Climate change is accelerating phosphorus transfer to catchments

Phil Haygarth

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FOOD depends on the PHOSPHORUS cycle

source: wikimedia commons

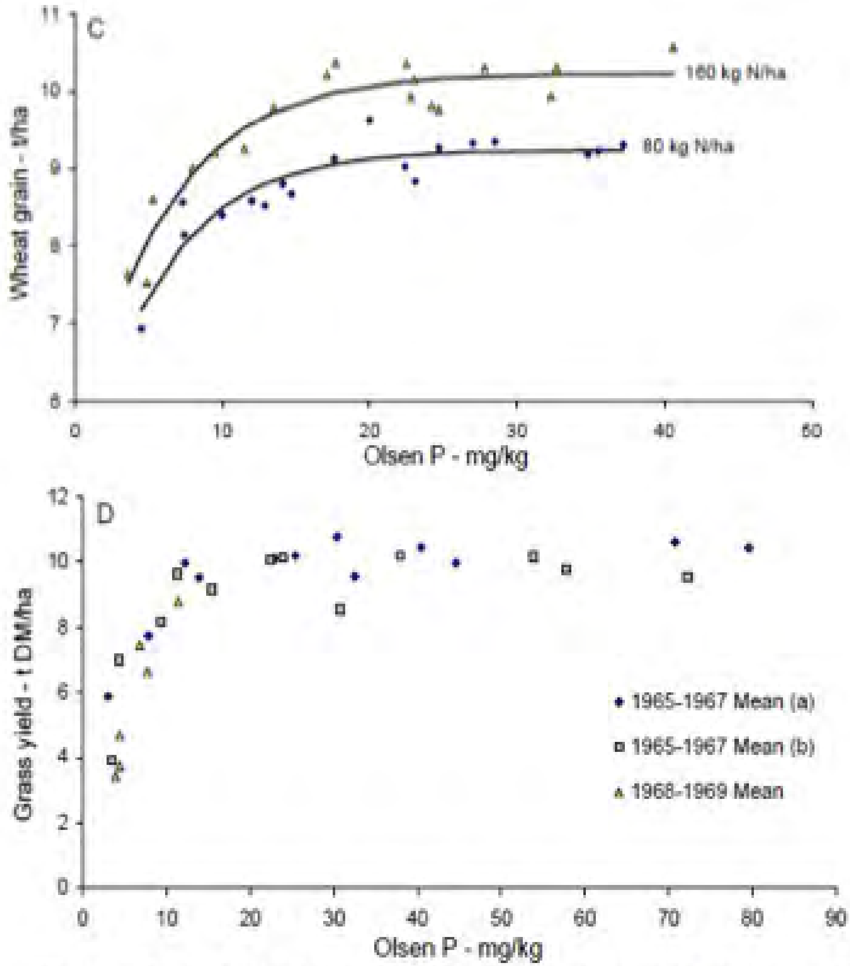

Figure 5: *Relationship between Olsen P and the yield of three arable crops and of grass. (Johnston, 2001; Johnston et al., 2001a).*


MASSEY FERGUSON
6475
CLAAS
It's in the blood!
850
JAGUAR
PU 300 HD
CLAAS
40

Demonstration Test Catchments in England

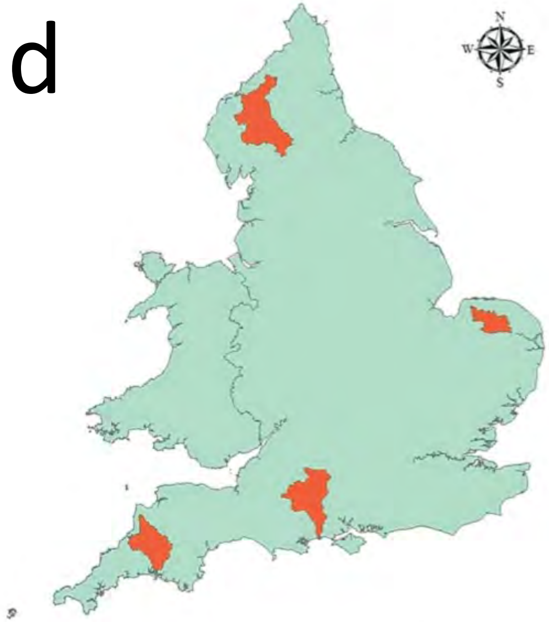

Fig. 2 The demonstration test catchments (shown clockwise from the most northerly; Rivers Eden, Wensum, Avon and Tamar).

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ROYAL SOCIETY OF CHEMISTRY
Environmental Science
Processes & Impacts

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Short term P dynamics in the EdenDTC


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Dominant mechanisms for the delivery of fine sediment and phosphorus to fluvial networks draining grassland dominated headwater catchments

M.T. Perks[a,*], G.J. Owen[b], C.McW.H. Benskin[c], J. Jonczyk[b], C. Deasy[c,d,e], S. Burke[f], S.M. Reaney[d], P.M. Haygarth[c]

"high magnitude events were observed to exhibit threshold- like behavior…....results in the movement of vast phosphorus fluxes"

Newby Beck, River Eden, England

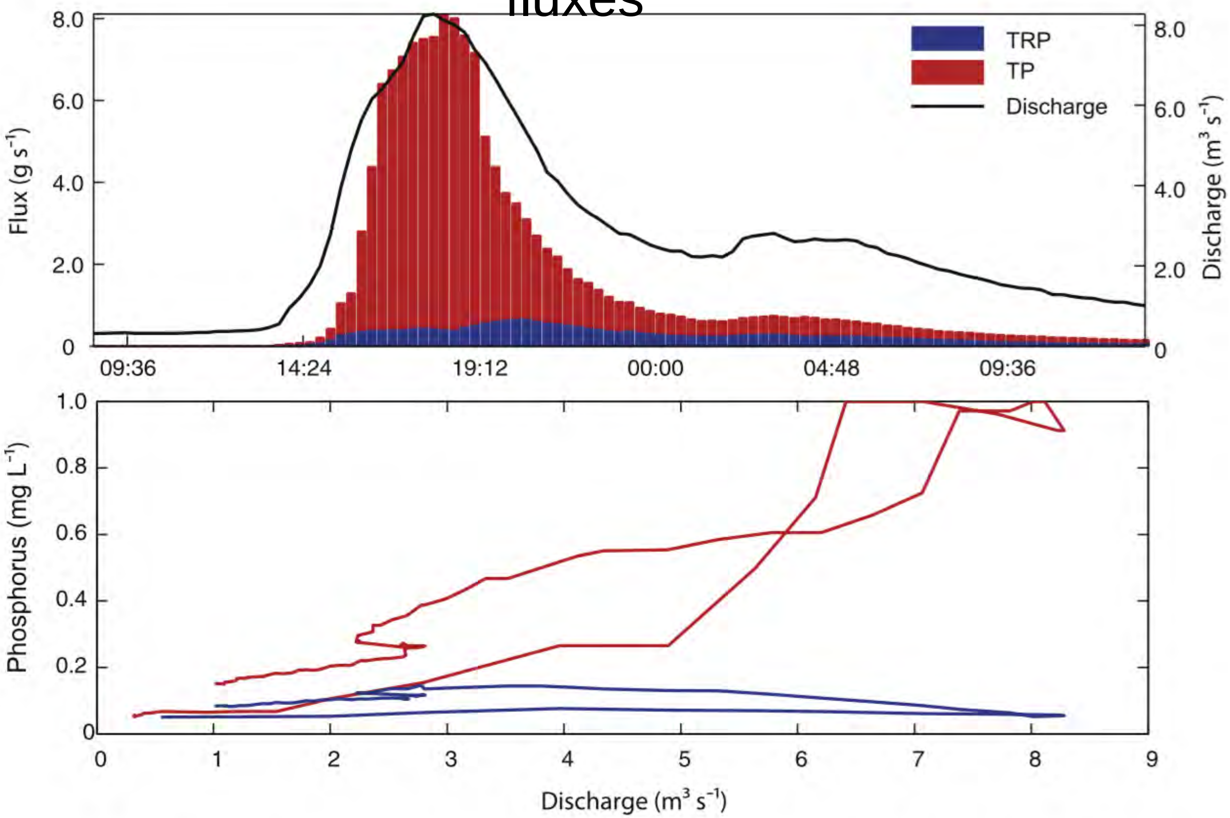

Fig. 6. An example of the figure-of-eight (clockwise loop) hysteresis dynamics exhibited for total phosphorus (TP) and total reactive phosphorus (TRP) during infrequent but high magnitude events. Fig. 6a illustrates the synchronicity of both TP and TRP fluxes in the catchment, with TRP becoming less dominant as runoff increases rapidly. Fig. 6b illustrates the timing of concentration pulses which lead to the production of the figure-of-eight (clockwise loop) hysteresis.

Environmental Science & Technology

Viewpoint

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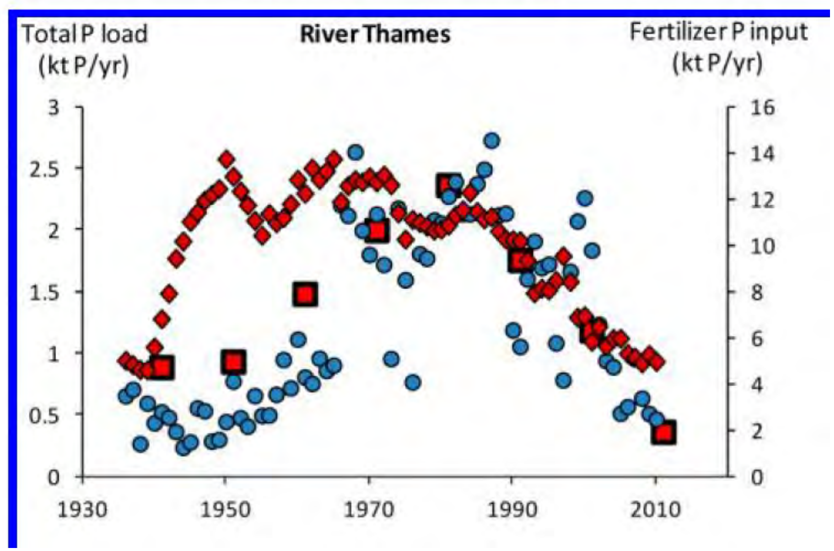
Sustainable Phosphorus Management and the Need for a Long-Term Perspective: The Legacy Hypothesis

Philip M. Haygarth,*[,†] Helen P. Jarvie,[‡] Steve M. Powers,[§] Andrew N. Sharpley,[‖] James J. Elser,[⊥] Jianbo Shen,[#] Heidi M. Peterson,[∇] Neng-Iong Chan,[⊥] Nicholas J. K. Howden,[○] Tim Burt,[◆] Fred Worrall,[¶] Fusuo Zhang,[#] and Xuejun Liu[#]

Red – Catchment P inputs →

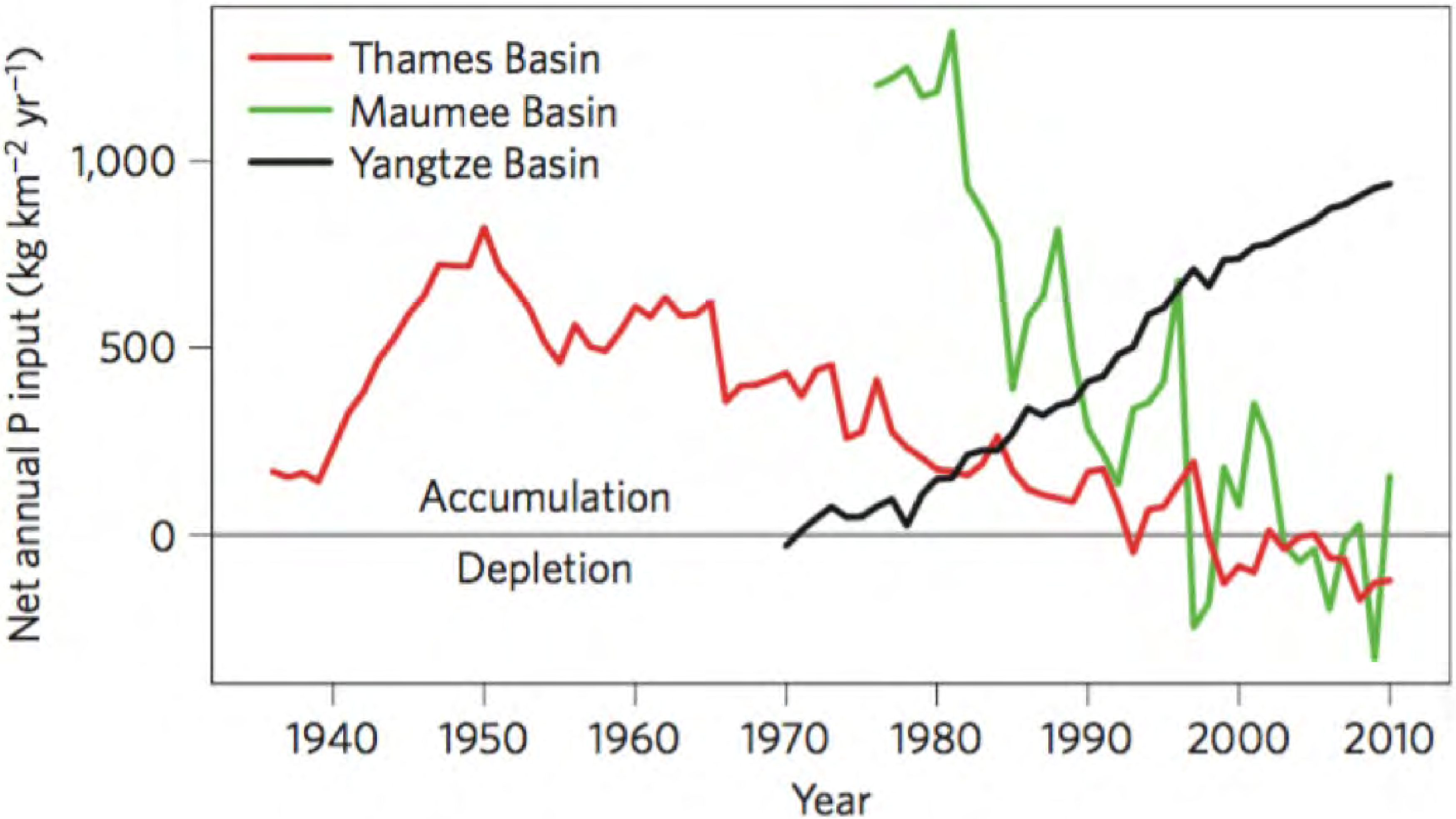
Blue – River P outputs →

Environmental Science & Technology



Long-term accumulation and transport of anthropogenic phosphorus in three river basins

nature geoscience LETTERS
PUBLISHED ONLINE: 11 APRIL 2016 | DOI: 10.1038/NGEO2693



Stephen M. Powers[1]*, Thomas W. Bruulsema[2], Tim P. Burt[3], Neng Iong Chan[4], James J. Elser[4], Philip M. Haygarth[5], Nicholas J. K. Howden[6], Helen P. Jarvie[7], Yang Lyu[8], Heidi M. Peterson[9], Andrew N. Sharpley[10], Jianbo Shen[8], Fred Worrall[11] and Fusuo Zhang[8]

Prof Phil Haygarth @ProfPHaygarth · 5 Dec 2015

Wading home through the Keer

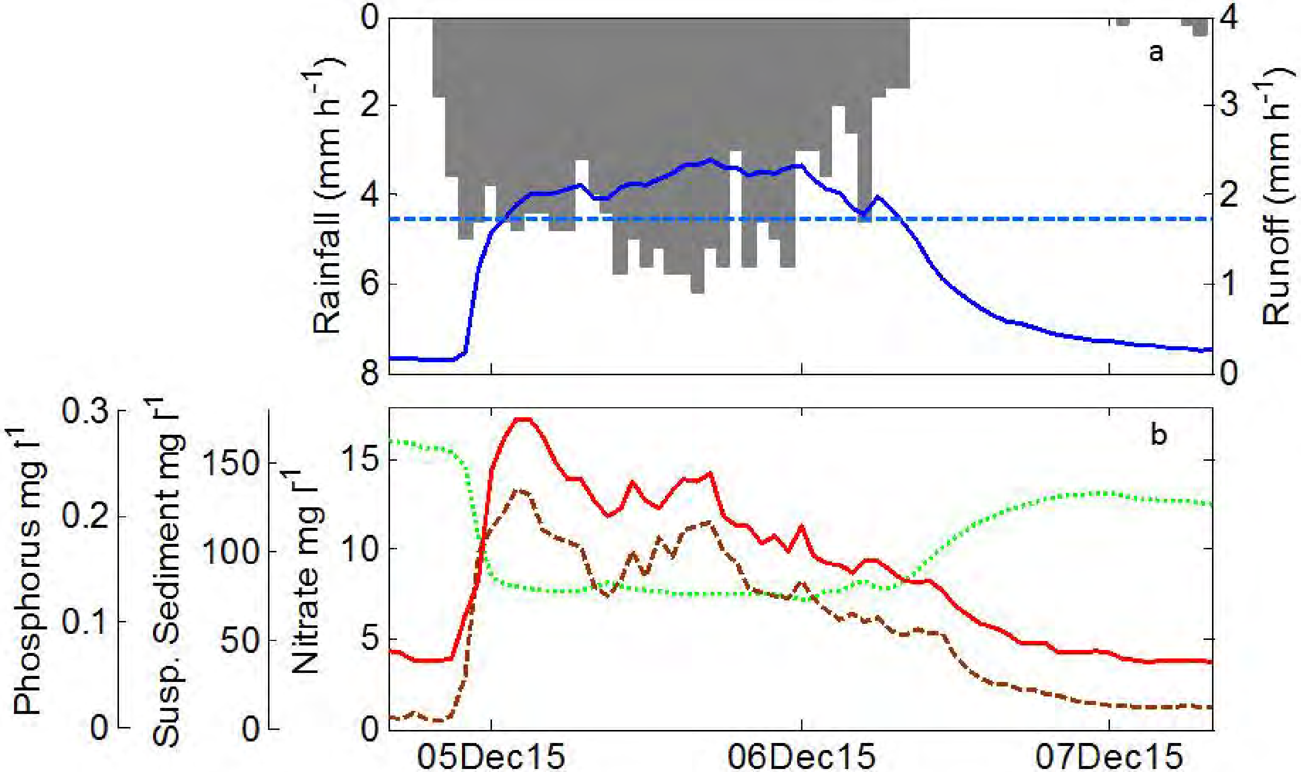
@ProfPHaygarth
#stormdesmond

Storm Desmond

- On 5th December 2015, 34cm of rainfall fell in one day at a weather station at Honister Pass in the Lake District. *To put this into perspective, this region would typically on average see around 1cm of rainfall each day in December.*

- A new 2-day record of 41 cm of rainfall over the two days at Thirlmere
- *El Nino* was also particularly strong increasing risk for higher than average rainfall in the UK between Dec 15 & Jan 16 (UK Met Office)

Storm Desmond at Newby Beck Morland, Eden



Hydrograph, sedigraph and chemograph at Newby Beck monitoring station (54.59°N, 2.62°W) in the River Eden during Storm Desmond, 4th – 6th December 2015

Newby Beck, Eden, During Storm Desmond

	Sediment (t)	Total P (kg)	Total Reactive P (kg)	Nitrate (t)
Storm Desmond export	84	194	78	8.9
Annual export	380 - 680	1670 – 2320	650 – 920	68 - 94
% of annual	12 - 22	8 - 12	8 - 12	9 - 13
During Desmond:	mg/l	mg/l	mg/l	mg/l
Min Conc.	5*	0.062*	0.037*	7.2
Max Conc.	134	0.288	0.096	15.7*
Time averaged conc.	61	0.151	0.065	9.9
Flow weighted conc.	81	0.186	0.074	8.4

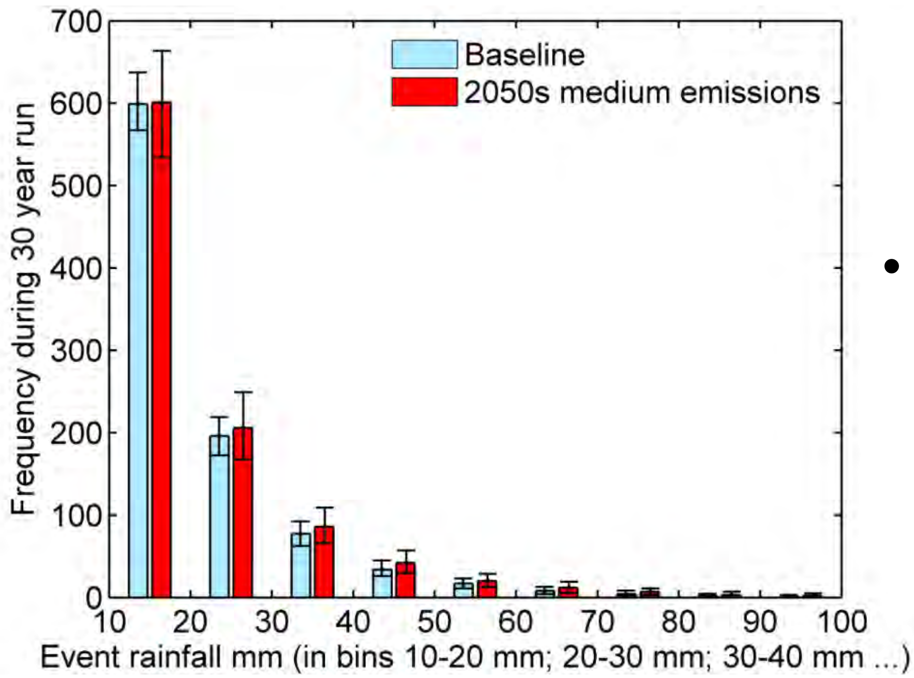
*Minimum concentrations of SS, TP, TRP and maximum nitrate were recorded at the beginning of the event (i.e. they represent initial values before response started)

Nutrients in Catchments 2050 (NUTCAT 2050)

Historical and future predictions for the River Eden (Ockenden et al 2016)

Newby Beck	Baseline	2050s
No. of events > 10 mm (for 30 year run, mean over 100 runs)	944	986
Percentage of total rainfall in events > 10 mm	62%	67%
Event rainfall 95th percentile (mean over 100 runs)	46	50
Event rainfall 99th percentile (mean over 100 runs)	70	79
Maximum Event rainfall (mean over 100 runs)	119	140

- UK climate predictions indicate a shift in distribution to larger events (rainfall >10 mm)



Historical in the R Eden:
1960-2013:
31% increase Winter
16% decrease Summer

- *Future **predictions** for 2050:*
  - *Winter increases by 8-17%*
  - *Summer decreases by 9-26%* ***(fewer summer storms, but more intense, more wetting and drying)***

nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-017-00232-0 OPEN

Major agricultural changes required to mitigate phosphorus losses under climate change

M.C. Ockenden[1], M.J. Hollaway[1], K.J. Beven[1], A.L. Collins[2], R. Evans[3], P.D. Falloon[4], K.J. Forber[1], K.M. Hiscock[5], R. Kahana[4], C.J.A. Macleod[6], W. Tych[1], M.L. Villamizar[7], C. Wearing[1], P.J.A. Withers[8], J.G. Zhou[9], P.A. Barker[1], S. Burke[10], J.E. Freer[11], P.J. Johnes[11], M.A. Snell[1], B.W.J. Surridge[1] & P.M. Haygarth[1]

The full paper can be accessed here:

https://www.nature.com/articles/s41467-017-00232-0

Methods: *A combination of….*

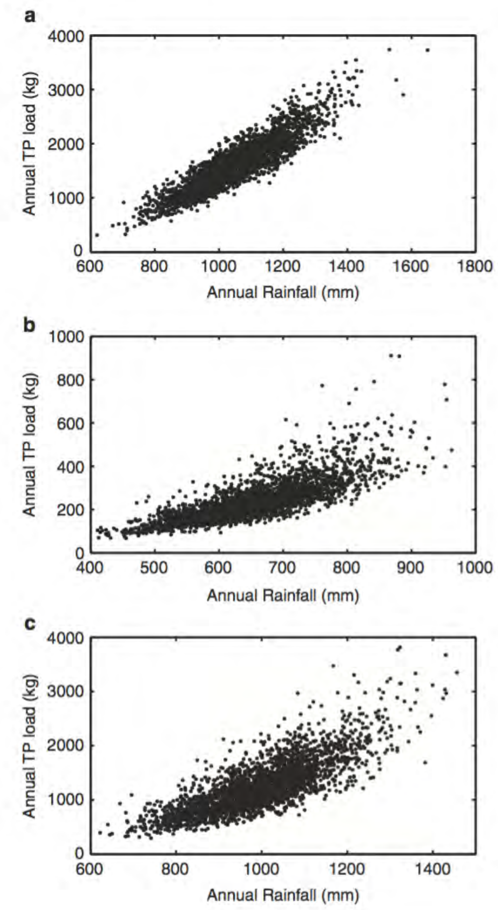
- High-frequency phosphorus flux data from *three* representative catchments across the UK
- A high-spatial resolution climate model, with uncertainty estimates from an ensemble of future climate simulations
- *Two* phosphorus transfer models of contrasting complexity
- Expert elicitation from land managers on future management scenarios

Modelling phosphorus loads

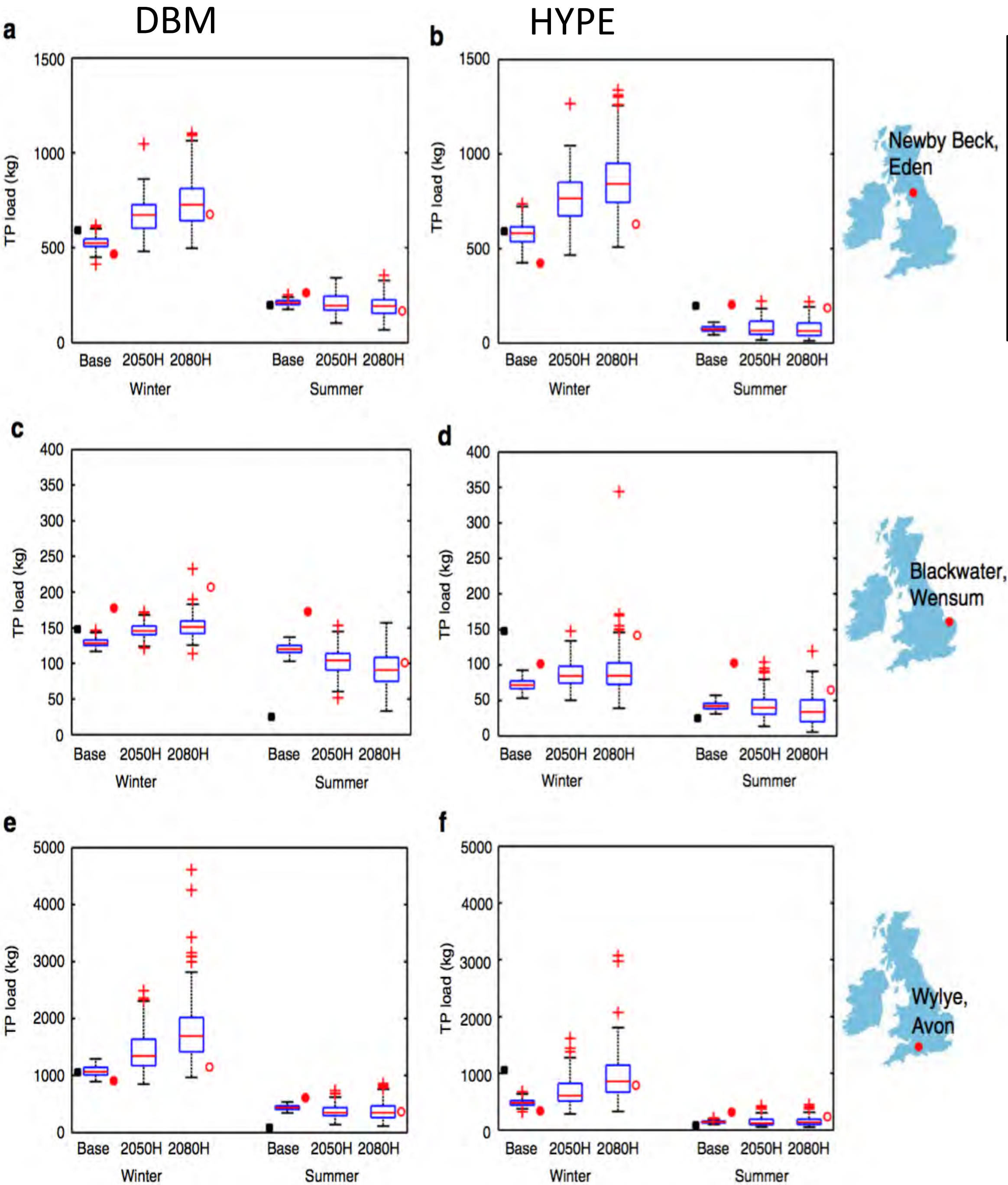
We applied two hydrological models of different complexity to the three DTC catchments. Parameter identification and validation done on separate parts of the time series.

*The **Hydrological Predictions for the Environment (HYPE)** model is a hydrological model for simulating water flow and transport and turnover of nitrogen and phosphorus and is semi-distributed, dividing the landscape into classes according to soil type, land use and altitude*

***Data-Based Mechanistic (DBM)** modelling, using the CAPTAIN Toolbox for MATLAB identified transfer function models for rainfall-runoff and rainfall-phosphorus load directly from the high temporal resolution (hourly) data, requiring very few parameters*



The dominant effect of rainfall in driving diffuse P loads is shown by the relationship between annual rainfall and annual P load, where annual rainfall explains 61% (Wensum), 63% (Hampshire Avon)and 82% (Eden) of the annual P load

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Range of likely winter and summer total phosphorus loads predicted by Data Based Mechanistic models (DBM) and process-based model HYPE for three UK DTC catchments (Ockenden et al., 2017).

Example Output: ***Medium Carbon Emissions, 2080s….***

Total Predicted Annual P load, % change in relation to current ‘baseline’

	Eden (Newby)
HYPE	19
DBM	16

Uncertainties and complexities

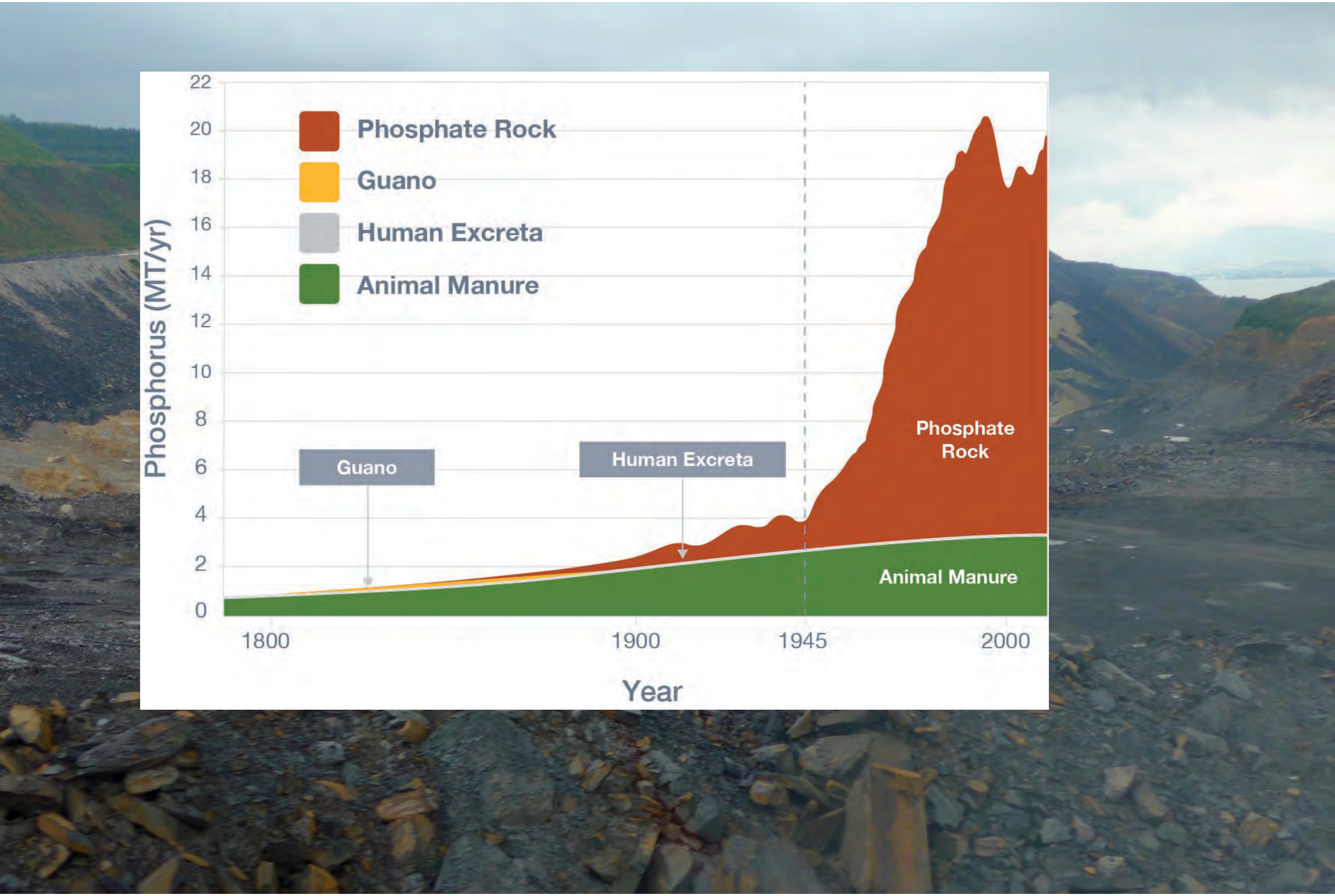
- Difficult to predict P transfers to catchments, much uncertainty, range of scenarios to assimilate
- Two models (approximately) supportive
- Winter emissions dominate load & will increase more than summer. Summer emissions will decrease, but will be more flashy

Headlines

Total phosphorus loads could increase by ~36% by 2080s (medium C scenario)

To maintain *present day* emission levels, we need to reduce P inputs:

- *~80% in the Avon,*
- *~20% in the Wensum*
- *~30% in the Eden*



Phosphate Rock
Guano
Human Excreta
Animal Manure
Phosphorus (MT/yr)
22
20
18
16
14
12
10
8
6
4
2
0
Guano
Human Excreta
Phosphate Rock
Animal Manure
1800
1900
1945
2000
Year

PHILOSOPHICAL TRANSACTIONS A

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Research

Check for updates

Cite this article: Watson AJ, Lenton TM, Mills BJW. 2017 Ocean de-oxygenation, the global

Ocean de-oxygenation, the global phosphorus cycle and the possibility of human-caused large-scale ocean anoxia

Andrew J. Watson

USA TODAY

'Dead zone': Data confirms dire ... about

into the oceans [2,3,47]. Our very simple model suggests that, under unrestricted mobilization of P, this could be important in the future as a result of human activity. Both the deliberate mobilization of phosphorus for agriculture, and the incidental effects of global warming and anthropogenic increases in erosion rates in accelerating the natural weathering of phosphorus, could be important. Conceivably, if our descendants are heedless of the consequences and generate major increases in the flux of phosphorus to the oceans lasting for hundreds or thousands of years, large-scale and long-lasting global anoxia might result.

We might assume that the scenarios modelled here are more extreme than will ever be realized, even if our industrial civilization lasts thousands of years, because our increasing understanding of the Earth system will enable us to foresee the consequences: such sustained mobilization of P

Are we living through a key turning point in the global phosphorus cycle?

Reflection

- Time scale and lags! We need to carefully consider the speed at which P moves through our catchments, and be prepared for lag times as ‘cause and effect’ can be difficult to see in our lifetime.
- System change! System Change! SYSTEM CHANGE!
- The phosphorus cycle has always changed through geologic history, but (1) our mining of P (2) losses from agriculture & (3) climate change, it seems to be experiencing an accelerating phase
- The predicted increase in winter P loads due to climate change (up to 36% by 2080s) ***is greater than the technically feasible reduction from mitigation measures*** **.** Only large-scale agricultural changes (e.g. 20–80% reduction in P inputs) will limit the projected impacts of climate change on P loads in these catchments
- Are we prepared for this?

Finale

Phosphorus provides enormous benefits for us in feeding the planet, but is also on a non-sustainable and damaging journey to our waters.

It is less than a century since we started mining rock phosphate, but in the context of a 4.5 billion-year-old earth we are living through a switching point for the earth system. And now climate change is also contributing to this acceleration.

Are we doing enough to recognise and avert this?

Thanks to many who have contributed…..

@ProfPHaygarth

landwaterblog.blogspot.com

Advert alert!

Aims to be published in 2020
by Oxford University Press

Jim Elser & Phil Haygarth

THE PAST AND FUTURE OF PHOSPHORUS

The story of how an oft-neglected element supports all life on Earth and holds a key to our future