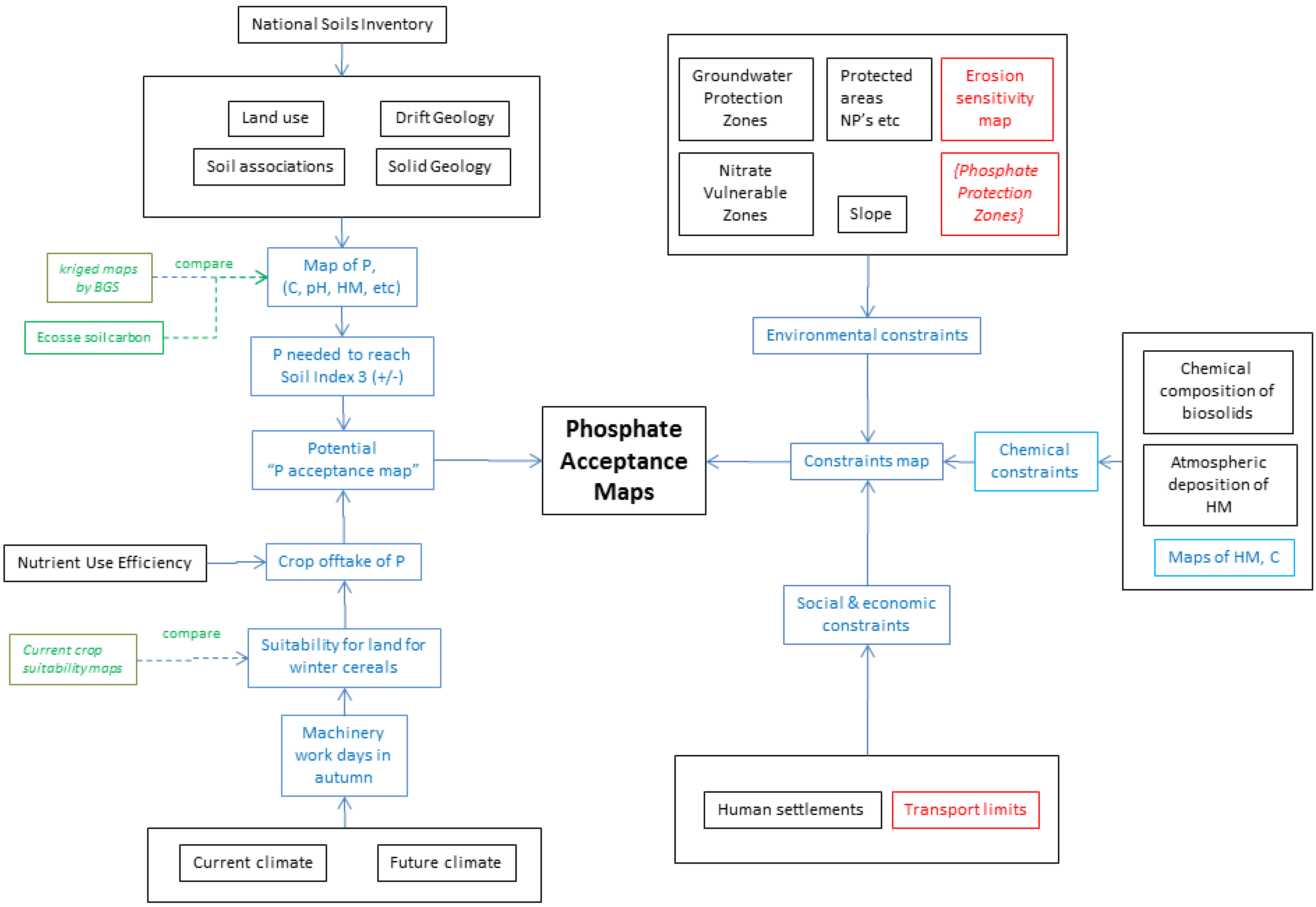
Agronomic Need

- "safe sludge matrix" allows application on many crops, but, most is on winter cereals or improved grass.
- cereals ~ offtake in seed and straw
- Improved grass ~ offtake in silage (usually) or hay
- Soils ~ mid-point of "index 2" ~ 20 mg/l Olsen-P

Subject to constraints from:

- Protected areas eg SSSI, National Parks, groundwater zones etc
- Heavy metal accumulation etc
- Risk of erosion and runoff etc
- Economic costs etc

Schematic Flow of Information



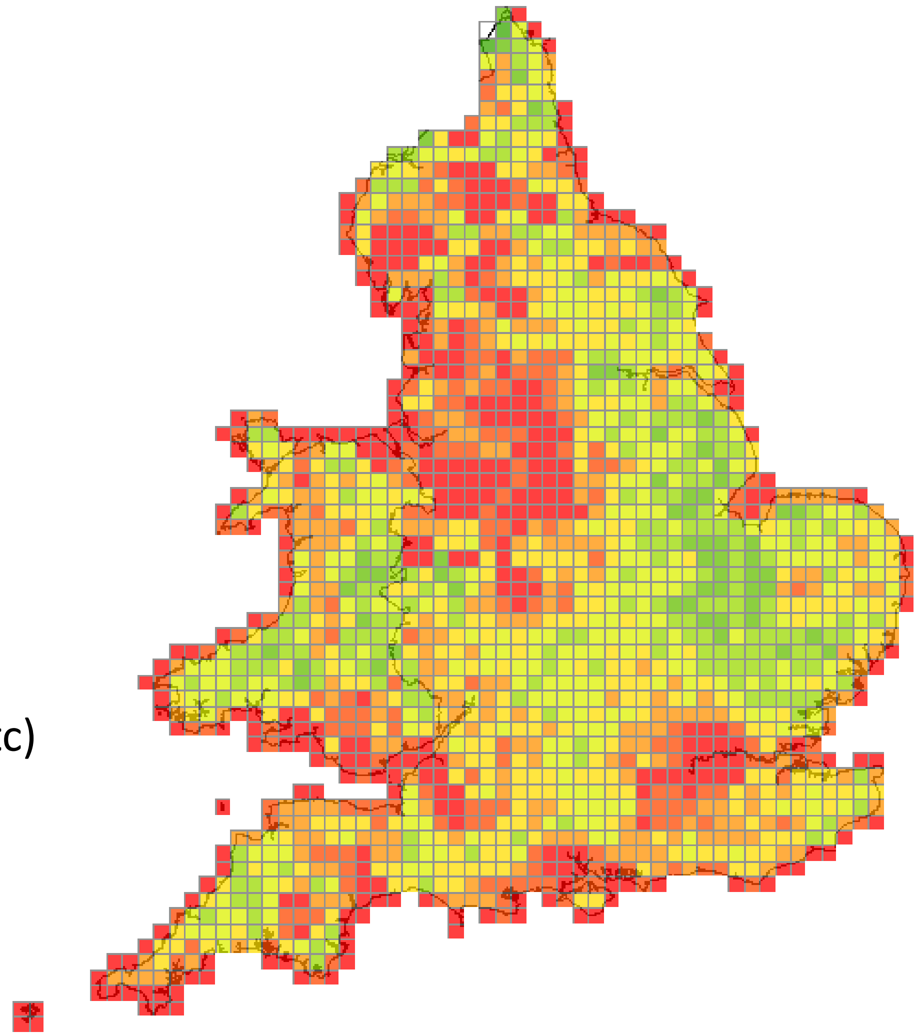
Where to use Biosolids

Agricultural Landbank Capacity Estimator (ALOWANCE) (developed by ADAS)

Issues:

- 10 km resolution
- Primarily ability of agricultural land to absorb additional Nitrogen
- (No measures of uncertainty / variability)
- (No longer funded)
- There is a more detailed version, but …

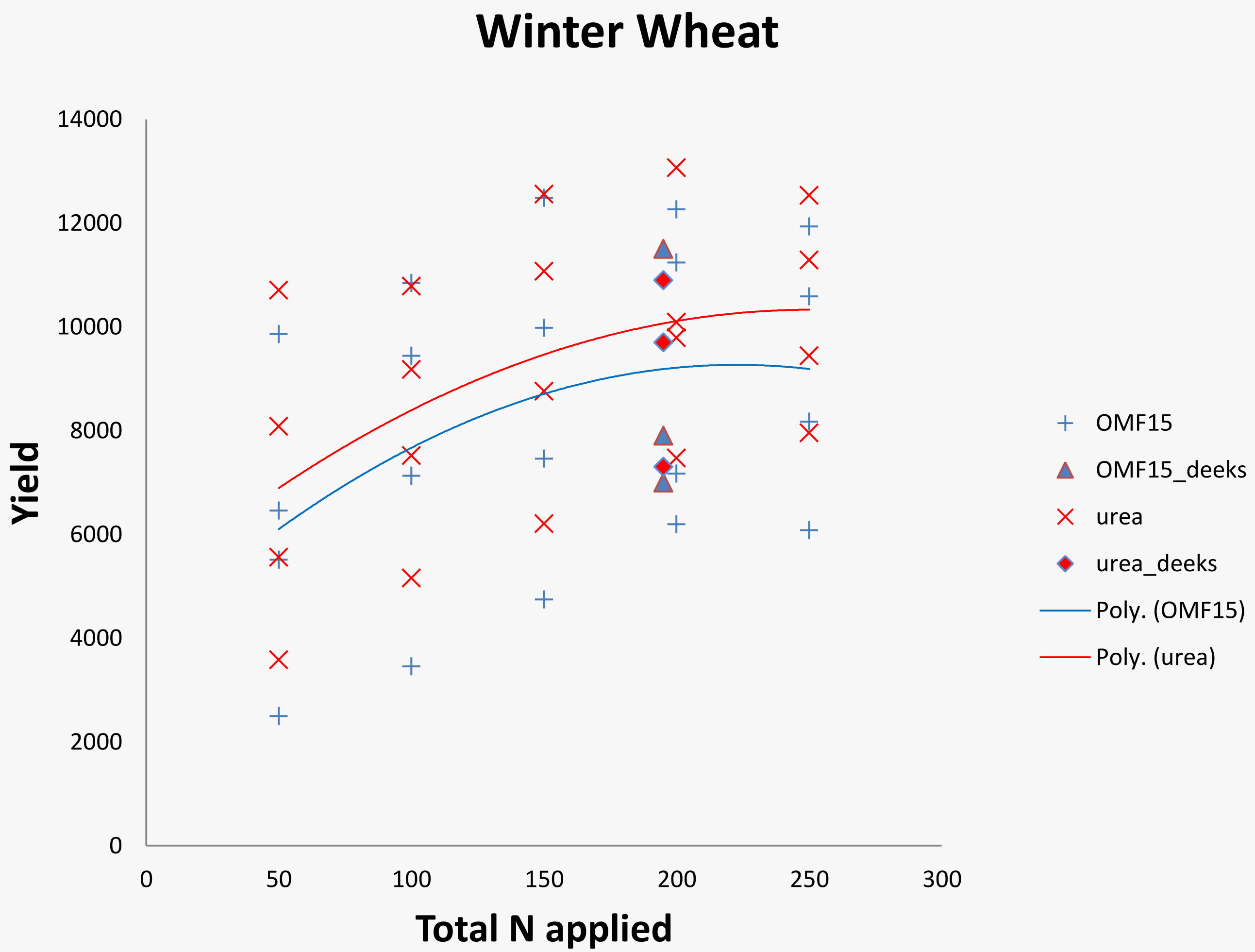
There also exist Slurry Acceptance Potential Models (based on soils, slope and climate etc)



Nutrient Use Efficiency

Meta-analysis suggests Biosolids and organo-mineral fertilisers slightly less effective than conventional fertilizers, but, lots of “noise” and not statistically significant.

Inter-annual variation (ie the weather) is the major source of variation.



Heavy Metals eg Cd

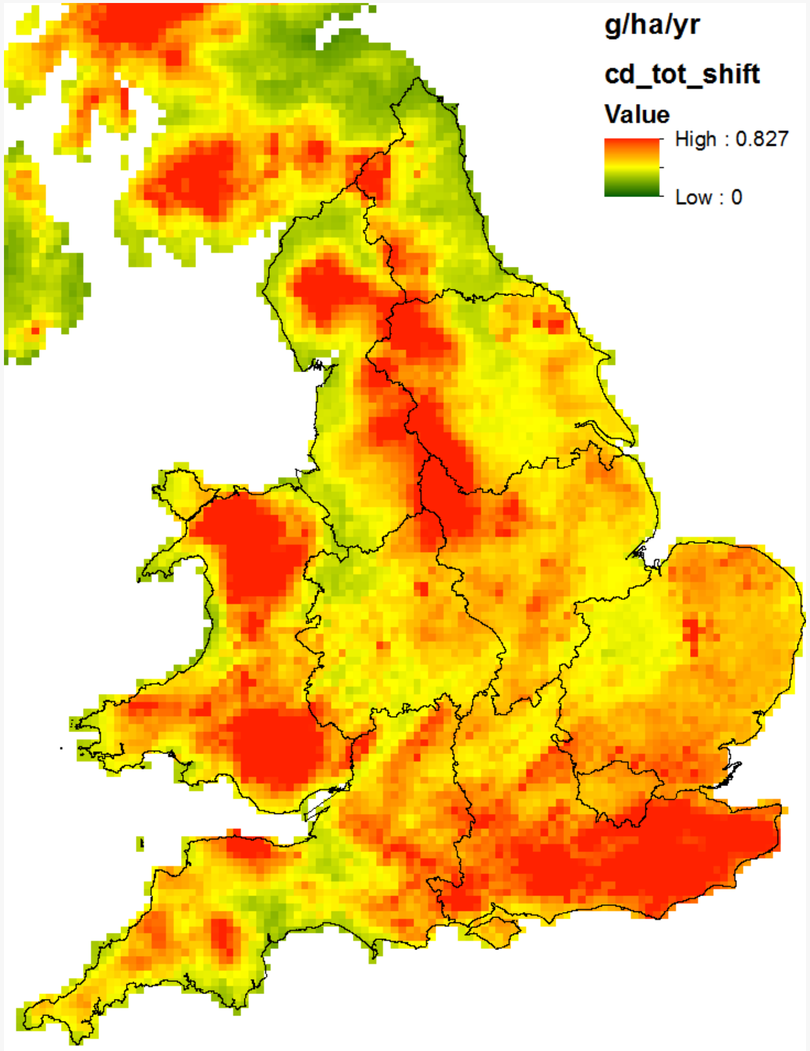
Total atmospheric Inputs of **Cd** in 2011 (wet + cloud + dry)

Most of England and Wales
< 600 mg/ha/yr

Atmospheric deposition ~53% of total input to agricultural land

(Rural monitoring network previously funded by Defra)

(Note recent experiments suggest that Zn and Cu more important for soil health)

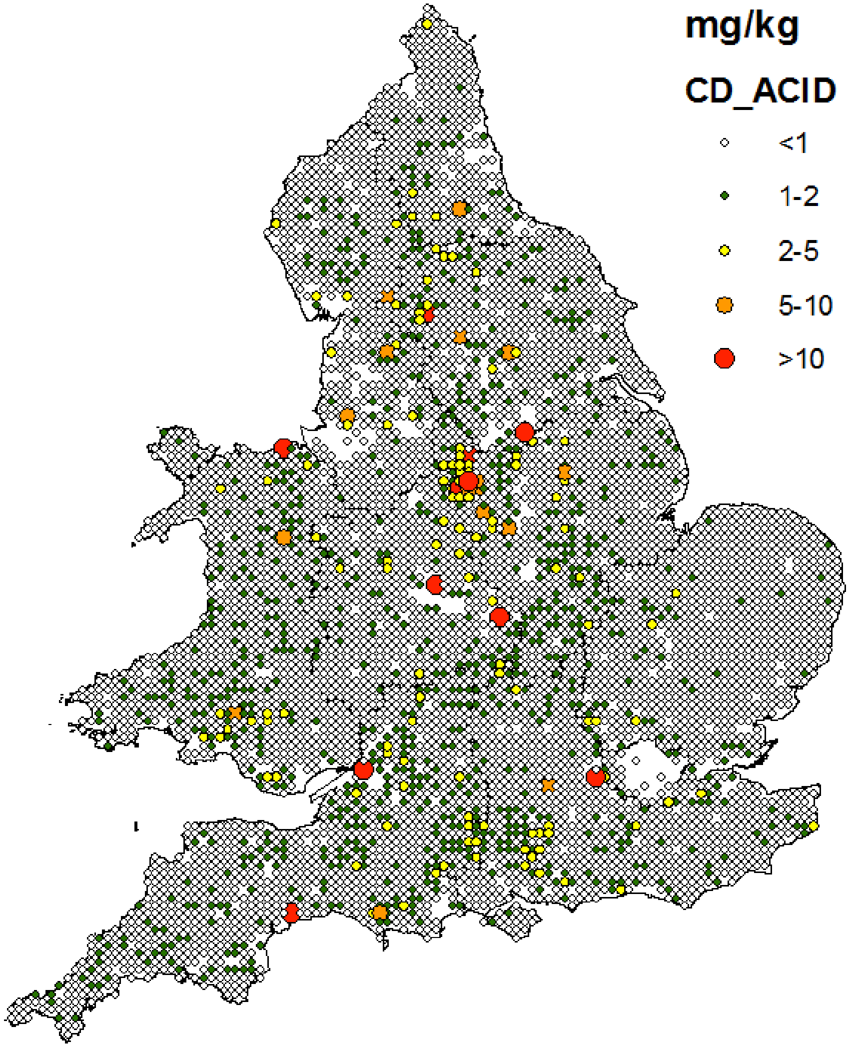


National Soils Inventory
Cd in Soils

Point data with a 5km spacing.

Some high values can be related to:

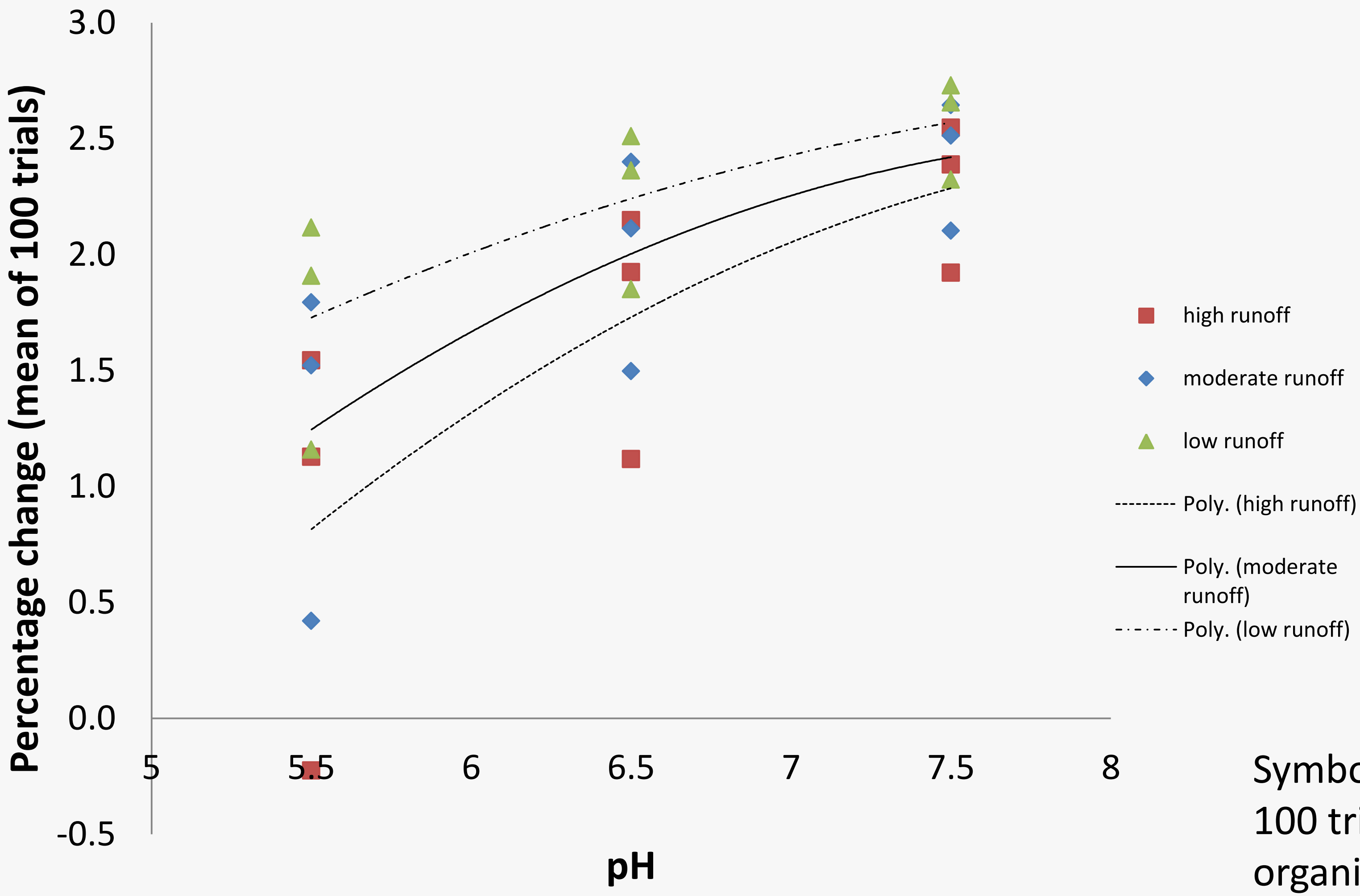
- Past land use, (eg low quality Phosphate fertilisers on Salisbury Plain),
- Pollution, (eg Avonmouth Smelter),
- Geology, (eg some marine clays)
- Topography (eg high rainfall areas).



Monte Carlo Simulations of a Cd in Arable Soils

- Crop – continuous wheat – yield 5 to 7 t/ha/yr
- P_2O_5 requirement 28.9 to 43.1 kg/ha/yr
- Assume no erosion, but some leaching
- Assume objective to keep soil P more or less constant
- Cd concentration in wheat 0.07 to 0.09 mg/kg DW
- Cd atmospheric input 200 to 300 mg/ha/yr (wet + cloud + dry)
- Runoff at 3 levels 0.15 to 0.45, 0.25 to 0.55 or 0.35 to 0.65 m/yr
- Percentage P in biosolids 1.48% to 2.78% (inter-quartile range UU)
- Concentration of Cd in biosolids 1.08 to 1.95 mg/kg (inter-quartile UU)
- Concentration of Cd in conventional fertiliser 20 to 40 mg/kg
- Conversion between P_2O_5 and P = 0.4364
- Cd leaching depends on concentration in soil pore water
- Concentration in soil pore water:
  - Increases with concentration in the soil
  - Decreases with soil pH (3 levels simulated 5.5, 6.5 & 7.5)
  - Decreases with soil organic matter (3 levels simulated 1%, 3% & 5%)
- 30 years simulation, 100 trials at each permutation of pH, OM and runoff range

Monte Carlo Simulation of Cd Continuous application of Biosolids



Symbols median of 100 trials (different organic matter contents)

Monte Carlo Simulation of Cd comparison of Biosolids and conventional P_2O_5 fertiliser

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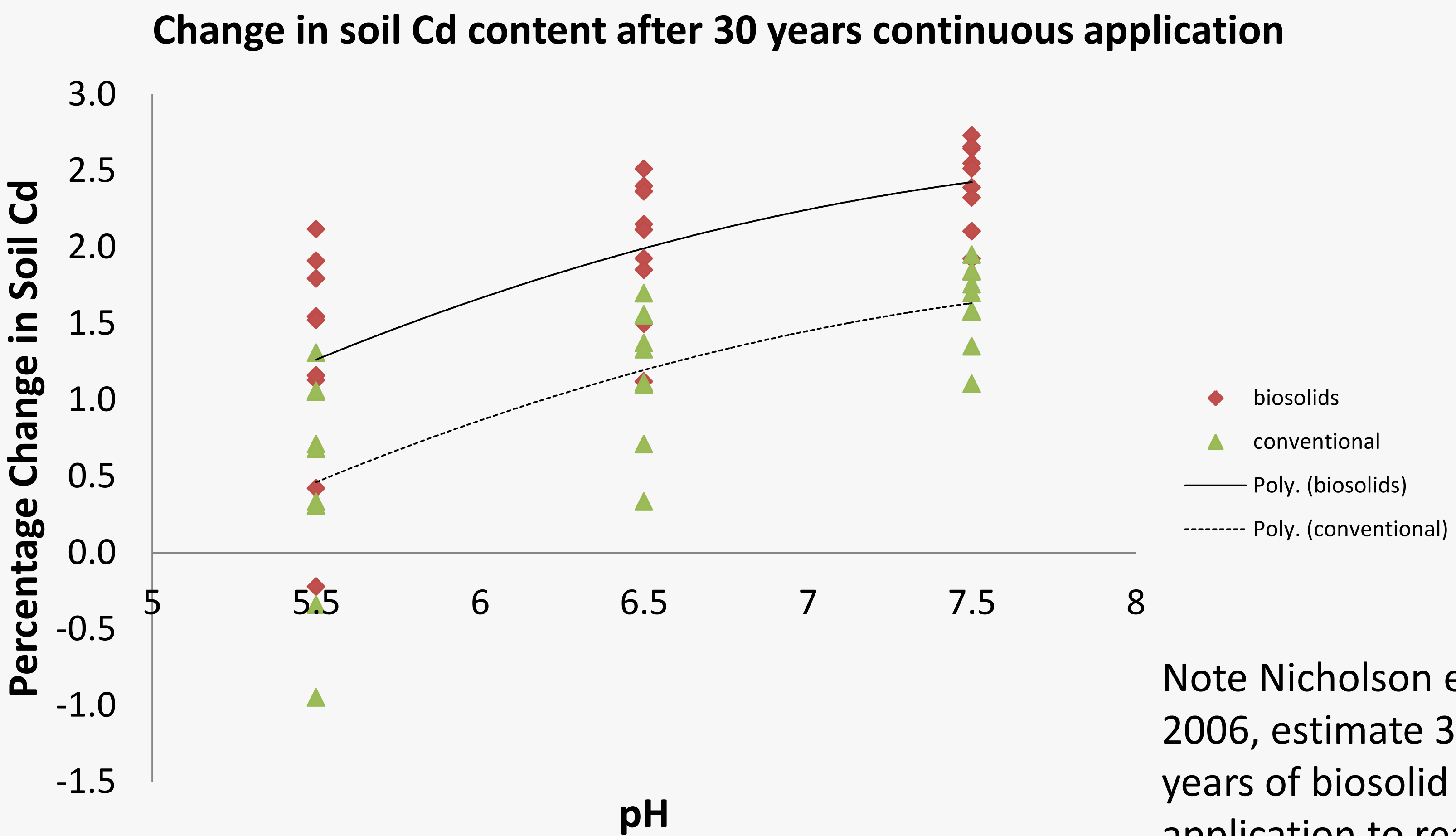
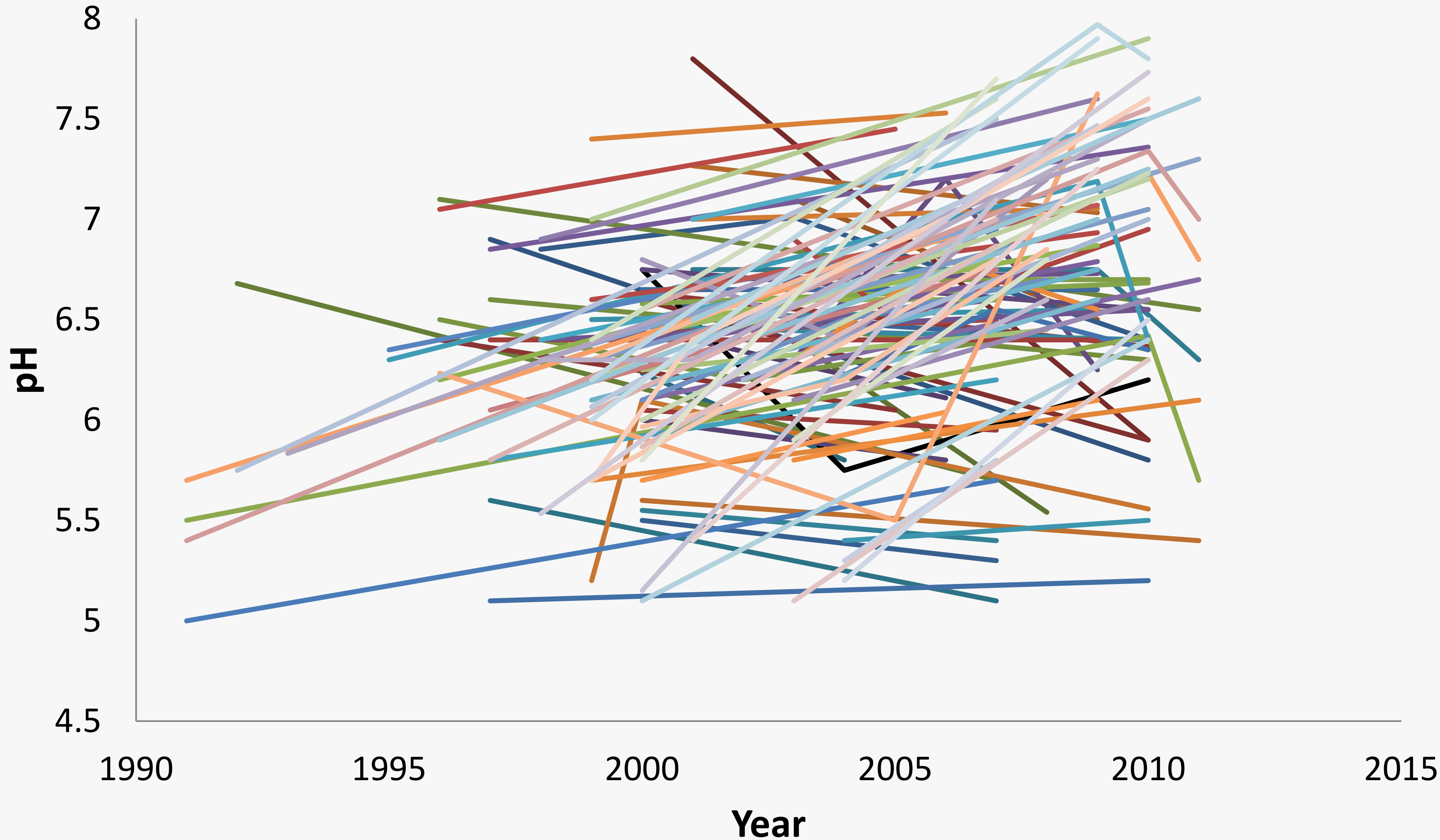


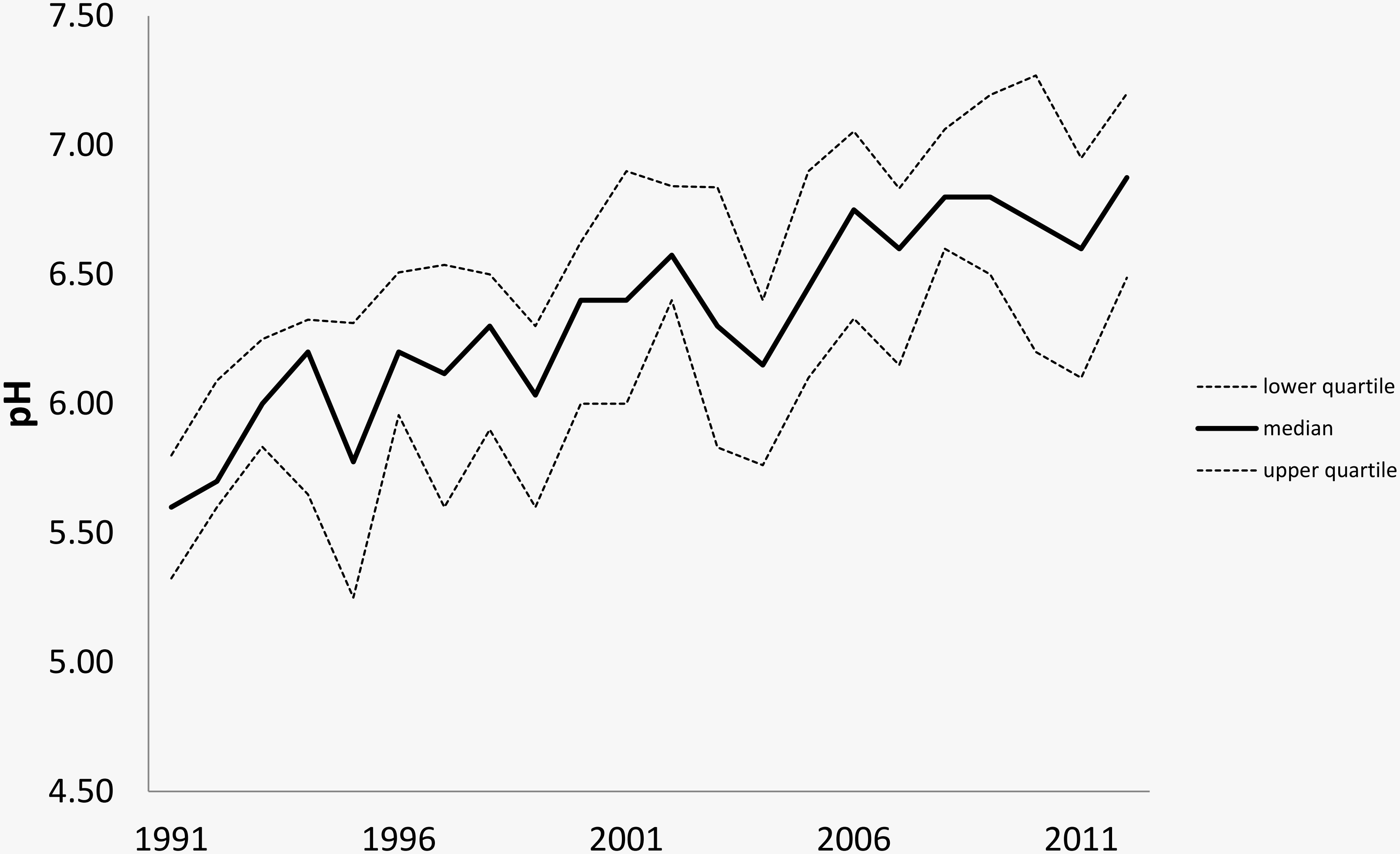
Note Nicholson et al 2006, estimate 352 years of biosolid application to reach advisory level

Change in soil pH over last 20 years (UU fields with planned application)

(sample of 100 fields)

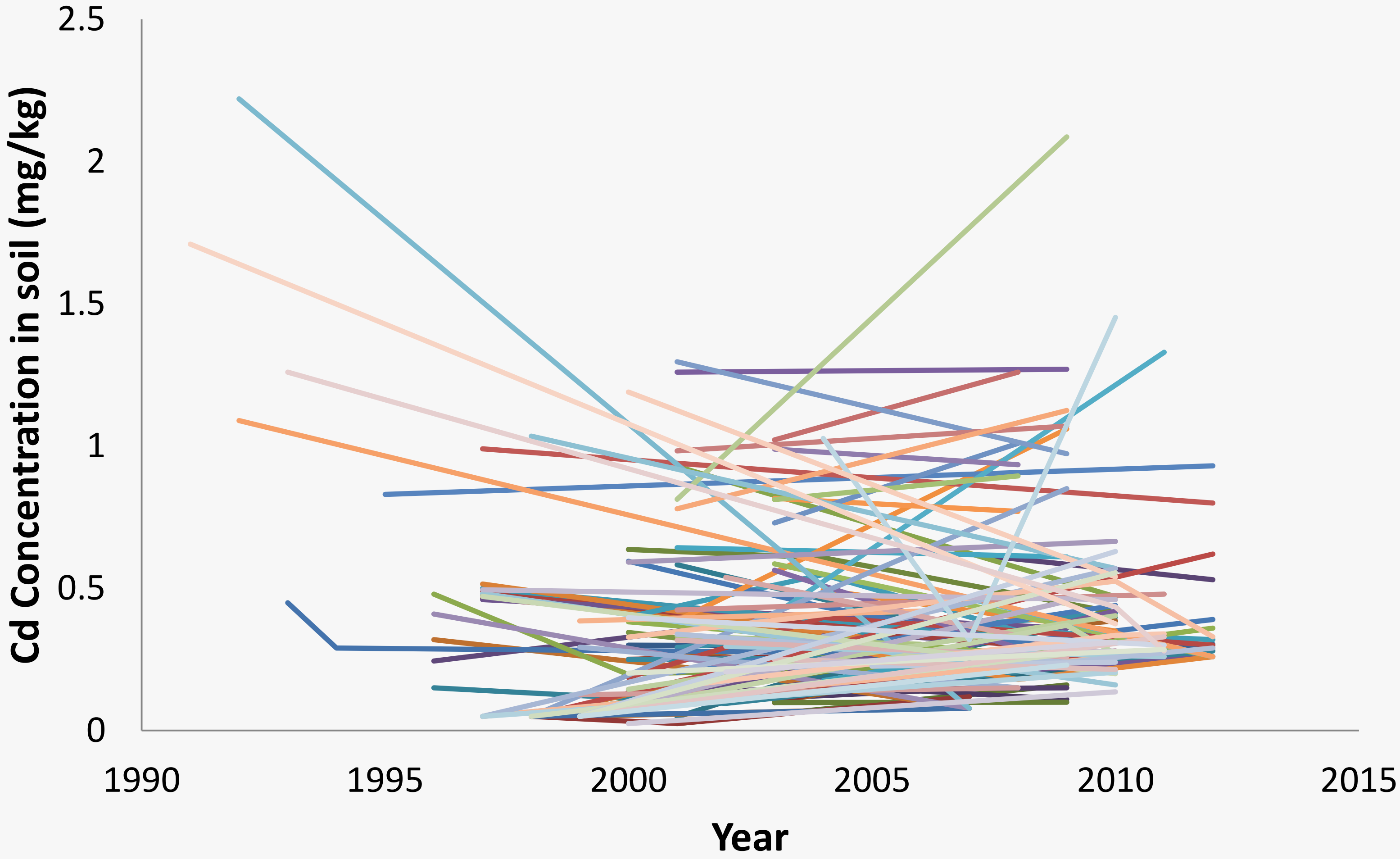


Change in pH over 20 years
(all UU data)

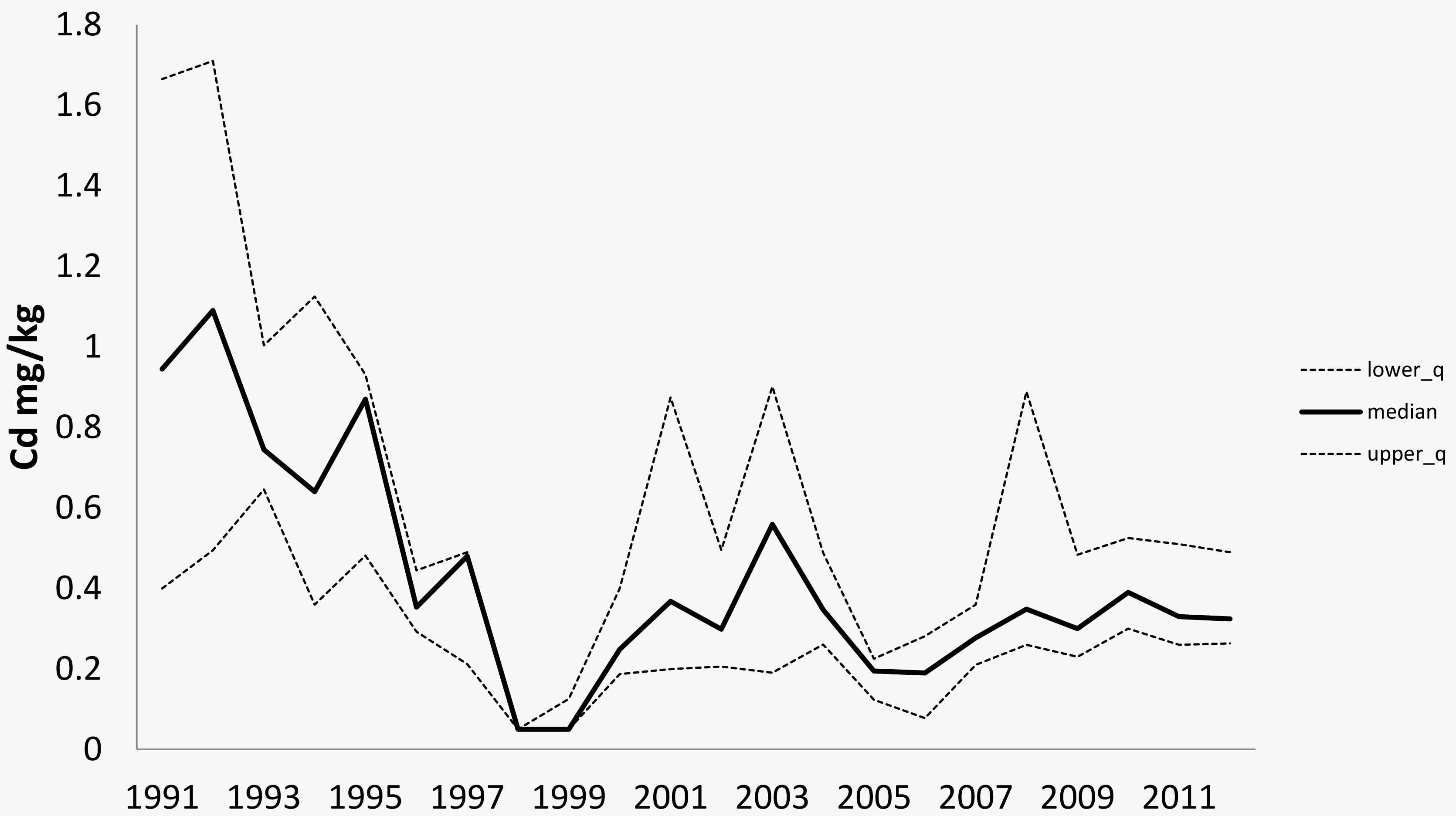


Observed Change in Cd in Soils

(sample of 100 fields from UU data)



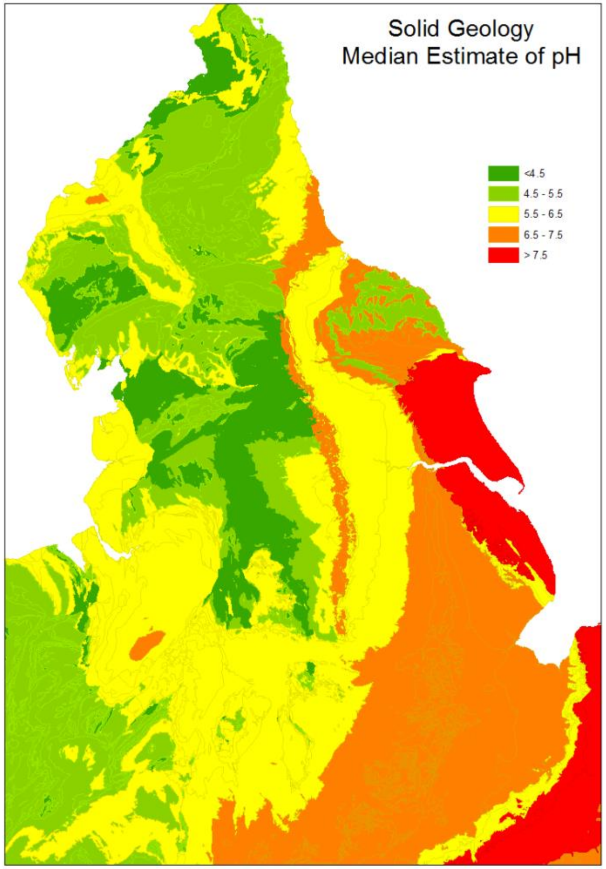
Observed changes in Cd
(all UU data)

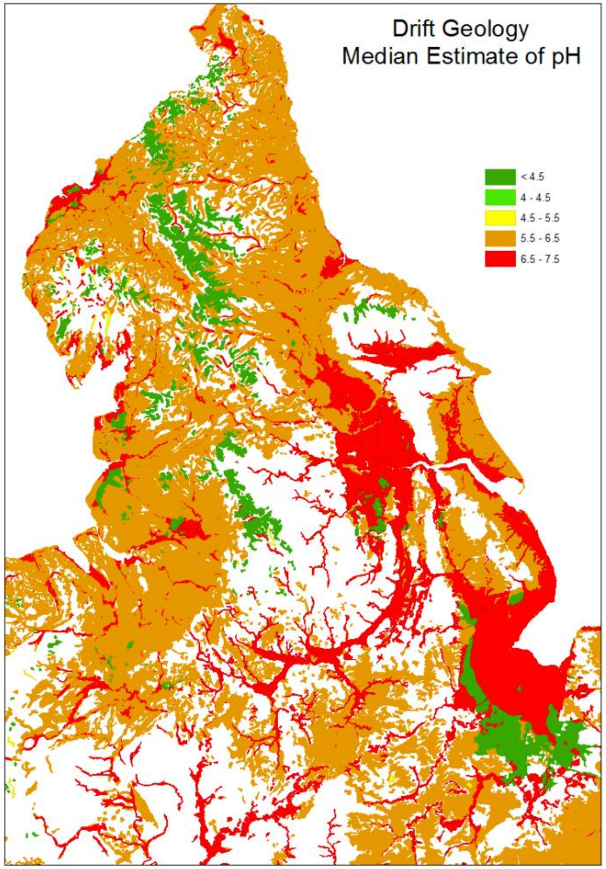


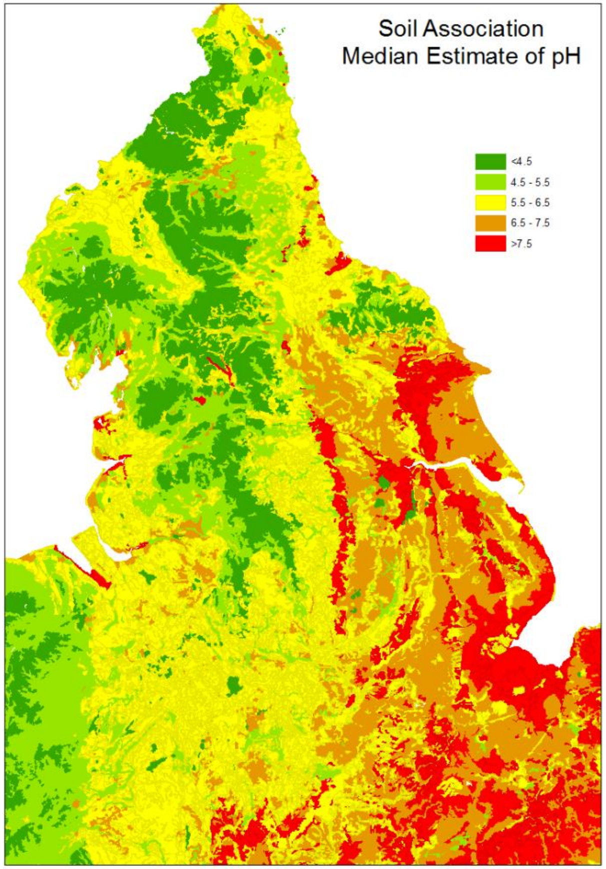
National Soil inventory, extrapolation

- National Soils Inventory – most comprehensive record of soil chemistry
- Samples at 5 km intervals
- Samples not chosen to be “representative” of the local landscape
- Spatial auto-correlation is low
- Interpolate NSI data by using median regression against soil associations, solid and drift geology and land use.
- Median regression allows direct calculation of inter-quartile range for any soil property in the NSI (carbon, pH, P-Olsen etc)
- Weighted average of predictions from the 4 regression equations where the “weight” is proportional the statistical significance of each class.
- Example: from “drift geology”
  - class “peat” = strong support (weight) for high soil carbon
  - class “clay with flints” = no support for any level of soil carbon.

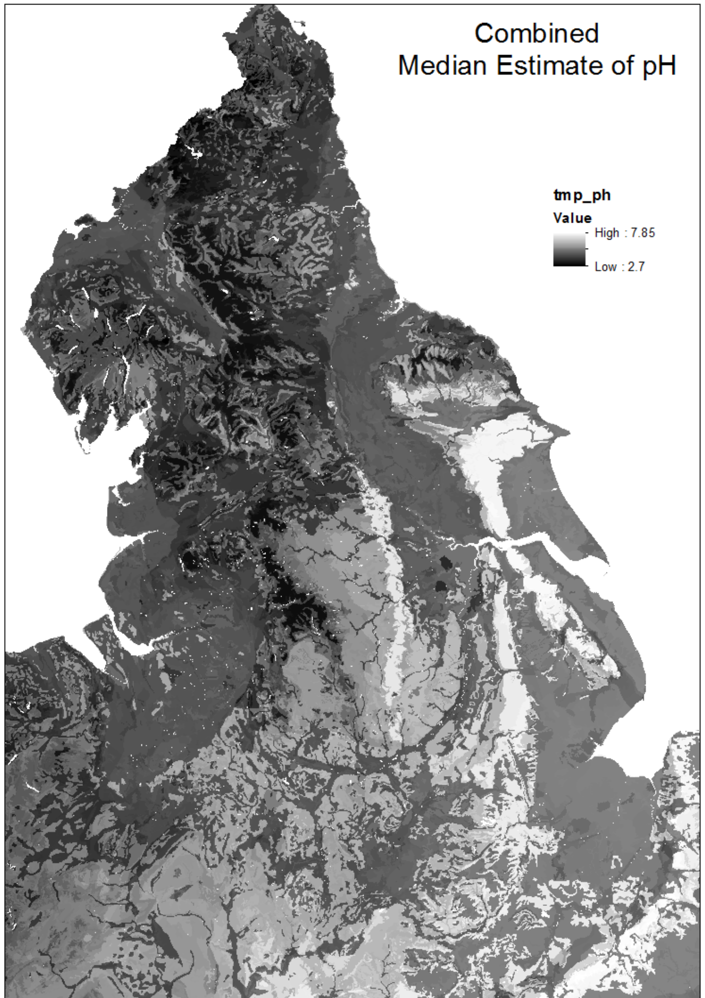
Example – Soil pH (median estimate)

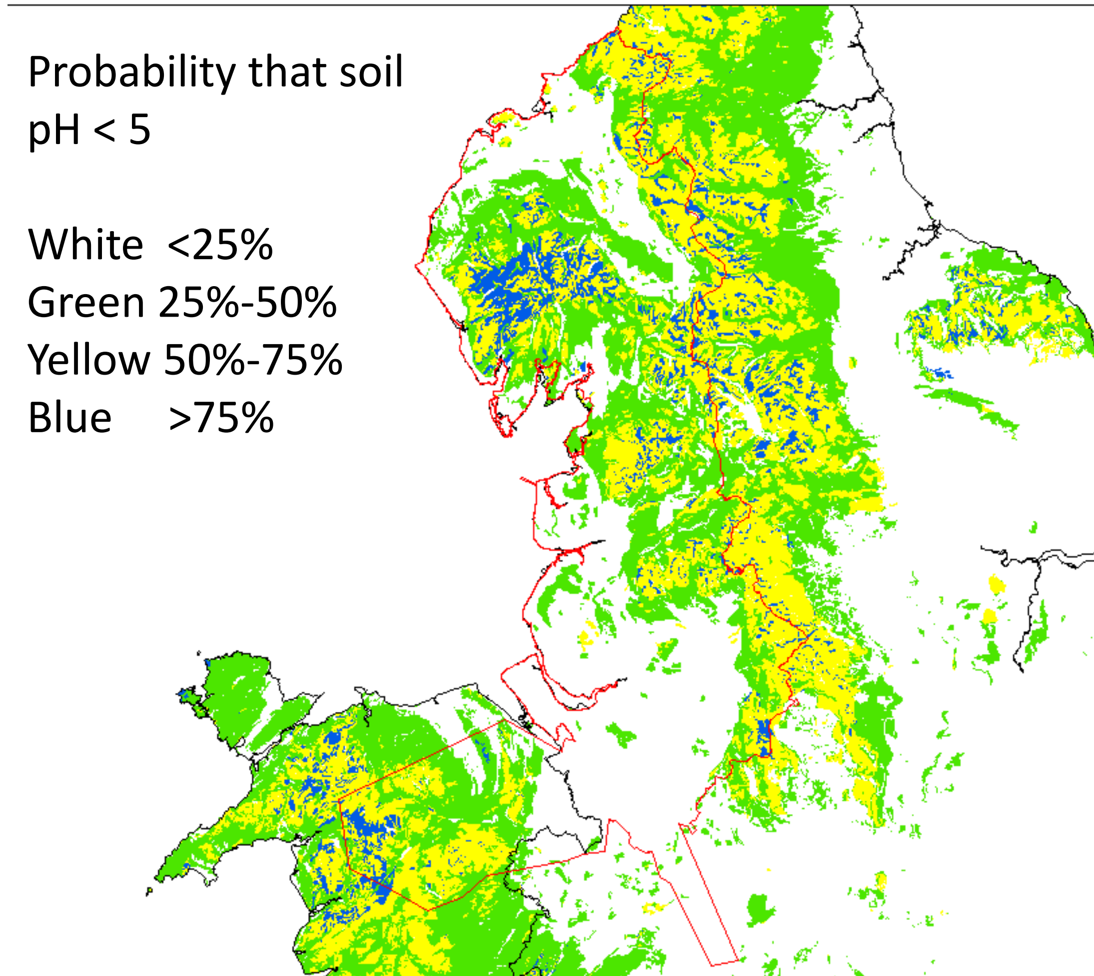






Combined data

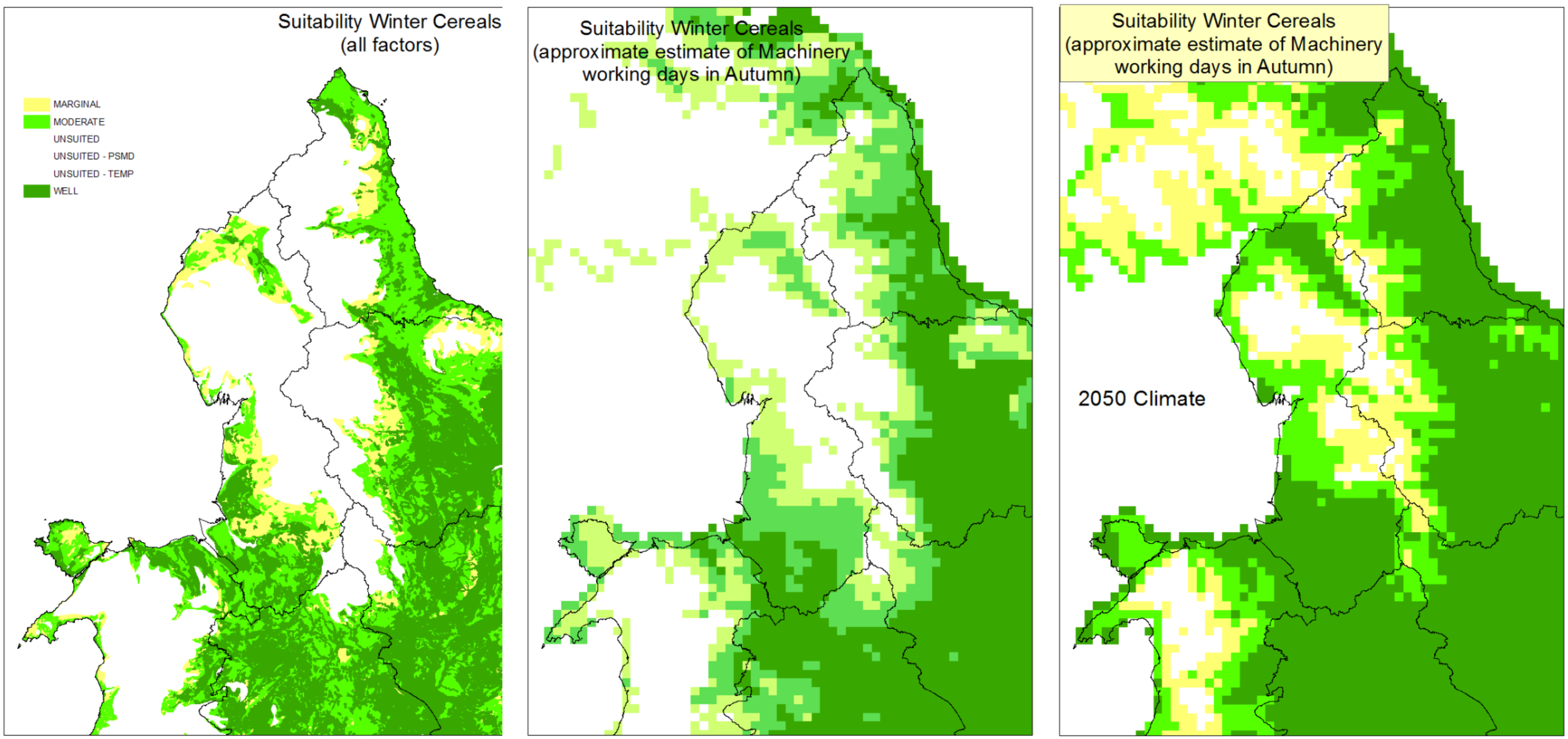




Need for Phosphate

- “Safe Sludge Matrix” allows application of biosolids to many crops.
- Some “unexpected” constraints on biosolids eg not allowed on organic farms, not allowed on malting barley …
- Modelled 2 crops, winter cereals and improved grass.
- Area suitable for the 2 crops under current climate and predicted climate in 2050
- Fertiliser recommendations from RB 209.

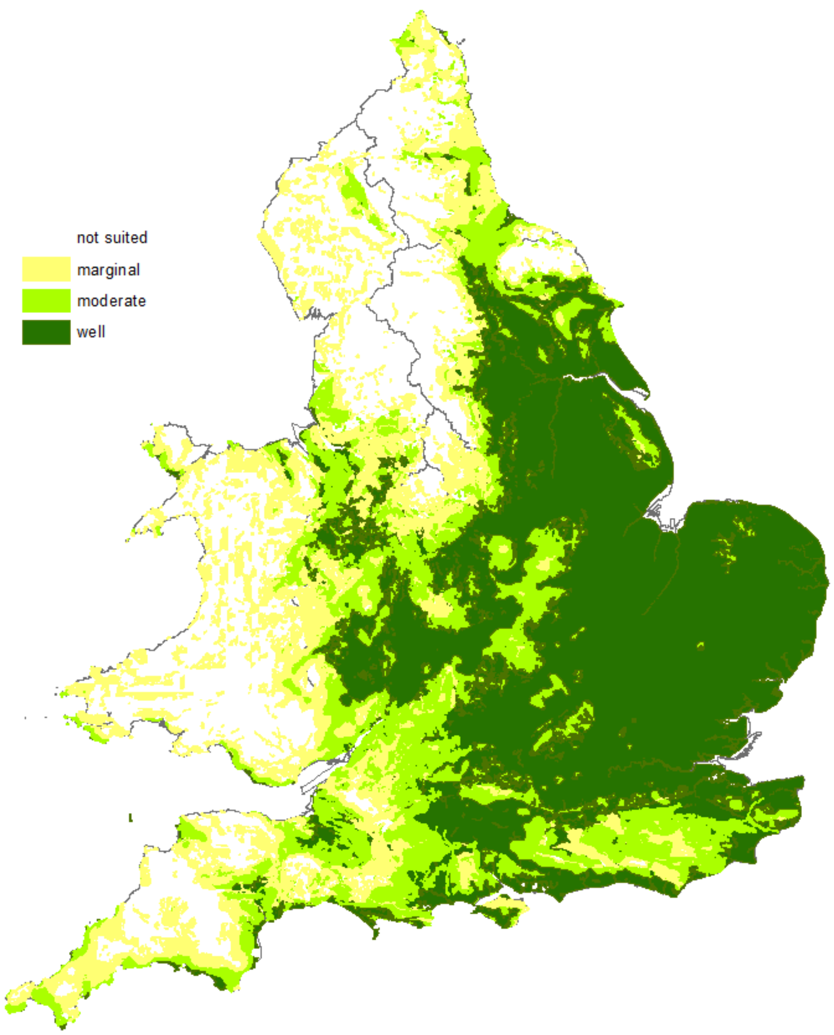
Land Suitable for Winter Cereals
(increase in suitable area by 2050)



P_2O_5 requirements Winter Wheat
(RB 209, Fertiliser recommendations)

Well suited = 8t/ha = 67 kg/P_2O_5
Moderately suited = 6 t/ha = 50 kg
Marginal = 4 t/ha = 34 kg

"Correction" for existing soil-P concentration
Soil P index 0 or 1 = + 40 kg
Soil P index 3 or more = – 40 kg



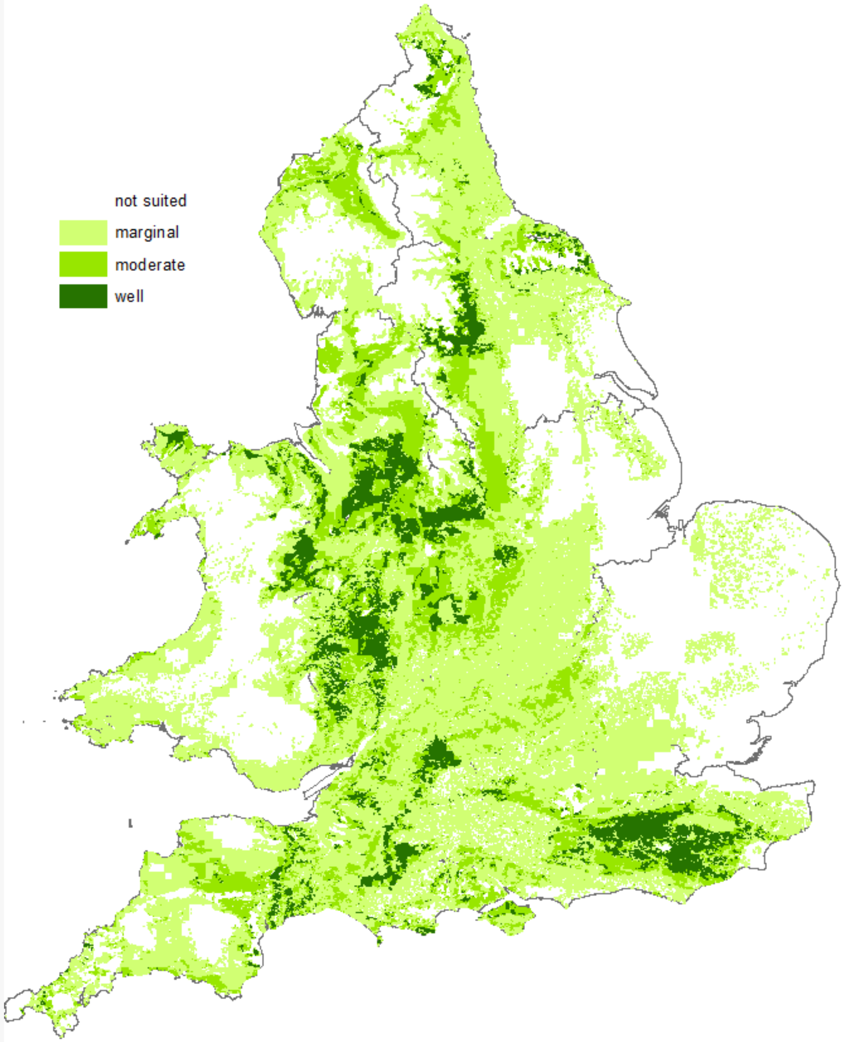
P_2O_5 requirements Silage & Hay

$P_2O_5 = 141 – 3.49 * Soil\_P$

Suitability for improved grass = f(elevation, soil association, pH, organic matter, rainfall)

Farm Business Survey – relative area of hay v silage

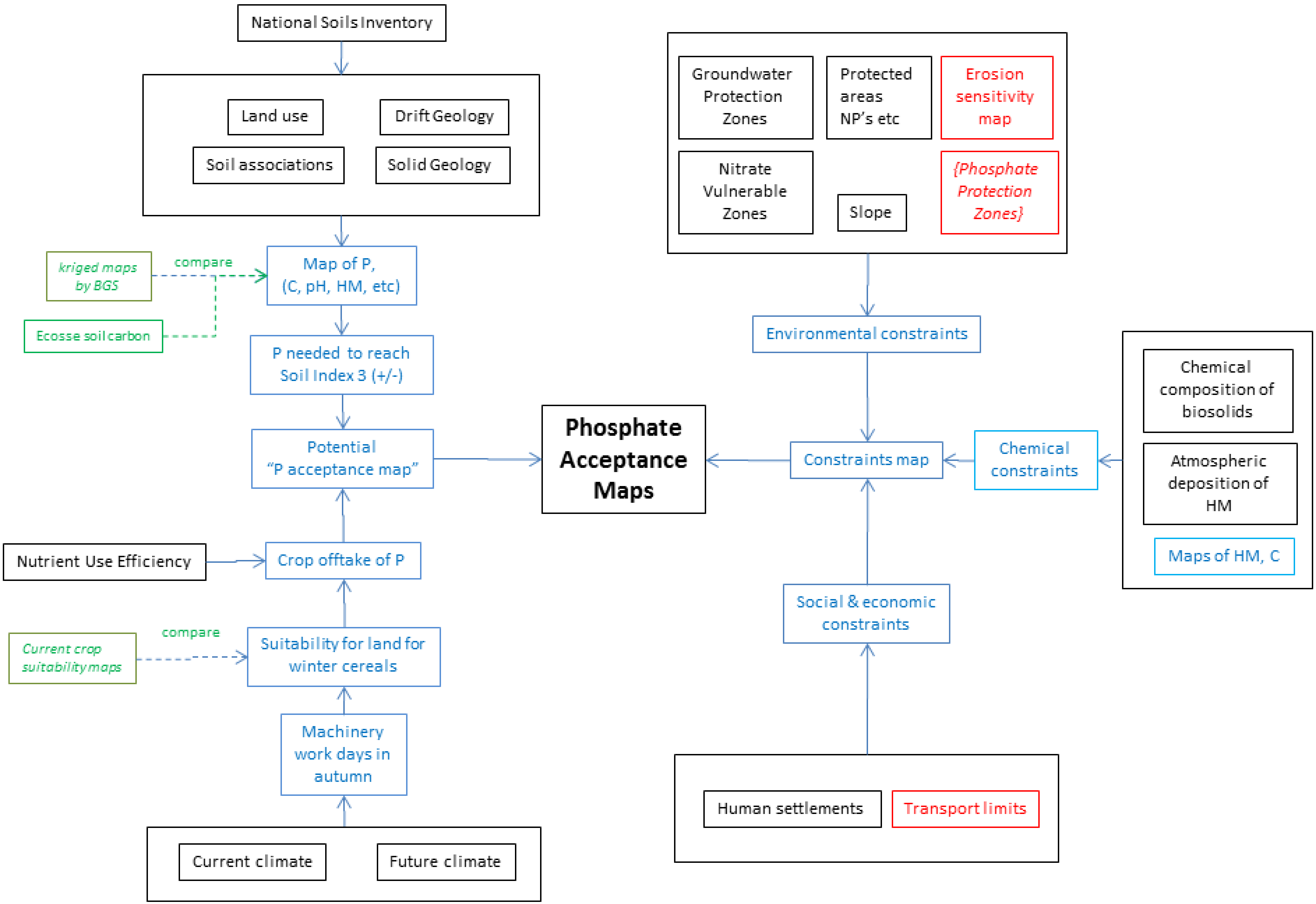
RB 209 – fertiliser requirements by intensity (number of silage cuts) and soil P-index



Phosphate Acceptance Maps

- Combined need from Winter Wheat plus improved grass under current climate and predicted for 2050
- Subject to constraints / concerns by different stakeholder groups

Schematic Flow of Information



Qualitative assessment of attitudes towards biosolids

Stakeholder	not used	problems		successful
		Pollution / nuisance	Poor yields	
Individual Farmers		☹	☹☹	☺ ☺ ☺
Food industry		☹☹☹		
NFU		☹	☹	☺
General public		☹☹		
Fertiliser producers	☺		☺	☹
Fertiliser merchants/blenders		☹	☹	☺
EA / Defra		☹ ☹ ☹		☺ ☺
Water companies	☹	☹ ☹		☺ ☺ ☺
DECC	☹ ☹	☹		☺ ☺
SARIC / RC		☹ ☹	☹	☺ ☺

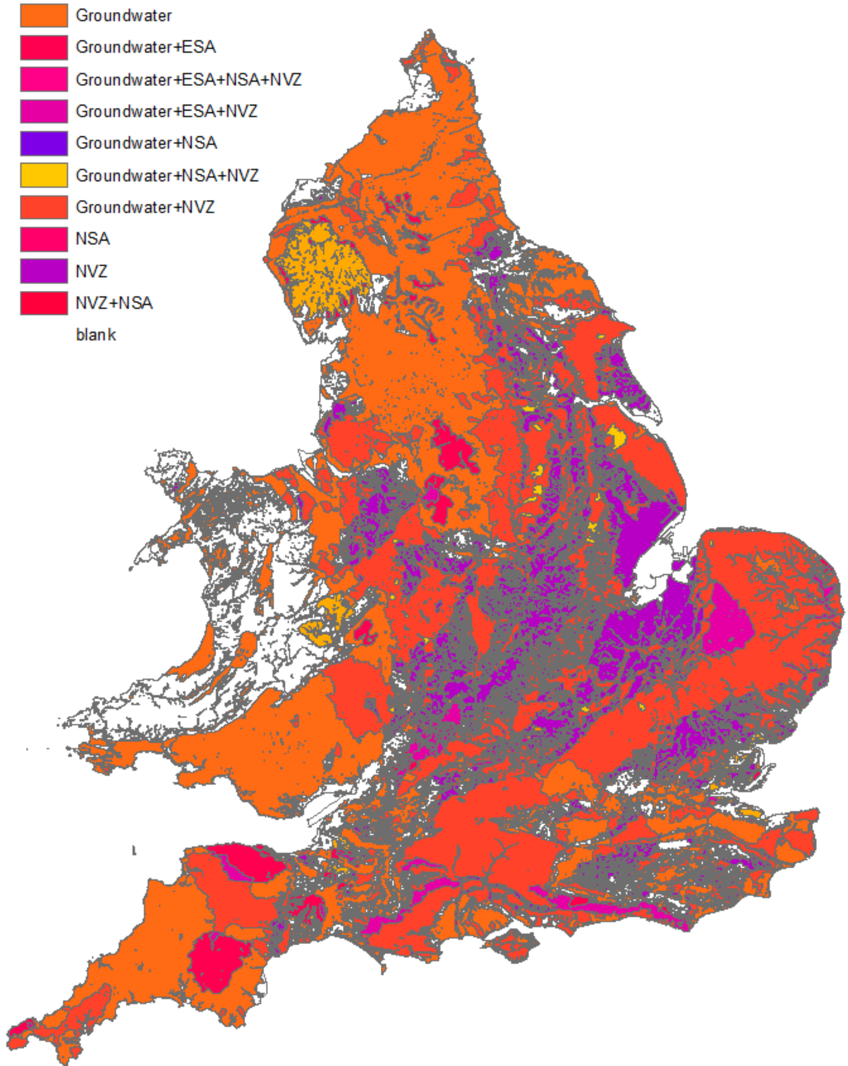
Stakeholder groups and physical constraints

Constraint	Group 1	Group 2	Group 3	Group 4	Group 5
Protected Area - pollution	*	*			
Protected Area - biodiversity	*		*		
Protected Area - landscape	*		*		
Heavy metal accumulation	*			*	
Erosion > soil formation	*			*	
Distance transported	*				*

Protected Areas – Pollution – (NVZ), NSA, Groundwater etc

Many multiple designations

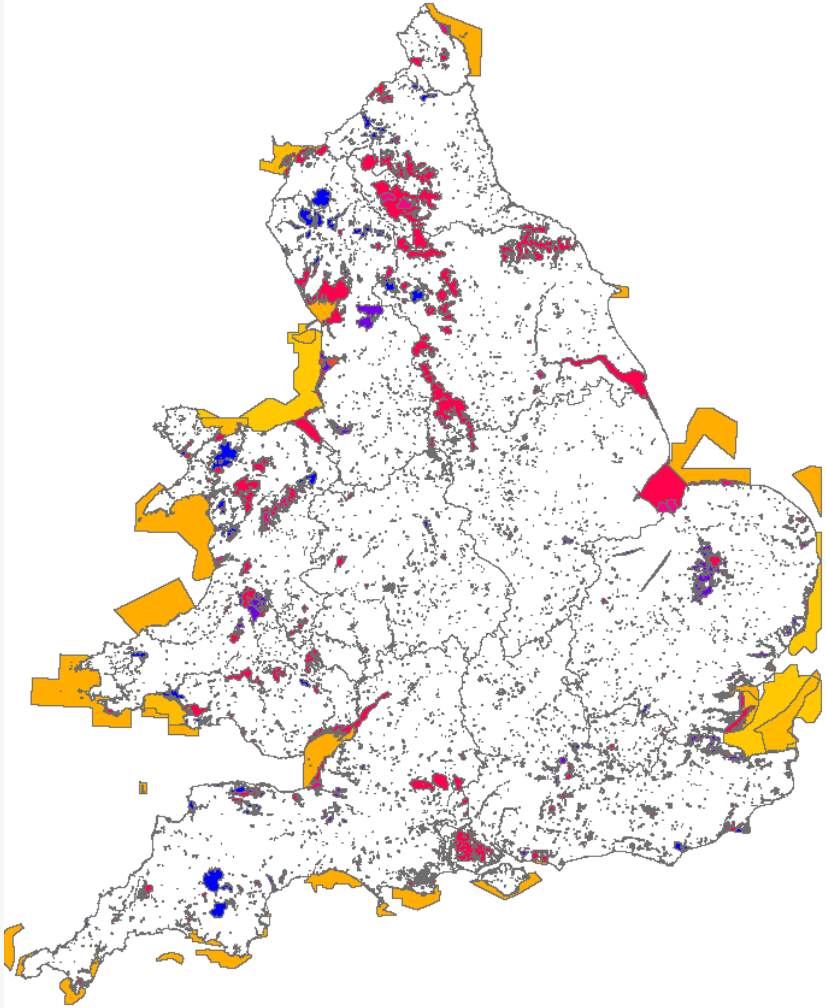
NVZ considered a constraint on management and timing not on use.



Protected Areas – Biodiversity – SSSI, NNR, SAC, SPA etc

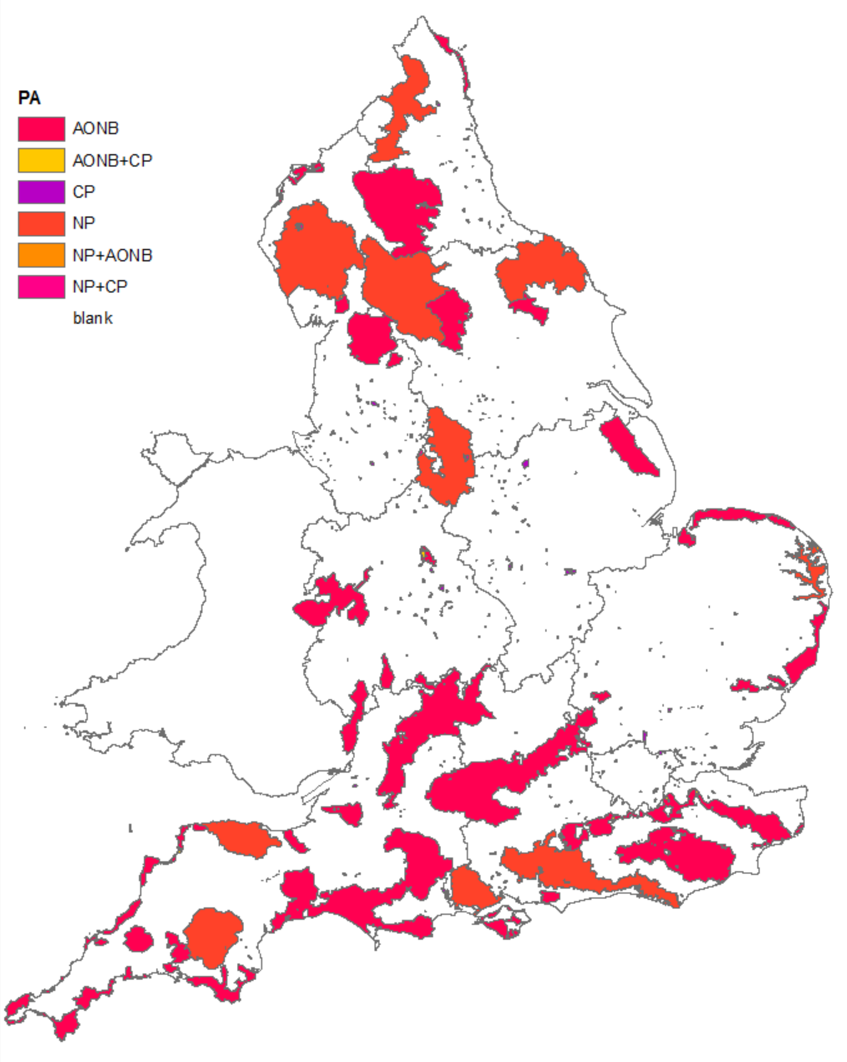
Many areas have multiple designations eg:

SSSI + NNR + SAC etc

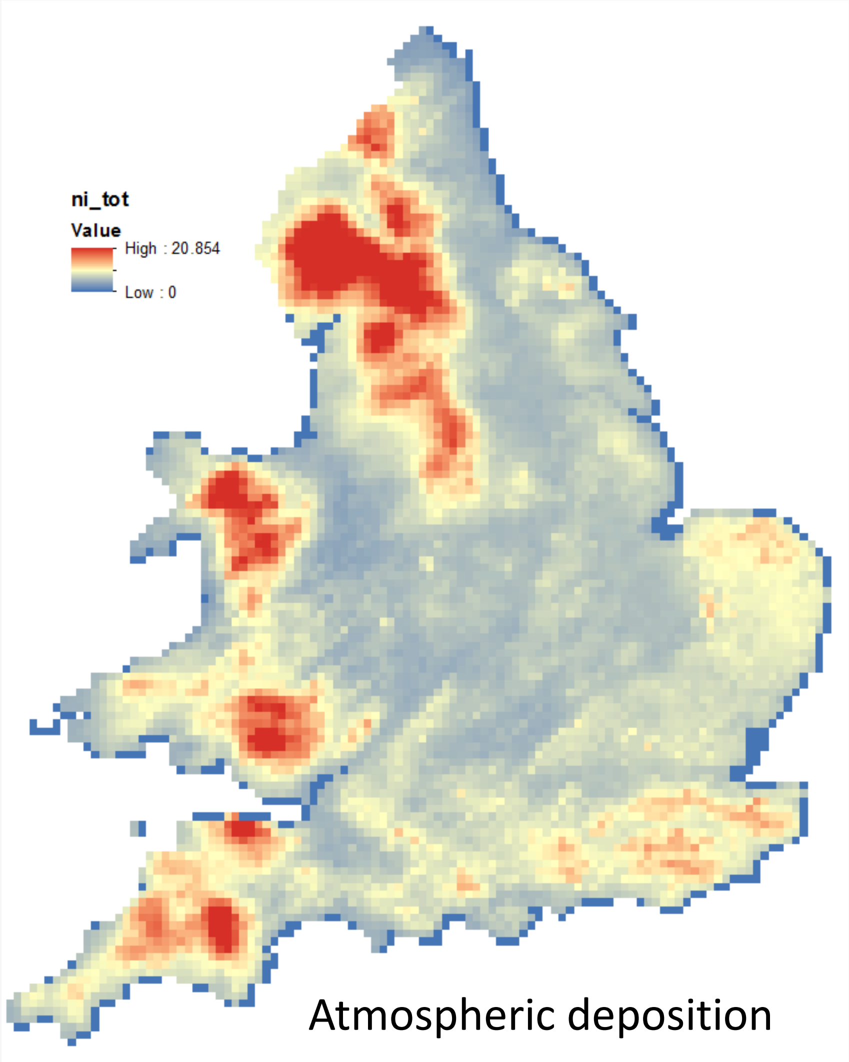


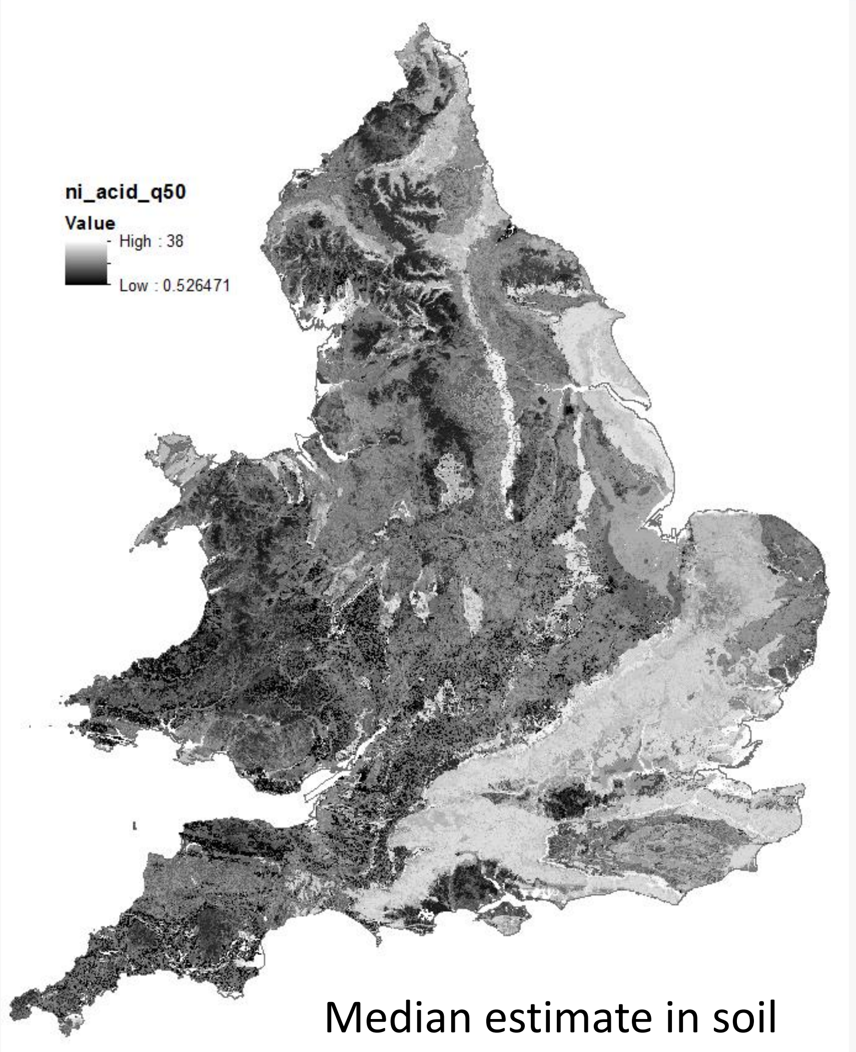
Protected Areas – Landscape – AONB, National Parks etc

Data pending for Wales



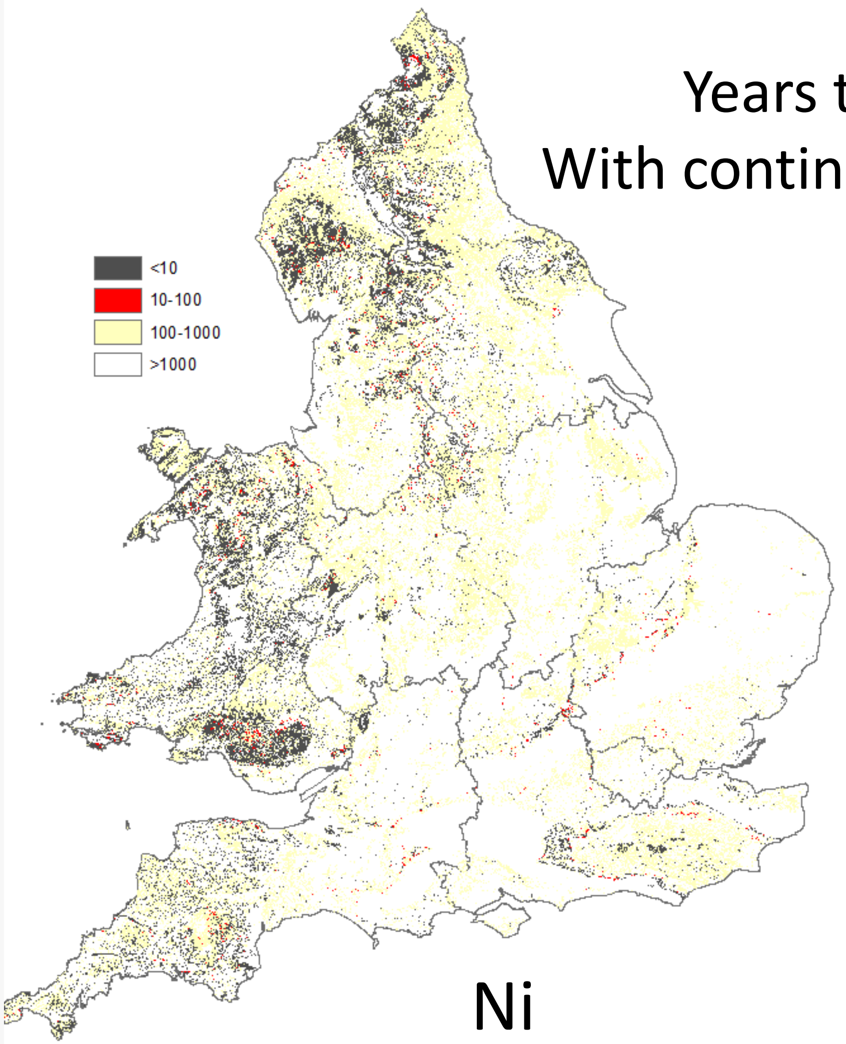
Heavy Metal Accumulation – eg Ni (Nickel)



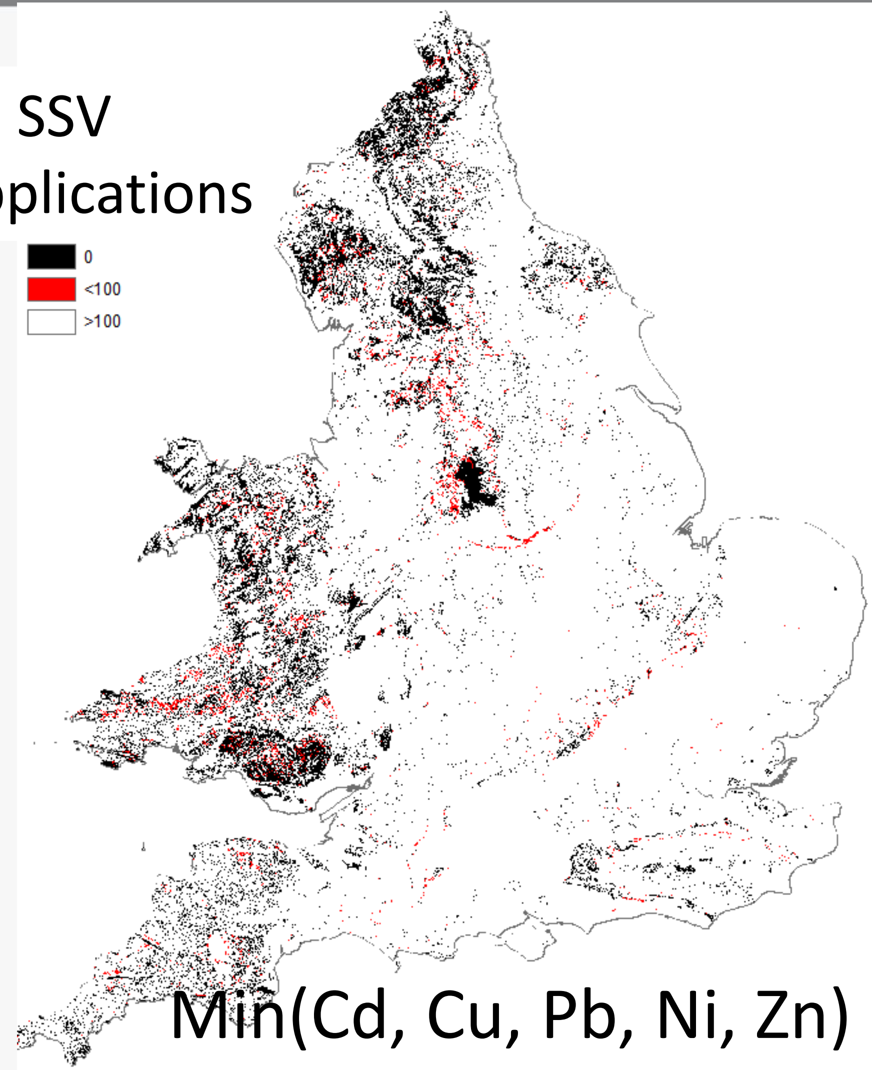


Heavy metal accumulation – time to reach “Soil Screening Value”

Years to reach SSV
With continuous applications



Ni



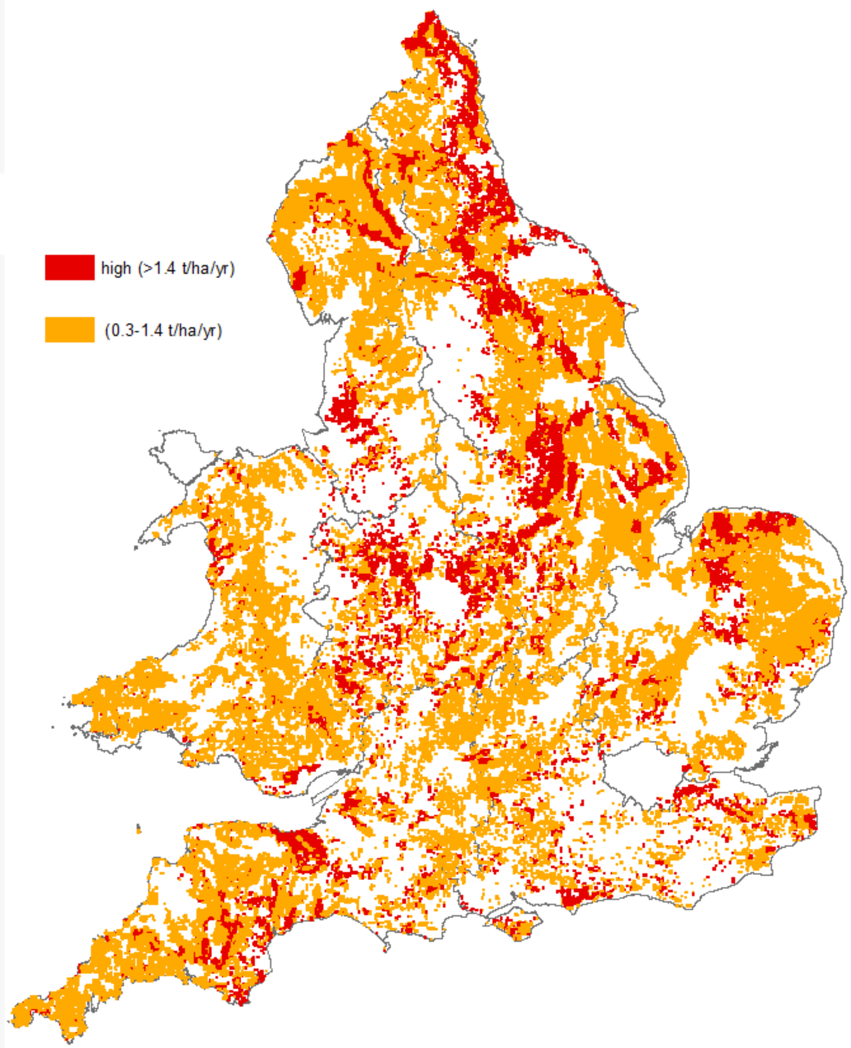
Min(Cd, Cu, Pb, Ni, Zn)

Erosion – Pan-European Soil Erosion Risk Assessment

Red areas

erosion > 1.4 t/ha/yr

(optimistic estimate of soil formation)



Distance

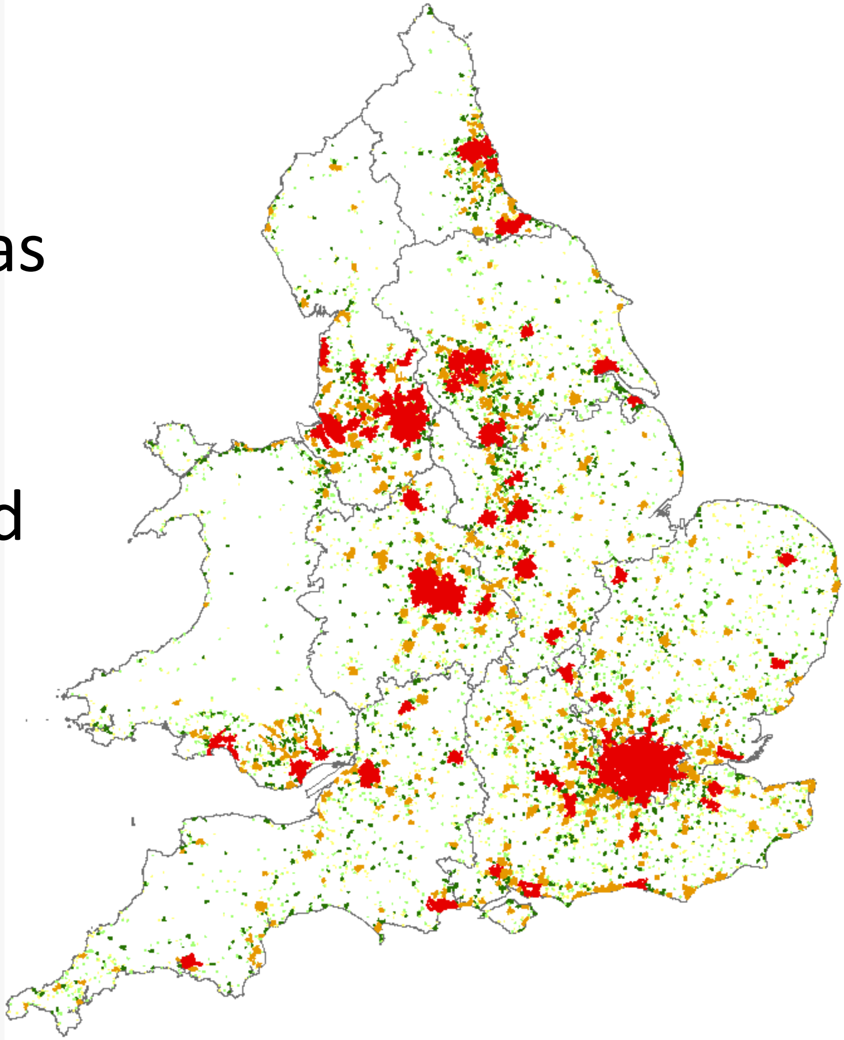
2011 Census

Biosolids > 1km from urban areas

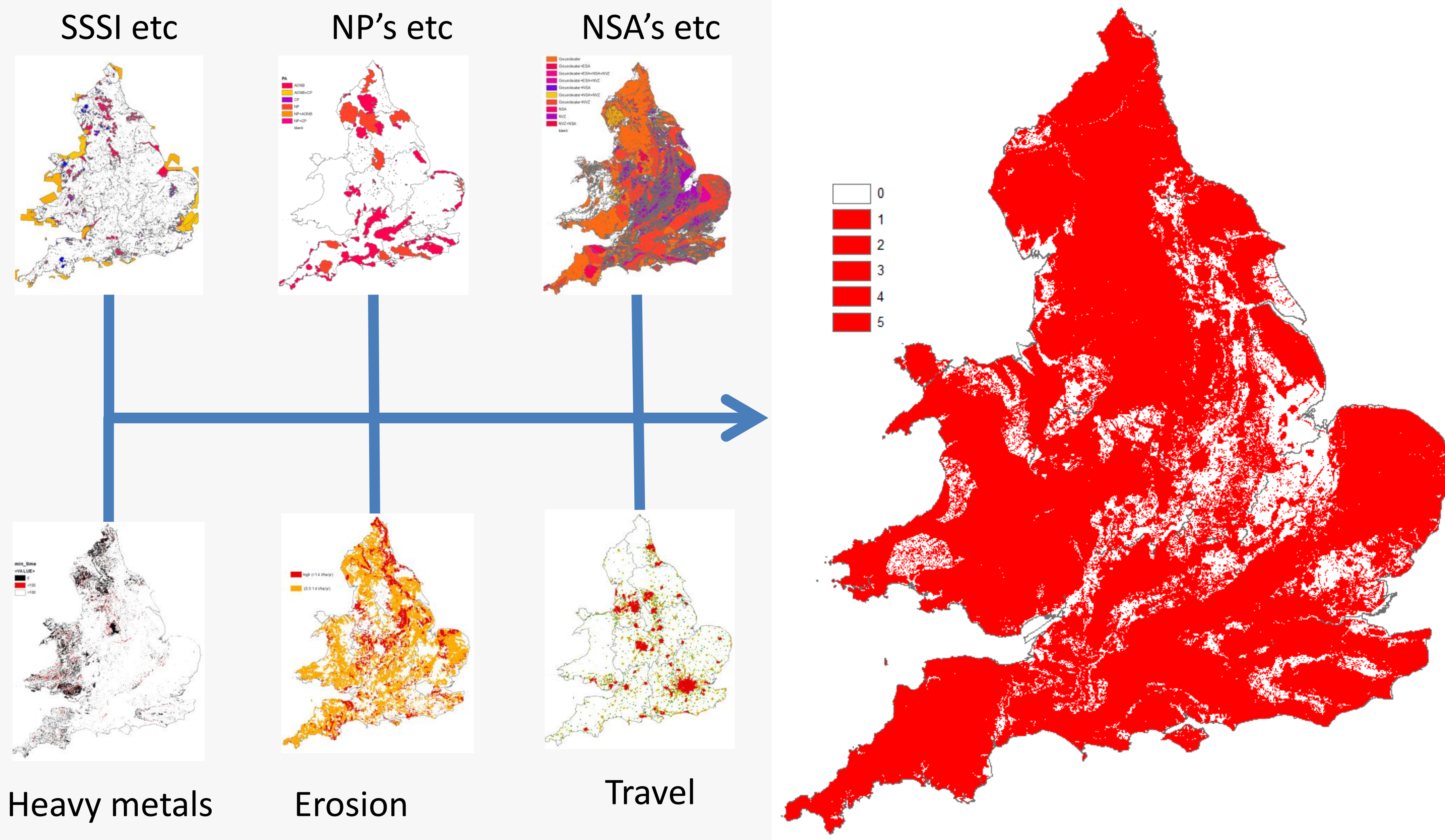
Biosolids < 25 km from urban areas

Urban areas > 100,000 people

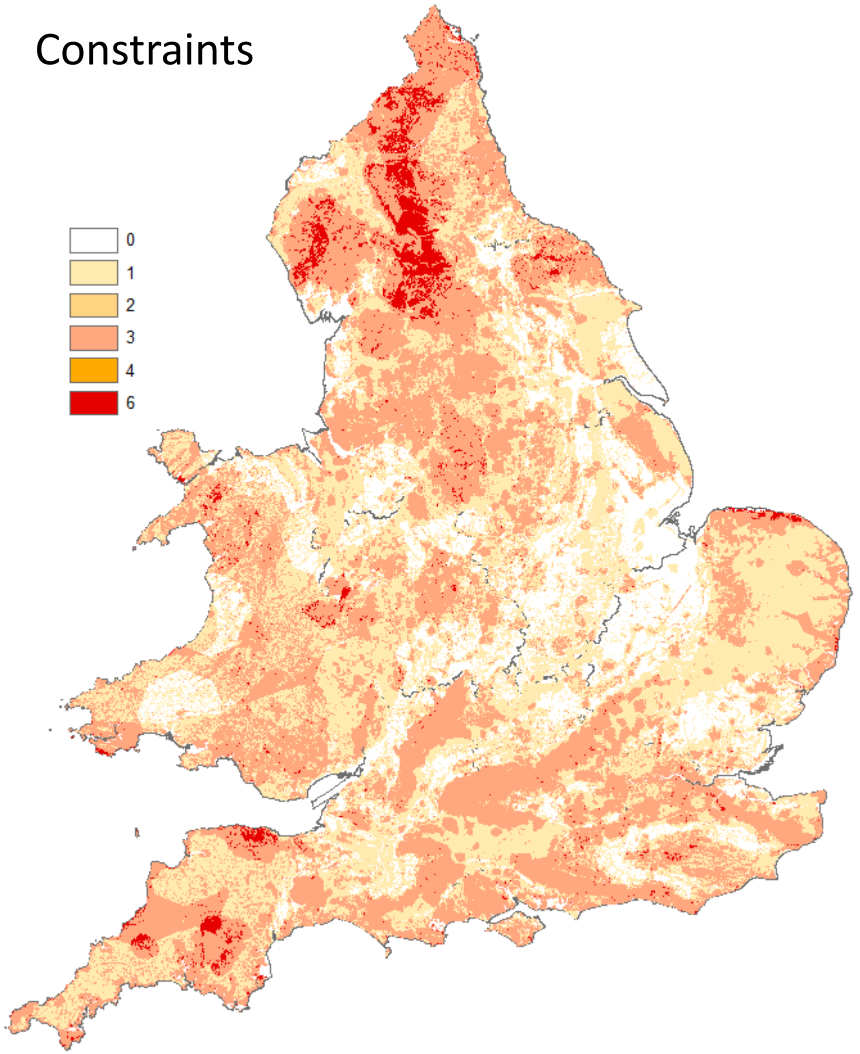
Distance thresholds can be altered

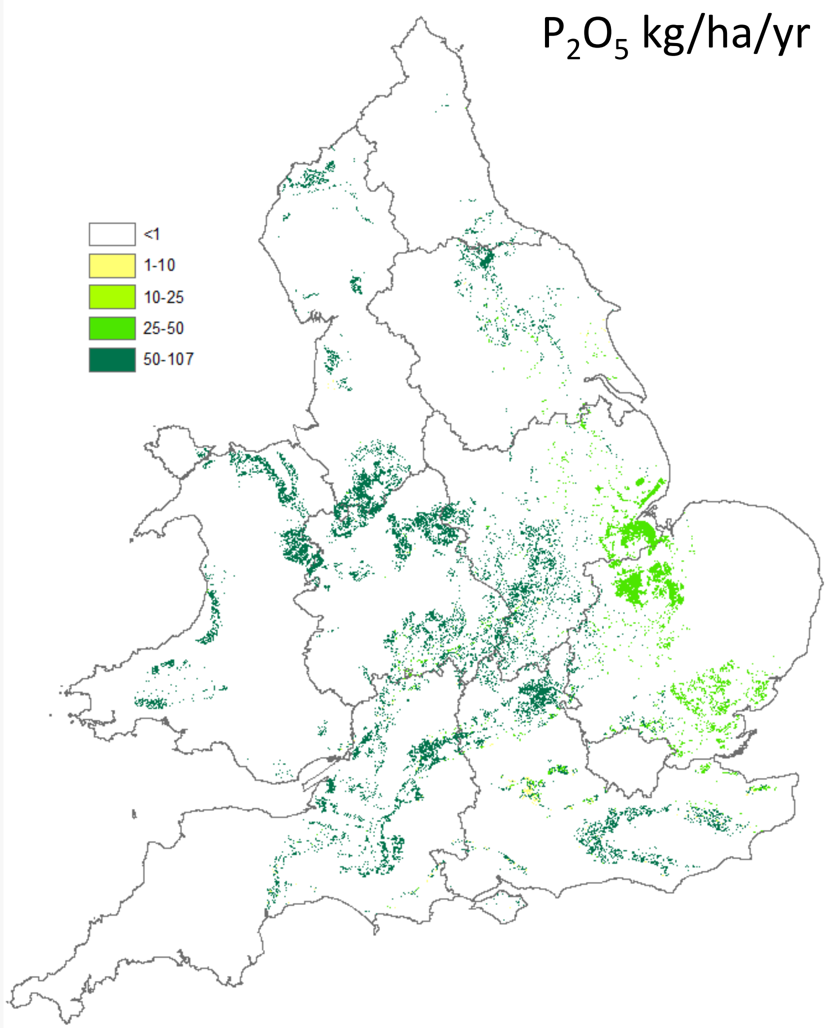


Combining Constraints



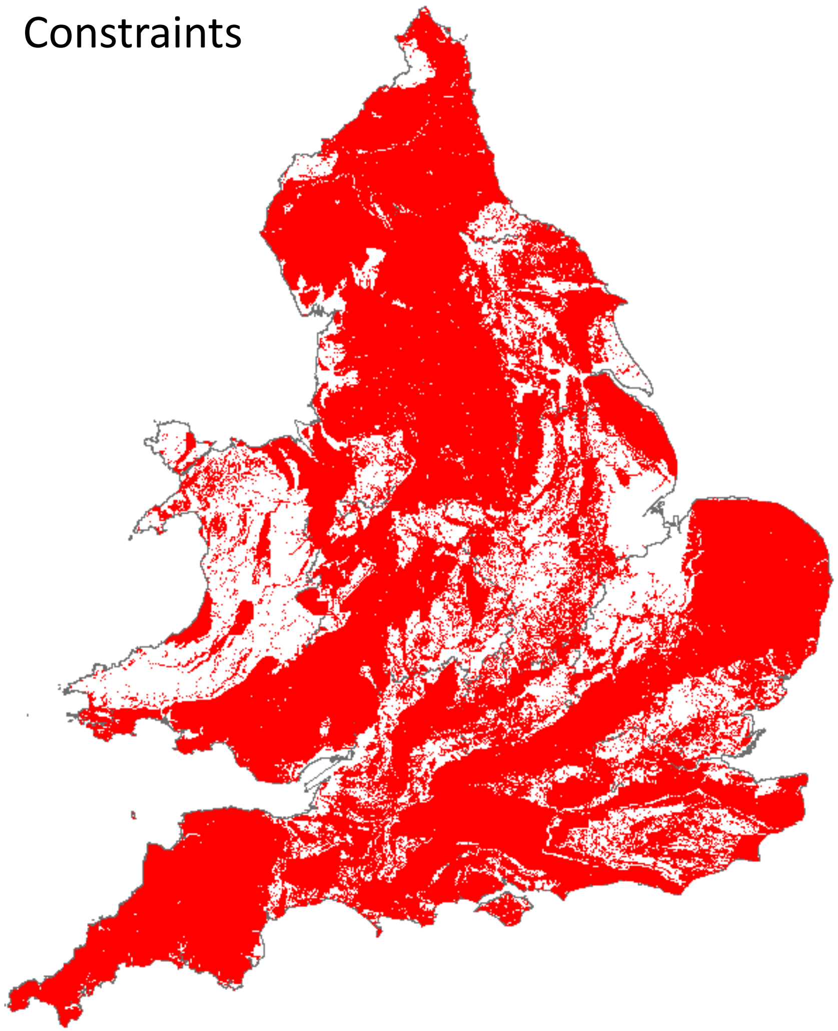
Group 1
All Constraints



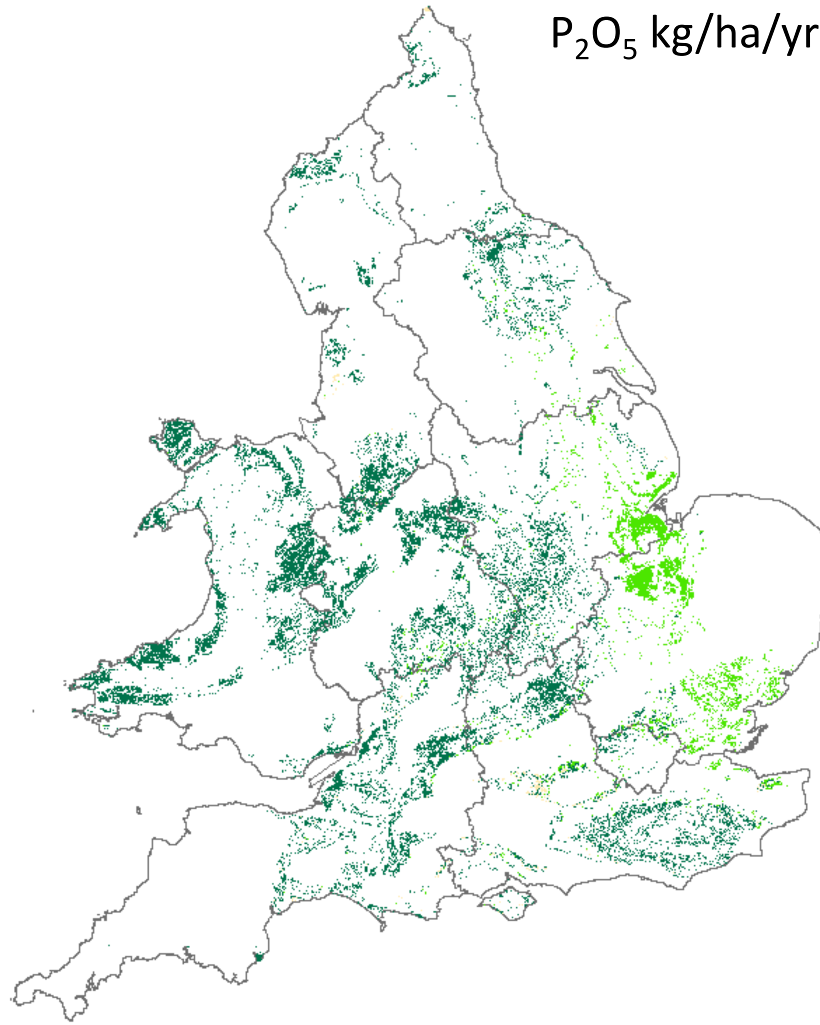


Group 2
NSA, ESA & Groundwater

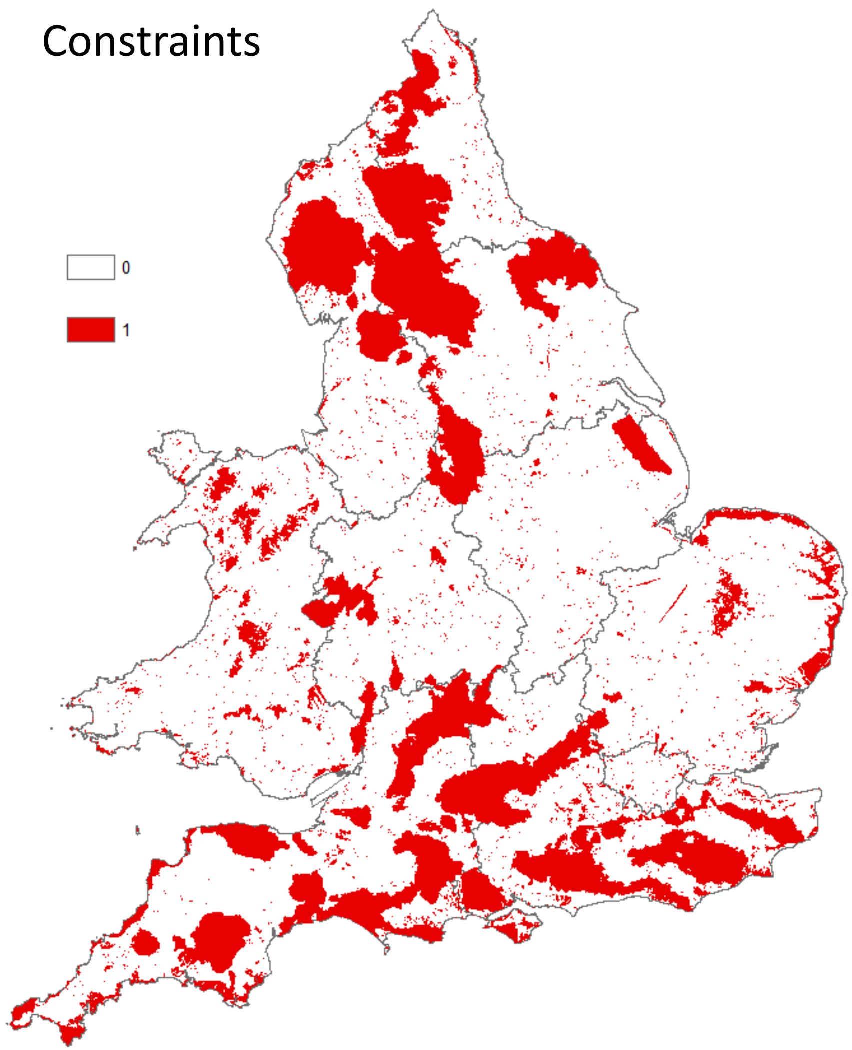
Constraints

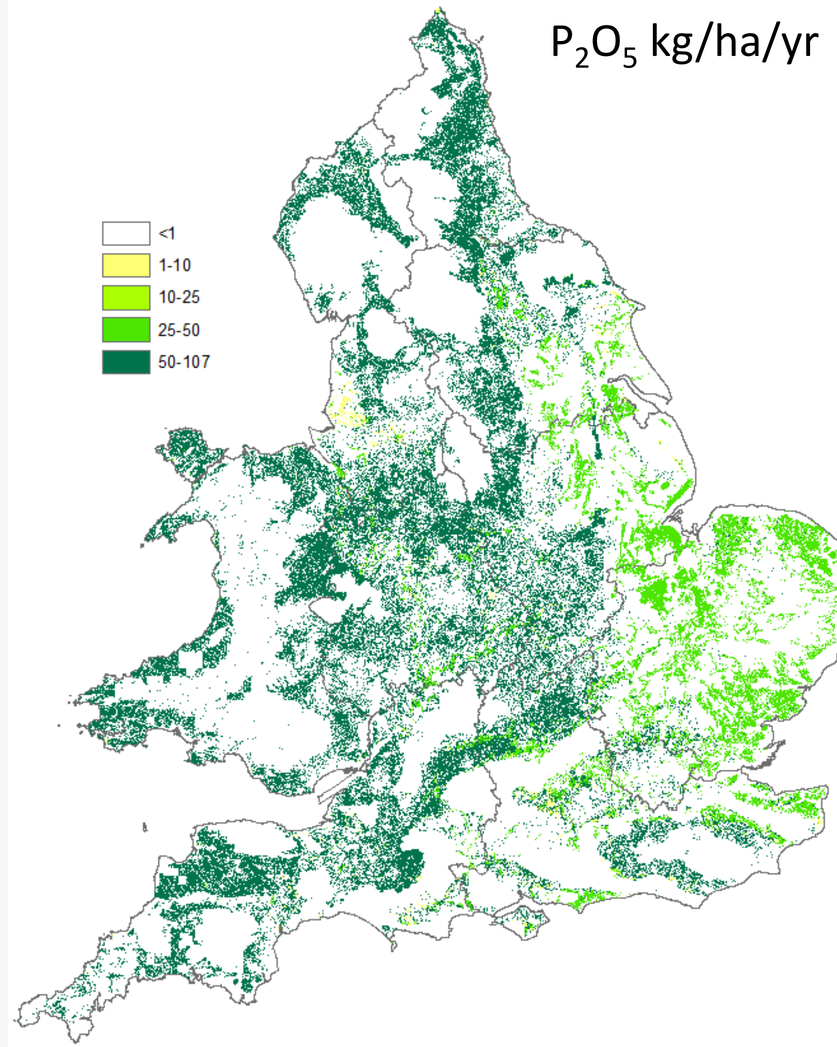


P_2O_5 kg/ha/yr



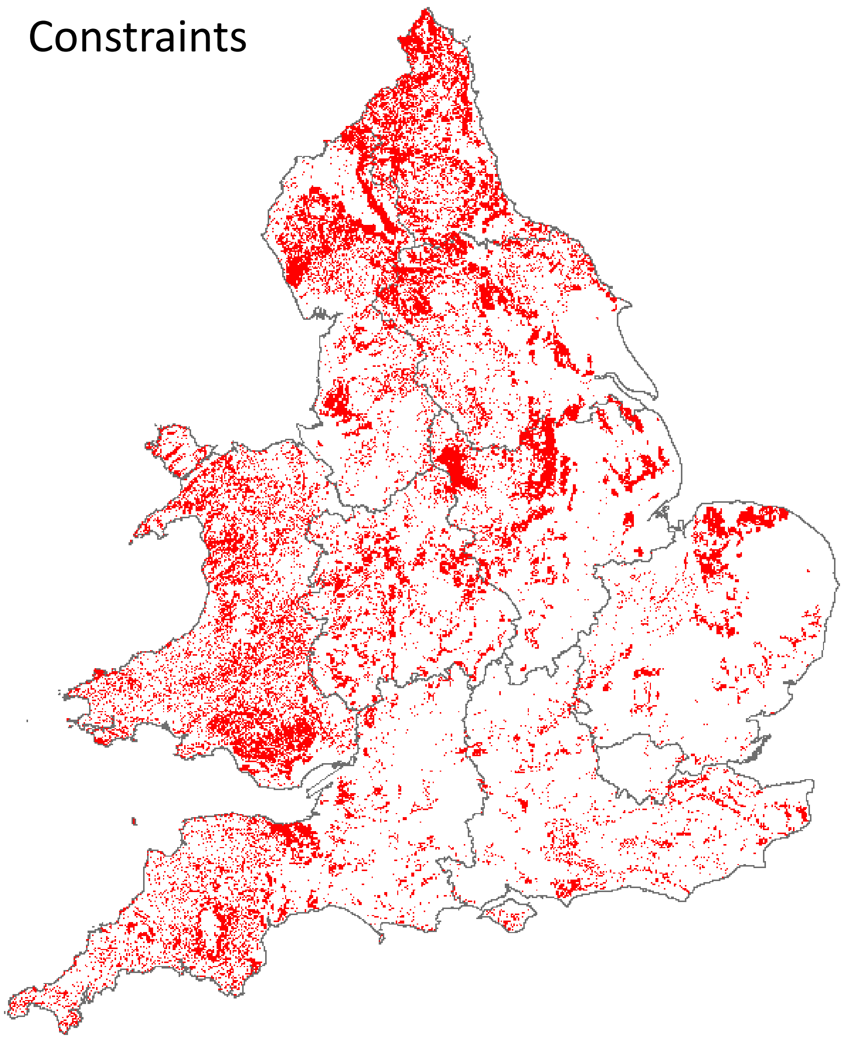
Group 3
Biodiversity + Landscape



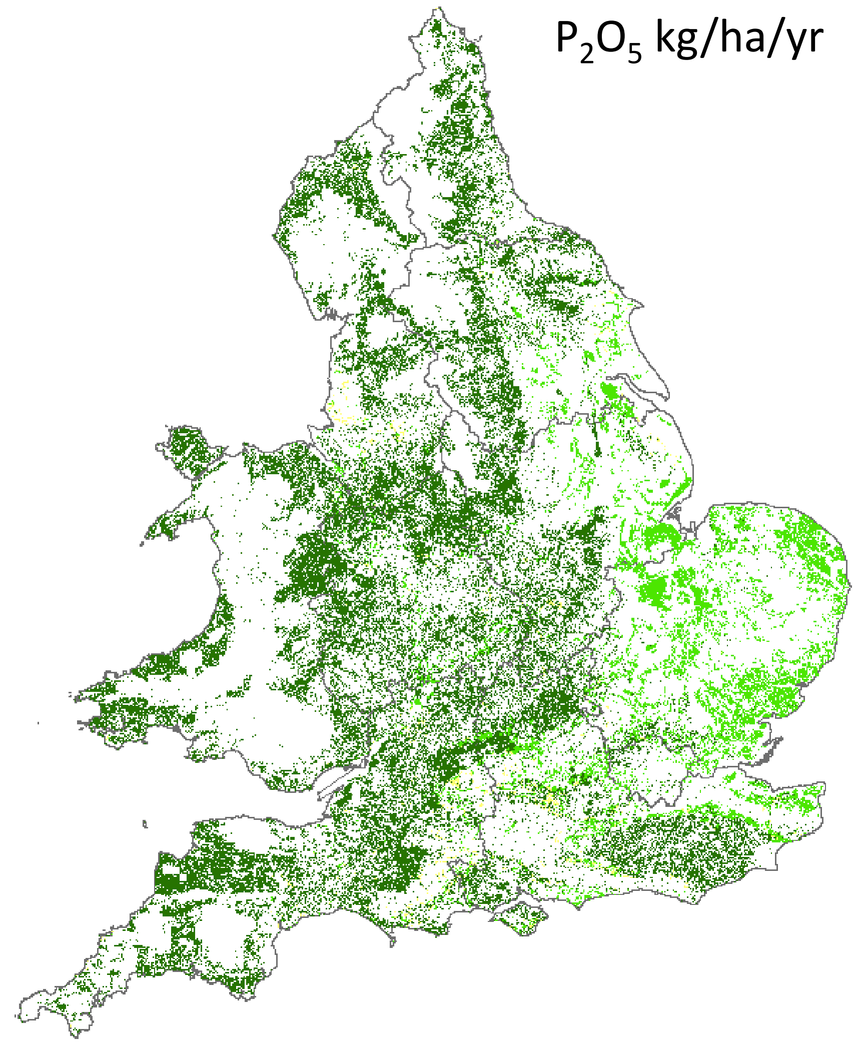


Group 4
Heavy Metals & Erosion

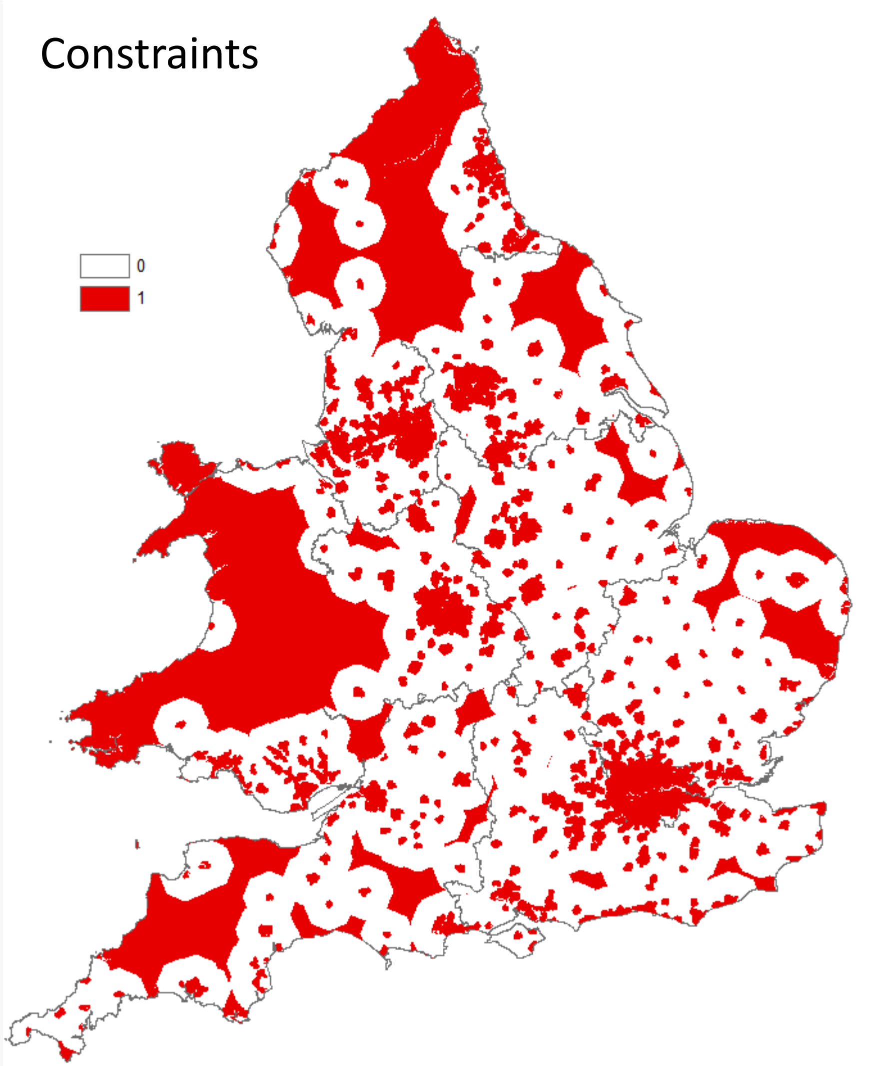
Constraints

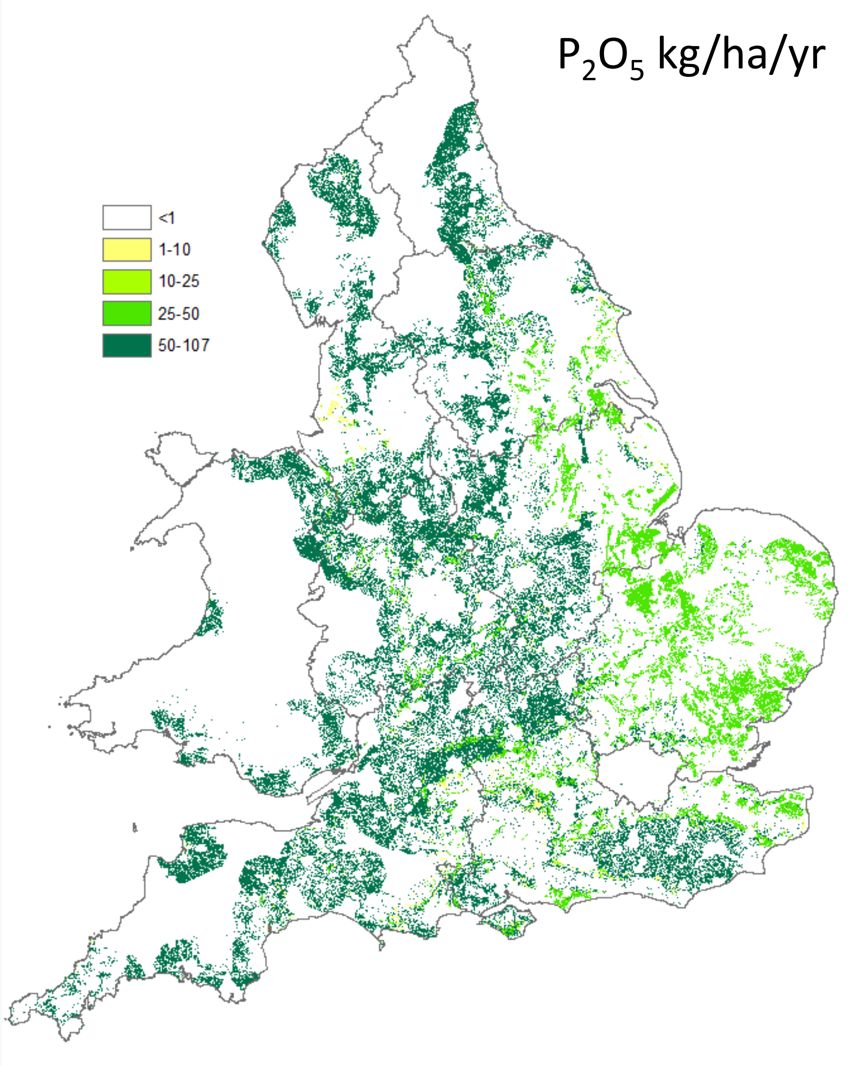


P_2O_5 kg/ha/yr



Group 5
Distance





Implications …

- 800,000 tons/year biosolids
- At 3% Phosphorous
- At 1kg P = 2.29 kg P_2O_5
- ~ 55,000 tons of P_2O_5

- British Survey of Fertiliser Use (Defra, 2012)
- Total P_2O_5 England and Wales = 140,000 tons
- (down from >300,000 tons 20 years ago)

- Therefore, Biosolids ~ 1/3 of P_2O_5 needed

By Region … in 2015 …
Percentage of Agronomic need that could be met by biosolids

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NUT 1	Equivalent P_2O_5 t/yr	All constraints	Protected Areas - pollution	Protected Areas – Biodiversity	Heavy metals + Erosion	Distance
North-East	2,604	**760**	**168**	12	17	24
North-West	7,077	**140**	**108**	27	26	33
Yorkshire+Humber	5,303	**202**	**115**	24	22	31
East-Midlands	4,550	54	42	17	18	18
West-Midlands	5,625	60	41	16	16	21
East-Anglia	5,879	**126**	**104**	34	35	42
London	*8,228*	*22329*	*1105*	*623*	*583*	*6745*
south-East	8,678	97	59	33	23	25
South-West	5,316	67	44	12	9	12
Wales	3,073	45	14	7	8	21

Land suitable if the agronomic need is at least 25 kg P_2O_5/ha

Target is for soil to be in Index 2

By Region .. In 2050 (+23% biosolids + CC)

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NUT 1	tons equiv	All	PA poll	Pa bio	HM	Dist
North-East	3202	**838**	**151**	13	19	28
North-West	8704	**175**	**133**	32	32	40
Yorkshire+Humber	6523	**226**	**130**	28	25	35
East-Midlands	5597	67	52	21	22	22
West-Midlands	6919	73	50	20	20	26
East-Anglia	7231	**159**	**130**	43	44	52
London	*10120*	*27465*	*1356*	*765*	*717*	*8256*
south-East	10674	**116**	70	39	27	30
South-West	6539	81	53	14	11	15
Wales	3780	62	18	9	10	24

Biosolids meet fractionally more of the agronomic demand

Summary

1) Application of Biosolids to land is the BPEO
2) A water treatment works is a Phosphate mine
3) There is “inertia” in water treatment systems due to; capital costs, public perception etc.
4) Stakeholders can be grouped depending on common interests
5) Under some scenarios the “land-bank” is already insufficient.

Discussion Points

1. Where would you like future research to go?
2. What additional data could enhance future research?
3. Does your organisation “map” onto these four stakeholder groups?
4. Is accessing and dissemination through LandIS sufficient?