OR/17/020 Results

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Farr, G, and Graham, J. 2017. Survey, characterisation and condition assessment of *Palustriella* dominated springs 'H7220 Petrifying springs with tufa formation (*Cratoneurion*)' in Gloucestershire, England. *British Geological Survey Internal Report*, OR/17/020.

Elevation and orientation

The study sites (Figure 1-3) occur across a range of elevations from coastal cliff faces on the Severn Estuary at 11 maOD up to 252 maoD at Workmans Wood (Table 3).

Table 3 Elevation from 10 m DTM and general orientation.

Site	Easting	Northing	Orientation	Elevation maOD
Alder_Carr	385297	207895	SE	77
Aust_Cliff	356427	189190	NW	12
Bathurst_Estate	395150	204409	SE	137
Cranham_Woods	390447	212803	NE	236
Dodeswell	399177	220573	SE	175
Fishponds_Wood	382938	197047	SE	168
Horsley_Wood	383514	197603	SE	130
Kingscote_Wood	382753	197126	NE	148
Kingscote_Wood_Main	382634	197202	NE	139
Midger Wood (Fissidens)	380033	189530	NW	128
Midger_Woods_(Main)	380054	189602	SE	150
Minchiampton_Stream	386997	200066	NW	130
Sedbury_Cliff	355645	193093	SE	11
Slade_Brook	356774	205546	SW	70
Strawberry_Banks	390892	203500	SW	117
Toadsmore	387783	204209	SE	155
Woodchester_Park 1	382005	200757	NE	162
Woodchester_Park 2	381790	201226	NE	164
Woodchester_Park 3	382448	200505	NE	133
Woorkmans_Wood_WW1	390664	210676	NW	216
Woorkmans_Wood_WW2	390868	211171	NW	252
Woorkmans_Wood_WW3	390500	211532	SE	211

Wetlands functional mechanisms (WETMECS)

Wetlands Functional Mechanisms or 'WETMECS' as they are more commonly known were defined for the Environment Agency and describe the main (but not all) of the most common ecohydrological units that occur within lowland wetlands in England and Wales. They offer a simple way to classify water supply mechanisms to wetlands. The most appropriate for the majority of the sites within this

study are ‘WETMEC 10a Permanent Seepage Slopes’ (Figure 4-1) and ‘WETMEC 17 (Figure 4-2) Groundwater flushed slopes’, which often occur together on following onto the other. They are often found in valley heads and slopes, typical of the Cotswold’s landscape where permanent groundwater discharge from semi-confined or unconfined bedrock or drift aquifers, issues from springs and seepages.

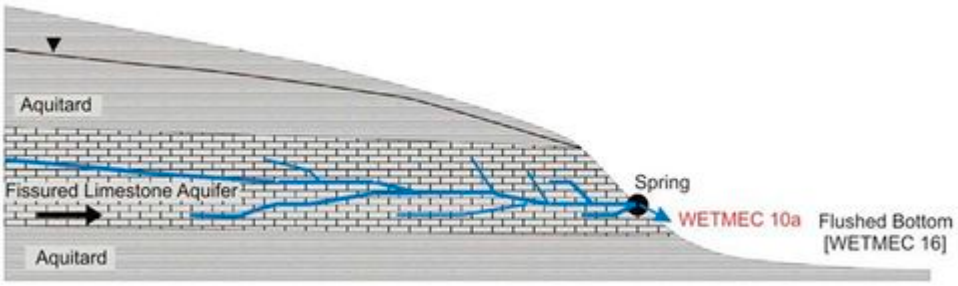

Figure 4-1 WETMEC 17 Groundwater flushed slopes (Environment Agency, 2009).

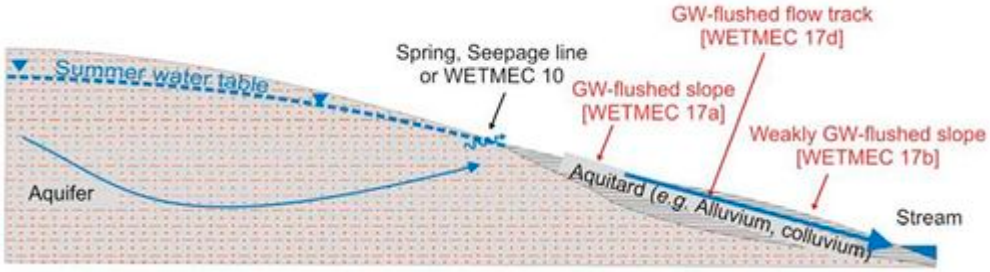

Figure 4-2 WETMEC 17 Groundwater flushed slopes (Environment Agency, 2009).

Most of the sites in this study are flushed with water that has emerged from a spring or seepage nearby. As tufa forms rapidly as groundwater reacts with the atmosphere, all of the tufa forming sites start almost immediately nearby the groundwater source that supplies them. The geology of Gloucestershire is varied and tufa is associated with a range of geologies and aquifers. The Great Oolite and Inferior Oolite Group of the Jurassic along with adjacent formations such as the Fullers Earth and Salperton Limestone were commonly associated with tufa forming springs in this study, although this may simply reflect our choice of study sites. The calcareous geology and the steep topography of the Cotswold’s valleys make this an ideal setting for springs and streams with active tufa formation. It is likely that there are many more tufa forming streams and springs associated with the Jurassic strata in the Stroud area. Tufa and H7220 habitat was also associated with Jurassic Whitby Mudstone Formation (Alder Carr); the Jurassic Blue Lias, and Triassic Penarth Group at cliff face seepages at Sedbury and the Carboniferous Limestone and Devonian Tintern Sandstone formation at Slade Brook.

Water chemistry

Field parameters

Field measurements were made for pH, temperature and electrical conductivity at the same time as collecting the water sample. Field readings for temperature ranged between 6.6°C to 10.7°C with a mean of 8.8°C, and field pH between 8.65 to 7.28 with a mean of pH 7.93. Field electrical conductivity ranged from 446 µscm to 1075 µscm with a mean of 598 µscm. Direct and careful on site measurements are water from tufa forming springs will change chemistry as it precipitates tufa. This is nicely illustrated by a comparison of field and lab electrical conductivity measurements taken on the same samples (Figure 4-4) where the lab electrical conductivities are all lower than the field

data, this is possibly due to major ionic components (calcium, sulphate and bicarbonate) dropping out of solution. This confirms the need for onsite electrical conductivity and temperature readings when sampling at tufa forming springs. In addition, due to the rapidly changing chemical nature of the waters, alkalinity should be performed in the field and not in the laboratory (pers. com. Thomas Barlow).

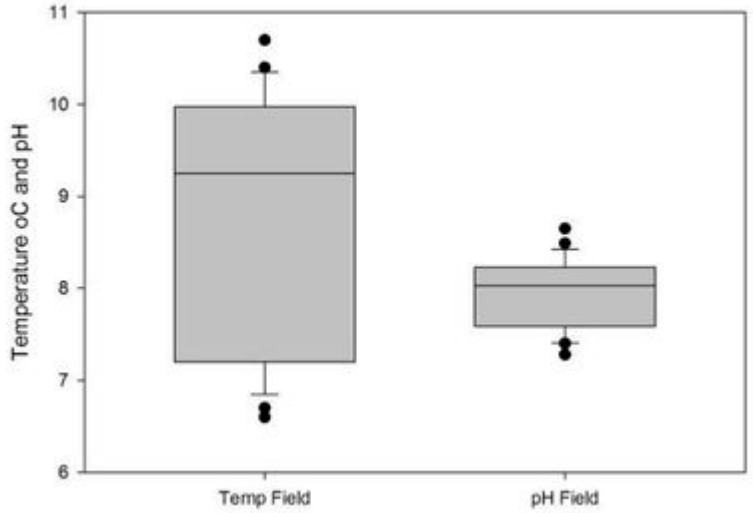

Figure 4-3 Field temperature and pH (n= 24).

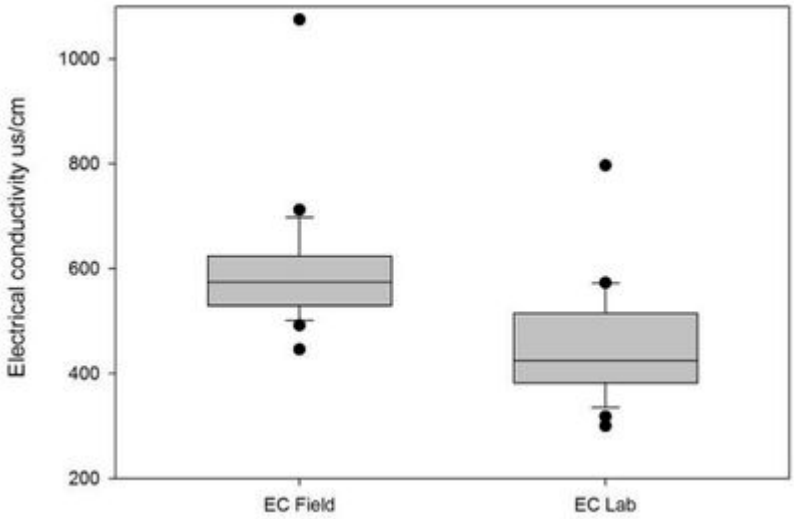

Figure 4-4 Electrical conductivity field versus laboratory (n= 24).

Major ions

The major ion chemistry allows us to look at the relative proportions of ions and to define baseline water types or facies. Firstly the table and box and whisker plot illustrate the samples collected from the site in this study (Table 4; Figure 4-5). The samples are mostly dominated by Ca^{2+} and HCO_3^- (calcium-bicarbonate type waters) however some samples do show relatively high proportions of Cl^- and SO_4 , namely samples from Woodchester Park, Midger Woods and also the coastal sites Aust and Sedbury Cliffs. The coastal sites may have some influence from sea spray or coastal rainfall. The major ions are also plotted on a Piper Diagram (Figure 4-6). Piper plots ae sometimes called ternary diagrams and are made up of two lower triangles, where the cations are plotted on the bottom left and the anions on the bottom right. The ‘results’ of these two plots are then projected up onto the upper diamond where it is possible to look at the ionic composition of the water samples in

comparison to one another. It is clear that most of the water samples are gathered on the left hand side of the upper triangle, this is the calcium bicarbonate type area, suggesting that they are mostly of similar composition, this is expected as the majority of samples have been from the Jurassic Great Oolite and Inferior Oolite aquifers. The samples with more Cl^- and SO_4^{2-} are also clearly visible in the upper part of the diamond.

LIMS Code	Site	Date	No	Field Temp °C	Field pH	Field EC µS cm^{-1}	EC µS cm^{-1}	Ca mg l^{-1}	Mg mg l^{-1}	Na mg l^{-1}	K mg l^{-1}	CO_3^{2-} mg l^{-1}	HCO_3^- mg l^{-1}	Cl^- mg l^{-1}	SO_4^{2-} mg l^{-1}	NO_3^- mg l^{-1}	N mg/l	Ionic Balance %	Br^- mg l^{-1}	NO_2^- mg l^{-1}	Total P mg l^{-1}	Total S mg l^{-1}	Si mg l^{-1}	SiO_2 mg l^{-1}
ICP-MS DL								0.3	0.01	0.2	0.02										0.01	1	0.05	
13959-0015	Alder Carr	22.1.2017	13	10.3	7.28	712	573	106	8.38	21.1	1.86	n/a	236	41.7	26.1	7.89	1.79	9.92	<0.1	<0.05	<0.01	11	3.75	8.02
13959-0023	Aust Clif	29.1.2017	20	9.5	8.03	621	512	86.8	14.7	13.7	4.69	n/a	209	17.1	63.0	0.292	0.066	9.10	0.079	<0.025	0.01	23	4.03	8.62
13959-0019	Bathurst Estate	27.1.2017	17	10.1	7.77	492	370	91.1	2.18	5.1	0.63	n/a	162	9.11	13.1	19.4	4.39	17.47	<0.05	<0.025	<0.01	5	2.29	4.90
13959-0004	Cranham Woods (top)	19.1.2017	3.1	9.9	7.45	625	382	99.3	2.12	8.4	0.53	45	96	15.1	9.00	6.86	1.55	18.09	<0.05	<0.025	<0.01	5	3.40	7.27
13959-0005	Cranham Woods (bottom)	19.1.2017	3.2	6.7	8.03	523	318	91.4	2.20	8.0	0.80	63	19	14.3	9.07	7.43	1.68	24.40	<0.05	<0.025	<0.01	4	3.38	7.23
13959-0024	Dowdeswell	29.1.2017	21	10.7	7.81	446	383	84.7	2.05	6.1	0.58	n/a	183	7.87	8.25	11.7	2.65	13.30	<0.05	<0.025	<0.01	4	2.16	4.62
13959-0012	Fishponds Wood	21.1.2017	10	9.1	7.40	550	466	109	2.62	7.3	0.50	n/a	204	14.3	20.5	33.2	7.52	11.81	<0.05	<0.025	<0.01	9	2.28	4.88
13959-0011	Horsley Wood	21.1.2017	9	7.0	8.21	611	427	114	4.10	6.3	1.92	n/a	207	9.35	29.8	9.24	2.09	18.03	<0.05	<0.025	<0.01	12	3.47	7.42
13959-0013	Kingscote Wood	21.1.2017	11	9.4	7.58	533	425	89.8	2.76	6.0	0.56	n/a	174	13.3	19.8	31.0	7.01	9.30	<0.05	<0.025	<0.01	8	2.29	4.90
13959-0014	Kingscote Wood	21.1.2017	12	9.0	8.11	563	424	106	2.89	7.0	1.33	n/a	174	13.2	20.1	30.3	6.86	17.13	<0.05	<0.025	<0.01	9	2.48	5.31
13959-0018	Lydney Cliff	26.1.2017	16	7.2	8.29	628	567	74.1	12.8	14.6	13.4	n/a	164	31.1	98.2	3.96	0.896	0.41	0.056	<0.025	<0.01	34	4.01	8.58
13959-0021	Midger Woods (mnin)	28.1.2017	19.1	10.1	7.43	583	520	106	4.94	8.7	2.97	n/a	202	13.2	30.5	49.5	11.2	9.30	<0.05	<0.025	0.03	13	2.41	5.16
13959-0022	Midger Woods (fissidens)	28.1.2017	19.2	7.2	8.31	609	493	91.3	9.31	11.0	4.10	n/a	164	18.5	76.1	7.17	1.62	9.24	<0.05	<0.025	<0.01	29	3.13	6.70
13959-0020	Minchiampton	27.1.2017	18	9.6	8.37	511	420	91.0	3.01	12.3	1.20	n/a	176	18.3	23.5	11.0	2.50	13.66	<0.05	<0.025	0.04	10	2.35	5.03
13959-0017	Slade Brook	26.1.2017	15	10.0	7.41	684	572	93.5	23.3	5.5	1.22	n/a	276	10.5	34.4	31.7	7.17	6.26	<0.05	<0.025	<0.01	14	2.20	4.71
13959-0009	Strawberry Bank	21.1.2017	7	10.4	7.61	529	411	89.2	2.71	8.7	2.36	n/a	163	12.1	16.4	33.8	7.65	13.49	<0.05	<0.025	<0.01	7	2.30	4.92
13959-0010	Toadsmoor	20.1.2017	8	8.9	8.17	606	468	101	4.06	7.1	1.58	80	40	13.1	29.4	28.2	6.38	9.32	<0.05	<0.025	0.01	12	3.09	6.61
13959-0001	Woodchester Park	18.1.2017	1	9.6	8.09	550	360	102	2.67	6.6	1.63	74	15	11.6	18.6	7.90	1.79	22.57	<0.05	<0.025	<0.01	8	2.76	5.90
13959-0016	Woodchester Park	22.1.2017	14	9.1	8.03	1075	797	190	5.95	23.6	7.80	n/a	199	50.2	157	24.3	5.51	14.54	<0.2	<0.1	<0.01	64	3.41	7.30
13959-0002	Woodchester Park	18.1.2017	2.1	6.6	8.65	680	516	126	2.77	9.4	0.92	n/a	153	13.8	116	12.7	2.87	11.56	<0.05	<0.025	<0.01	43	2.15	4.60
13959-0003	Woodchester Park	18.1.2017	2.2	7.1	8.49	510	300	89.5	2.45	8.0	0.79	n/a	122	14.9	15.5	8.37	1.89	27.29	<0.05	<0.025	<0.01	7	2.52	5.39
13959-0006	Workmans Wood (WW1)	20.1.2017	4	9.9	7.69	573	353	91.8	2.33	10.0	4.09	42	39	19.0	15.1	23.3	5.26	23.72	<0.05	<0.025	0.12	7	3.90	8.34
13959-0007	Workmans Wood (WW2)	20.1.2017	5	7.1	8.24	575	390	98.0	2.35	7.5	0.47	51	61	16.7	21.9	9.31	2.11	17.91	<0.05	<0.025	<0.01	9	4.92	10.5
13959-0008	Workmans Wood (WW3)	20.1.2017	6	7.5	7.74	569	385	106	4.00	6.1	0.95	55	63	10.8	18.8	13.5	3.05	22.27	<0.05	<0.025	<0.01	8	3.76	8.04

Table 4 Major ion water chemistry.

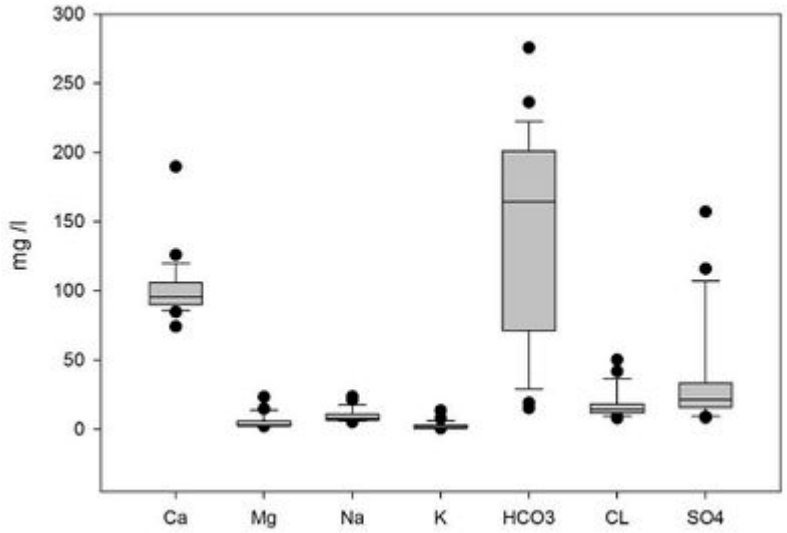

Figure 4-5 Major ions Box plot (n=24).

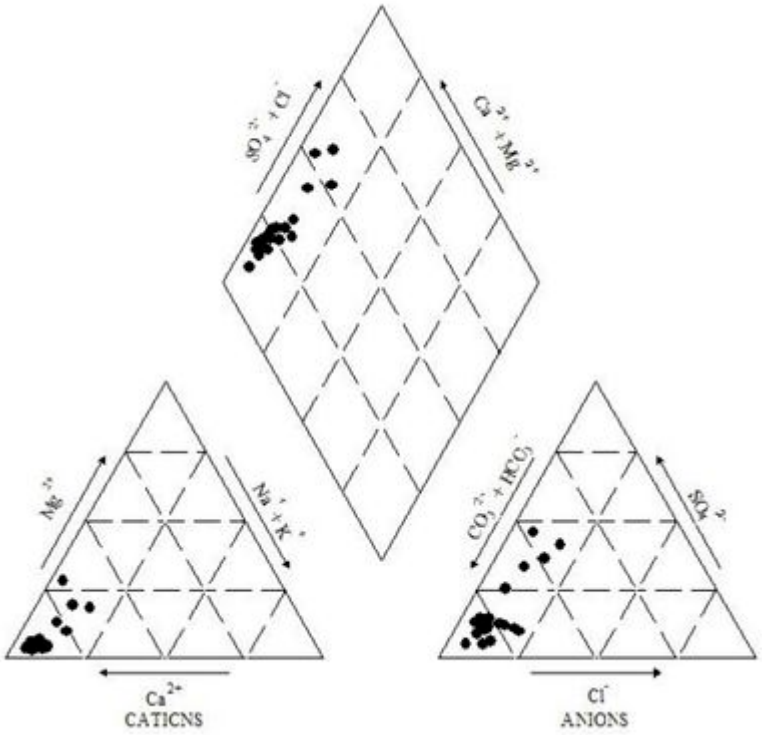

Figure 4-6 Piper plot showing the relative proportions of cations and anions (n=24). The bottom left hand triangle represents the cations and the bottom right hand triangle the anions, they are both projected into the upper diamond.

Nitrate & Phosphate

Recent work in the Netherlands (Royal Haskoning, 2016[1]) has, for the first time, tried to assign threshold values for nitrate and phosphate to the H7220 habitat. The work which also incorporates data collected from previous studies in Wales by the authors (see Farr et al., 2014[2]) suggests threshold values of 28 mg/l NO_3^- or 6.35 mg/l N and 0.05 mg/l P. The nitrate threshold value is higher than the UKTAG Threshold Values of 1 mg/l for medium altitude (>175 maOD) and 4.5 mg/l N for low altitude (<175 maOD) fens that include tufa forming springs (UKTAG, 2012a). For comparison the often quoted drinking water standard for nitrate is 50 mg/l as NO_3^- or 11.3 mg/l as N.

The data for each of the sites in this study is reported in descending order, for nitrate (as NO_3^- and N) (Figure 4-7), nitrite and total phosphate (Table 5). Nitrate ranges from 0.29 to 49.5 mg/l with a mean of 17.58 mg/l reported as NO_3^- or 0.06 to 11.12 with a mean of 3.98 mg/l reported as N (Figure 4-7).Nitrate levels in the Gloucestershire H7220 sites are higher than those reported from Welsh sites (Farr et al., 2014[2]), however this is to be expected as the land use for the majority of the Welsh sites was very low intensity. The sites with the highest nitrate are Midger Woods 1, Strawberry Bank, Fishponds Wood, Slade Brook, Kingscote Woods and Toadsmoor all of which have some form of agricultural activity within their potential catchments. We have compared the data collected for this study against the threshold values produced by Royal Haskoning (2016)[1] and using their threshold values for the H7220 habitat only Midger Woods, Kingscote and Horsley Woods, Strawberry Bank, Slade Brook and Toadsmoor 'fail' when compared to these nitrate threshold values (Figure 4-7). None of the sites exceed the phosphate threshold value of 0.05 mg/l (Figure 4-8). Although the nitrate threshold value was exceeded at several sites, it was not considered that vegetation was in unfavourable condition at any of the sites. This suggests that perhaps other factors such as flow, slope, shade, etc. also need to be considered in more detail.

LIMS Code	Site	Date	No	NO_3^- mg l^{-1}	N mg/l	NO_2^- mg l^{-1}	Total P mg l^{-1}
ICP-MS DL							0.01
13959-0021	Midger Woods 1	28.1.2017	19	49.5	11.2	<0.025	0.03
13959-0009	Strawberry Bank	21.1.2017	7	33.8	7.65	<0.025	<0.01
13959-0012	Fishponds Wood	21.1.2017	10	33.2	7.52	<0.025	<0.01
13959-0017	Slade Brook	26.1.2017	15	31.7	7.17	<0.025	<0.01
13959-0013	Kingscote Wood	21.1.2017	11	31.0	7.01	<0.025	<0.01
13959-0014	Kingscote Wood	21.1.2017	12	30.3	6.86	<0.025	<0.01
13959-0010	Toadsmoor	20.1.2017	8	28.2	6.38	<0.025	0.01
13959-0016	Woodchester Park	22.1.2017	14	24.3	5.51	<0.1	<0.01
13959-0006	Workmans Wood 1	20.1.2017	4	23.3	5.26	<0.025	0.12
13959-0019	Bathurst Estate	27.1.2017	17	19.4	4.39	<0.025	<0.01
13959-0008	Workmans Wood 3	20.1.2017	6	13.5	3.05	<0.025	<0.01
13959-0002	Woodchester Park	18.1.2017	2.1	12.7	2.87	<0.025	<0.01
13959-0024	Dowdeswell	29.1.2017	21	11.7	2.65	<0.025	<0.01
13959-0020	Minchiampton	27.1.2017	18	11.0	2.50	<0.025	0.04
13959-0007	Workmans Wood 2	20.1.2017	5	9.31	2.11	<0.025	<0.01
13959-0011	Horsley Wood	21.1.2017	9	9.24	2.09	<0.025	<0.01
13959-0003	Woodchester Park	18.1.2017	2.2	8.37	1.89	<0.025	<0.01
13959-0001	Woodchester Park	18.1.2017	1	7.90	1.79	<0.025	<0.01
13959-0015	Alder Carr	22.1.2017	13	7.89	1.79	<0.05	<0.01
13959-0005	Cranham Woods (top of site)	19.1.2017	3.2	7.43	1.68	<0.025	<0.01
13959-0022	Midger Woods 2	28.1.2017	19	7.17	1.62	<0.025	<0.01
13959-0004	Cranham Woods (base fo site)	19.1.2017	3.1	6.86	1.55	<0.025	<0.01
13959-0018	Lydney Cliff	26.1.2017	16	3.96	0.896	<0.025	<0.01
13959-0023	Aust Clif	29.1.2017	20	0.292	0.066	<0.025	0.01

Table 5 Nitrate and phosphate with the Royal Haskoning (2016)[1] threshold value in red.

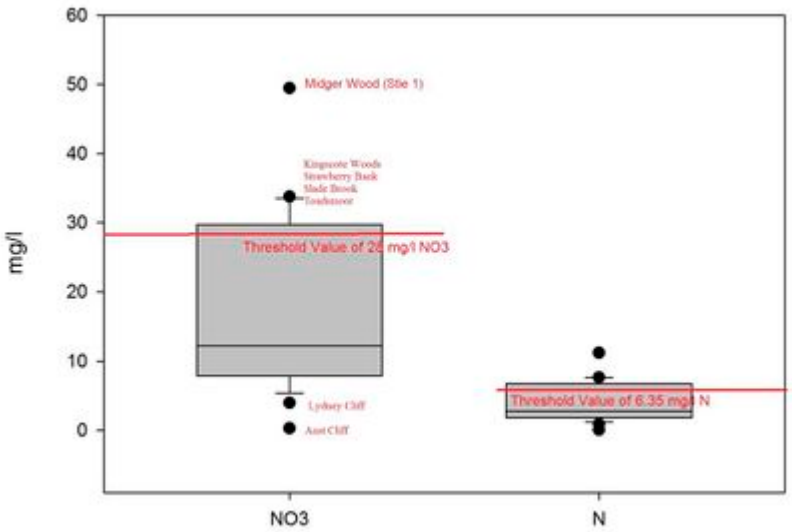

Figure 4-7 Nitrate NO_3 mg/l compared to the Royal Haskoning (2016)[1] threshold value of 28 mg/l NO_3 (n=24). Sites that exceed the threshold value are indicated on the graph (threshold value is 6.35 mg/l when nitrate is reported as N).

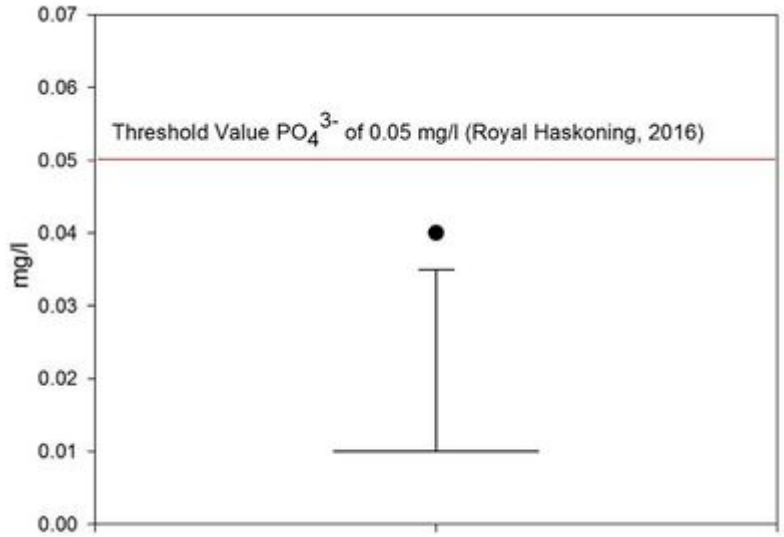

Figure 4-8 Total Phosphate as P mg/l (with LOD of 0.01 mg/l) compared to the Royal Haskoning (2016)[1] threshold value of 0.05 mg/l PO_4^{3-} (n=24).

Trace elements

LIMS Code	Site	Date	No	Ba	Sr	Mn	Total Fe	Li	Be	B	Al	Ti	V	Cr	Co	Ni	Cu	Zn	Ga	As	Se	Rb	Y	Zr	Nb	Mo	A
				µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µ
ICP-MS DL				0.1	0.1	0.2	1	1	0.01	10	1	0.05	0.1	0.05	0.01	0.1	0.4	0.5	0.03	0.02	0.1	0.01	0.005	0.05	0.02	0.03	0
13959-0015	Alder Carr	22.1.2017	13	4.8	536	4.5	250	13	<0.01	65	5	0.09	0.4	0.18	0.12	0.3	<0.4	0.5	<0.03	0.23	0.2	0.50	0.042	<0.05	<0.02	0.07	<
13959-0023	Aust Clif	29.1.2017	20	57.4	414	3.9	17	16	<0.01	55	11	0.09	<0.1	0.12	0.06	2.5	3.2	11.3	<0.03	0.17	0.4	1.50	0.039	<0.05	<0.02	0.88	<
13959-0019	Bathurst Estate	27.1.2017	17	7.1	113	0.3	1	<1	<0.01	14	1	<0.05	0.1	0.06	0.02	0.2	<0.4	0.9	<0.03	0.11	0.1	0.27	<0.005	<0.05	<0.02	0.05	<
13959-0004	Cranham Woods (top)	19.1.2017	3.1	22.0	158	0.6	<1	1	<0.01	17	<1	<0.05	<0.1	<0.05	0.02	0.1	<0.4	7.6	<0.03	0.08	0.1	0.21	0.007	<0.05	<0.02	0.05	<
13959-0005	Cranham Woods (bottom)	19.1.2017	3.2	9.8	159	<0.2	<1	1	<0.01	<10	<1	<0.05	<0.1	<0.05	0.02	<0.1	<0.4	4.8	<0.03	0.11	0.1	0.39	<0.005	<0.05	<0.02	0.07	<
13959-0024	Dowdeswell	29.1.2017	21	274	136	<0.2	<1	2	<0.01	32	<1	<0.05	0.2	0.19	0.06	0.1	<0.4	77.1	<0.03	0.34	0.2	0.14	0.008	<0.05	<0.02	0.03	<
13959-0012	Fishponds Wood	21.1.2017	10	27.9	162	<0.2	<1	1	<0.01	19	<1	<0.05	0.2	0.13	0.03	0.1	<0.4	11.9	<0.03	0.08	0.2	0.13	0.016	<0.05	<0.02	0.09	<
13959-0011	Horsley Wood	21.1.2017	9	7.1	242	2.9	6	3	<0.01	21	3	0.06	0.2	<0.05	0.04	0.3	<0.4	<0.5	<0.03	0.14	0.3	1.04	0.012	<0.05	<0.02	0.10	<
13959-0013	Kingscote Wood	21.1.2017	11	25.0	174	0.2	<1	2	<0.01	33	<1	<0.05	<0.1	0.07	0.03	0.1	<0.4	17.8	<0.03	0.09	0.2	0.19	0.013	<0.05	<0.02	0.09	<
13959-0014	Kingscote Wood	21.1.2017	12	6.7	166	<0.2	<1	1	<0.01	18	<1	<0.05	<0.1	0.07	0.03	0.2	<0.4	<0.5	<0.03	0.12	0.2	0.56	<0.005	<0.05	<0.02	0.14	<
13959-0018	Lydney Cliff	26.1.2017	16	45.2	225	0.4	<1	14	<0.01	65	<1	<0.05	<0.1	<0.05	0.04	1.6	1.5	0.8	<0.03	0.11	1.1	2.24	<0.005	<0.05	<0.02	1.66	<
13959-0021	Midger Woods (main)	28.1.2017	19.1	12.5	310	1.9	16	3	<0.01	41	11	0.11	0.1	0.09	0.07	1.1	1.5	16.7	<0.03	0.17	0.1	0.99	0.039	<0.05	<0.02	0.18	<
13959-0022	Midger Woods (fissidens)	28.1.2017	19.2	14.1	403	1.1	2	11	<0.01	50	<1	<0.05	<0.1	<0.05	0.04	0.4	1.2	3.3	<0.03	0.13	0.1	1.34	0.007	<0.05	<0.02	0.16	<
13959-0020	Minchiampton	27.1.2017	18	353	155	0.7	5	3	<0.01	136	4	0.12	0.2	0.16	0.04	0.2	<0.4	40.0	<0.03	0.31	0.3	0.44	0.024	<0.05	<0.02	0.15	<
13959-0017	Slade Brook	26.1.2017	15	52.7	103	<0.2	<1	1	<0.01	26	<1	<0.05	0.2	0.36	0.03	<0.1	<0.4	11.1	<0.03	0.09	0.3	0.30	0.036	<0.05	<0.02	<0.03	<
13959-0009	Strawberry Bank	21.1.2017	7	318	115	<0.2	<1	<1	<0.01	43	<1	<0.05	0.1	0.18	0.05	0.1	<0.4	66.7	<0.03	0.18	0.1	0.45	0.011	<0.05	<0.02	0.10	<
13959-0010	Toadsmoor	20.1.2017	8	64.4	175	<0.2	<1	2	<0.01	22	<1	<0.05	0.1	0.13	0.03	0.2	<0.4	10.8	<0.03	0.17	0.1	0.61	0.006	<0.05	<0.02	0.13	<
13959-0001	Woodchester Park	18.1.2017	1	34.5	154	0.6	2	2	<0.01	21	<1	<0.05	<0.1	0.06	0.03	0.9	0.4	9.7	<0.03	0.10	0.2	0.42	0.014	<0.05	<0.02	0.13	<
13959-0016	Woodchester Park	22.1.2017	14	16.1	318	0.5	5	3	<0.01	38	<1	<0.05	<0.1	<0.05	0.09	0.9	0.8	<0.5	<0.03	0.16	0.2	1.52	0.009	<0.05	<0.02	0.11	<
13959-0002	Woodchester Park	18.1.2017	2.1	6.5	162	0.7	2	<1	<0.01	19	<1	<0.05	<0.1	<0.05	0.05	0.3	0.5	<0.5	<0.03	0.13	0.1	0.27	0.022	<0.05	<0.02	0.10	<
13959-0003	Woodchester Park	18.1.2017	2.2	4.4	143	0.2	2	1	<0.01	12	<1	<0.05	<0.1	0.10	0.03	0.4	1.0	<0.5	<0.03	0.13	0.2	0.19	0.010	<0.05	<0.02	0.10	<
13959-0006	Workmans Wood (WW1)	20.1.2017	4	399	144	<0.2	<1	1	<0.01	38	<1	<0.05	0.4	0.34	0.03	0.2	<0.4	96.9	<0.03	0.92	0.2	1.31	0.010	<0.05	<0.02	0.35	<
13959-0007	Workmans Wood (WW2)	20.1.2017	5	229	164	0.2	2	2	<0.01	20	<1	<0.05	0.1	0.13	0.03	0.2	<0.4	46.3	<0.03	0.14	0.1	0.16	0.021	<0.05	<0.02	0.10	<
13959-0008	Workmans Wood (WW3)	20.1.2017	6	6.8	198	<0.2	2	2	<0.01	15	<1	<0.05	<0.1	<0.05	0.03	0.1	<0.4	<0.5	<0.03	0.15	0.2	0.39	0.008	<0.05	<0.02	0.10	<

LIMS Code	Site	Date	No	Cd	Sn	Sb	Cs	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Th	U
				µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1	µg l-1
ICP-MS DL				0.01	0.02	0.005	0.005	0.003	0.01	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.01	0.02	0.05	0.01	0.02	0.04	0.002
13959-0015	Alder Carr	22.1.2017	13	<0.01	<0.02	0.023	<0.00	0.012	0.05	0.009	<0.00	0.010	<0.00	0.006	<0.00	0.004	<0.00	0.002	<0.00	<0.01	<0.02	<0.05	<0.01	0.16	<0.04	0.482
13959-0023	Aust Clif	29.1.2017	20	0.02	0.04	0.144	0.024	0.012	0.05	0.010	<0.00	0.009	<0.00	0.007	<0.00	0.004	<0.00	0.004	<0.00	<0.01	<0.02	<0.05	0.13	0.91	<0.04	2.43
13959-0019	Bathurst Estate	27.1.2017	17	<0.01	<0.02	0.015	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.22	<0.04	0.294
13959-0004	Cranham Woods (top)	19.1.2017	3.1	<0.01	<0.02	0.049	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.04	<0.04	0.206
13959-0005	Cranham Woods (bottom)	19.1.2017	3.2	<0.01	<0.02	0.041	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	<0.02	<0.04	0.273
13959-0024	Dowdeswell	29.1.2017	21	<0.01	<0.02	0.107	<0.00	<0.00	<0.01	0.003	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	0.003	<0.00	<0.01	<0.02	<0.05	<0.01	0.05	<0.04	0.169
13959-0012	Fishponds Wood	21.1.2017	10	<0.01	<0.02	0.051	<0.00	<0.00	0.01	0.002	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.05	<0.04	0.253
13959-0011	Horsley Wood	21.1.2017	9	<0.01	<0.02	0.013	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.19	<0.04	0.355
13959-0013	Kingscote Wood	21.1.2017	11	<0.01	<0.02	0.050	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	<0.02	<0.04	0.245
13959-0014	Kingscote Wood	21.1.2017	12	<0.01	<0.02	0.019	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.14	<0.04	0.267
13959-0018	Lydney Cliff	26.1.2017	16	<0.01	<0.02	0.228	0.024	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	0.11	<0.02	<0.04	0.987
13959-0021	Midger Woods (main)	28.1.2017	19.1	0.02	0.03	0.043	0.005	0.010	0.04	0.009	0.003	0.009	<0.00	0.007	<0.00	0.004	<0.00	0.004	<0.00	<0.01	<0.02	<0.05	0.02	0.67	<0.04	0.266
13959-0022	Midger Woods (fissidens)	28.1.2017	19.2	<0.01	<0.02	0.064	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	0.02	0.06	<0.04	0.392
13959-0020	Minchiampton	27.1.2017	18	0.01	<0.02	0.218	<0.00	0.004	0.02	0.006	<0.00	0.004	<0.00	0.004	<0.00	0.002	<0.00	0.004	<0.00	<0.01	<0.02	<0.05	<0.01	0.07	<0.04	0.185
13959-0017	Slade Brook	26.1.2017	15	<0.01	<0.02	0.045	<0.00	0.003	0.02	0.003	<0.00	0.003	<0.00	0.004	<0.00	0.003	<0.00	0.003	<0.00	<0.01	<0.02	<0.05	<0.01	0.35	<0.04	0.163
13959-0009	Strawberry Bank	21.1.2017	7	<0.01	<0.02	0.145	<0.00	<0.00	<0.01	0.004	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	0.002	<0.00	<0.01	<0.02	<0.05	<0.01	0.11	<0.04	0.305
13959-0010	Toadsmoor	20.1.2017	8	<0.01	<0.02	0.064	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.12	<0.04	0.261
13959-0001	Woodchester Park	18.1.2017	1	0.01	<0.02	0.079	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.06	<0.04	0.320
13959-0016	Woodchester Park	22.1.2017	14	<0.01	<0.02	0.051	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	1.95	0.06	0.505
13959-0002	Woodchester Park	18.1.2017	2.1	<0.01	<0.02	0.034	<0.00	0.003	<0.01	0.003	<0.00	0.003	<0.00	0.003	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	<0.02	<0.04	0.321
13959-0003	Woodchester Park	18.1.2017	2.2	<0.01	<0.02	0.025	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	0.03	<0.04	0.255
13959-0006	Workmans Wood (WW1)	20.1.2017	4	<0.01	<0.02	0.200	<0.00	<0.00	<0.01	0.003	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	0.003	<0.00	<0.01	<0.02	<0.05	<0.01	0.10	<0.04	0.209
13959-0007	Workmans Wood (WW2)	20.1.2017	5	<0.01	<0.02	0.099	<0.00	<0.00	<0.01	0.003	<0.00	0.004	<0.00	0.003	<0.00	<0.00	<0.00	0.002	<0.00	<0.01	<0.02	<0.05	<0.01	0.07	<0.04	0.219
13959-0008	Workmans Wood (WW3)	20.1.2017	6	<0.01	<0.02	0.024	<0.00	<0.00	<0.01	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.00	<0.01	<0.02	<0.05	<0.01	<0.02	<0.04	0.230

Table 6 Trace elements (ug/l).

Atmospheric deposition and site relevant critical load

Excessive atmospheric deposition of nitrogen can be detrimental to most habitats, and in some cases could result in unfavourable status for Habitats Directive assessment. PlantLife (2016) estimate that 63% of the UKs most sensitive habitats are exposed to excessive nitrogen deposition. Although we could not find any information on the H7220 habitat, recent work has highlighted the risk to epiphytic bryophytes and lichens (Wolseley, et al., 2006[3]; Mitchell et al., 2005[4]; Stevens et al, 2012[5]).

A recent analysis of groundwater dependent terrestrial ecosystems (GWDTEs) in England and Wales (Farr and Hall, 2014[2] which includes the Petrifying Springs Habitat H7220, found that nitrogen deposition exceeded the critical loads for a least one habitat features in 64% of GWDTEs (which also includes the H7220 habitat). However, the multiple potential sources of nitrogen (source), its fate within wetlands (pathway) and the impact on habitats (receptor) is not simple to unravel. Coupled with the need to consider the combined effects of multiple sources of nitrogen (atmospheric, surface water, groundwater) that may result in detrimental pressures to a habitat we also need to consider the potential effect of poor site management, under — over grazing and succession may have on

habitat condition.

Critical Loads for the petrifying springs habitat have not been defined specifically in the UK, however a recommended critical load is available and this is based upon based upon the corresponding EUNIS class (Hall et al., 2015[6]). In England and Wales, or the current Annex 1 assessments, the EUNIS class D4.2 critical loads are applied. The current critical load range for this habitat is 15–25 kg N/ha/yr, with a recommended critical load of 15 kg N/ha/year which we have applied to the petrifying springs habitats in this study. The results (Table 7) show that all but three of the sites have modelled total nitrogen deposition that exceeds the recommended critical load. Only the coastal sites, Aust and Lydney are significantly below the critical load, and one island site Strawberry Banks has an average annual deposition just less than 15 kg N/ha/year.

	Easting	Northing	Ammonia			Nitrogen oxides			Total nitrogen			
			NHx_av	NHx_m	NHx-w	Nox_av	Nox_m	Nox_w	TOTN_av	TOTN_m	TOTN_w	Exceed Critical
			kg/N/ha/year			kg/N/ha/year			kg/N/ha/year			Loading Value ?
Alder Carr	385297	207895	9.38	13.72	21.84	7.7	6.02	13.16	17.08	19.74	35	Yes
Aust Clif	356427	189190	4.48	14.7	26.04	5.04	4.62	9.52	9.52	19.32	35.56	No
Bathurst Estate	395150	204409	9.38	11.48	18.2	8.54	5.88	12.88	19.92	17.36	31.08	Yes
Cranham Woods	390447	212803	9.38	12.88	21.14	8.4	6.16	14.7	17.78	19.04	35.84	Yes
Dowdeswell	399177	220573	7	14	22.82	8.54	6.02	13.16	15.54	20.02	35.98	Yes
Kingscote & Horsley Woods (1-4)	382634	197202	9.24	14.98	23.94	7.42	6.02	13.16	16.66	21	37.1	Yes
Midger Woods (1-2)	382634	197202	8.4	15.26	24.64	6.86	5.74	12.18	15.26	21	36.82	Yes
Minchiampton	386997	200066	9.24	14.42	22.96	7.84	6.16	13.16	17.08	20.58	36.12	Yes
Sedbury Cliff	355645	193093	7.14	9.52	15.96	4.48	4.43	8.96	11.62	13.86	24.92	No
Slade Brook	356774	205546	11.06	14.14	22.68	7.28	5.46	11.48	18.34	19.6	34.16	Yes
Strawberry Bank	390892	203500	7.28	12.74	20.3	7	5.88	13.16	14.28	18.62	33.46	No
Toadsmoor	387783	204209	9.24	14.42	22.96	7.84	6.16	13.16	17.08	20.58	36.12	Yes
Woodchester Park (1-3)	382005	200757	10.22	15.26	25.2	7.42	5.6	11.9	17.64	20.86	37.1	Yes
Workmans Wood (1-3)	390664	210676	9.38	12.88	21.14	8.4	6.16	14.7	17.78	19.04	35.84	Yes

av= average weighting for the 5 x 5 km square
m = moorland (non forest)
w = woodland
recommended ciritcal load of 15 kg N/ha/yr

Table 7 Atmospheric deposition for NH_3, NOx and Total Nitrogen compared to a recommended critical load value of 15 kg N/ha/year.

Tufa morphology and association with bryophytes

The definition of H7220 is 'petrifying springs with tufa formation (*Cratoneurion*)' and is somewhat suggestive that it is only *Palustriella commutata* that is associated with, or important for tufa formation. This is far from the truth, and the following discusses our general observations on the occurrence of tufa and association with other bryophytes during this study, illustrated in Figure 4-9. The various types of tufa structures are illustrated in Figure 4-10.

- The occurrence of tufa is by no means a proxy for the likely extent of H7220 habitat. Slade Brook is an excellent example of how several hundred meters of impressive tufa dams can be formed but with relatively little H7220.
- Tufa was deposited upon all sorts of substrates however it generally preferred to form on harder material (e.g. stones or living roots) rather than on soft organic mat erial such as rotting twigs (Beech leaves perhaps being an exception).
- More often, *Palustriella commutata* was observed to grow upon tufa-encrusted stones rather than tufa-encrusted living tree roots or deadwood, and this has implications for potential restoration of tufa dams, with use of imported stone more likely to be successful when considering restoration of tufa dams and pools.
- *Eucladium verticillatum* is well known for its association with tufa, and forms spectacular cushions on some of the cliff sites, but where *Palustriella commutata* was not present (e.g.

Aust Cliffs Figure 3-10).

- Perhaps the most interesting observation was the formation of large pools, retained behind tufa dams formed mainly of *Pellia endiviifolia* and *Conocephalum conicum* (e.g. Dowdeswell Figure 3-26).

Figure 4-9 Types of moss-tufa structures.
(a) Tufa dams formed in association with algae and very few bryophytes (Slade Brook); (b) blue/grey-coloured tufa formed in association with algae and no bryophytes (Workmans Wood site 2); (c) developing single patch of *Palustriella commutata* on tufa dam (Dowdeswell); (d) Large cushions of *Eucladium verticillatum* on tufa (Aust Cliff) (e) large tufa dam associated with *Pellia endiviifolia* and *Conocephalum conicum* (Dowdeswell); (f) the small aquatic moss *Fissidens crassipes* on tufa-encrusted stone (Minchinhampton Brook).

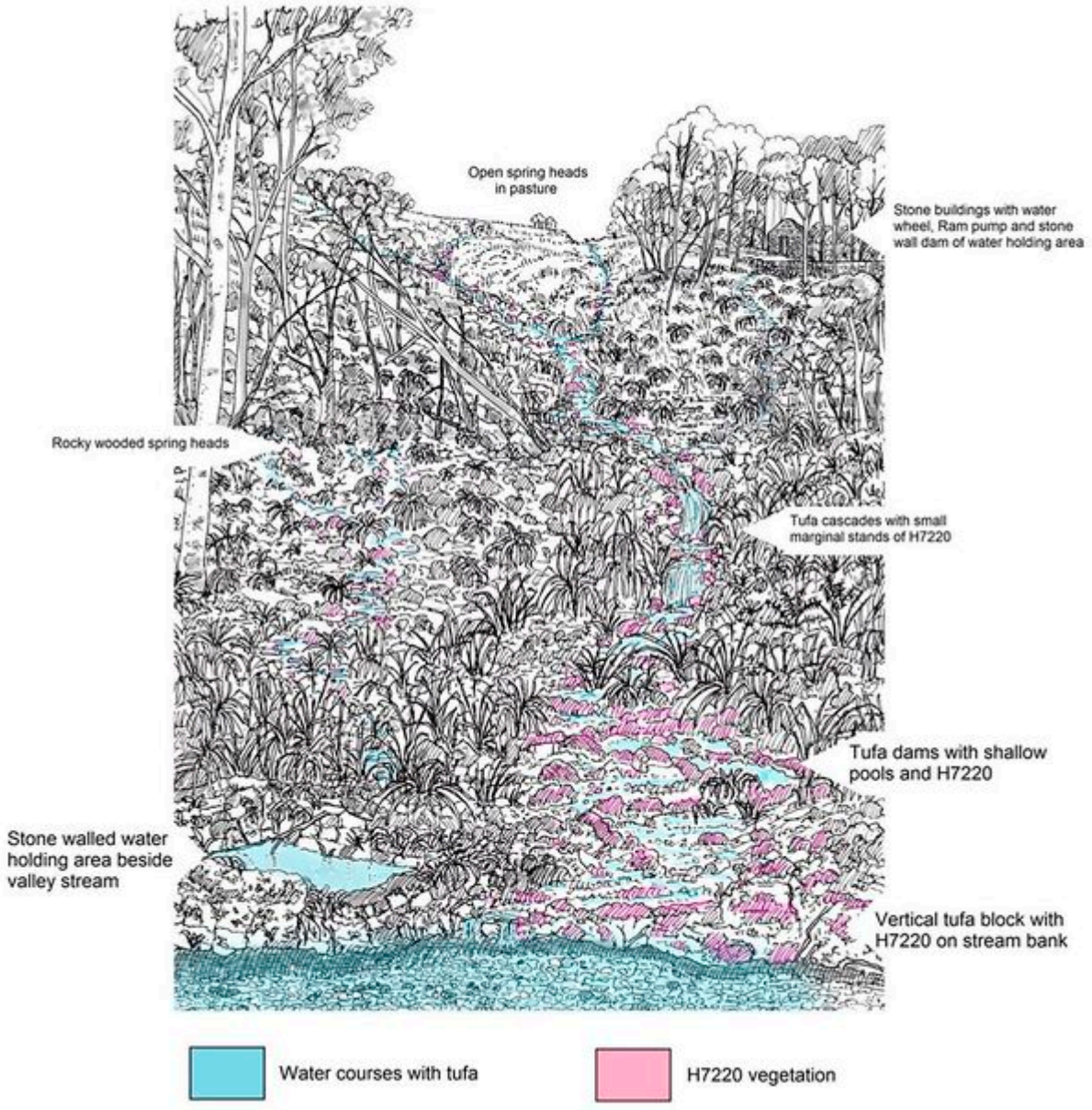

Figure 4-10 Illustration of the principal H7220 habiats in Gloucstershire.

Pressures and condition assessment

Table 8 lists the extent of the H7720 feature for each site and potential associated pressures, including hydrological, grazing, management, soil erosion and nutrient water chemistry. Many of these pressures have the potential to affect the H7220 feature positively or negatively so can be regarded as risks to the favourable conservation status of sites.

The following pressures have been highlighted:

Statutory Protection: a high proportion of sites with the H7220 feature (60%) lie within Sites of Special Scientific Interest (SSSI) and are therefore afforded a degree of protection. In addition, Cranham Wood and Workmans Wood site 3 lie within the Cotswold Beechwoods Special Area of Conservation (SAC) and are afforded a higher level of protection from wider land use pressures such as changes to hydrology and housing development. However, the H7220 feature is listed only in one SSSI citation for the sites surveyed (Cotswold Commons and Beechwoods SSSI) and 40% of sites surveys have no statutory protection or are afforded only mild protection in statutory planning law as County Wildlife sites.

Woodland Management: the majority of sites surveyed occurred in open (often rocky) woodland on valley sides. Woodland management has the potential to impact (both positively or negatively) on H7220 vegetation associated with flushes by affecting locally both levels of light and humidity. Such management could include tree planting (notably conifers), felling and thinning of woodland stands. In addition, brash (following various types of woodland management) can block seepage channels, shade or smother flush vegetation. Two sites (Dowdeswell and Woodchester Park site 3) have been highlighted where some sections of H7220 vegetation are negatively affected by shading from adjoining conifer plantations. Studies in Germany (Jokić, 2007) show that removal of conifers and replacement with an appropriate native woodland type promotes the regeneration of tufa-forming mosses.

Grazing: Two sites surveyed (Strawberry Bank and Toadsmoor) have open areas of H7220 vegetation that are lightly and traditionally grazed by cattle or ponies. In these situations, traditional light grazing is essential for maintaining the open mix of *Palustriella commutata* cushions with various wetland species. In the case of Toadsmoor, H7720 vegetation was grazed in conjunction with a small adjoining area of different 'marshy vegetation'. Changes to the grazing regime at these sites (either an increase or abolition of grazing) has the potential to impact both positively or negatively on H7220 vegetation. Over grazing has been observed to negatively affect H7720 sites in Germany by physically damaging tufa formations (some forms of which can be fragile) causing soil erosion and increasing nutrients through dung (Jokic, 2007).

Soil Erosion: Several sites surveyed showed general signs of soil erosion (Workmans Wood sites 1 and 2) and in some cases this erosion may relate to the erection of stock fences (Toadsmoor, Kingscote and Horsley Woods site 4). In addition, several sites showed signs of soil erosion that may relate to the temporary increases in channel flow associated with installation of culverts and a single site (Toadsmoor) had soil erosion near to the springhead associated with the inappropriate location of a pig field.

Hydrological (abstractions): There are plenty of defunct piston pumps which are of no concern. We only identified one potentially active abstraction at the main spring head at Workmans Wood 3, however the plentiful outflow from the spring did not suggest that the water supply to the site was being degraded. **Hydrological (drainage):** we identified several historic and modern drainage features, including culverts and drains. The effect, weather positive or negative, of these features is unclear. We propose, based on visual observations only, that some drainage features such as culverts may alter the velocity of the water within proximity to the culvert and thus minimising the ability of tufa and tufa forming mosses to develop.

Water quality: Using the recently defined threshold values for N and P only four sites exceeded the nitrate threshold and no sites exceeded the phosphate threshold value.

Atmospheric deposition: although there is no specific critical load value for the H7220 habitat, the best estimate of 15 N kg/ Ha/ year is exceeded at all but three sites.

Condition assessment: The H7720 feature has been assessed as being in favourable condition for all of the 15 sites where it has been shown to occur. This is based on sites having the greater majority of the H7220 feature in good general condition (in terms of both tufa formations and *Palustriella commutata*- dominated vegetation) and land management being favourable. However, a number of concerns are highlighted for some sites including a number of sites failing for nitrate threshold values (Midger Wood site 1, Toadsmoor, Strawberry Bank, Slade Brook, Kingscote and Horsley Woods sites 1 and 3) and shading associated with conifer plantations (Dowdeswell, Woodchester Park site 3).

Site	SSSI	H7220 channel length (m) (estimated from aerial maps)	H7220 extent (ha) (estimated from aerial maps)	Currently grazed	Nitrate Threshold Values (28 mg/l NO3 or 6.35mg/l as N)	Phoipshate Threshold Value (0.05mg/l)	Soil erosion	Old water control features present	Other pressures
Alder Carr	No	80	0.76	No	No	No	No	No	n/a
Bathurst Estate	No	100	0.3	No	No	No	No	Holding pond	n/a
Cranham Wood	Yes	70	0.3	No	No	No	No	No	n/a
Dowdeswell	No	600	0.3	No	No	No	No	No	shading from conifer plantation
Kingscote & Horsley Wood (Site 4)	No	130	0.1	No	No	No	Yes	No	n/a
Midger Wood (Site 1)	Yes	60	0.08	No	YES	No	No	No	n/a
Toadsmoor	No	230	0.07	Yes	YES	No	Yes	Old Ram Pump	n/a
Workmans Wood (Site 3)	Yes	210	0.06	No	No	No	No	Old Ram Pump	Small abstraction at springhead
Woodchester Park (Site 3)	Yes	210	0.06	No	No	No	No	No	shading from conifer plantation
Strawberry Bank	Yes (part)	180	0.05	Yes	YES	No	No	Yes	n/a
Midger Wood (Site 2)	Yes	50	0.02	No	No	No	No	No	n/a
Slade Brook	No	30	0.01	No	YES	No	No	Possible Ram pump	Quarry
Kingscote & Horsley Wood (Site 1)	Yes	40	0.008	No	YES	No	No	No	n/a
Kingscote & Horsley Wood (Site 3)	Yes	4	0.0004	No	YES	No	No	No	n/a
Sedbury Cliff	No	1	0.0001	No	No	No	No	No	Natural cliff falls
Aust Cliff	No	0	0	No	No	No	No	No	Natural cliff falls
Kingscote & Horsley Wood (Site 2)	Yes	0	0	No	No	No	No	Possibly	n/a
Minchinhampton Stream	No	0	0	Yes	No	No	No	No	n/a
Woodchester Park (Site 1)	Yes	0	0	No	No	No	No	Old water catch pit	n/a
Woodchester Park (Site 2)	Yes	0	0	No	No	No	No	Pond	n/a
Workmans Wood (Site 1)	Yes	0	0	No	No	No	Yes	Culvert	n/a
Workmans Wood (Site 2)	Yes	0	0	No	No	No	Yes	Culvert	n/a
Total (estimate)			2 ha						

n.b all areas have been calaculted using GIS and site specific survey is needed for definative measurments

Table 8 Estimated extent of H7220 habitat, pressures and chemical threshold values.

References

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