An assessment of the hydrology of Snipe Marsh with regard to the potential effects of groundwater abstraction

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1 INTRODUCTION

1.1 Background

The renewal of two groundwater abstraction licences belonging to Andrew Alston (AA) in the Catfield / Ludham area of north east Norfolk are currently being determined by the Environment Agency (EA). AA commissioned Dr Tim Grapes *Consulting Groundwater Scientist*, to provide technical support regarding the hydrological aspects of the renewal process. Dr Grapes is an independent consultant with expertise in hydrogeology and hydrology and with over 15 years' experience as a practising technical specialist.

1.2 Context

In their 'Minded-to' decision, the EA indicated that they would revoke the two Alston abstraction licences due to modelled 'In-combination' impacts (with the Anglian Water Services {AWS} Ludham PWS {Public Water Supply} abstraction) upon the Crag aquifer and associated impacts upon Habitats Directive (HD) Special Area of Conservation (SAC) features at Snipe Marsh, located at Sharp Street between Catfield and Ludham.

1.3 Objective

This document seeks to evaluate the EA approach to the assessment of abstraction-related hydrological and ecological impacts at Snipe Marsh and provide a critique of potential weaknesses that may have a bearing upon the licence determination process.

The wider regulatory process regarding impact assessment and hydrological management at Snipe Marsh is also addressed to provide a relevant long term context for the current determination process.

1.4 Sources of data

Data for this assessment were derived from the following sources:

- The online repository of documents pertaining to the determination process maintained by the EA
- Reports prepared for AWS by Atkins and @one that were copied by AA with permission of AWS;
- Publicly available EA data
- Data collected directly by, or on behalf of, AA including:
    - groundwater level data from Alston OB3 piezometer
    - anecdotal recollections of local hydrological conditions from local residents/landowners
    - a topographic survey of some key locations of interest
    - a survey of pH readings of waters on Snipe Marsh

2 SURFACE WATER LEVELS FROM SNIPE MARSH AND ITS VICINITY

Surface water levels have been observed at various locations on and adjacent to Snipe Marsh over the period 2002 to present. These data are described in Section 2.4 below. A snapshot of the current surface water levels in the area was recorded on 04/12/14 via a longitudinal transect from east of the eastern margin of Snipe Marsh in a westerly direction to a major sluice (labelled WCS4 on Figure A3.1 of Amec, 2014'h') at the westerly extent of the hydrological system. This sluice was constructed during flood defence works in early 2009 (BFAP, 2014) and is located at approximate National Grid Reference (NGR) TG 3705 1970. This transect is described in Section 2.3 and the observed water levels used in it were partly based upon a brief topographic survey undertaken on 04/12/14, which is described in the following section.

2.1 Topographic survey details

A brief topographic survey of some locations of hydrological interest around the eastern margin of Snipe Marsh was undertaken on 04/12/14 by an experienced surveyor (Philip Millington, with over 40 years surveying experience). Traditional survey equipment (theodolite and staff) were used to find vertical levels only, and a vertical accuracy of +/- 10mm was expected. The ground (datum) level and well top level of AWS Sharp Street borehole P1 (derived from the borehole log presented in Appendix I of Amec, 2012) were used as local benchmarks to reference other surveyed locations to Ordnance Datum. The ground level benchmark location used at P1 was measured relative to the previously surveyed well top level and found to be 0.47m below, whilst the published difference was calculated as 0.474m, giving confidence that the ground level benchmark point chosen here was representative of the previously surveyed ground level datum point and thus levels surveyed here could be accurately calculated to within +/- 15mm of Ordnance Datum levels. The results of the survey for key locations are given in Table 1 below.

Location	'Local level' (m)	Difference to AWS P1 GL (m)	Actual level (mOD)	Notes
AWS piezometer P1 ground level	9.41	0.00	**1.685**	Local datum level used to reference other locations to Ordnance Datum
Top of Alston OB3 (Clarke) piezometer	10.00	0.59	2.28	Top of piezometer pipe at 0.36m above ground level, thus ground level = 1.92mOD
Water level in OB3			0.77	Based on dip reading of 1.51m at 1100 on 04/12/14
Water level in pond next to OB3	9.20	-0.21	1.48	Directly connected to ditch adjacent to OB3, so water level in ditch is also this level
Grove Farm upper pond water level	9.18	-0.23	1.46	
Grove Farm lower pond water level	8.81	-0.60	1.09	
NE corner of brick culvert structure (used as local datum for ditch water level)	9.18	-0.23	1.46	Located immediately adjacent to the outlet pipe from Grove Farm lower pond, and on the northern side of How Hill Road where water enters at the extreme eastern margin of Snipe Marsh
Ditch water level at brick culvert			0.65	Based on a level of 0.81m below local datum above. This level equates to dyke water levels at the eastern end of Snipe Marsh

Table 1 Results of the topographic survey

2.2 Grove Farm ponds

The ponds at Grove Farm were dug by the current owner in 1973 (see letter from provided separately). They were dug into sand to a depth of some 4' to 5' (1.2 to 1.5m) and filled up with water whilst being dug. They have remained full of water ever since, and the annual variation in the water level is around 1' (0.3m) (pers. comm). The upper (southern) pond is fed from a shallow ditch that extends almost due east of the upper pond for a distance of some 50m, along the southern margin of the Grove Farm buildings. The ground levels around the ponds vary from c. 2mOD to the east of the upper pond down to c. 1.2mOD to the west of the lower pond. The bottoms of the ponds are likely to be at around 0mOD. The observed water level in the upper pond on 04/12/14 was 1.46mOD and in the lower pond was 1.09mOD. Water from the upper pond overflows into the lower pond and from the lower pond into the roadside ditch, on the north side of How Hill Road, and thence onto Snipe Marsh.

The current and historic absolute water levels and the historic magnitude of variability in the lower pond both appear similar to the groundwater levels recorded in AWS P3, located less than 100m to the south west, and described in Section 3.2.

2.3 Water level transect down Snipe Marsh

A brief east to west transect longitudinally through Snipe Marsh was undertaken on 04/04/12 to investigate changes in water levels to complement a similar transect undertaken by Amec in July 2014, and the topographic survey also undertaken on that date (Section 3.1.1; Amec, 2014'h'). A ditch water level of c. 0.02mOD was recorded towards the western end of Snipe Marsh. [Figures describing the results of the survey (Figures A3.3 and 3.4; Amec, 2014'h') were omitted from the EA Sharefile version of the document and unfortunately this was discovered too late for them to be obtained directly from the EA so that they could be reviewed for inclusion in this document].

From the survey on 04/12/14, the water level in the ditch adjacent to Alston OB3 was at c. 1.48mOD (which was essentially the same as in the upper {southern} pond at Grove Farm, at c. 1.46mOD). The water from this ditch flowed in a piped culvert under Sharp Street and then beside the road around the western margin of the Grove Farm property, as shown in Figure 1. It then joined with piped overflow from the Grove Farm lower pond, with a water level of c. 1.09mOD, and water from the roadside ditch to the east and flowed west under How Hill Road in a brick culvert to enter the eastern edge of Snipe Marsh. The water level in the ditch on the north side of the How Hill Road is c. 0.65mOD, and this is essentially the same as the water level in the dyke along the eastern margin of the marsh. These locations are also shown in Figure 1.

Note that the statement in paragraph 3 on page 22 of Amec (2014'h') stating that the Grove Farm ponds are not connected to the site [Snipe Marsh] *drainage system is only partially correct, as overflow from the lower pond drains into the Marsh dyke system.*

The marginal ditch extends along both the north and south side of the easternmost section of Snipe Marsh. On the northern margin there is a track entry point on to the marsh from the road, underneath which there is a double piped culvert to carry the water of the marginal drain. At this location the water level descended by c. 0.16m as it passed west through the southern of the two pipes (the northern pipe having no flow through it) such that the water level in the dyke to the west was c. 0.49mOD.

A fall in level was also recorded on the southern side of the marsh, where water levels are controlled by a vertical outlet structure adjacent to a large diameter, black plastic pipe, which appears to have been used as a stilling well (see Figure 1). The fall in level here is also c. 0.16m, such that all the dykes immediately to the west of this location had a water level of c. 0.49mOD.

Based on the 'upper' dyke water level of 0.65mOD, ground levels in the easternmost area of Snipe Marsh appear to range between c. 0.6mOD on the southern side and c. 0.8mOD on the northern side. The depths of the water in the marginal dykes was generally c. 0.1 to 0.2m, indicating that local minimum dyke invert levels were c. 0.45mOD.

The presence of the two control structures described above essentially isolates the dyke water at the eastern extremity of Snipe Marsh, as when the dyke water levels are c. 0.05m lower than that recorded on 04/12/14 (i.e. at c. 0.60mOD), there are no formal outlets for the water to flow to the west.

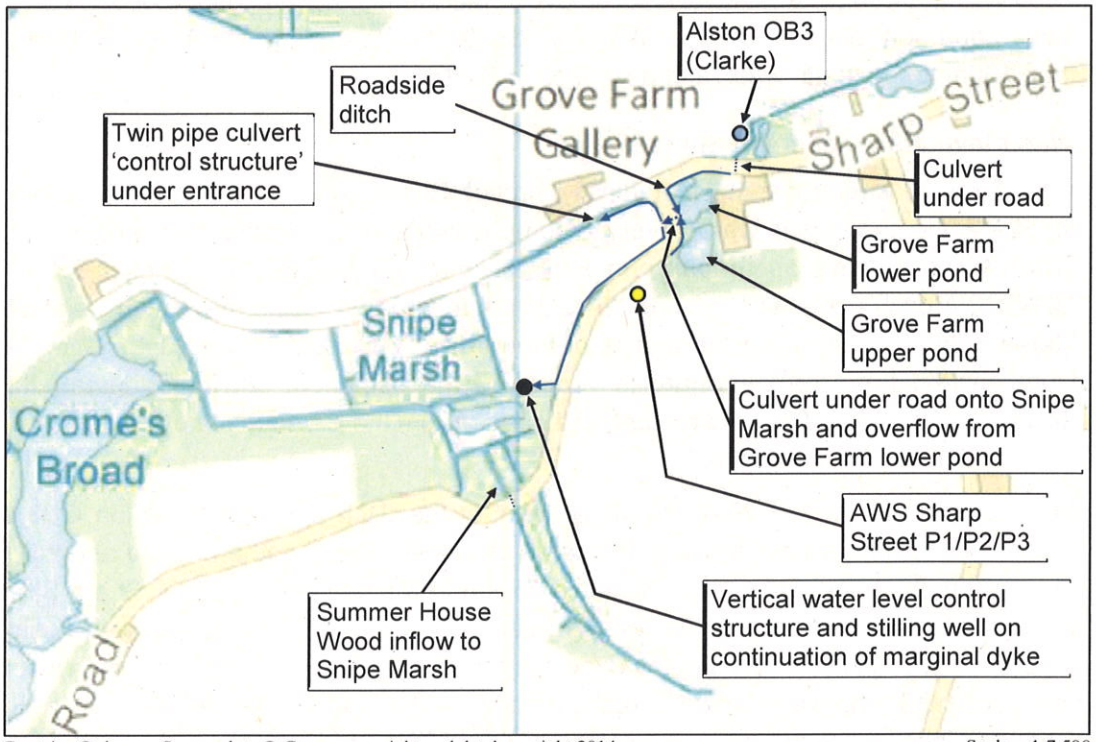

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Figure 1 Hydrological features around the eastern end of Snipe Marsh

To provide a 'downstream' water level for the Snipe Marsh/Cromes Broad system, relative levels were measured at the sluice structure WCS4, located to the west of the southern end of the southern section of Cromes Broad. At this location, the 'internal' marsh level was recorded as 0.25m lower than the external, river level.

Online data from the Barton Tidal Gauge (EA, 2014), showed that the level on Barton Broad was c. 0.60mOD at 1100 on 04/12/14. Considering that the natural downstream fall in river level between the Tidal Gauge site and the sluice structure may be c. 0.02m over the intervening 2km river length, this would make the external water level at the sluice c. 0.58mOD and the subsequent internal marsh level c. 0.33mOD, some 0.16m below the calculated dyke water level in the western section of Snipe Marsh. This difference in levels appears too great to be due to natural downstream gradient and suggests that there may be another small control structure between the western end of Snipe Marsh and the WCS4 sluice, although no such structure appears to be recorded (Figure A3.1; Amec, 2014'h').

Another sluice structure was identified by AA between WCS4 and Cromes Broad at approximate NGR TG 3720 1970 (not shown in Amec Figure A3.1) and includes a one-way valve allowing water to move west out of Cromes Broad (AA, pers. comm.). However, at the time of the visit by AA on 06/12/14 there was no difference between the water levels either side of this sluice, which suggests it may not be the cause of the 0.16m fall in water levels from east to west recorded on 04/12/14.

2.4 Recorded surface water levels in the Snipe Marsh hydrological system

It is surprising that the only specific hydrological data actually recorded on Snipe Marsh, which are shaft encoder records of surface water levels at the stilling well location described above (at NGR TG 3795 1997: Atkins, 2005) from 2002 (Figure 15, Atkins, 2003) and 2003/2004 (Figure 15, Atkins, 2005), appear not to have been considered in the recent hydrological assessment of the area (Amec, 2014 'h').

The data from 2002 appear to show some unreliable sections and are not referenced to Ordnance Datum (OD), but still provide some useful background information. However, the data from 2003/2004 appear to be good quality, supported by manual readings, and are referenced to OD, allowing comparison with water levels from other locations. Between October 2003 and September 2004, the observed water levels varied between 0.55mOD and 0.74mOD, although were generally around 0.58mOD to 0.62mOD, with only short lived peaks exceeding 0.63mOD. These data correspond reasonably well with the eastern dyke water level of c. 0.65mOD observed during the survey on 04/12/14.

Logged levels at a gaugeboard on the west side of Cromes Broad (identified as ABM26A in reports by @one [2008a, b]), apparently at the same location as current EA gaugeboard TG31/794, are presented for the period October to December 2007 in Figure 4 of @one (2008a), which shows that levels were consistently at around -0.4mOD, with total variability being less than 0.1m. This is completely different to the pattern of levels in TG31/794 in Figure A3.6 of Amec (2014'h') and it appears that the data presented by @one as from ABM26A is actually derived from a gaugeboard further to the south west, near Toad Hole. The range of levels are similar to those presented for TG31/790c in Figure A3.6 of Amec (2014'h').

The TG31/794 data from Amec (204'h') for the period late 2006 to early 2014 indicate that water levels on the west side of Cromes Broad are generally around 0.3mOD (which corresponds well with the level at WCS4 of 0.33mOD observed on 04/12/14 described above), but vary between c. 0.05mOD and 0.45mOD. The most recent logged data plotted, from March/April 2014, are clearly erroneous and would normally have been edited out for quality control reasons. There appears to be some upper level control at c. 0.4mOD affecting levels at this location, as levels are often maintained at this elevation but seldom exceed it, except for short durations. The nature of this control is unclear, but may relate to a possible crest level at WCS1 (Figure A3.1; Amec, 2014'h'), which separates Cromes Broad from the much lower levels (c. -0.4mOD) at gaugeboard TG31/790c, located in Clayrack Marshes to the west. The water levels here are controlled by IDB pumping, ultimately at the Ludham Bridge pumping station.

Alternatively the postulated 0.4mOD level control may relate to the elevation of the discharge valve in the unrecorded sluice to the west of Cromes Broad identified by AA (see final paragraph, Section 2.3) or could relate to a minimum ground level on Pigeon Wood Marsh (to the west of Cromes Broad) as discharge from the Cromes Broad system appears to overflow across Pigeon Wood Marsh into the lower, western, IDB-controlled dyke system (AA, pers. comm.).

In conclusion, various surface water control structures significantly influence water levels on Snipe Marsh/Cromes Broad, separating them from the control of water levels in the nearby River Ant. Water levels at Cromes Broad can be up to 0.5m below river level, and water levels at the western end of Snipe Marsh are likely to be at a similar elevation. This type of water level management control clearly has a very significant influence on the hydrology of the site, and by extension the water-dependent ecology of the site. This scale of on-site water level control must provide a backdrop for any assessment of off-site influences, such as groundwater abstractions, on the hydrology of Snipe Marsh.

3 GROUNDWATER LEVELS FROM SNIPE MARSH AND ITS VICINITY

3.1 Water levels in the Alston OB3 piezometer

Groundwater levels in the Upper Crag aquifer unit close to Snipe Marsh have been recorded manually by AA in the Alston OB3 ( ) piezometer in most summers from 1999 to 2008. The OB3 piezometer is located some 120m north east of the north eastern corner of Snipe Marsh, as shown in Figure 1. From the limited available information (compiled in Amec, 2012), OB3 was installed to a depth of c. 15m, with the monitored interval being from 5 to 15m below ground level. There is no geological information available from OB3, due to the nature of its installation technique (jetting). The datum level for OB3 is the top of the piezometer pipe at 2.28mOD, 0.36m above the ground level of 1.92mOD (see Table 1).

All available water level data from OB3 are presented in Figure 2, together with available manual data and logged data for Alston piezometers OB1 and OB2 (designated by the EA as TG32/805 and TG32/801, respectively), for reference.

Observed levels in OB3 range from 0.08mOD on 19/08/02 to 1.08mOD on 16/06/01, but it must be noted that these are almost exclusively levels recorded between April and October each year, and will thus not represent the full range of levels, with winter maxima being excluded. The minimum observed value in August 2002 is at the end of a week of pumping from the Alston Ludham Road borehole at a rate of c. $400m^3$/day (0.4Ml/d) but also coincides with a period of signal testing at Ludham PS, which involved an increase in abstraction rate from c. 1.6Ml/d to c. 2.4Ml/d for the period 15/08/02 to 14/11/02. The Alston Ludham Road borehole is located 450m north east of OB3 while Ludham PS is located some 450m to the south east of OB3.

The average summer levels in OB3 of c. 0.5mOD appear to be similar to the ground levels in the eastern section of Snipe Marsh of c. 0.6 to 0.8mOD. When water levels in OB3 are compared with levels in AWS P3 (located some 200m to the south west) for periods of overlapping data, it is found that OB3 is consistently some 0.5m lower. The groundwater level in OB3 is also significantly lower than the water level in the adjacent ditch, being c. 0.93m lower on 26/09/14 (AA, pers. comm.) and c. 0.71m lower on 04/12/14. The ditch level on the latter occasion corresponded closely with the water level observed in the upper pond at Grove

Farm. The reason for these differences is unclear, but may suggest some localised lithological division in the Upper Crag unit.

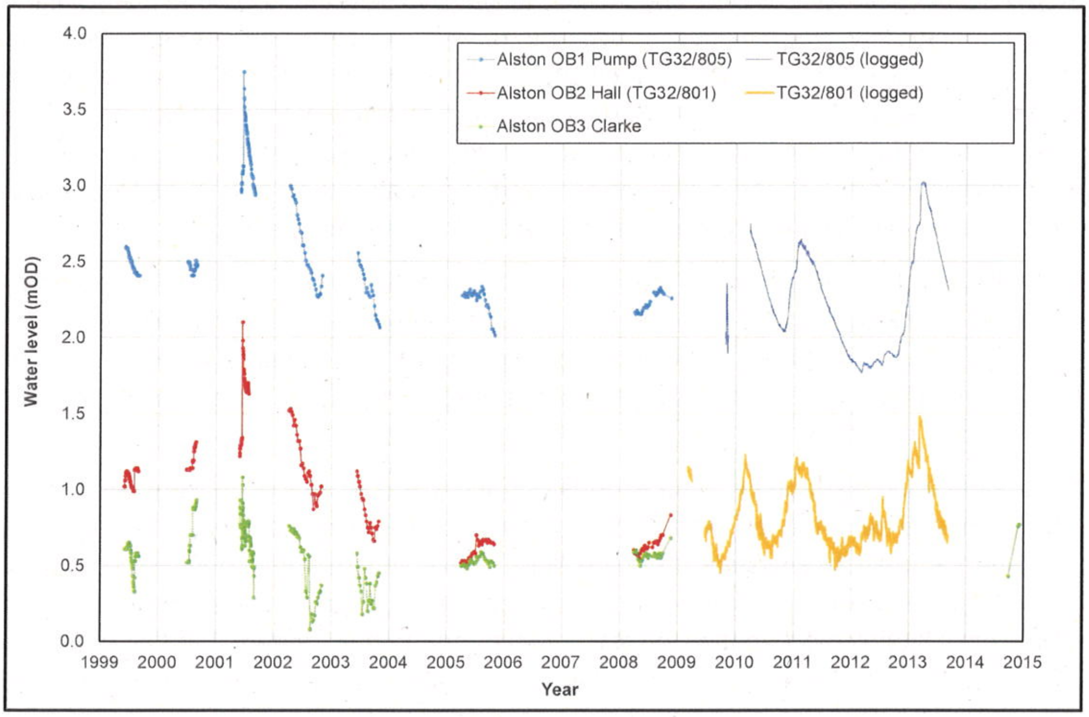

Figure 2 Hydrograph of available data for the Alston Ludham piezometers

The difference in levels between OB3 and AWS P3 is also difficult to explain, as both piezometers are monitoring the Upper Crag aquifer unit at a similar depth (5 to 15mbgl at OB3; 5 to 10mbgl at AWS P3) and ground levels are similar at both sites (1.92mOD at OB3 {see Table 1} and 1.72mOD at AWS P3 {Appendix I; Amec, 2012}). This difference in levels is at odds with the Upper Crag groundwater levels presented in Figure B2 of Amec (2012) which, given the orientation of the groundwater contours, suggests levels at OB3 and P3 should be very similar.

3.2 Groundwater levels in the AWS Sharp Street piezometers

Groundwater levels in the Deep, Middle and Upper Crag units have been logged in AWS Sharp Street piezometers P2, P1 and P3 respectively, from 2001 (2002 for P2) to date. Ground level at P3 is 1.72mOD and the south eastern margin of Snipe Marsh, where ground levels are at c. 0.6 to 0.8mOD, is less than 20m to the north.

Long term data from P3 are presented in Figure A3.7 of Amec (2014 'h') for the period late 2001 to early 2014 and show that water levels display limited variability, ranging from c. 0.6 to c. 1.3mOD, but being generally close to 1.0mOD. Data presented from mid-2013 onwards look suspicious and are out of keeping with the character of the long term record. Other, clearly erroneous data, from both P1 and P3 are presented in Figure A3.7 (ibid) and the resulting distortion of the vertical axis undermines the clarity of the information. Undertaking rudimentary quality control of the dataset would have significantly improved presentation here, as would improving the labelling of the x-axis.

3.3 Significance of local groundwater – surface water interaction

The fact that groundwater levels in P3 (recorded from a monitoring interval with a minimum depth of 5mbgl in a permeable, unconfined aquifer), are dominantly above the ground level in Snipe Marsh and permanently above the inverts of dykes on the eastern marsh (at c. 0.45mOD: see Section 2.3) indicates that *the Upper Crag unit at this location cannot be in direct hydraulic contact with the hydrological system on Snipe Marsh.* If it was, the marsh dyke system would function as a local base level control and Upper Crag groundwater levels would be constrained close to the dyke water / invert levels at c. 0.45 to 0.65mOD, and would be unable to rise significantly above these levels for any extended period.

In reality, the P3 levels reach a maximum of c. 1.3mOD and can remain significantly above 1.0mOD for many months in a row, as occurred between October 2001 and June 2002 (Figure E67; Amec, 2012). In which case it appears that the hydraulic contact between the Upper Crag unit at P3 and the hydrological system on Snipe Marsh is at most highly restricted and at least, negligible.

This understanding appears to be at odds with the hydrogeological conceptualisation used in the EA groundwater model, which assumes direct hydraulic contact between the Upper Crag unit and the peat/dyke system on Snipe Marsh. This apparent failure in conceptualisation of the local groundwater – surface water interaction has significant implications for the estimation of potential hydrological impacts on Snipe Marsh due to the Ludham PWS abstraction, which in turn has detrimental implications for the determination of the Alston abstraction licences.

The groundwater levels at Alston OB3 suggest a greater degree of hydraulic contact between the Upper Crag to the north east of Snipe Marsh than to the south east, although the implications of this for estimation of impacts from Ludham PWS are unclear.

3.4 Observed vs modelled data for the Upper Crag aquifer unit at Snipe Marsh

Observed vs modelled groundwater levels

A comparison of observed and modelled groundwater levels at AWS P1, P2 and P3 is presented in Figure A3.12 of Amec (2014'h'). Modelled levels in layer 1 (which is specifically stated as NOT being peat {para. 1, p.41; Amec, 2014'h'}, and so is presumed to be Upper Crag) at the eastern end of Snipe Marsh (in model cell K, at row 140 column 526) demonstrate a similar pattern of response to observed levels in the Upper Crag unit in P3 but the modelled levels are consistently some 0.5m too low.

In fact the modelled levels in layer 1 are actually lower than in layer 2 (implied to be the Middle Crag unit), indicating an upward hydraulic gradient from the Middle Crag unit to the Upper Crag. There is no evidence for this pattern from observed data and this representation appears to indicate a failure of local hydrogeological conceptualisation or representation within the groundwater model. This failure in hydraulic gradient simulation appears to have been completely overlooked, as Amec (2014'h'; para 2, p.41) states that '*At the Sharp Street boreholes (Figure A3.12) the model simulation is much better* [than simulated surface water levels at gaugeboard TG31/794]: *heads compare well to observed data showing <u>a downward gradient in the Crag</u>*'. This latter comment appears factually incorrect, which has implications for the credibility and reliability of simulated abstraction impacts in model cell K.

Observed vs modelled impacts

Impacts on the Upper Crag aquifer near Snipe Marsh due to the AWS abstraction at Ludham are generally so small as to be equivocal, but are most clearly demonstrated during recovery after the signal test of September 2003, shown in Figure 20 of Atkins (2005). These data are highly significant as the pumping rate for this signal test of c. 4Ml/day was apparently the highest sustained rate achieved by the Ludham PS between 1973 and 2004 (Figure 2; Atkins 2005), and based on operational constraints described in @one (2008a), is likely to have been the highest rate ever achieved by the PS.

At the end of the 7-day constant rate test in September 2003, the pumping rate reduced from 4Ml/day to c. 1.5Ml/day and there was a clear, pumping-related recovery of levels in AWS P3, but the magnitude of recovery was at most only 0.1m, even ignoring a rainfall event which may have assisted recovery. During the test the water levels in AWS P3 had quite clearly stabilised at c. 0.75mOD, indicating that even at this exceptionally high pumping rate (well above historic or current daily average rates), groundwater levels in the Upper Crag unit near Snipe Marsh remained at or above the ground level of Snipe Marsh.

Given that a *reduction* in the Ludham PS abstraction rate of c. 2.5Ml/d produced an observed recovery of no more than 0.1m in the Upper Crag at AWS P3, it is likely that the total drawdown in the Upper Crag unit close to Snipe Marsh, due to the Ludham PS abstraction at its current licensed average daily rate of c. 1.4Ml/d, is approximately 0.06m. This is less than 50% of the *minimum* modelled impacts for cell K for the '*Current FL - FL with AWS Ludham Off*' scenario given in Table A3.14 of Amec (2014'h'), suggesting these impacts may have been significantly over-estimated. Taking into account the apparent lower degree of hydraulic contact between the Upper Crag unit at P3 and the peat/dyke water levels on Snipe Marsh than used in the groundwater model (as discussed above), the possible impact from the Ludham PWS abstraction may be significantly less than 0.05m.

Observed vs modelled surface water levels

Modelled levels of the Cromes Broad gaugeboard (TG31/794) are compared with field observations in Figure A3.11 of Amec (2014'h'). The magnitude of variability of the modelled levels of c. 0.57m (from c. -0.3mOD to c. 0.27mOD) is slightly higher than the range recorded in the field over the same period of c. 0.4m (from c. 0.05mOD to c. 0.45mOD), but is an acceptable simulation. However, the absolute modelled levels are consistently too low and generally lie outside the range of levels observed in the field. The pattern of simulated levels is also poor, with generally little similarity to the pattern of levels observed on site. In fact the modelled and observed levels are often completely unsynchronised, with troughs in the observed data coinciding with peaks in the modelled levels. This appears to demonstrate that there is either a problem with the local conceptualisation of the Snipe Marsh/Cromes Broad area in the groundwater model or locally inappropriate parameters have been used.

Given that the simulated water levels in layer 1 of the model at Snipe Marsh play an important role in assessing the potential impact of abstraction upon the ecology, the poor calibration of simulated levels to observed surface water levels undermines the credibility of any assessments based upon the modelled data. These include the decision tables (Tables A3.10 to A3.13 of Amec, 2014'h) that flag up medium risk for the AWS abstraction, which by extension then includes the Alston abstractions in the 'In-combination' effects.

4 WATER SOURCES AND HYDROCHEMISTRY

4.1 Surface water inputs

Based upon a brief survey of the site on 04/12/14, there were clear surface water inputs to Snipe Marsh from the roadside drain (including field drainage from the north east and Grove Ponds overflow) beneath How Hill Road and also from minor watercourses draining Summer House Wood (see Figure 1).

4.2 Hydrochemical evidence

No specific hydrochemical conceptualisation of the Snipe Marsh area appears to have been undertaken for the EA assessment process, although compilations of hydrochemical data from the wider area have been presented in Amec (2012) and then summarised with minor additions in Amec (2014'f'), together with interpretation of water types. Additional information based upon field surveys of physicochemical parameters (apparently not used by Amec) is given in Atkins (2005). Sampling was carried out in August or September every year from 2001 to 2004.

Hydrochemical analysis data

In the Snipe Marsh area water samples were taken and analysed for major ions and some other common determinants (nitrate, iron) at four localities:

- Sample Point N; a dyke located in the centre of Snipe Marsh north of Summer House Wood (Figure 16; Atkins, 2003)
- AWS P1
- AWS P2
- AWS P3

In the context of this assessment, the key data are from Point N and from the shallow piezometer P3, which intersects the Upper Crag aquifer unit. The data, presented in Table F2 of Amec (2012), show that over the four years of sampling the hydrochemistry of both these sample locations was generally consistent over time, but the two locations were very different. Point N water was a typical calcium – bicarbonate water with calcium (Ca) at c. 105mg/l and alkalinity at c. 190mg/l (with magnesium {Mg} at c. 18mg/l and sulphate {SO_4} at c. 80mg/l). The P3 water was a more mixed Ca-Mg-SO_4 water with lower Ca at c. 70mg/l, higher Mg at c. 25mg/l, higher SO_4 at c. 110mg/l and lower alkalinity at c. 55mg/l. The differences in the water from the two locations are shown in a Trilinear (Piper) Diagram in Figure 18 of Atkins (2003).

Given the very significant differences in the hydrochemistry of these waters, it is appears that the Upper Crag aquifer makes a negligible contribution to surface water on Snipe Marsh, at least in late summer/early autumn. This supports the water level evidence described above that suggests the Upper Crag at P3 is in very poor hydraulic continuity with the surface water system on Snipe Marsh. In addition, the relatively low Ca concentrations in the Upper Crag groundwater appear to makes this a poor water source to support calcareous fen vegetation.

Physicochemical field survey data

Surveys of physicochemical parameters (pH, electrical conductivity {EC}, and field alkalinity) were conducted at the same time of year as the hydrochemical sampling at 14 locations on or immediately adjacent to Snipe Marsh, as shown in Figure 16 (Atkins, 2003). The locations and results are summarised in the table below. The field alkalinity values appeared to be of poor quality and are not included here.

Parameter / Location	Sample Points	pH	EC (uS/cm)
Roadside ditch to east of Snipe Marsh	C, H	c. 7.0 to 7.5	c. 750 to 940
Northern margin of Snipe Marsh	F, G	c. 6.6 to 6.9	c. 630 to 880
Summer House Wood stream	M, P, O, Q	c. 6.8 to 7.6	c. 630 to 780
South western corner of Snipe Marsh	I, K, N	c. 6.9 to 8.0	c. 620 to 780

Table 2 Results of physicochemical surveys (from Atkins, 2005)

The key result from this dataset is that all the pH values are far higher than those recorded from the Upper Crag in AWS P3, which varied between 5.64 and 5.95 (including both field and lab reported results: Table F2; Amec, 2012), suggesting that the aquifer pH is mainly rainfall-controlled, with little buffering by calcareous material in the Upper Crag unit. The fact that there was such a well-defined pH difference between the Snipe Marsh surface water and Upper Crag groundwater strongly suggests that none of the surface waters sampled included a significant component of Upper Crag water. Meanwhile, EC values from P3 varied from 595 to 742uS/cm, which was more similar to the range of values reported from the surface water locations.

4.3 Recent pH survey

A survey of 13 pH samples from ground surface and near-surface water on Snipe Marsh was undertaken on 01/12/14 by , who has 28 years' experience of field pH sampling. A barium sulphate-based testing kit was used to measure the pH. For comparison, a recent rainfall pH of 5.6 for a site in west Norfolk (as reported in Amec, 2012; p. 80, Section 4.4) is considered here.

The results showed relatively little variability, indicating good mixing and/or a generally consistent source of water. Most samples were slightly acidic, with 9 samples being pH 6.8, apparently derived from a more base-rich source than rainfall, or possibly a base-rich source water mixed with rainfall. Three samples were pH 6.0, suggesting these were rainfall dominated, and the remaining sample was pH 5.0, suggesting a more acidic source than rainfall (and more acidic than Upper Crag groundwater), with little dilution.

Overall, the survey indicated that at the time of sampling there appeared to be negligible discharge of Upper Crag groundwater (with a pH of less than 6; see range above) on to the marsh, supporting the conceptual idea described previously that the Upper Crag is in poor hydraulic continuity with the Snipe Marsh hydrological system.

5 OTHER ELEMENTS

5.1 Geological observations

The following observations relate to use of geological data in the assessment process:

- The borehole logs from the AWS Sharp Street piezometers have been used to estimate the geological sequence beneath Snipe Marsh, suggesting that the peat deposits of the Marsh are directly underlain by the Crag Formation.
- This approach does not take into account the change in ground level from the piezometer sites at c. 1.7mOD to the Marsh surface at c. 0.6 to 0.8mOD.

- This difference, though only 1m, is highly significant in marginal floodplain locations such as Snipe Marsh because they are occur at the edge of the depositional areas of the Breydon Formation.
- The British Geological Survey mapping of the area (BGS, 1999) shows clay and silt deposits of the Breydon Formation (deposited under estuarine conditions) extending some distance up the 'Sharp Street valley' to the east of Snipe Marsh, indicating the approximate maximum extent of flooding during the Holocene.
- The mapped peat deposits of the Breydon Formation, upon which Snipe Marsh lies, indicate a lower sea level stand, but there would have been little or no significant erosion between the deposition of the clay/silt and the deposition of the peat.
- The depositional environment at Snipe Marsh is very similar to the eastern margins of Catfield Fen, where a fairly consistent thickness of clay of c. 0.5m has been observed overlying the Crag Formation (e.g. Figure B8; Amec, 2012).
- Thus the clay/silt deposits are highly likely to underlie Snipe Marsh and will act to significantly reduce any hydraulic connectivity between the Upper Crag unit and the peat.
- Due to poor conceptualisation of the local depositional environment in the groundwater model, this crucial element has not been properly considered and the simulation has assumed a direct connection between the Upper Crag and the peat, which is unrealistic.
- This leads to overestimation of the groundwater inflow to Snipe Marsh and overestimation of the potential impacts of groundwater abstraction on the hydrology and water-dependent ecology of the site.

5.2 Water level management and the ecological condition of Snipe Marsh

In the text of a document from Natural England (NE, 2008) [see Amec, 2014'h', Appendix B, p.169], in a section entitled ***Advice on functionality of component sites within the Broads SAC and Broadland SPA***, there is the following statement, which appears highly relevant regarding the current situation at Snipe Marsh: '*Past actions on sites such as isolation, damming, embankment and pumping have been undertaken to overcome the symptoms of eutrophication and adverse hydrological regimes. However, it is now acknowledged that while these measures have been mostly effective, at moderating the initial threats to the site, it has resulted in significant secondary impacts such as reduced natural functioning and resilience. For sites to again function with integrity both the initial impact <u>and the impact of the secondary measures need to be addressed</u>*'.

There then follows a table outlining the types of action required at each SSSI and the resulting functional consequence. For the Ant Broads and Marshes SSSI, the *Type of action* required is described as '*Remove dams and reconnect/improve connection of fen ditch network to the river Ant*', with the resulting *Change in functionality* described as '*Floodplain fen, ditches and water bodies in greater hydrological connectivity with the river Ant*'.

Given that there appear to be considerable current concerns regarding the hydrological condition of Snipe Marsh (BA, 2014a), it appears highly contradictory that the advice from NE themselves regarding hydrological management within the Ant Broads & Marshes SSSI does not seem to have been acted upon. In fact, the construction of the WCS4 sluice structure in 2009 appears to have efficiently continued the isolation of the Snipe Marsh/Cromes Broad area from the River Ant. This structure has fulfilled its flood defence function but appears to be completely at odds with the water reconnection regime recommended to fulfil conservation objectives.

The effects of long term water level management on surface water levels in Cromes Broad (and by extension Snipe Marsh) are clearly shown in Figure A3.6 of Amec (2014'h'), which plots water levels from the gauge board on Cromes Broad (TG31/794; location shown in Figure A3.1 of Amec, 2014'h') with the level of the River Ant recorded at Barton Broad (Station T340903). For the overlapping period of data, which extends from late 2006 to early 2014, the water level at TG31/794 is below the level in the River Ant for over 80% of the time. This does not appear to be fulfilling *'greater hydrological connectivity with the river Ant'* as recommended by NE and surely must be considered as a significant contributory factor to any possible hydrologically-related degradation of the current condition of the site. In this context, the modelled impacts of the Ludham PWS abstraction, which may be themselves overestimated, appear insignificant and the 'impacts' of the Alston abstractions appear ecologically trivial.

The presence of the WCS4 sluice is recognised by the BA as fulfilling an important flood defence function, but its potential hydrological impact upon the ecology of Snipe Marsh does not appear to be considered particularly important in this context (BA, 2014b), whilst in the context of a much smaller potential hydrological impact caused by abstraction, the ecological impact **is** considered to be important (BA, 2014a). This apparently inconsistent approach does not seem to demonstrate an evidence-based methodology for assessing potential hydrological changes at sites managed by the BA.

Further evidence of this approach is shown in Section 4.1 of BA (2014a): '*...Broads Authority site managers have noted that the site* [Snipe Marsh] *has a problem with water levels and is often too dry to maintain the S24 vegetation community on much of the site'*. Based upon the recorded water level data from gaugeboard TG31/794 at Cromes Broad (Figure A3.6; Amec, 2014'h'), there has been no recognisable downward trend in water levels over the last seven years of monitoring.

5.3 Comments on the EA 'triviality' classification

The non-'trivial' classification of the hydrological impacts of the Alston abstractions is partly due to the triviality threshold of 1mm applied by the EA being overly conservative. For monitoring of any water levels the effective minimum recognisable impact would be 5mm, which is the best a dip tape or manual surface water level can be read to. These manual readings must provide the definition of the 'triviality' limit, as they are used to calibrate any equipment used to record water levels. Having a triviality threshold of 2mm is suggested as be appropriate, and this is still conservative at less than 50% of the minimum measurable impact.

Based on the modelled impacts of the Alston abstractions presented in Table 3.14 of Amec (2014'h'), the Plumsgate Road abstraction has impacts varying between 2mm and 5mm, with an average of 3mm and a worst case scenario in July 1976 of a 4mm impact. If these modelled impacts have been overestimated by, for example, a factor of two, as it appears may be the case for the Ludham PWS abstraction, then the average and worst case scenario impacts would then be less than the suggested amended triviality threshold of 2mm, and the average impact could be reduced to within the error margin of the current triviality threshold of 1mm.

5.4 Regulatory failure to timeously recognise SAC features at Snipe Marsh

Included in Appendix B of Amec (2014'h') is a NE document (NE, 2008) that is entitled CONSERVATION OBJECTIVES and DEFINITIONS OF FAVOURABLE CONDITION for DESIGNATED FEATURES OF INTEREST that relates to the Ant Broads and Marshes SSSI. The coverage of features is clarified by the statement; *'These conservation objectives relate* *to all designated features on the SSSI, whether designated as SSSI, SPA, SAC or Ramsar features'.*

In the *Fen, Marsh and Swamp* section of Table 1 of the document, the SSSI *S24* feature is grouped together with the SAC *Calcareous Fen* feature under the explanatory description *Tall-herb fen*, suggesting that there is recognition of a significant association between these features.

Considering a map produced by Entec for the EA (Entec, 2007), also given in Appendix B of Amec (2014'h'), it was clearly recognised in 2007 that S24 features were present on Snipe Marsh. Given the significant association between the SSSI S24 feature and the SAC Calcareous Fen feature, it was surely beholden upon the EA to confirm whether there were any SAC features present on Snipe Marsh during the HD RoC process which culminated in the reduction in the Ludham PWS abstraction licence in 2011. The failure of communication between NE and the EA, both at this point and during the extended preceding period of AMP3 Impact of Abstraction Investigations and AMP4 Water Resources Environment Programme investigations undertaken on behalf of AWS (apparently including significant consultation with both NE and the EA), resulted in the SAC features on Snipe Marsh being overlooked and thus they were neither appropriately investigated nor appropriately assessed during the RoC process.

If it had been recognised at that time that insufficient information was available to make proper assessment of the Snipe Marsh SAC features, then it would have led to more detailed investigation of the Snipe Marsh site, including characterisation of the shallow strata beneath the marsh and also monitoring of shallow groundwater levels on the marsh. This would have either led to a greater reduction in the Ludham PWS licence or, if no significant impacts were identified, to a better calibrated and better conceptualised section of the groundwater model in the Snipe Marsh area, such that the current issues with the 'In-combination' revocation of the Alston licenses would not have occurred.

Whilst the timeline to the current situation is long and involved, the route to it has clearly involved regulatory failure over a period of many years. It seems highly unsatisfactory that the Alston licenses will be revoked, for absolutely no measurable conservation gain (based upon the best available information), solely due to historic failings in communication between the relevant regulatory authorities.

6 SUMMARY AND CONCLUSIONS

a) The Alston abstractions are being revoked due to modelled 'In-combination' impacts (with the Ludham PWS abstraction) upon SAC features at Snipe Marsh.

b) The modelled impacts of the Alston abstractions on the Upper Crag aquifer unit beneath Snipe Marsh are very small (a maximum combined value of 22mm: Table A3.14; Amec, 2014'h') and that alone are considered insignificant to the hydrology/ecology of the site, but are not classified as hydrologically 'trivial' by the EA, as they individually exceed 1mm.

c) The non-'trivial' hydrological assessment of the Alston abstractions is partly due to the triviality threshold of 1mm applied by the EA being overly conservative. A suggested threshold of 2mm could be used, which is still less than 50% of the minimum measurable impact.

d) Based on the modelled impacts of the Plumsgate Road abstraction (Table 3.14; Amec, 2014'h'), and the potential over-estimate of hydrological impacts by a factor of two, then the average and worst case scenario impacts would then be less than the suggested amended triviality threshold of 2mm, and the average impact could be reduced to within the error margin of the current triviality threshold of 1mm.

e) The abstraction-related impacts on the ecology of Snipe Marsh for both the Alston abstractions and the Ludham PS abstraction may be significantly overestimated due to weaknesses in the groundwater model.

f) The simulated maximum impact of c. 150mm on water levels in the Upper Crag unit at Snipe Marsh due to the Ludham PS abstraction (Table A3.14; Amec, 2014'h') may be a significant over-estimate, as observed data from the 2003 pumping test suggests the true impact may be as low c. 60mm.

g) This impact itself relates to a drawdown in the Upper Crag unit and if this unit is in poor hydraulic contact with the Snipe Marsh hydrological system (as is suggested by a number of pieces of evidence) then any impact on the Upper Crag may have effectively no measurable impact on the local surface water system and hence no impact upon the ecology of the marsh.

h) The poor simulation of the restricted groundwater – surface water hydraulic contact described above is due to the non-inclusion of an expected low permeability (silt/clay) layer underlying the peat of Snipe Marsh. This layer is expected to significantly restrict the hydraulic connection between the Upper Crag aquifer unit and the Breydon Formation peat underlying Snipe Marsh.

i) The poor simulation of water levels in layer 1 of the Snipe Marsh area, which are significantly lower than the observed levels in both the Upper Crag aquifer unit and surface water levels at gaugeboard TG31/794, acts to undermine confidence in the modelled shallow water levels.

j) The poor representation of observed levels by the groundwater model in this area is partly due to the fact that there are no appropriate calibration measurements of shallow groundwater levels from upon Snipe Marsh itself and no field observations of the shallow strata directly underlying the Marsh.

k) The lack of this information is also one major reason why a strongly precautionary approach is being taken to assessing the impact of the abstractions, including that from Ludham PS. This has a direct impact on the determination assessment by adding 'precautionary' scores to the decision tables presented in Tables A3.10 to A3.13 of Amec (2014'h').

l) It must be recognised that the lack of field observations on Snipe Marsh is first and foremost a regulatory failing in that SAC features at Snipe Marsh were not properly assessed during the HD RoC process.

m) Certainly the scale of likely impacts from Ludham P.S upon water levels at Snipe Marsh are approximately an order of magnitude less than water level 'impacts' caused by the current sluice management regime, and the 'impacts' produced by the Alston abstractions are a further order of magnitude less than those caused by the Ludham PS abstraction.

n) In this context, it should be recognised that the 'impacts' of the Alston abstractions are insignificant on the hydrology of Snipe Marsh and the corresponding effects on the ecology of Snipe Marsh should be recognised as trivial.

o) In these circumstances, there is no compelling reason why the Alston abstraction licences should not be renewed, at least while further investigation is carried out at Snipe Marsh to refine and improve the geological conceptualisation and its representation in the groundwater model, especially as the failure to carry out such work is due to failings in regulatory communication over a period exceeding ten years.

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