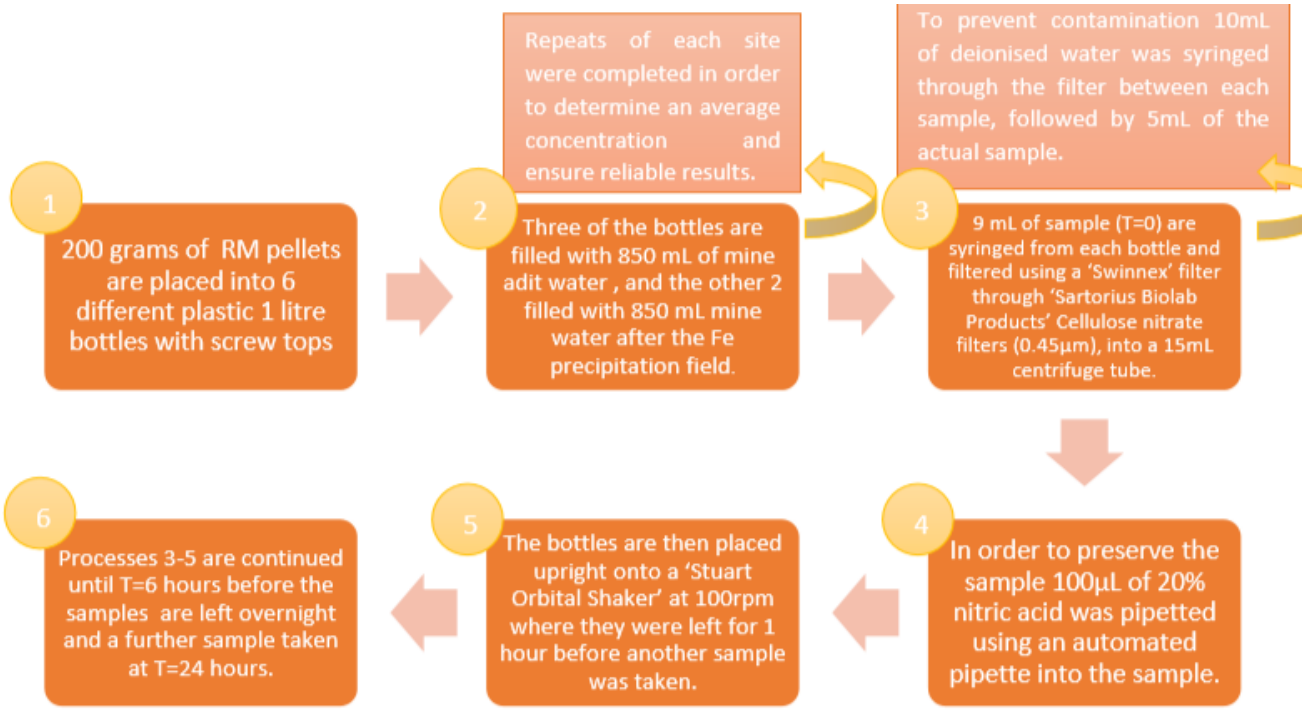
Assessing options for remediation of contaminated mine site drainage entering the River Teign, Southwest England

Abigail Jordan[1], Rachel Hill[1], Adrienne Turner[1], Tyrone Roberts[1], Sean Comber[1]*

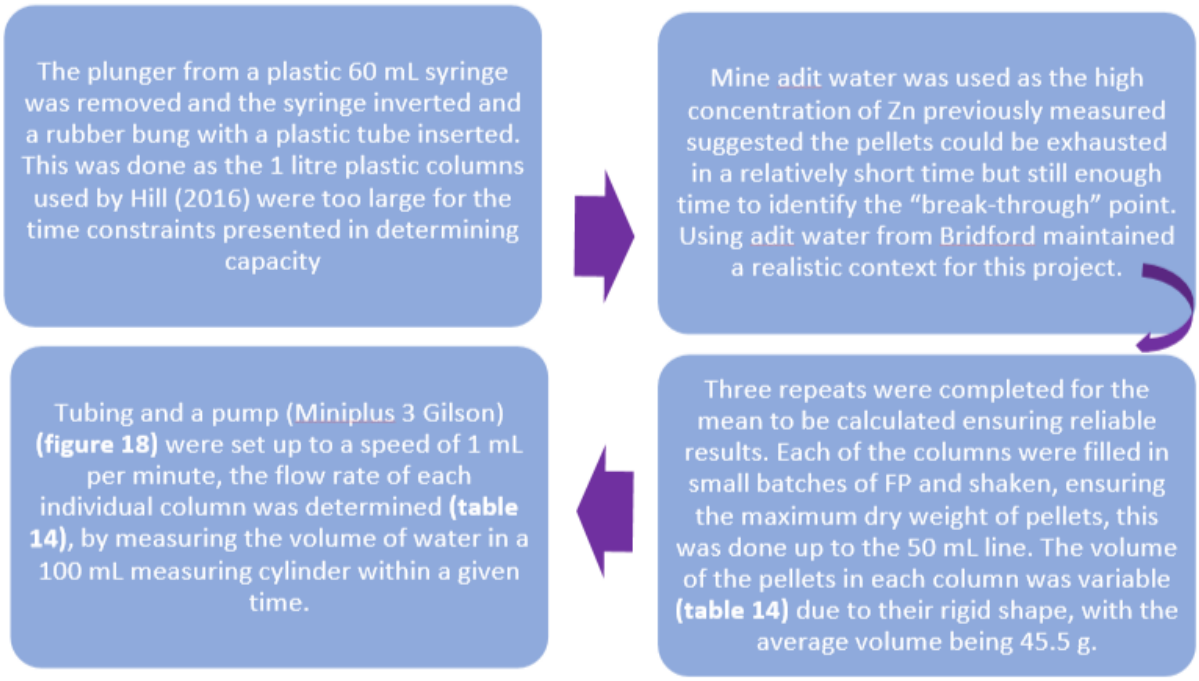
* Corresponding author: sean.comber@plymouth.ac.uk

[1] School of Geography, Earth and Environmental Sciences, University of Plymouth, Drakes Circus, Plymouth, PL4 8AA.

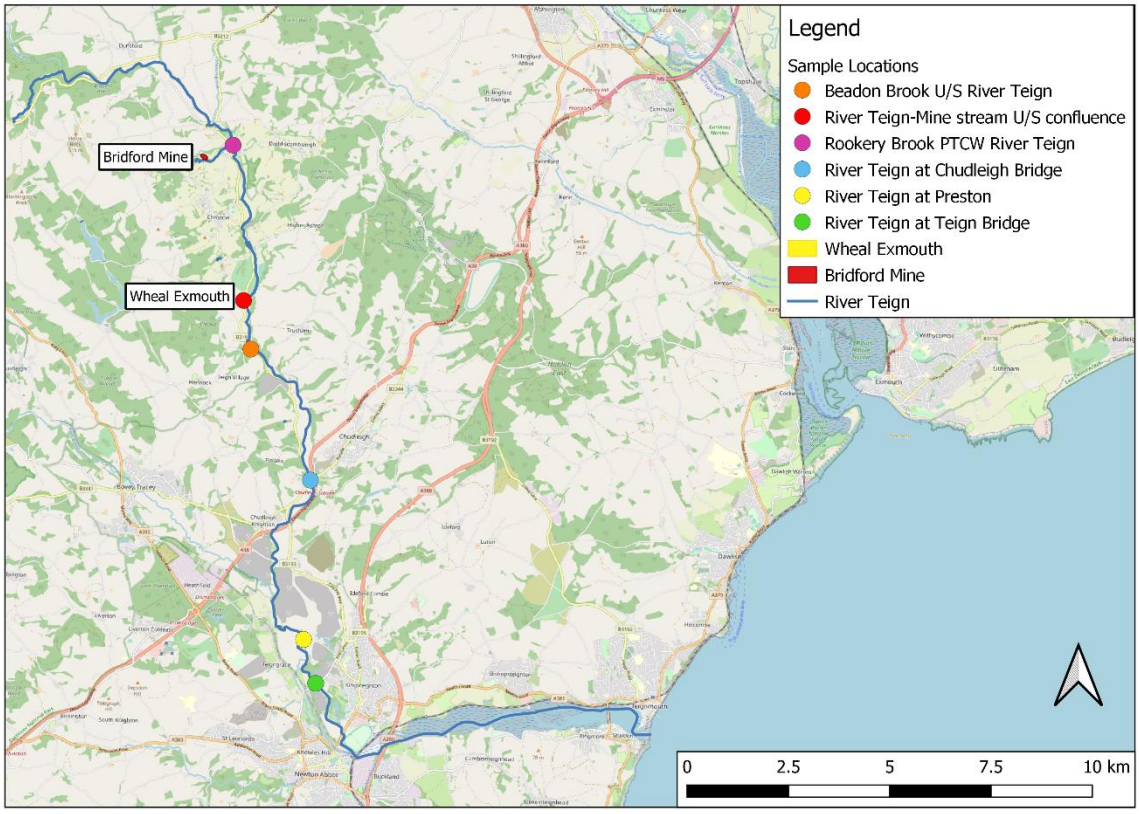
S1 Steps outlining the kinetics experiment to determine analyte adsorption rates



S2 Steps outlining column experiment.



S3 Environment Agency sampling points for the River Teign



S4: Zinc concentration after 24 hours with the different pellets from Turner (2017) and Hill (2016)

24 hours	Turner (2017)			Hill (2016)	
	New	Fired	FAE	Fired	Compressed
Hours passed	**Zinc concentration µg/l**				
0	11600	10400	11300	9643	9643
1	9800	8720	9880	1582	1636
2	8900	8120	8410	1388	575
3	5600	7180	7470		366
4	4460	2640	6150		243
5	3400		5400		175
6	2250		4880		153
24	616	909	311	68.9	43.8
removal efficiency after 24 hrs	**94.7**	**91.3**	**97.2**	**99.3**	**99.5**

S5 Removal efficiencies for Zn, Cd and Pb at 2, 24 and 53 hours *(Turner 2017; Hill 2016).*

Duration	Zinc removal %			
	Compressed	Fired	FAE	New
2 hours	73.7	22	25.6	23.3
24 hours	99.5	99.3	97.2	94.7
53 hours	99.8	99.9	-	-

Duration	Cadmium removal %			
	Compressed	Fired	FAE	New
2 hours	94.4	25.3	28.2	27.6
24 hours				
53 hours	99.5	99.9		
Duration	**Lead removal %**			
	Compressed	Fired	FAE	New
2 hours	99.2	92.7	64	96.3
24 hours				
53 hours	99.9	99.8		

S6 Field scale trial at Bridford mine. Percentage removal of Zn, Cd and Pb over a 3-month period *(Comber 2015)*

Day	% removal Zn		% removal Cd		% removal Pb	
	filtered	unfiltered	filtered	unfiltered	filtered	unfiltered
3	91	84	94	94	99	99
9	81	80	91	91	99	99
20	77	78	87	86	99	98
26	63	62	75	74	97	95
33	45	39	56	48	85	51
38	36	31	45	43	74	68
44	28	28	44	42	66	58
51	24	24	39	36	68	53
58	27	22	41	37	66	60
67	31	24	40	35	46	36
72	37	34	51	42	43	39
79	28	31	45	48	73	51
89	26	23	38	39	73	43
104	36	19	57	36	79	58

S7 Biochar removal efficiency results for Zn, Cd and Pb at 550°C and 700°C *(Roberts 2018)*

Removal efficiency (%) 2 hrs						
Biochar	550°C			700°C		
	zinc	cadmium	lead	zinc	cadmium	lead
Forestry waste	5	-1	18	8	0	62
Municipal waste	9	0.023	60	17	19	76
Rice husk	28	43	100	9	20	98
Miscanthus straw pellet	21	35	97	50	62	100
Wheat straw pellet	80	86	94			
Oil seed rape	80	88	91	81	90	100

S8 Environment Agency monitoring data from 2000-2020 available at

https://environment.data.gov.uk/water-quality/view/landing

All units µg/l

Beadon brook								
	Zn EQS	**Dissolved zn**	**bio zn**	**Cd EQS**	**mean Cd**	**Pb EQS**	**mean Pb**	**bio Pb**
2012	13.8	145		0.08	1.99	7.2	2.15	
2013	13.8	203		0.08	2.47	7.2	2.28	
2014	13.8	61		0.08	0.98	7.2	2	
2015	13.8	176	120	0.08	2.02	7.2	1.15	0.72
2016	13.8	358	325	0.08	3.69	7.2	2.80	2.28
2017	13.8	249	211	0.08	2.76	7.2	1.95	1.34
2018	13.8	200	168	0.08	1.92	7.2	1.42	0.84
2019	13.8	138	107	0.08	1.64	7.2	1.72	0.74

RT at Preston	Zn EQS	Dissolved Zn	bio zn	Cd EQS	mean Cd	Pb EQS	mean Pb
2000	13.8	21.5		0.08	0.11	7.2	1.06
2001	13.8	30.9		0.08	0.08	7.2	1.25
2002	13.8	19.4		0.08	0.01	7.2	1.0
2003	13.8	20.3		0.08	0.09	7.2	2.09
2004	13.8	19.0		0.08	0.09	7.2	2.57
2005	13.8	21.1		0.08	0.09	7.2	2
2006	13.8	16.4		0.08	0.08	7.2	2.02
2007	13.8	16.1		0.08	0.10	7.2	2
2008	13.8	15.9		0.08	0.10	7.2	2

2009	13.8	15.8		0.08	0.105	7.2	2
2010	13.8	18.5		0.08	0.107	7.2	2
2011	13.8	15.0		0.08	0.100	7.2	2
2012	13.8	16.8		0.08	0.103	7.2	2
2013	13.8	15.9		0.08	0.107	7.2	2
2014	13.8	17.2		0.08	0.101	7.2	2
2015	13.8	13.8	9.19	0.08	0.0763	7.2	2
2016	13.8	16.9	8.90	0.08	0.0763	7.2	0.535
2017	13.8	16.7	10.90	0.08	0.0684	7.2	1.05
2018	13.8	18.4	9.74	0.08	0.0847	7.2	1.12
2019	13.8	16.3	10.13	0.08	0.0823	7.2	1.12

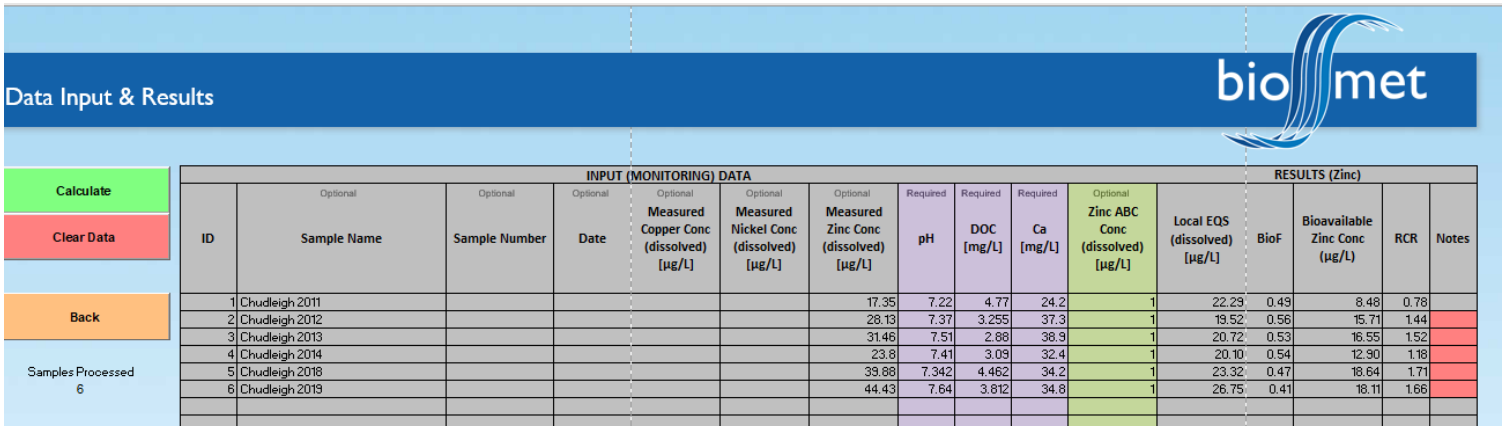
RT at Chudeigh bridge	Zn EQS	Dissolved zn	bio zn	Cd EQS	mean Cd	Pb EQS	mean Pb
2011	13.8	17.4		0.08	0.1	7.2	2
2012	13.8	28.		0.08	0.103	7.2	2
2013	13.8	31.5		0.08	0.175	7.2	2.83
2014	13.8	23.8		0.08	0.19	7.2	2
2018	13.8	39.9	9.74	0.08	0.219	7.2	2.00
2019	13.8	42	10.1	0.08	0.191	7.2	2.65

Rookery Brook PTCW RT	Zn EQS	Dissolved zn	bio zn	Cd EQS	mean Cd	Pb EQS	mean Pb
2011	13.8	551		0.08	1.85	7.2	19
2012	13.8	453		0.08	1.98	7.2	21.6
2013	13.8	368		0.08	1.7	7.2	27.3
2016	13.8	407		0.08	1.36	7.2	20

Bioavailable data at Chudleigh bridge *(Environment Agency water quality archive):*

RT at Chudleigh bridge			
Year	**pH**	**DOC (mg/l)**	**Hardness (Total a CaCO3) mg/l**
2019	7.57	3.81	34.8
2018	7.33	4.46	34.1
2014	7.41	3.09	32.4
2013	7.49	2.88	36.8
2012	7.33	3.2	37.3
2011	7.17	4.775	24.2

S9 Screenshot of Biomet tool, used to calculate the bioavailable concentrations of Zn at Chudleigh bridge, using pH, hardness and DOC.



Data Input & Results

biomet

Calculate

Clear Data

Back

Samples Processed
6

INPUT (MONITORING) DATA											RESULTS (Zinc)				
ID	Sample Name (Optional)	Sample Number (Optional)	Date (Optional)	Measured Copper Conc (dissolved) [µg/L] (Optional)	Measured Nickel Conc (dissolved) [µg/L] (Optional)	Measured Zinc Conc (dissolved) [µg/L] (Optional)	pH (Required)	DOC [mg/L] (Required)	Ca [mg/L] (Required)	Zinc ABC Conc (dissolved) [µg/L] (Optional)	Local EQS (dissolved) [µg/L]	BioF	Bioavailable Zinc Conc (µg/L)	RCR	Notes
1	Chudleigh 2011					17.35	7.22	4.77	24.2	1	22.29	0.49	8.48	0.78	
2	Chudleigh 2012					28.13	7.37	3.255	37.3	1	19.52	0.56	15.71	1.44	
3	Chudleigh 2013					31.46	7.51	2.88	38.9	1	20.72	0.53	16.55	1.52	
4	Chudleigh 2014					23.8	7.41	3.09	32.4	1	20.10	0.54	12.90	1.18	
5	Chudleigh 2018					39.88	7.342	4.462	34.2	1	23.32	0.47	18.64	1.71	
6	Chudleigh 2019					44.43	7.64	3.812	34.8	1	26.75	0.41	18.11	1.66	

S10 Screenshot of Real World Application model, used to calculate the amount of pellets/biochar needed to reduce Zn levels below the EQS at Chudleigh

Metal	EQS	Metal Conc. In water body (µg/l)	Metal Conc. In water body (mg/l)	Amount above EQS (ug/l)	Amount above EQS (mg/l)	Flow (m3/s) (annual avg.)	Flow m3/s into l/s	Flow (l/s) x 60 = l/min	Flow (l/min) x 60 = l/hour	Flow (l/hr) x 24 = l/day	Flow l/day x 365 = l/yr	Exceedance (mg/l) x flow (l/yr) = (load) mg/yr	Load into kg/year	Capacity of pellets* (mg/kg)	g/kg	kg/kg	Load (kg/yr) / adsorption capacity (kg/kg) = kg of pellets for 1year to reach EQS in water body	Tonnes of pellets a year required to reach EQS in water body	So, kg/yr of pellets / 586* = m3 required for amount of pellets
Zinc	10.9	18.1	0.01811	7.2	0.007	5.3200	5320	319200	19152000	459648000	1.678E+11	1209632659	1210	395.8	0.40	0.0004	3056171	3056	5215
Cadmium	0.08	0.2	0.00019	0.1	0.000	5.3200	5320	319200	19152000	459648000	1.678E+11	18454867.2	18	1.56	0.00	0.0000	11830043	11830	20188
Lead	7.2	2.7	0.00265	-4.6	-0.005	5.3200	5320	319200	19152000	459648000	1.678E+11	-763360416	-763	2089	2.09	0.0021	-365419	-365	-624

*From laboratory, 586kg in 1m3

Instructions:

Columns coloured orange require input, the remaining columns populate automatically

1. Input the EQS of the metal into column B
2. Input metal concentration (µg/l) of the water body into column C
3. Input annual flow of water body in column G
4. Input pellet capacity in column O
5. Column S shows the amount of tonnes of pellets required per a year to reach the EQS

is this a realistic - you should have better numbers now

if Bridford up to 2000 kg/yr then Bridford could go within 50% of exceedance

*Compressed pellet capacities:		
Cadmium:	35.40	mg/kg
Copper:	3.65	mg/kg
Iron	42464	mg/kg
Lead:	2089	mg/kg
Zinc:	8743	mg/kg

Agricultural biochar capac		wood biochar capcity	
Zinc	11000mg/kg	Zinc	395.8mg/kg

Manure biochar capacity	
Zinc	4250mg/kg
Cadmium	16600mg/kg
Lead	19850mg/kg

Fired pellets capacity	
Zinc	>150mg/kg
Cd	>1.56
Pb	>3.89