Interpreting historic lake water phosphorus changes and catchment sources at Semer Water

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Sediment core provided by:

Richard Chiverrell & David Sear

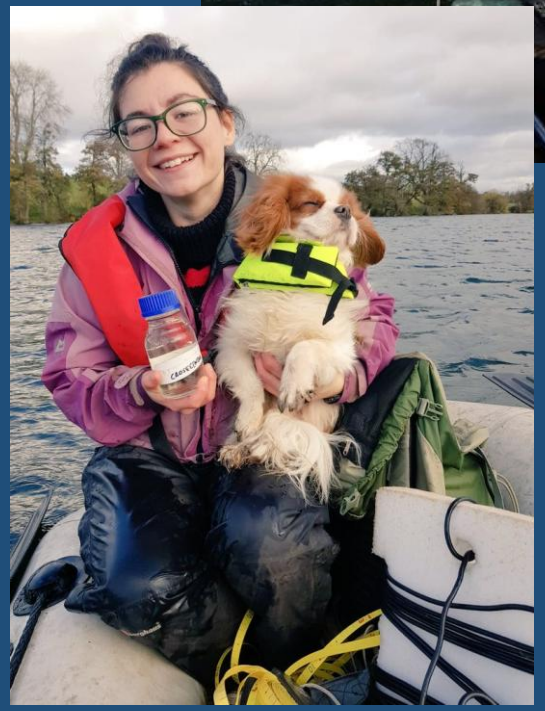
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1. Using lake sediment record to examine historic phosphorus trends
2. Modelling a phosphorus budget for Semer Water
3. Determining phosphorus sources

About us





Palaeolimnologist
Sedimentologist
Geochemist
Hydrologist
Limnologist
Geologist
Archaeologist
Field researcher
Lab researcher
Modeller



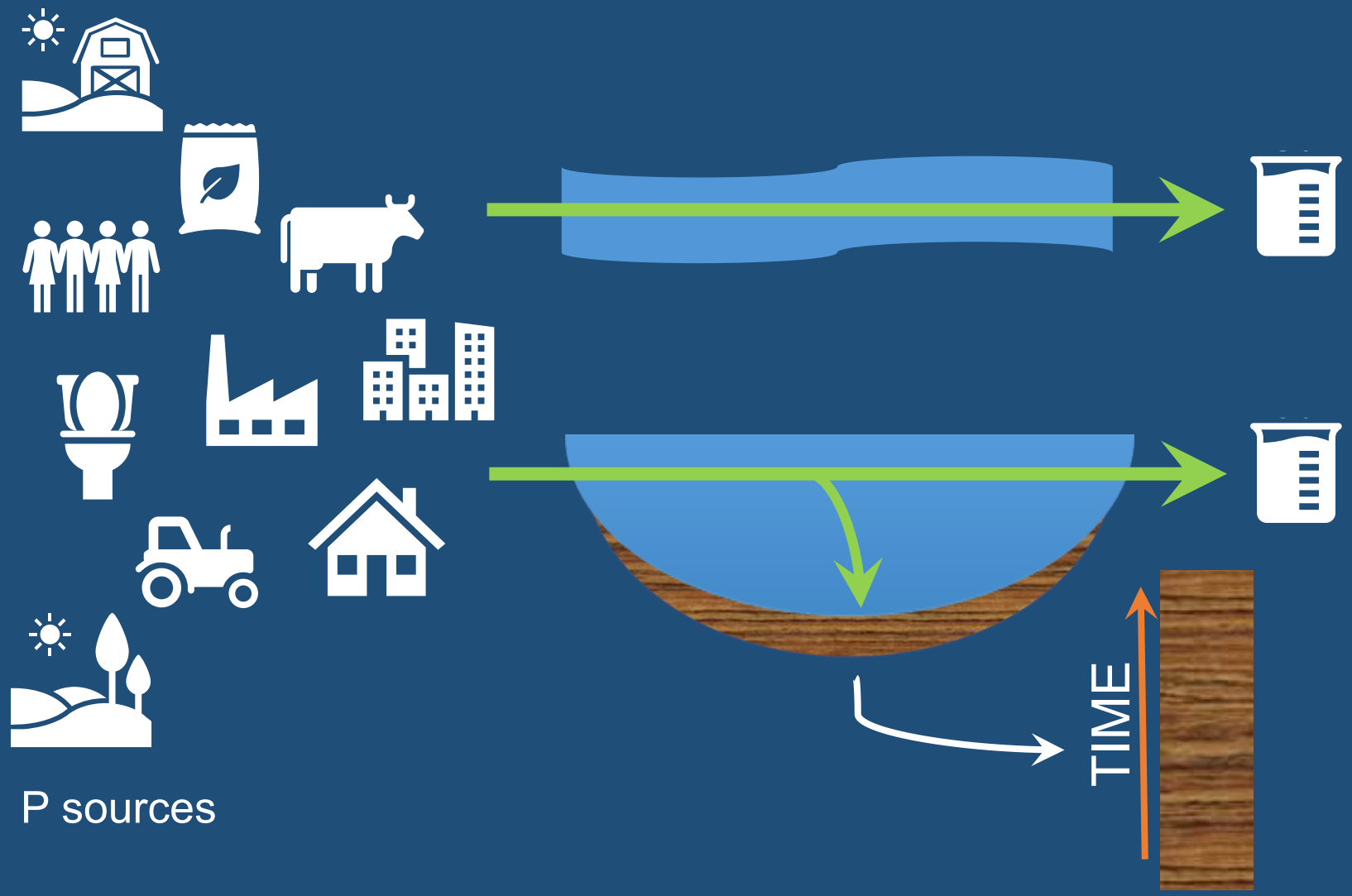


What do we do?

We take sediment (mud) from the bottom of lakes. We look at its chemical composition and compare it with measured water quality and catchment nutrient sources.

Why do we sample lake sediment?

How does it give us information about catchment phosphorus?

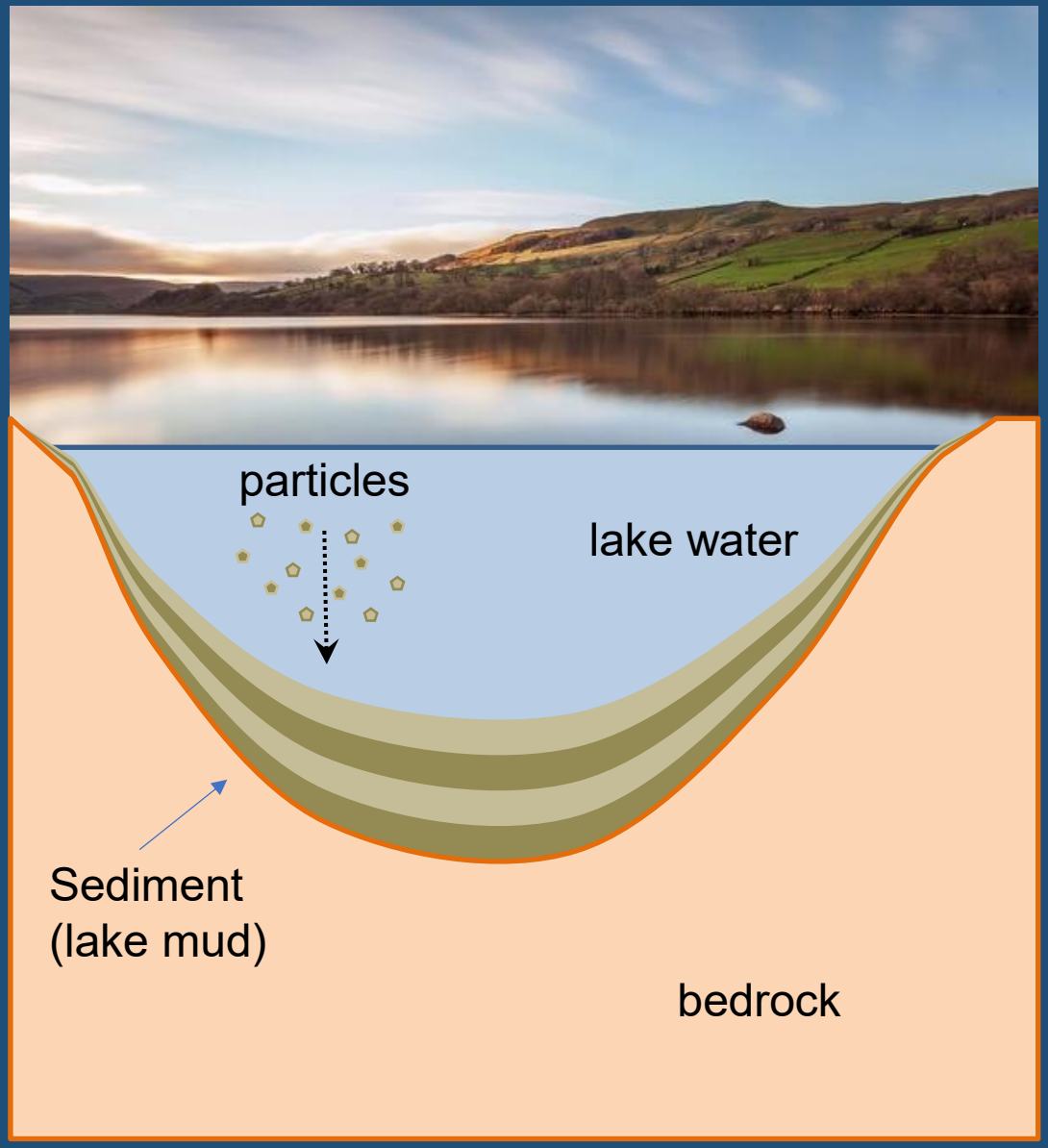


Monitoring of both rivers and lakes can tell us about current catchment P exports



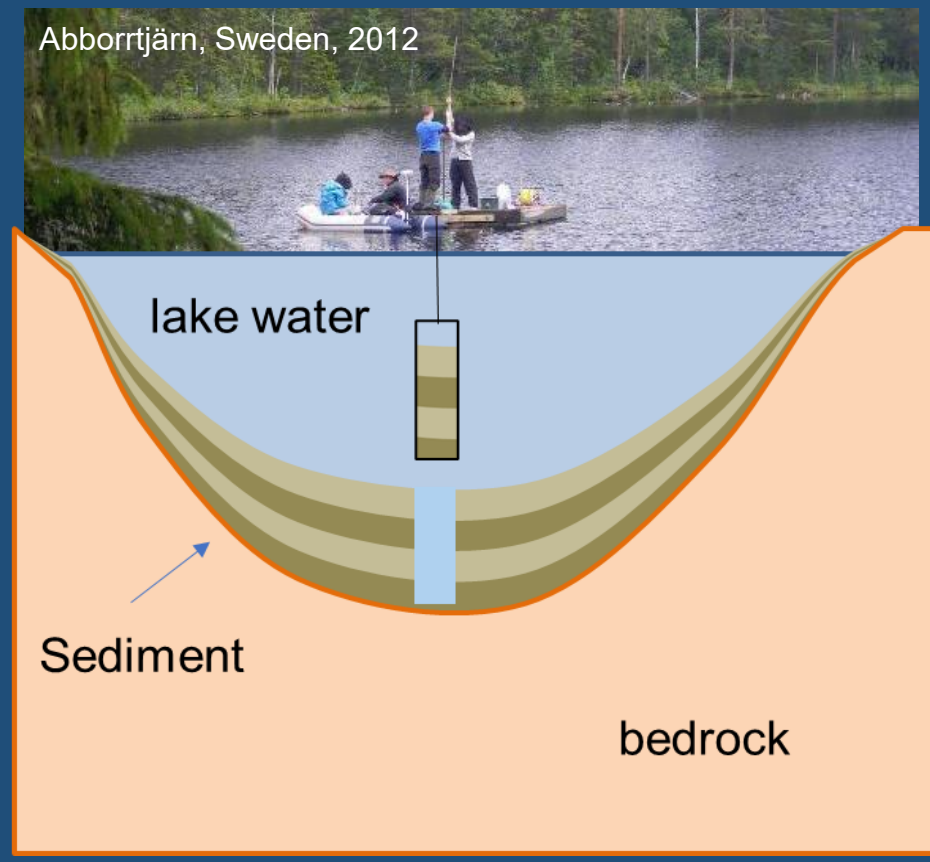
Lakes also have a “memory” of historic catchment P exports in the form of the sediment record

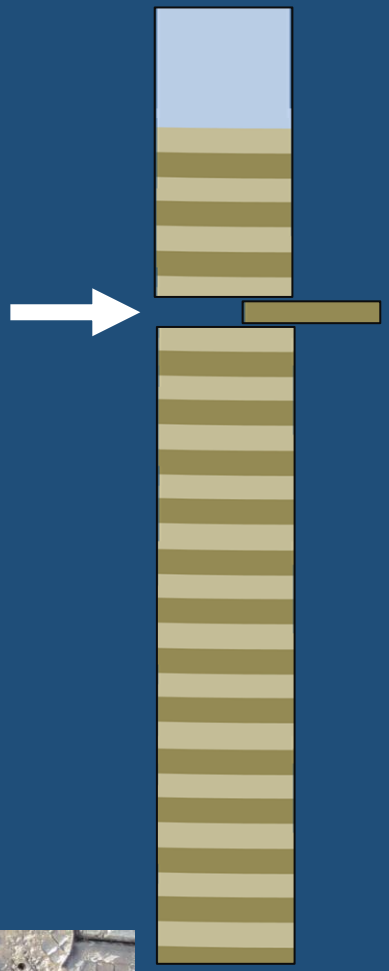
How does this sediment “memory” work?



- Particles are washed into the lake from the catchment. They also form inside the lake
- These particles reflect the state of the lake and catchment
- Particles settle to the lake bed and form sediment (lake mud)
- Today’s particles lie above yesterday’s
- So, a sediment sequence forms that is older with depth
- If we can “read” our sediment, then we have a record of change in the lake and the landscape over time.

How do we sample the sediment?









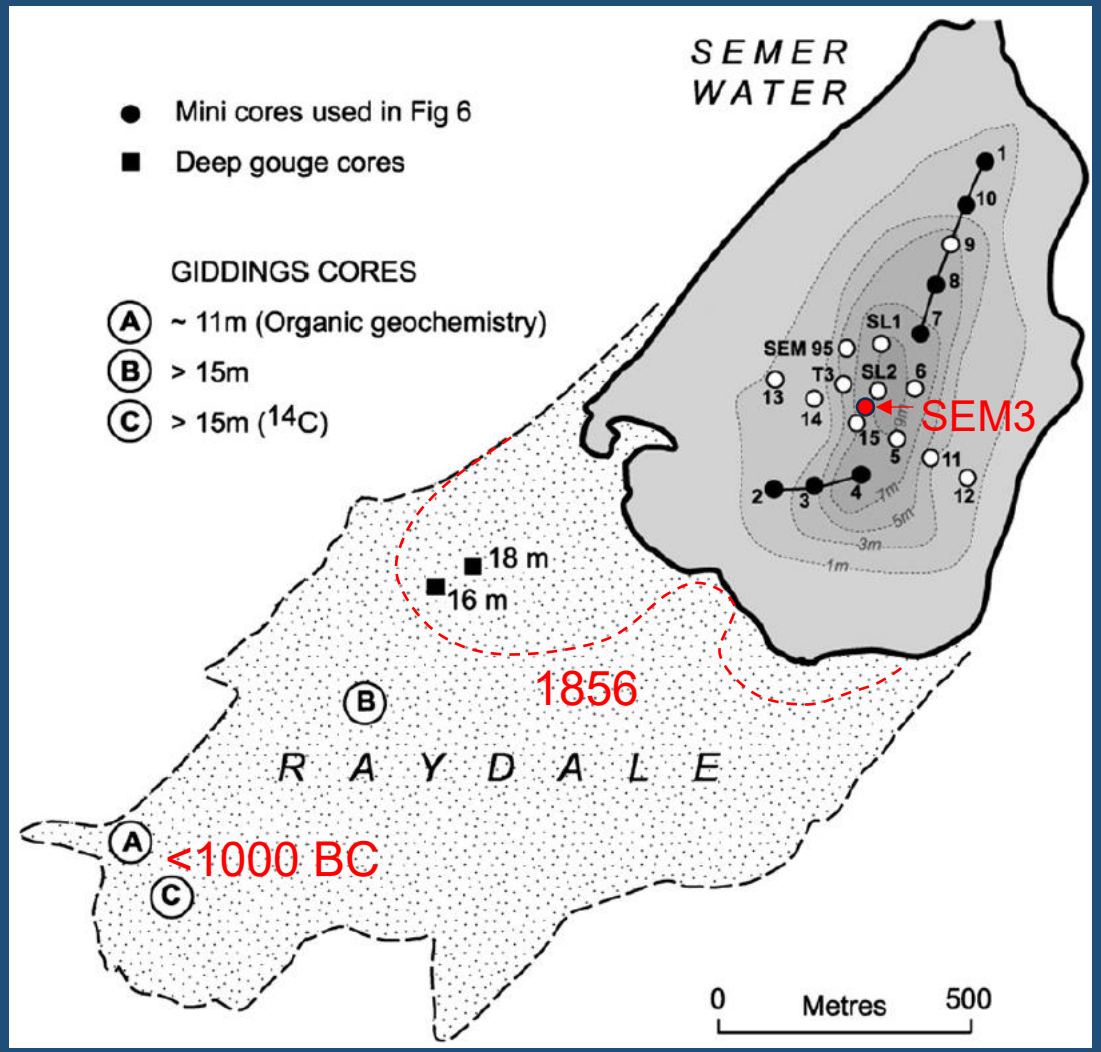
A sediment core from Crose Mere, UK

- We collect sediment as sediment cores
- We slice each core into samples
- We measure the chemical elements in the samples by X-Ray Fluorescence (XRF)
- We work out the age of each sample

1. **Using lake sediment record to examine historic phosphorus trends**
2. Modelling a phosphorus budget for Semer Water
3. Determining phosphorus sources

The Semer Water cores

Map from Chiverrell et al. (2008)



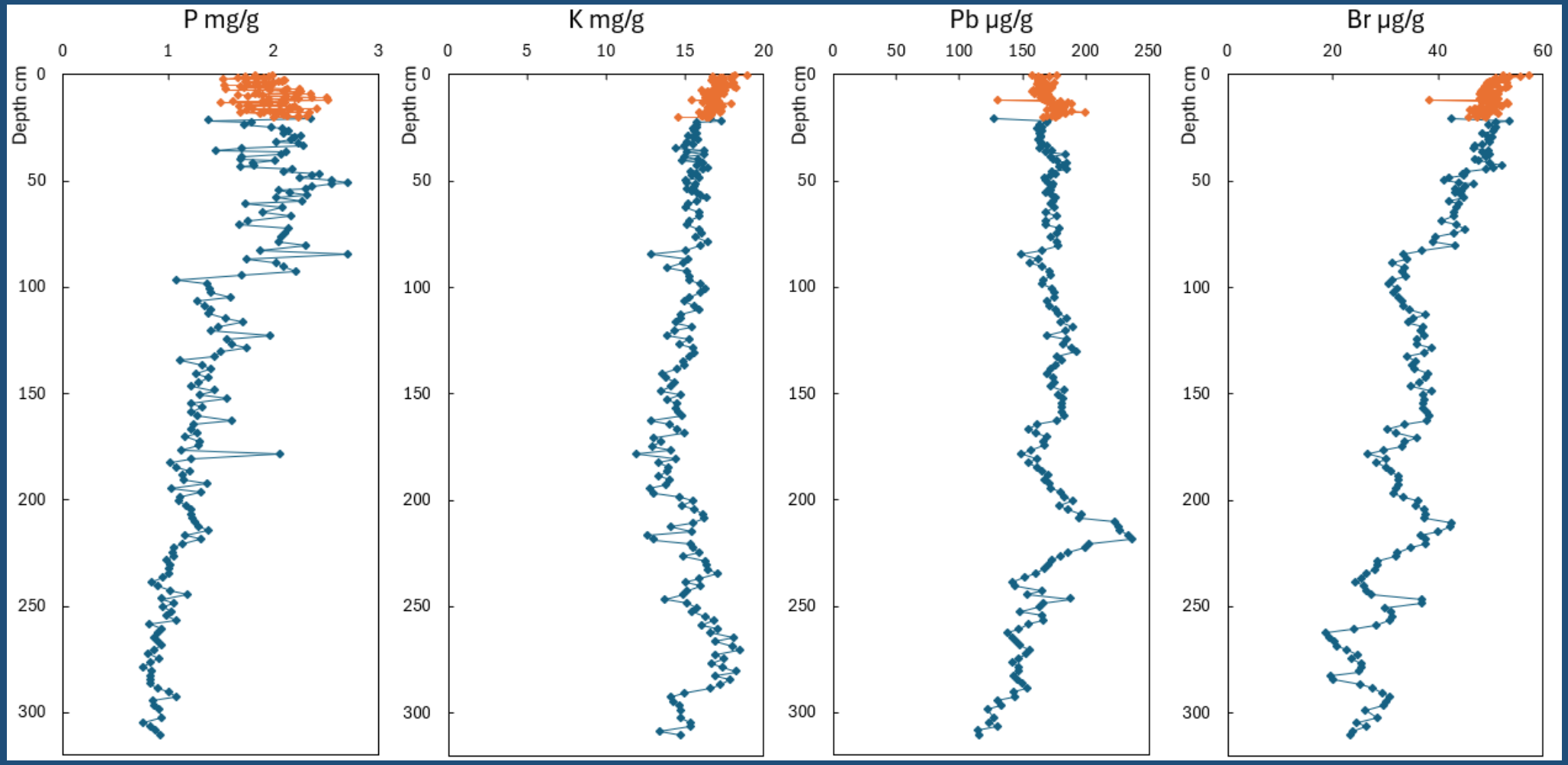
The core we have analysed, SEM3, was collected in 2018 by our colleague Richard Chiverrell & David Sear (University of Southampton)



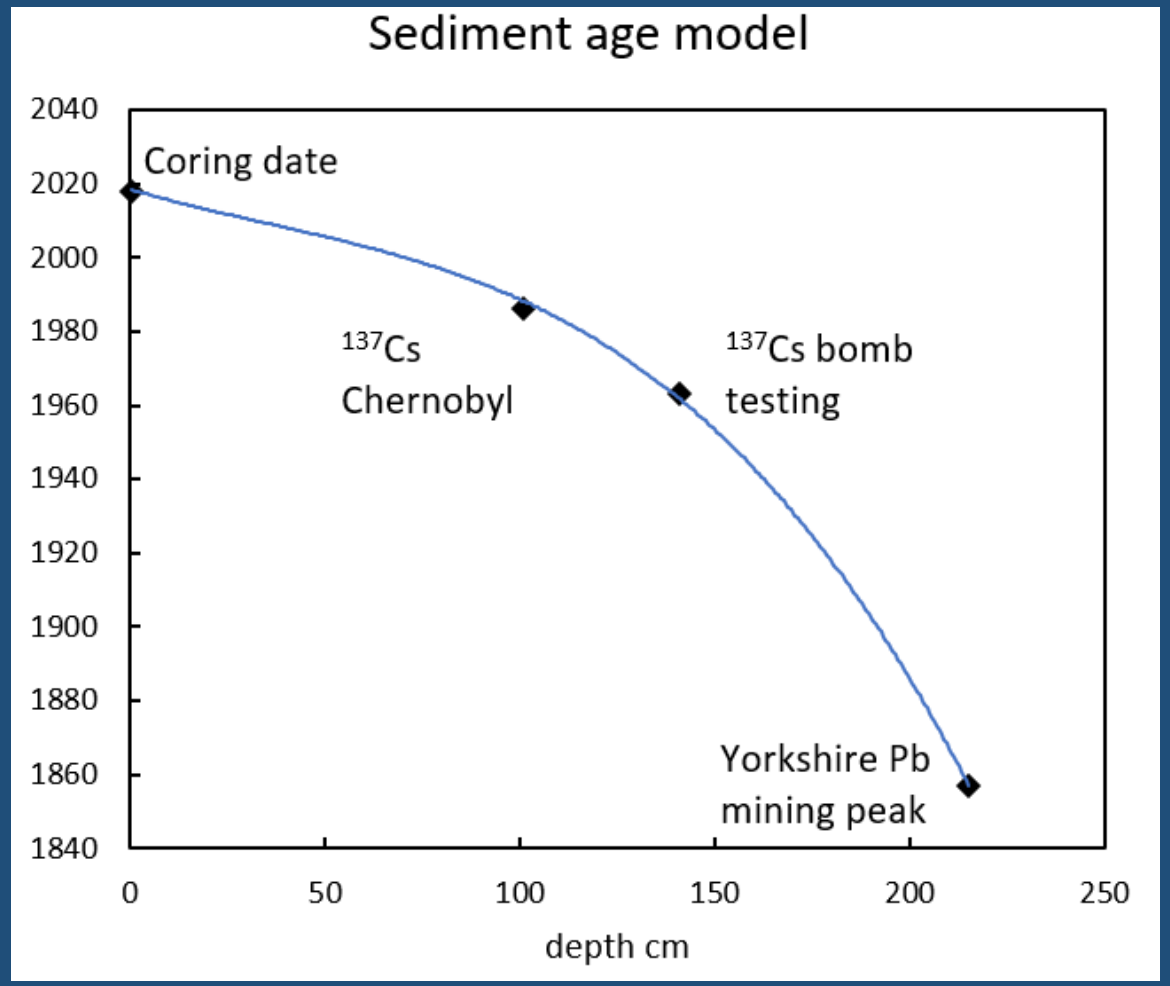


The sediment record

Phosphorus load → Mineral soil erosion → Local mining → Peat erosion



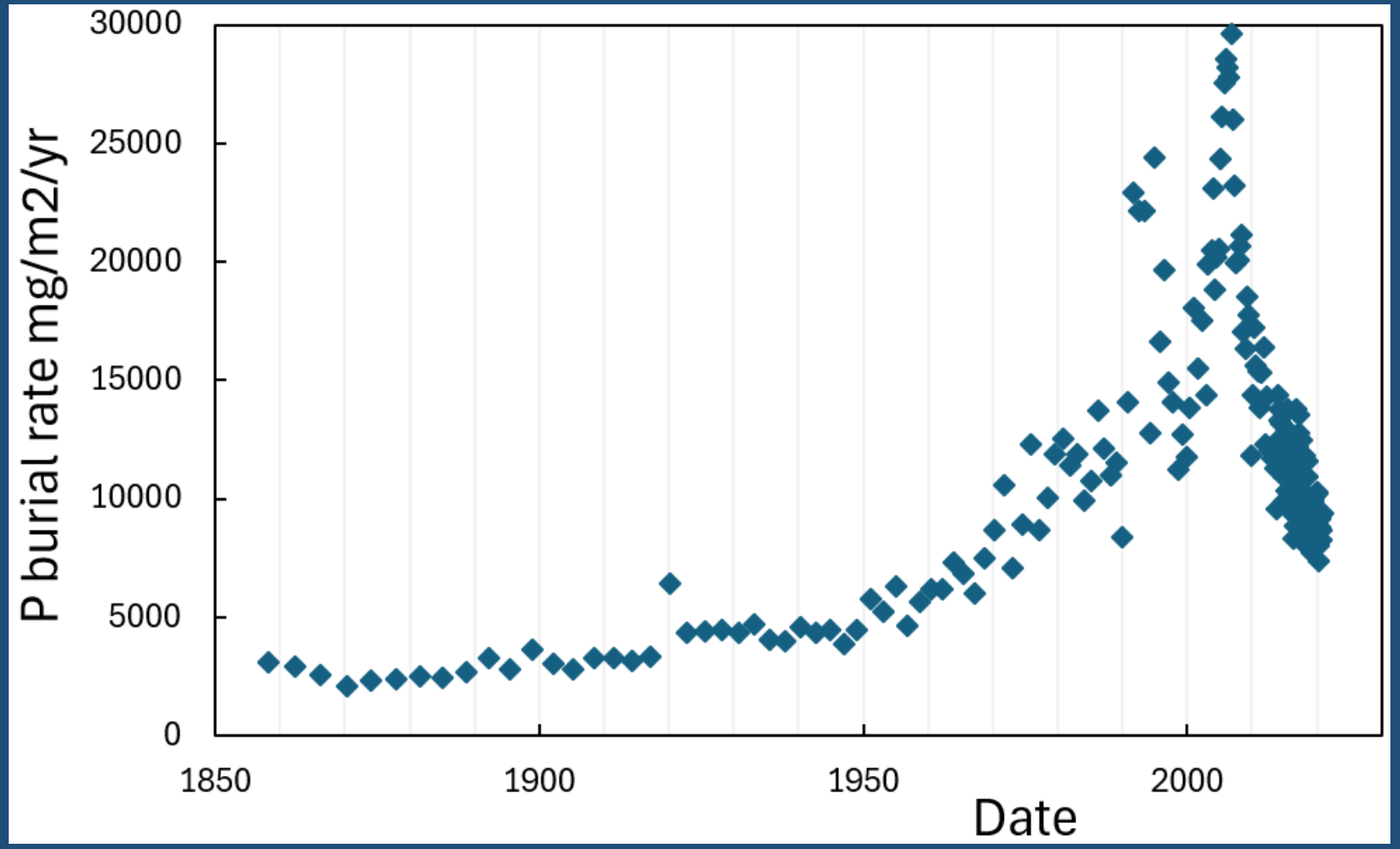
A tentative age model



How does age modelling work?

- We identify markers of known age in our sediment record for as many depths as possible.
- We make an age model using these markers.
- We apply this model to the whole record, giving us an age for each sample.

Phosphorus burial rate in SEM3

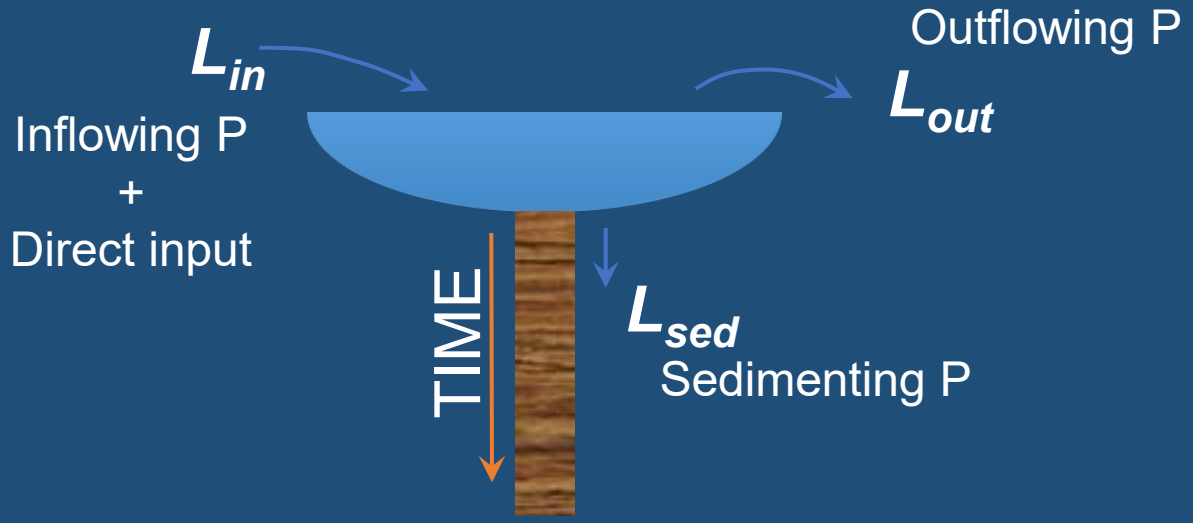


Combining information on sediment chemistry and information on how quicky the sediment has accumulated gives us burial rates for each element.

The SI-TP* model

*sediment-inferred (lake water) TP

$$L_{in} = L_{sed} + L_{out}$$



We can calculate lake water TP from our measurement of sediment P

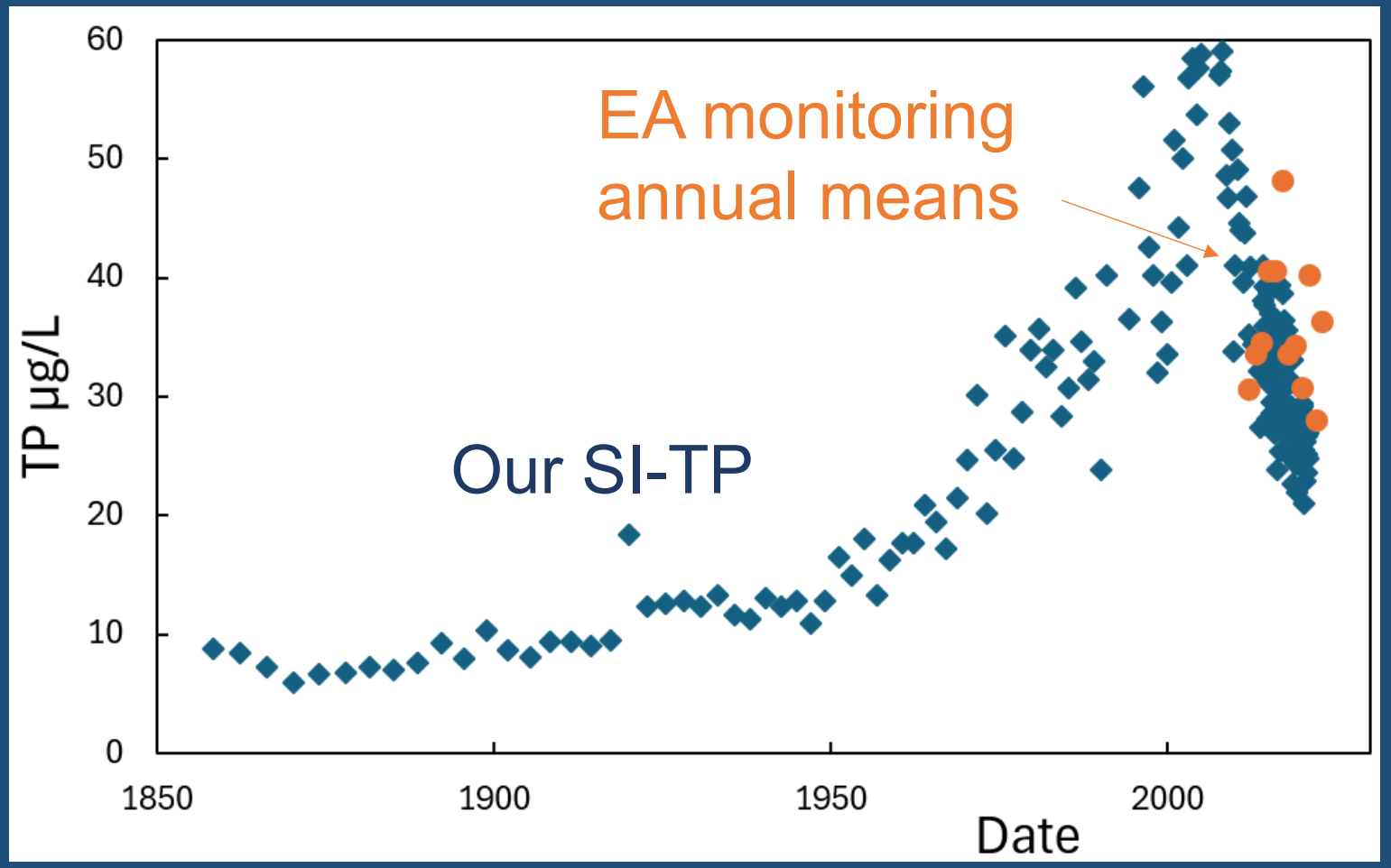
Our model uses mass balance principles:

All the P entering the system (Lin) must equal all the P leaving the system, either in the outflowing water (Lout) or buried in the lake sediment (Lsed).

Moyle and Boyle (2021)
JOPL 65, 461– 478

Scan here for the paper

Inferred and measured lake water total phosphorus concentration



Here we have used out SI-TP model to turn our measured sediment P concentrations into lake water TP concentrations

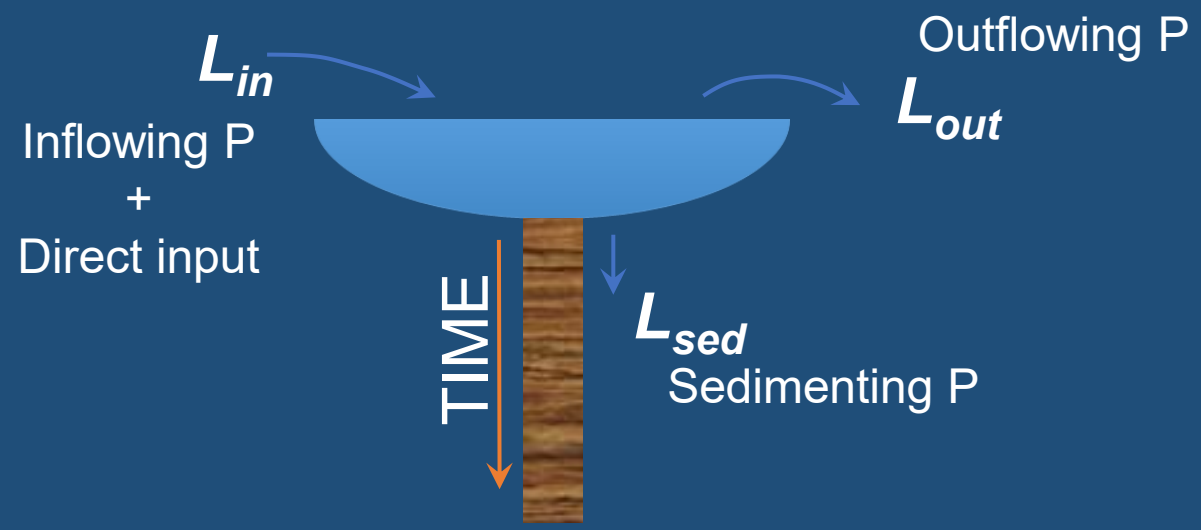
1. Using lake sediment record to examine historic phosphorus trends
2. **Modelling a phosphorus budget for Semer Water**
3. Determining phosphorus sources

A phosphorus budget for Semer Water

Lin = ?

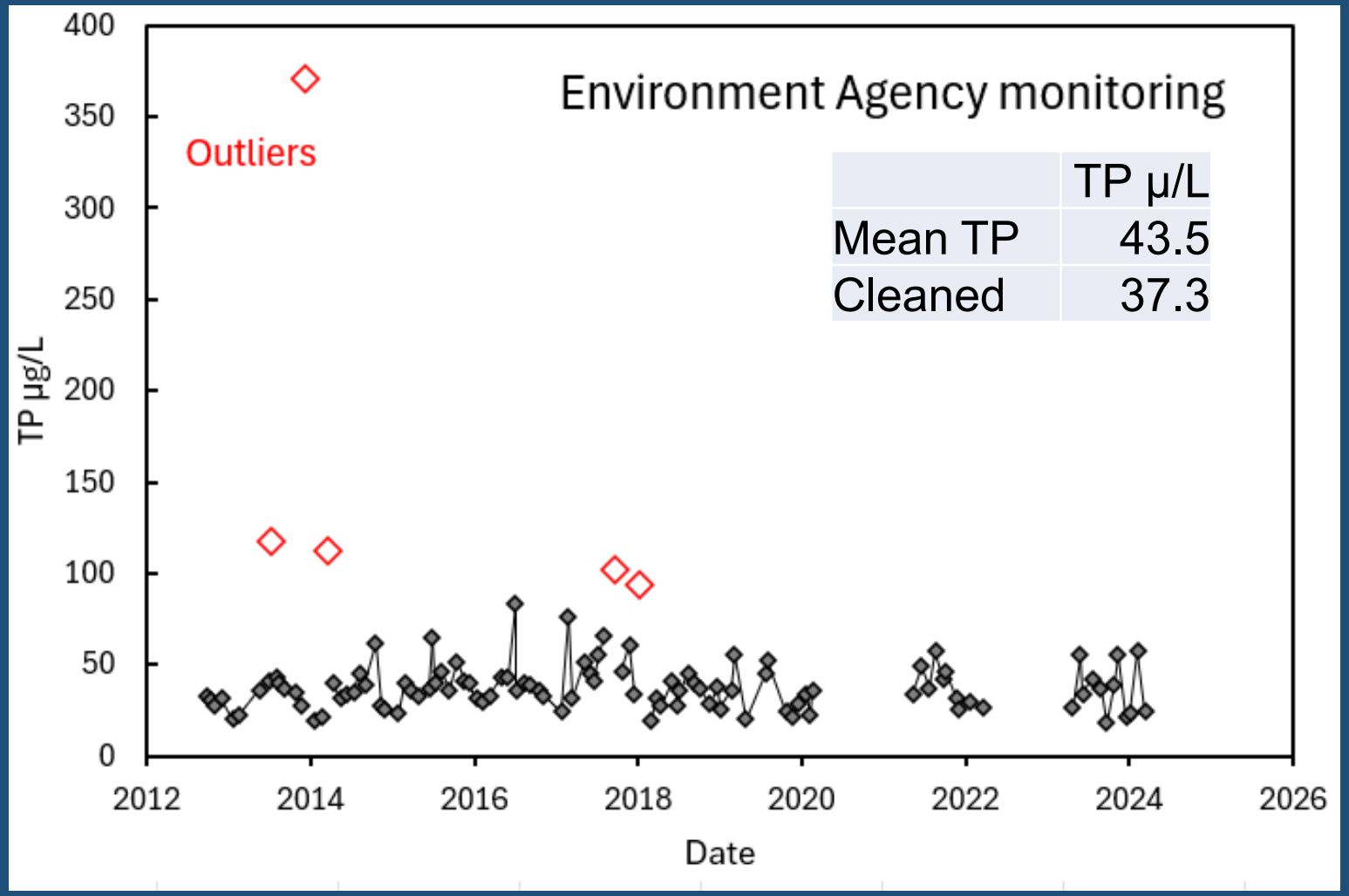
$$L_{in} = L_{sed} + L_{out}$$

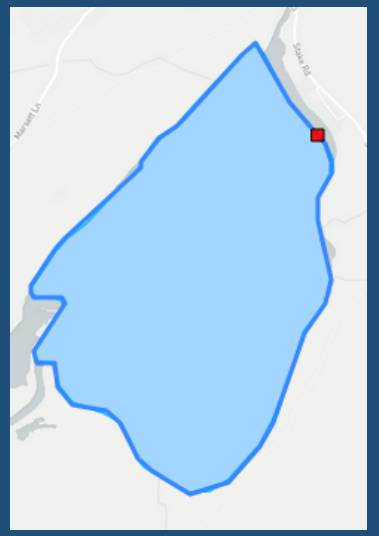
Lout = ?



Lsed = 1.6 g/m2/yr
= 461 kg/yr

The outflow loading





EA sampling point



Regional water discharge
= 1.29 m/yr

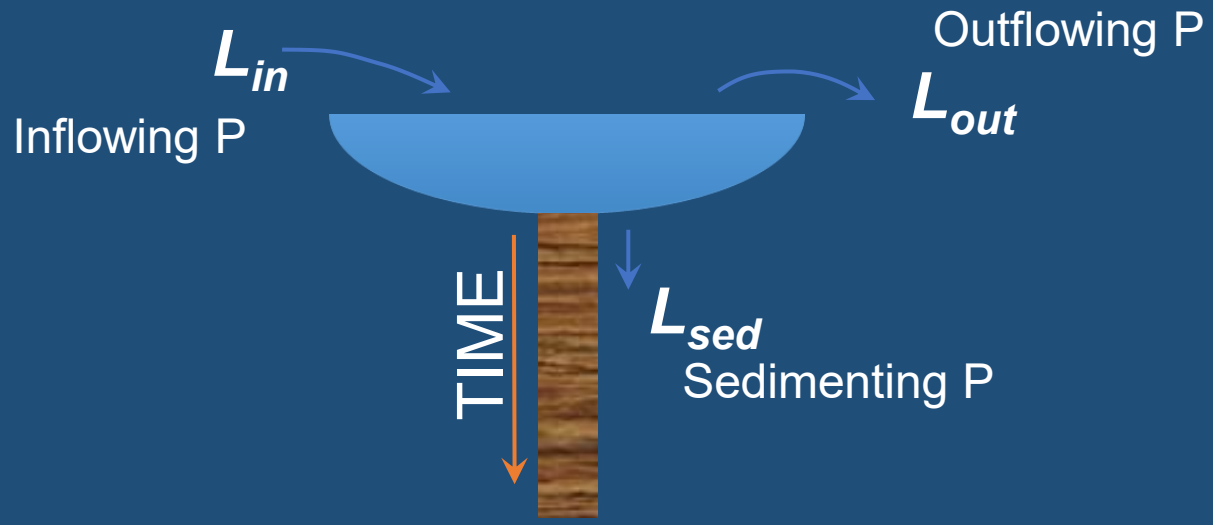
Therefore, Lout
= 2068 kg/yr

A phosphorus budget for Semer Water

Lin = Lsed + Lout
= 2529 kg/yr

$L_{in} = L_{sed} + L_{out}$

Lout = 2068



Lsed = 1.6 g/m2/yr
= 461 kg/yr

1. Using lake sediment record to examine historic phosphorus trends
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3. **Determining phosphorus sources**

Determining phosphorus sources

Catchment diffuse sources
- Land cover/use
- Livestock
- People

Direct sources
- Atmospheric deposition
- Birds
- Sediment P release

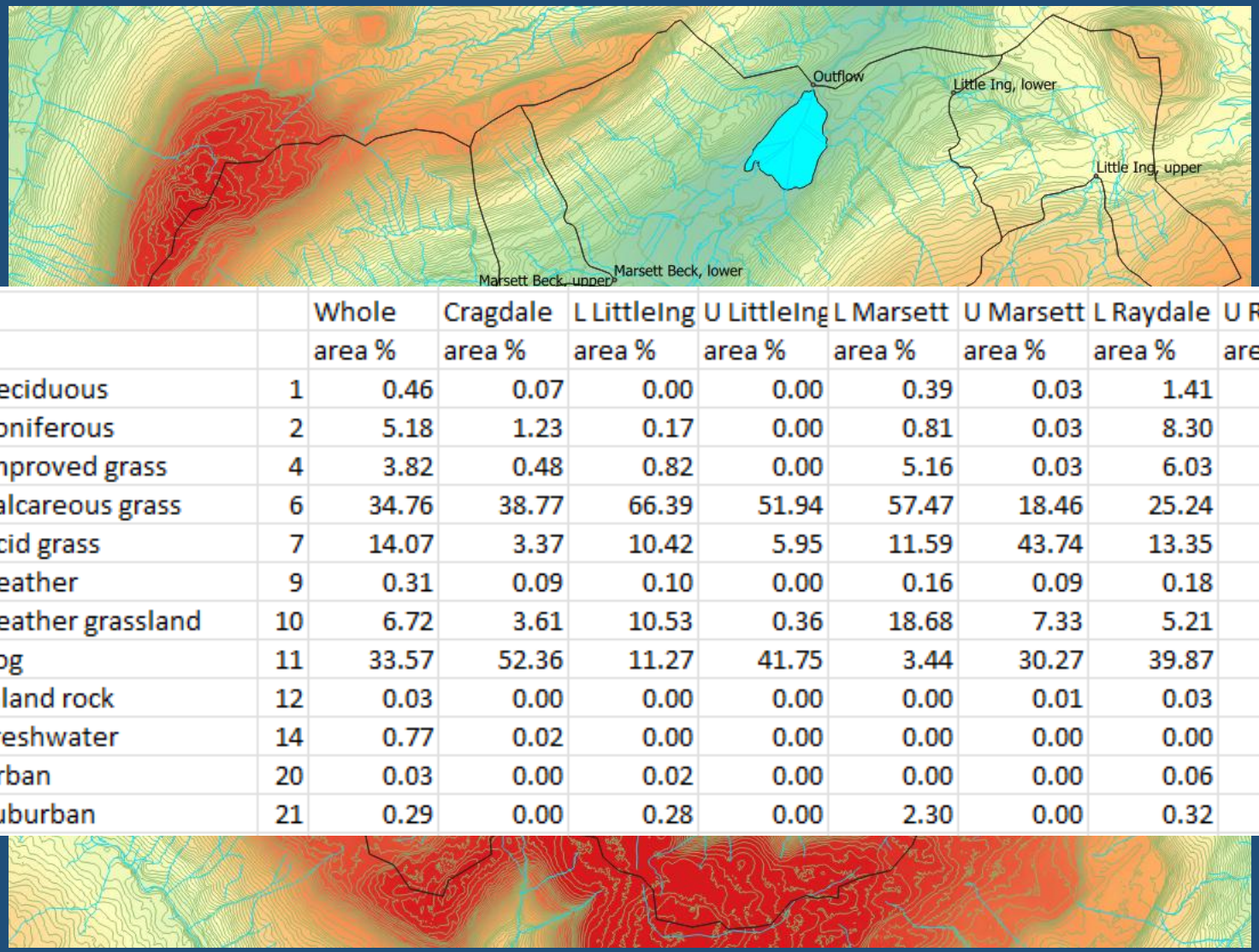
Indicative estimates based export coefficient modelling

For example:

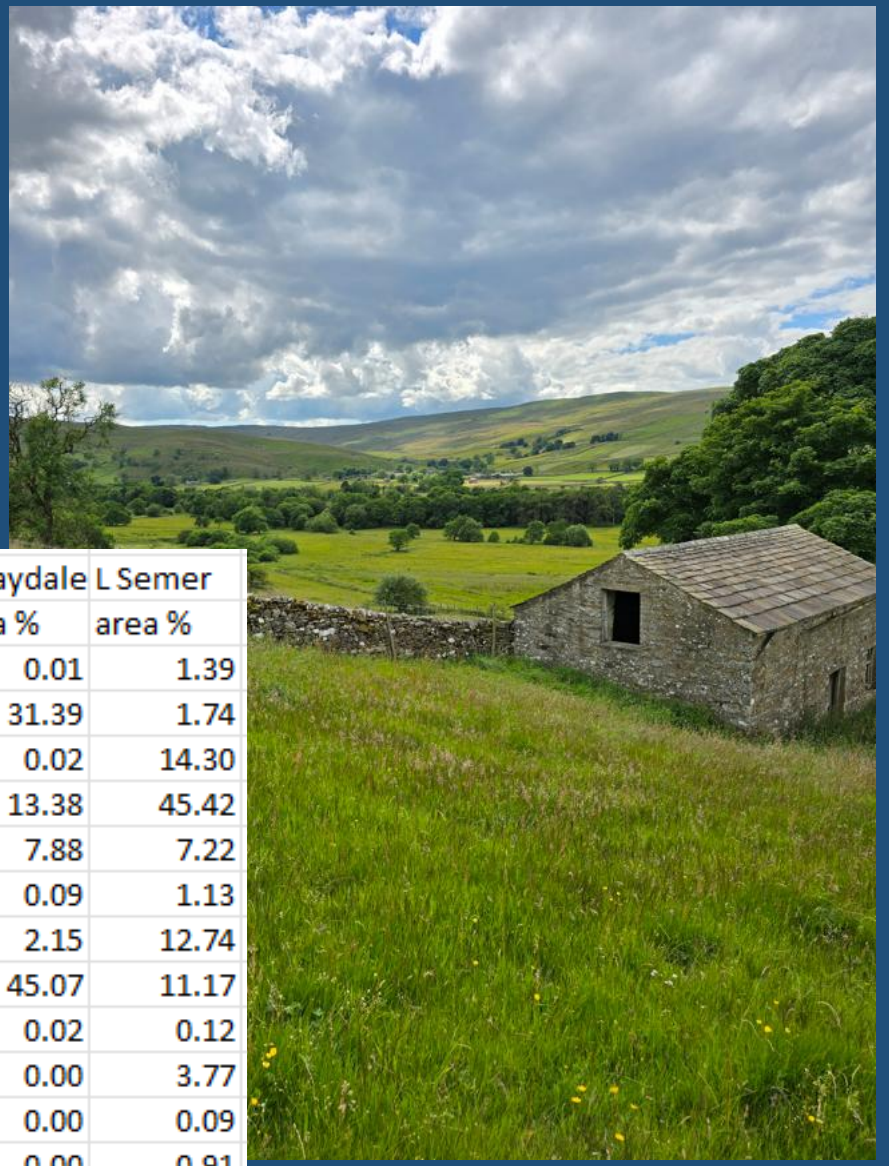
$$Cattle\ EC = 0.7 \frac{kg\ P}{head} /yr$$

$$Cropland\ EC = 60\ \frac{mg\ P}{m^2} /yr$$

Land cover



		Whole	Cragdale	L LittleIng	U LittleIng	L Marsett	U Marsett	L Raydale	U Raydale	L Semer
		area %	area %	area %	area %	area %	area %	area %	area %	area %
Deciduous	1	0.46	0.07	0.00	0.00	0.39	0.03	1.41	0.01	1.39
Coniferous	2	5.18	1.23	0.17	0.00	0.81	0.03	8.30	31.39	1.74
Improved grass	4	3.82	0.48	0.82	0.00	5.16	0.03	6.03	0.02	14.30
Calcareous grass	6	34.76	38.77	66.39	51.94	57.47	18.46	25.24	13.38	45.42
Acid grass	7	14.07	3.37	10.42	5.95	11.59	43.74	13.35	7.88	7.22
Heather	9	0.31	0.09	0.10	0.00	0.16	0.09	0.18	0.09	1.13
Heather grassland	10	6.72	3.61	10.53	0.36	18.68	7.33	5.21	2.15	12.74
Bog	11	33.57	52.36	11.27	41.75	3.44	30.27	39.87	45.07	11.17
Inland rock	12	0.03	0.00	0.00	0.00	0.00	0.01	0.03	0.02	0.12
Freshwater	14	0.77	0.02	0.00	0.00	0.00	0.00	0.00	0.00	3.77
Urban	20	0.03	0.00	0.02	0.00	0.00	0.00	0.06	0.00	0.09
Suburban	21	0.29	0.00	0.28	0.00	2.30	0.00	0.32	0.00	0.91



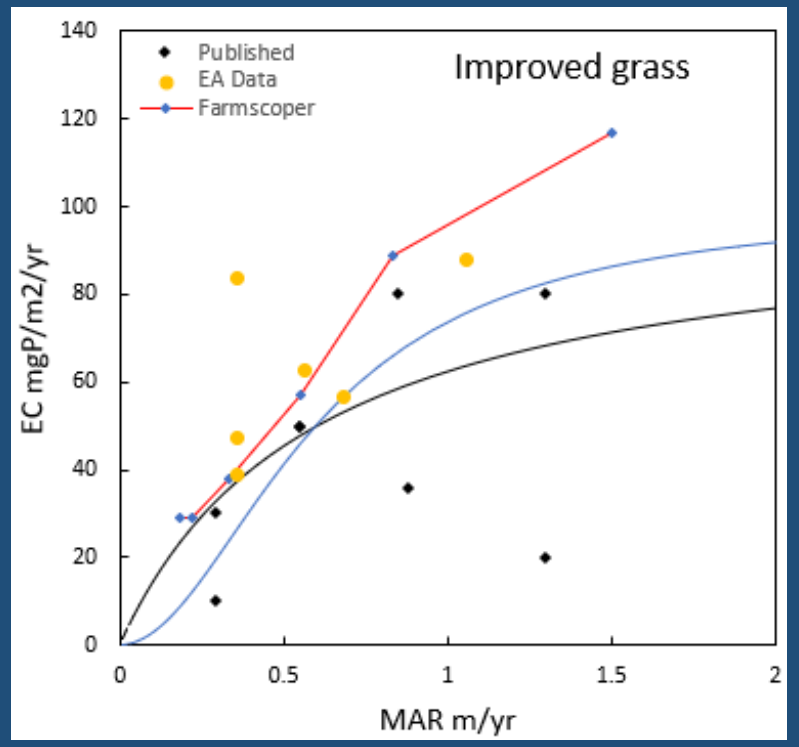
Land cover

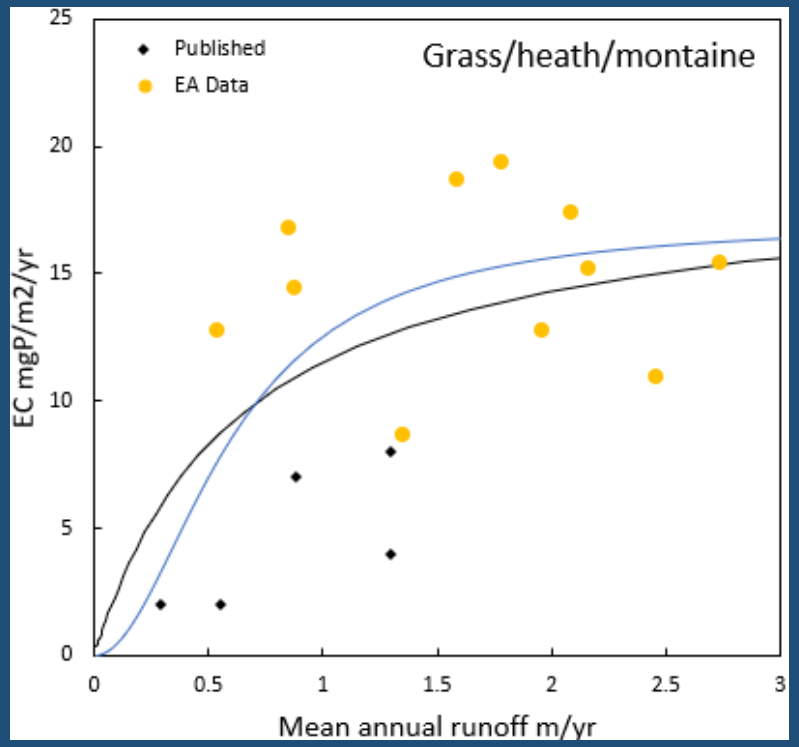
Published TP export coefficients (PLUS)

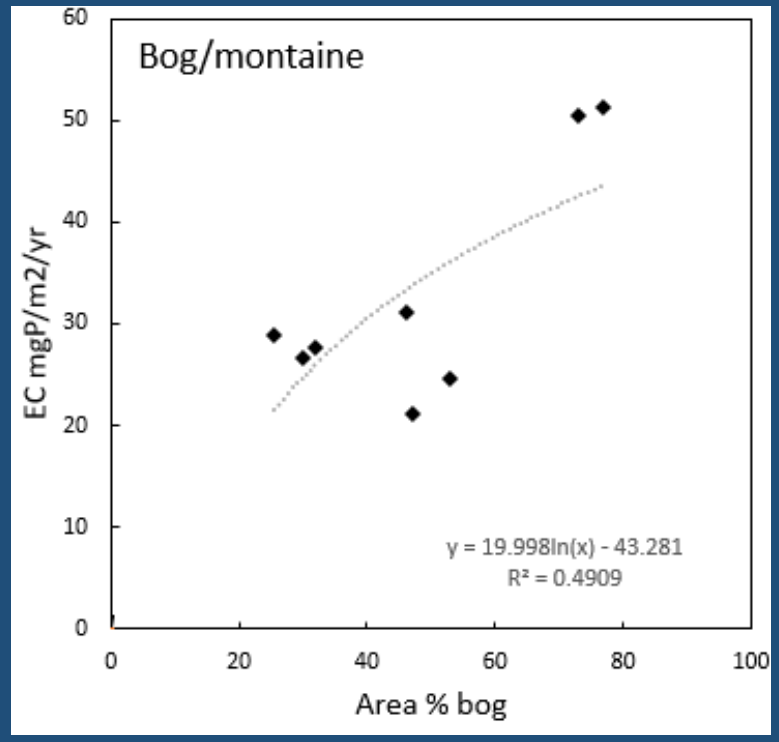
Table 2 Land cover and slope P export coefficients (kg ha^{-1})

Land cover code	Land Cover Description	Export Coefficient for each slope classification											
		Low (Slope code 100)				Medium (Slope code 200)				High (Slope code 300)			
		Match Code	Min	Max	Av.	Match Code	Min	Max	Av.	Match Code	Min	Max	Av.
1	water	101	0.07	0.20	0.135	201	0.00	0.00	0.000	301	0.00	0.00	0.000
2	wetland	102	0.02	0.15	0.085	202	0.00	0.00	0.000	302	0.00	0.00	0.000
3	blanket bog & peatland	103	0.01	0.03	0.020	203	0.02	0.04	0.030	303	0.03	0.05	0.040
4	arable	104	0.40	1.08	0.740	204	0.74	1.54	1.140	304	1.08	2.00	1.540
5	improved grassland	105	0.20	0.44	0.320	205	0.32	0.62	0.470	305	0.44	0.80	0.620
6	coarse grassland	106	0.04	0.08	0.060	206	0.06	0.12	0.090	306	0.08	0.15	0.115
7	smooth grassland	107	0.04	0.08	0.060	207	0.06	0.12	0.090	307	0.08	0.15	0.115
8	heather all types	108	0.04	0.08	0.060	208	0.06	0.12	0.090	308	0.08	0.15	0.115

Land cover


Improved grass
Published
EA Data
Farmscoper
EC mgP/m2/yr
MAR m/yr
0
20
40
60
80
100
120
140
0
0.5
1
1.5
2


Grass/heath/montaine
Published
EA Data
EC mgP/m2/yr
Mean annual runoff m/yr
0
5
10
15
20
25
0
0.5
1
1.5
2
2.5
3


Bog/montaine
EC mgP/m2/yr
Area % bog
y = 19.998ln(x) - 43.281
R² = 0.4909
0
10
20
30
40
50
60
0
20
40
60
80
100

Land cover

	EC values	Whole	Cragdale	L Littleing	U Littleing	L Marsett	U Marsett	L Raydale	U Raydale	L Semer
	mg/m2/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr	kg/yr
Deciduous	**27.5**	5.4	0.2	0.0	0.0	0.1	0.1	1.7	0.0	3.3
Coniferous	**19.5**	43.0	2.5	0.1	0.0	0.2	0.0	7.0	30.3	2.9
Improved grass	**80**	130.1	4.0	1.6	0.0	4.1	0.2	20.8	0.1	99.3
Calcareous grass	**15**	222.3	61.7	24.3	19.9	8.6	22.3	16.3	9.9	59.1
Acid grass	**15**	90.0	5.4	3.8	2.3	1.7	52.9	8.6	5.9	9.4
Heather	**15**	2.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1	1.5
Heather grassland	**15**	42.9	5.7	3.8	0.1	2.8	8.9	3.4	1.6	16.6
Bog	**49**	701.3	272.3	13.5	52.2	1.7	119.6	84.3	109.3	47.5
Inland rock	**0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Freshwater	**0**	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Urban	**138**	1.5	0.0	0.1	0.0	0.0	0.0	0.4	0.0	1.1
Suburban	**138**	16.9	0.0	0.9	0.0	3.2	0.0	1.9	0.0	10.9
Total		1255.6	352.0	48.1	74.5	22.5	204.2	144.6	157.1	251.5

Livestock

Cattle

- Jane Le Cocq guesstimated 200 dairy cattle, and 100 beef
- At 500 kg/head, and 3% to 10% export, this adds up to:
- ~123 - 410 kg P/yr



Livestock

Sheep – we have no data

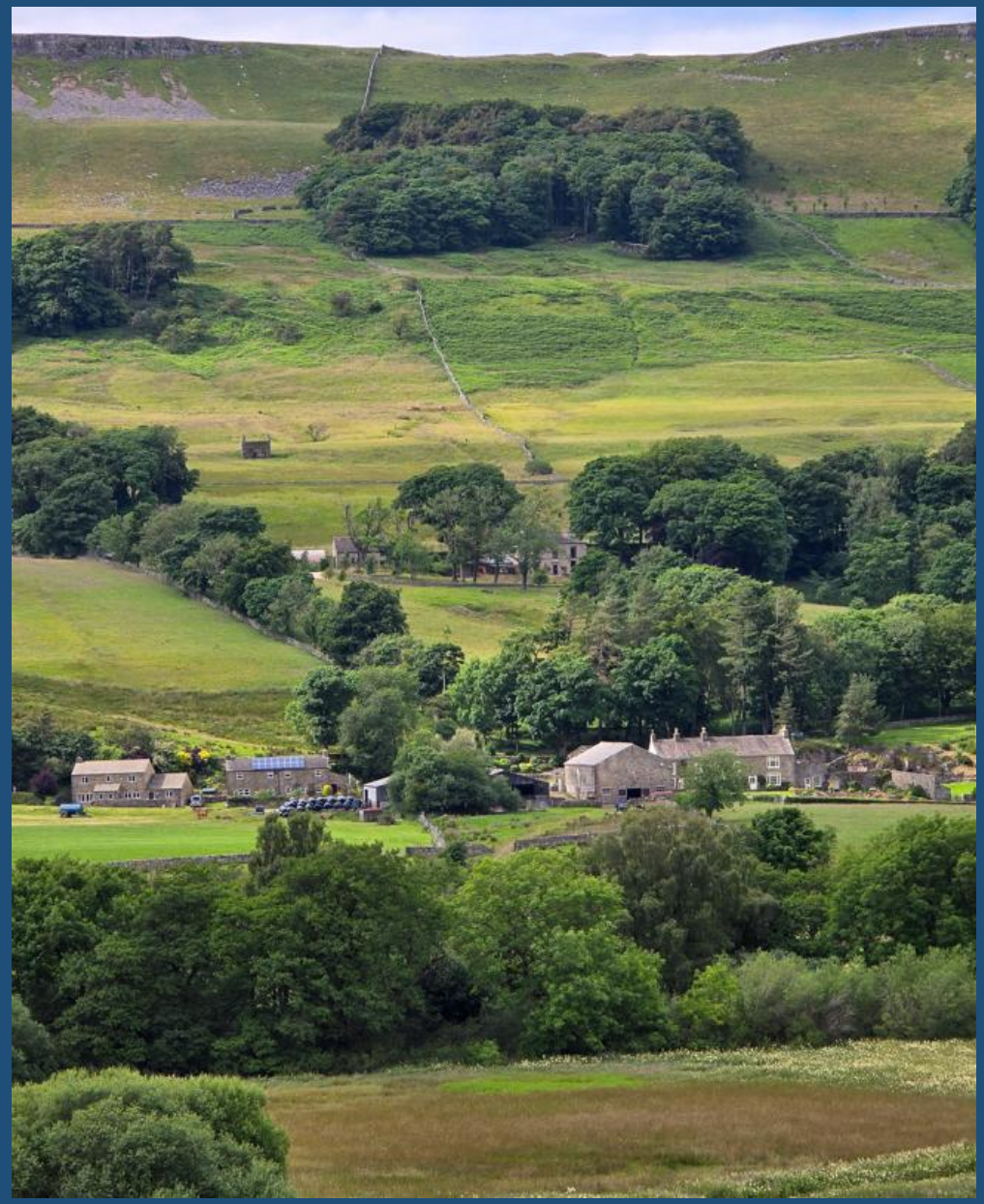
- We assume:
  - Stocking density 0.8 – 1.6 head/ha (UPL2 – NFU)
  - 23.8 km2 of grassland/heather grassland
  - 0.045 kg/head P export (Johnes 1996)
- 1905 – 3811 sheep
- 86 – 171 kg P/yr



People

We have no data

- We assume:
  - 100 people
  - 0.38 kg P/person/yr
- 38 kg P/yr

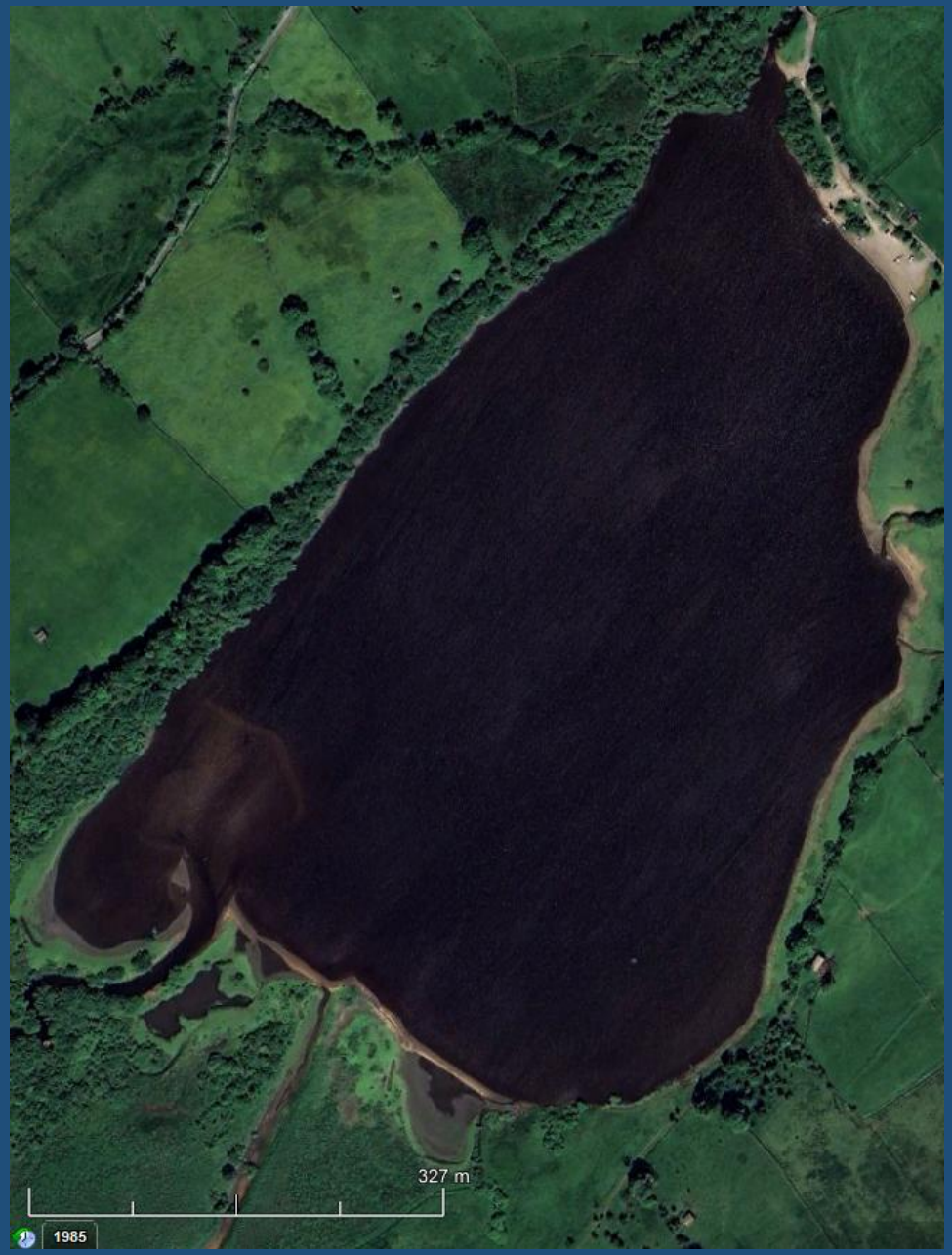


Atmospheric deposition

27 kg P/km2/yr

0.29 km2 of lake surface

8 kg/yr



Birds

We assume 400 geese on average

Based on Manny et al. (1994), Canada geese delivery 0.49 g/day of P to lake water

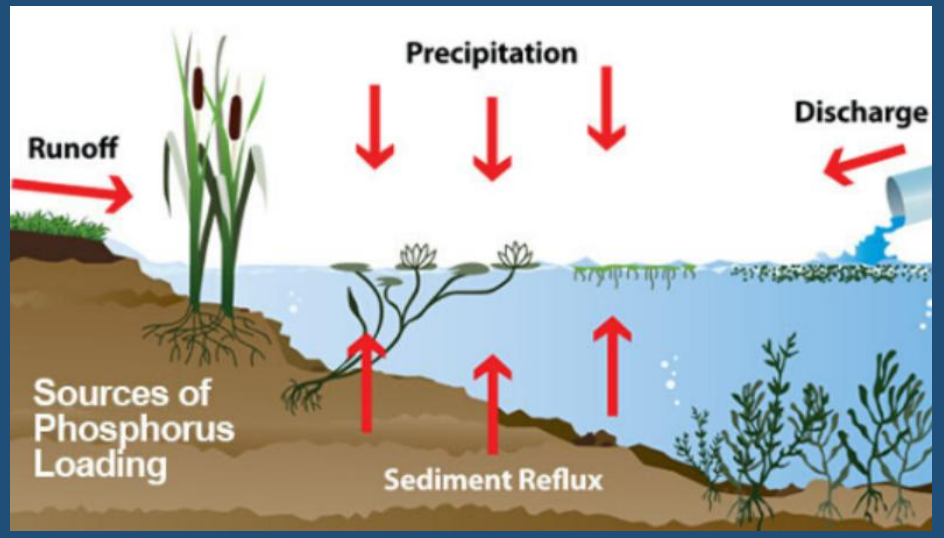
72 kg P/yr

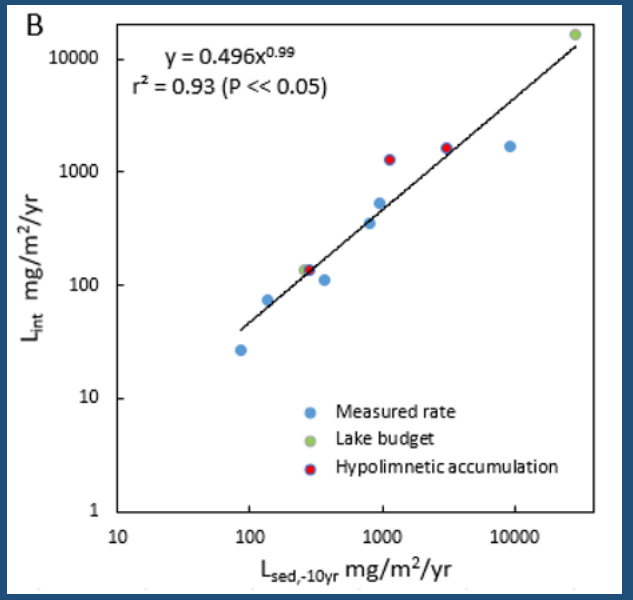


Sediment P release

We assume sediment P release is 50% of recent sediment burial rate (Boyle et al. in prep.)

230 kg P/yr

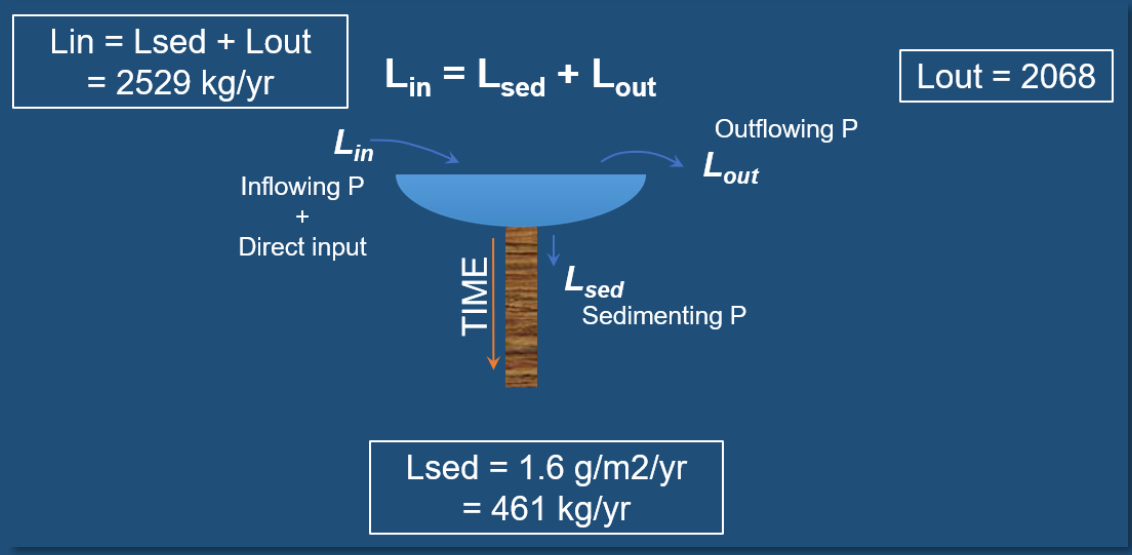




External phosphorus loading history as primary predictor of lake internal phosphorus loading.
John F Boyle, Madeleine Moyle & Gertrud K. Nürnberg

Total estimated P supply

Catchment diffuse sources	g P/yr
• Land cover/use	1256
• Livestock	395
• People	38
Direct sources	
• Atmospheric deposition	8
• Birds	72
• Sediment P release	230
Total	1999



Loading reduction?

	% of load
• Land cover/use	63
• Livestock	20
• Sediment P release	12
• Birds	4
• People	2
• Atmospheric deposition	<1

Bog load estimate – 701 kg P/yr
35% of load



Summary

- The P budget is balanced
- Direct human/agricultural load 22%
- Birds 4% of total load
- Bog load may be 35%



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Focussing factor FF

Mud limit ~ 5 m

5 m depth contour area
1/7 of total lake area

FF = ~7

SEM3 P burial (2010-2018) = 11 g/m2/yr

Lake wide P burial =
~ 1.6 g/m2/yr

