Natural England Commissioned Report NECR349

Ecohydrological Investigation and Characterisation of three proposed SSSI Units: Boswens North, Bussow Moor & Boswarva North West Penwith, Cornwall (2019)

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Foreword

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Background - Penwith Downs Moors and Heaths in west Cornwall has been submitted for possible SSSI designation. The potential SSSI site consists of 55 units and Natural England have gathered much supporting evidence for the proposed designation. One of the key features is valley mires and further hydrological information is required for three of the potential units that contain valley mire habitat: Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54). In addition to these three proposed valley mire units a further unit named Bostraze Bog was hydrologically surveyed by Rigare Ltd (2018).

Disclaimer:

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Further information
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1 Introduction

1.1 Background

Penwith Downs Moors and Heaths in west Cornwall has been submitted for possible SSSI designation. The potential SSSI site consists of 55 units and Natural England have gathered much supporting evidence for the proposed designation. One of the key features is valley mires and further hydrological information is required for three of the potential units that contain valley mire habitat: Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54). In addition to these three proposed valley mire units a further unit named Bostraze Bog was hydrologically surveyed by Rigare Ltd (2018).

Boswens (Report 1 of 3) and Boswarva (Report 2 of 3) are located within 1 km of each other, around 4.5 km northeast of St Just, and Bostraze Bog (Rigare, 2018) is approximately 2 km southwest of Boswens. The locations of Boswens, Boswarva and Bostraze are shown on Figure 1. Bussow Moor (Report 3 of 3) is 10 km northeast of Boswens and Boswarva and is 2 km inland from St Ives. The results of the ecohydrological investigations are presented as a set of three reports, the first being this one for Boswens (the 'site').

In order to progress with the designation of the valley mire SSSI units Natural England require further investigation and assessment of the ecohydrology. The existing Natural England fen and bog SSSI selection guidelines advise that sufficient land should be included within the SSSI boundary to protect the interest feature and its hydrology. Guidance for determining boundaries for valley mire features states:

> *Wetlands in basins and valley bottoms can be supplied with water from various sources including surface run-off from within the catchment, groundwater seepage and direct rainfall. The site boundary of these wetlands should encompass the following:*
>
> - *all influencing slopes;*
> - *all springs, flushes and seepages that supply the wetland;*
> - *all ditches, channels and peripheral drains that influence site hydrology;*
> - *depending on the ecohydrology of the site and landscape setting, it may be necessary to include whole fields above the slope as well in order to protect the wetland feature from nutrient-enriched run-off and sub-surface flow e.g. through sandy soils;*
> - *the outflow stream for some distance to prevent lowering of the stream bed which would lower the water level in the wetland.*

The area including all of the above features can be considered as that in which land use, management and activities can influence hydrological supporting conditions for interest features within the proposed SSSI.

1.2 Scope of work

Natural England requested an ecohydrological survey and suitably tailored hydrological and hydrogeological surveys of the surface water and groundwater catchments for Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54).

The objectives of the ecohydrological survey are as follows:

- Identify, describe, and map all site water features including streams, ditches, seepages, flushes. Flow rates in watercourses will be estimated.
- Identify, describe, and map off-site water features identified during the desk study phase, as land access allows. Flow rates in watercourses will be estimated.
- Visual assessment of field drains based on the findings of the desk study and information provided by Natural England.
- Take field measurements of pH and Electrical Conductivity.
- Undertake a peat depth survey along transects through the site. The locations of 3 to 4 transects will be discussed with and agreed with Natural England during the desk study phase.

The findings from the ecohydrological field survey and a desk study will be used to develop a conceptual model for the site. The conceptual model will provide a visual representation of the ecohydrological functioning of the site and will include:

- the hydrological processes (WETMECS, Wheeler *et al*, 2009) that provide the necessary supporting conditions for the wetland vegetation
- identify the principal water sources and characterise the hydrological regime of the site, including surface and groundwater flow directions
- characterise the water chemistry of the site based on the pH and Electrical Conductivity measurements

The conceptual model, in conjunction with existing vegetation data and information derived from the ecohydrological survey and peat depth measurements will be used to define the ecohydrological boundary of each of the three proposed SSSI units.

The ecohydrological survey of the site was undertaken on 10th and 11th December 2018.

1.3 Data sources

The following data sources were used in the investigation:

- Ordnance Survey mapping
- Historic mapping available online
- Aerial photography provided by Natural England
- Online soil type data available at the LandIS Soilscapes website, developed by Cranfield University
- British Geological Survey mapping and geological data
- NVC survey of the site (Hewins Ecology, 2014)

2 Site Setting

2.1 Location

The site has an approximate area of 8.6 ha and is located on the Lands End Peninsula, Cornwall, at grid reference SW 40740 33360 (approximate site centre). It is 4.3 km north-east of St Just and 7 km north-west of Penzance. The peninsula is relatively narrow and the site is only 2.7 km from the coast.

2.2 Land use

The site is located in a rural location, with the surrounding land predominantly used for agriculture. The fields adjacent to the site are managed by local farmers and used for livestock grazing (cattle) and arable grass silage. The fields around Penwith Moors are mostly pasture, but there is also occasional rotational arable. The site itself is currently unmanaged except for a single field on the north of the site as indicated on Figure 2.

The closest residential dwellings are Trehyllys Farm on the north-east corner of the site and properties at Boswens to the south-east.

2.3 Topography

The site is oriented east-west in a valley lying between hills to the northwest and southeast. The site has a shallow gradient and slopes gently down to the east from 175 mAOD to 160 mAOD over approximately 500 m. Chun Downs hill is approximately 500 m northwest of the site and has a summit elevation of 215 mAOD. The hill to the southwest of the site has a summit elevation of the 224 mAOD and the Air Traffic Control Station is located here. Boswens Common hill is approximately 660 m south, with a summit elevation of 223 mAOD.

2.4 Ecology

An NVC survey of the site was carried out by Hewins Ecology in July 2014 and the results are summarised on Figure 5. The survey found the following main habitat types, with summary descriptions taken from the NVC field guides (JNCC, 2001 and JNCC, 2004):

Humid heath (H4): Found in the North field. This community is confined to the warm oceanic parts of southwest Britain where it occurs on a variety of moist, acid soils. Occurs on acid soils that are too moist for dry heath but not so consistently waterlogged as to be able to sustain wet heath.

Wet heath (M16b): A narrow band is found at the south end of the North field, situated between the humid heath on the higher ground to the north, and the mire communities to the south. This wet heath community is found on acid and oligotrophic mineral soils or shallow peats that generally have a surface pH of 3.5 – 4.5 and that are at least seasonally waterlogged. It is characteristic of the south of lowland England, being particularly associated with the slightly drier upper margins of valley mires.

Mire (M23, M25): The NVC survey maps these two communities across the majority of the site. M23 is *Juncus effusus/acutiflorus – Galium palustre* rush-pasture. It occurs over a variety of moist, moderately acid to neutral (pH 4 – 6), peaty and mineral soils in the cool and rainy lowlands of western Britain. It is found on gently-sloping ground, often around the margins of soligenous flushes, as a zone around topogenous mires and wet heaths, and especially widespread in wet, comparatively semi-natural pasture.

M25 is *Molinia caerulea – Potentilla erecta* mire and is found on moist, but well-aerated, acid to neutral peats and peaty mineral soils in the wet and cool western lowlands of Britain. It occurs over gently-sloping ground, marking out seepage zones and flushed margins of sluggish streams, water-tracks and topogenous mires, but also extends onto the fringes of ombrogenous mires. Soil and drainage conditions of this community have similarities to those of M23.

Scrub (W1): Mapped as an east-west band through the centre of the site. The NVC survey notes that the W1 habitat is dominated by *Salix cincerea* with stands ranging from immature that have recently encroached upon former mire to more established scrub-woodland. This is a community of wet mineral soils on the margins of standing or slow-moving water and in moist hollows, mainly in the lowlands.

The summary information above indicates that the wet heath and mire communities occur on wet acid soils and that the mire communities can be found in a range of locations including topogenous mires and soligenous flushes. We can therefore conclude that these communities are water dependent, but are they ground water dependent?

The UKTAG[1] guidance (2004) on the identification and risk assessment of groundwater dependent terrestrial ecosystems (GWDTE), provides a groundwater dependency score for the mire and woodland NVC communities as follows:

- M23 and M25. Low groundwater dependency (score = 3). This means that sites including these habitats should only be included in risk assessments under the GWDTE test of the Water Framework Directive if they are found to be coincident with a groundwater body with high surface interaction.
- W1. Moderate groundwater dependency (score = 2). As above, but the groundwater body must have at least moderate surface interaction.

2.5 Hydrology

The site is located within the River Newlyn catchment and the River Newlyn is approximately 1 km east of the site and flows south to the sea at Newlyn. The OS 1:25,000 mapping shows a series of streams close to the eastern site boundary which discharge from the site into Boswens stream which flows east into the River Newlyn.

- Stream 1 is mapped as flowing south from an Issues at Trehyllys Farm, along the eastern boundary and into Boswens stream.
- Stream 2 is mapped as originating at a Well and flowing north into Boswens stream
- Stream 3 is mapped as flowing north from a Collects into Boswens stream

The OS 1:25,000 mapping also shows a water well on the east side of the site.

Figure 2 shows the site water features and the upgradient catchment which contributes to the outflow point from the site into Boswens stream.

[1] The UK Technical Advisory Group on the Water Framework Directive

A review of historic maps of the site has been undertaken using maps available at www.old-maps.co.uk (accessed 14/01/2019). The earliest map is the 1878 OS County series for Cornwall and Isle of Scilly, which shows all of the water features listed above.

The annual average rainfall for the region is around 1000 mm/yr based on the Met Office annual average data from the Camborne and Culdrose weather stations, around 25km east-north-east and east of the site respectively.

2.6 Soils

The soil type has been taken from the *LandIS Soilscapes* website, developed by Cranfield University. The soil type underlying the site and the surrounding surface water catchment is classified as: "Very acid loamy upland soils with a wet peaty surface". Smedley and Allen (2004) describe the soils in the region as thin, well-drained and representative of the bedrock of the local geology. Peaty soils are also seen in some upland areas.

2.7 Geology

The regional geology of the site has been taken from the British Geological Survey (BGS) 1:50,000 scale sheet Penzance (351 & 358) and associated memoirs. The bedrock and superficial geology are presented in Figures 3 and 4. The following review is taken from the BGS (Sheet 351, Penzance), BGS (1989), Smedley and Allen (2004) and Jones *et al* (2000).

2.7.1 Bedrock and structural geology

The site and its surface water catchment are underlain by a fine-grained biotite granite bedrock, which is part of the Land's End granite pluton, a body of magma that intruded into the area about 280 million years ago and slowly cooled. The Land's End granite is an offshoot from the Cornubian batholith, which is a much larger mass of magma. The Cornubian batholith is a thought to be around 200 km wide and 50 km long.

The fine-grained biotite granite found at Boswens was formed from an earlier granite which was then subsumed. The boundary between the fine-grained granite underlying the Boswens site and the surrounding granite (medium- and course-grained) is faulted on two sides. The faults run in a roughly northwest direction with the downthrow to the northeast.

2.7.2 Superficial geology

The fine-grained granite bedrock is overlain by shallow superficial Head deposits between 0.5 – 2 m thick. These deposits are not shown on the BGS mapping for clarity but are expected to cover much of the Land's End Peninsula. The Head deposits are described as a heterogeneous mixture of local rock in a matrix of fine sand, silt and clay that was formed through the reworking of earlier weathering products by peri-glacial processes. These deposits are locally deeper in valleys and basins where accumulations have infilled. The BGS mapping shows these deeper Head deposits underlying the site.

2.8 Hydrogeology

The granite underlying the site is classified by the Environment Agency as a Secondary A aquifer capable of supporting small abstractions and providing baseflow to groundwater supported surface water features.

Groundwater storage and flow within the granite occurs entirely within fractures in the upper weathered bedrock. Fractures decrease with depth and the base of the aquifer is generally considered to be 30 - 40 m below ground level. There is little literature data regarding the Land's End Granite. However, studies have been carried out on the nearby Carnmenellis Granite (around 30 km to the east, between Cambourne and Falmouth) which is considered to be comparable (Jones et al., 2000).

The BGS maintains a database of water wells and boreholes, and three boreholes near the site have been reviewed. The borehole logs record that the boreholes penetrate the granite and borehole depths are 29 – 41 m which supports the base of the aquifer to be between 30 – 40 m.

The granite is overlain by up to 2 m of Head deposit which is in connectivity with the granite aquifer and allows recharge. Therefore, over most of the area the aquifer is unconfined. The water table is generally less than 10 m below ground and tends to follow the topography. Due to the low permeability of the granite and the topography, the hydraulic gradient can be steep (BGS, 1989).

Where thicker deposits of Head occur in valleys and basins, as is the case at the site, these tend to act locally to confine the aquifer. This is due both to the silty, clayey nature and the thickness of the deposits.

Recharge into the granite aquifer will occur on the higher ground to the northwest and southwest of the site where the Head is thinner and surface water infiltrates into the aquifer.

Due to the mainly unconfined nature of the aquifer and the connectivity with the superficial deposits it is considered that the groundwater catchment for the site will be coincident with the surface water catchment. The surface water catchment is detailed in Section 2.5 and shown on Figure 2.

One other factor that has the potential to influence the hydrogeology is historic mine workings. There is no evidence of local mine workings in the area immediately surrounding Boswens and is therefore not considered to be a factor at this site.

3 Ecohydrological Survey

The ecohydrological survey was undertaken on 11th and 12th December 2018. The summer had been dry, but there had been a heavy storm two days before the site visit, and rain on the night of the 11th December.

The site is currently unmanaged (except for the North field), although there has been some scrub clearance in recent years which was undertaken by the local Wildlife Trust (personal communication, Mr Trewern of Trehyllys Farm). Despite this work, a central swathe of the site is inaccessible due to dense scrub and brambles.

The surrounding fields are managed by local farmers and used for livestock (cattle) and arable grass silage. The fields around Penwith Moors are mostly pasture, but there is also occasional rotational arable. The North field of the site is accessible for cattle from the adjacent fields, and although no cattle were present during the site visit, it appears to have been grazed in some areas.

The water well marked on the OS 1:25,000 mapping in the southeast corner of the site is a housed spring and is the water supply for Trehyllys Farm. According to Mr Trewern (personal communication) the spring has never run dry and was housed around 60 years ago for hygiene.

3.1 Site Survey

Key features were identified during the desk study and visited during the ecohydrological and walkover survey. Survey points were recorded using a handheld Garmin GPS accurate to approximately 5 m. The results of the ecohydrological survey are presented, with photos, on Figure 5, and detailed in Table 1 below.

During the survey, field measurements were made of pH and Electrical Conductivity for water samples around the site. In Table 2, the points where field water chemistry was measured are indicated with a dagger symbol (†). Full field water chemistry results are presented in Section 3.2.

Table 1 Findings of the ecohydrological survey

Survey point (SP)	Grid ref Easting, Northing	Description	Mapped	Influence on site
Issues SP1	140909, 33613	Issues not present and no local knowledge of them (personal communication Mr Trewarn). Surface water flows into the site from the track to the southwest and also down the road from the northeast. In periods of wet weather, water pools close to where the Issues are located on the OS map and runs into Stream 1 (personal communication, Mr Trewarn). On the days of the visit there was very little surface water flow into Stream 1 despite it raining heavily the previous night.	On OS map, not present	Mainly east edge of site
Stream 1 SP2†	140899, 033530	Stream 1 starts dry. At SP2 slow moving water was seen in the channel, but higher flow was clearly audible further south indicating a gaining stream considered to be due to a spring/seepage. Width of channel: 35 cm, depth of water: 10 cm	Yes	Mainly east edge of site

SP3†	140894, 033459	Very low flow Dense vegetation in this area precluded investigation to determine the specific locations of inflows. However, near to SP3 it is thought that Stream 4 (see below) flows into Stream 1. Width of channel: 200 cm, Depth of water: 25 cm Medium-fast flow		
Stream 2 SP4†	140900, 033355	The 'Butterhouse' is a small granite building constructed to house a spring providing the water supply to Trehyllys Farm. According to Mr Trewarn it has never run dry. This spring is marked as a Well on the OS map and was housed c.60 years ago for hygiene as it provides a water source for the farm. Stream 2 appears from inaccessible scrub and flows in front of the Butterhouse. It was not possible to find the source of Stream 2 but it is most likely to be another spring similar to the one at the Butterhouse. Width of channel: 150 cm, Depth of water: 20 cm Medium flow	Yes	Mainly east edge of site
SP5†	140912, 033379	At SP5, Stream 2 is heavily vegetated, water is clear. Width of channel: 135 cm, Depth of water: 15 cm Medium flow		
Stream 3 SP6†	140856, 033261	At SP6, Stream 3 emerges from thick scrub. Width of channel: 50 cm, Depth of water: 10 cm Medium-fast flow 20 m north of SP6 Stream 3 flows through a very wet area of ground surrounded by dense stands of Molinia. This is possibly another spring/seepage.	Yes	Mainly east edge of site
SP7†	140877, 033362	At SP7, Stream 3 continues to flow north until it converges with Stream 2 and flows out of the site. The water is clear but the channel is densely vegetated with bracken and brambles. Width of channel: 60 cm, Depth of water: 20 cm Medium flow		
Stream 4 SP8	140482, 033365	A seepage was found at SP8 and flows east along the field boundary. Flow becomes channelled south to SP9.	Not marked on the OS map	Yes
SP9†	140547, 33363	Visible slow flow in a stream channel which follows the field boundary at this point. Flow becomes more vigorous to the southeast. Width of channel: 100 - 300 cm, Depth of water: 5 - 10 cm Visible flow, slow		
SP10†	140615,			

	033355	At SP10, Stream 4 has become fast flowing. Dense scrub in this area prevented access but the stream was audible running through the scrub in the centre of the site. It is considered that Stream 4 flows across the site and into Stream 1 near SP3. Width of channel: 300 cm, Depth of water: 20 cm Medium to fast flow		
SP11	140819, 033354	At SP11 there is an area of Molinia and boggy ground. There is visible surface water which probably flows north towards Stream 4.	No	Yes
SP12	140811, 033266	Standing water with no visible flow, very boggy.	No	Yes
SP13	140833, 033441	Standing water with no visible flow, very boggy.	No	Yes
Drain SP14†	140283, 033325	At SP14 a concrete pipe runs under a field entrance. The concrete pipe channels water running from the moorland lying to the west into the site. Despite heavy rain the previous night, there was very low flow through the drain and some standing water. It is considered that this drain does not contribute a significant amount of surface flow to the site due to the low flow after heavy rainfall. From SP14 there is a ditch that runs east into the site along the southern field boundary. The ditch was dry on the days of the site visit. A cattle trough is found at the first field boundary 95 m east of SP14. Water is pumped to the trough from an unknown location. Water overflowing from the trough enters the ditch, but quickly dissipates.	No	Yes
Stream 5 SP15	140670, 033265	Stream 5 originates at a spring/seepage and is channelled along the field boundary to the east, as shown on Figure 5. Stream 5 is currently used by the landowner to provide water for his horses. This stream was particularly difficult to access but it is considered likely that it finally flows into Stream 3	No	Not at present, but possibly historically
Boswens stream SP16†	140963, 033431	Boswens stream receives all flows from the site streams. The water was clear and the channel was partially vegetated. Width of channel: 110cm, Depth of water: 26cm Medium to fast flow	Yes	No
Hydroram SP17	140970, 033378	During the visit Mr Trewarn indicated the location of a Hydroram which provides a water source for the farm. The hydroram is a hydraulic pump driven by the head of water and this one pumps water ~300 m in distance and 10 m in elevation. The hydroram supplies water to the farm and for cattle.	No	No

The main findings of the ecohydrological survey are summarised as follows:

- The three mapped Streams 1 – 3 were surveyed and all found to be fed by groundwater springs/seepages. The streams were seen to be gaining which is considered to be due to additional groundwater sources that were not seen during the survey due to dense vegetation.
- Streams 1 – 3 are all on the east side of the site and close to the site boundary. They have similar characteristics with shallow sides and rocky bottoms. The channels are all partially vegetated, while the banks are densely vegetated, often with bracken and brambles. The depth of water in the streams was rarely above 20 cm and the width varied between 0.5 –2 m.
- The historic mapping shows that the streams have been present for over 100 years. However, the location of the streams along the site boundary to capture and drain spring water from the site suggests that the streams are likely to be historic man-made water features. The streams do not appear to have been maintained for a number of years. There is no evidence that the streams have been recently deepened or straightened but historically these streams could have been aligned with field boundaries.
- Streams 1 – 3 all capture water emerging from groundwater springs/seepages and channel it to discharge from the site into Boswens stream. Therefore, the water within these streams is not available to contribute to the site wetland areas except around the spring/seepage itself at the head of the stream.
- Stream 1 is well confined and has limited potential to flood onto the site. Stream 2 is also well-confined, except when flowing along the eastern field boundary, where both Streams 2 and 3 have the potential to flood onto the site during times of flooding. However, the influence of the flood water would be limited to the east edge of the site.
- The OS mapping shows Stream 1 to be fed by Issues close to Trehyllys Farm. These Issues were not found and the farmer was not aware of them existing. Stream 1 started at SP2 and is considered to be fed by groundwater springs/seepages
- Stream 4 is not shown on the current or historic OS mapping. The stream rises at a seepage on the west of the site and flows east into Stream 1 at SP 3 on Figure 6. The stream flows through the band of woodland across the centre of the site (NVC survey: W1 – Scrub). The vegetation was dense and it was not possible to follow the route of the stream. The estimated path of the stream is shown as a dashed line in Figure 6.
- Stream 5 is not within the site but originates on the neighbouring ground just to the south of the site. It is fed by a groundwater spring/seepage and channelled along the field boundary to the east. It is considered likely that it currently flows into Stream 3, although historically it may have flowed north into the site.
- All the streams, 1 – 5, are fed by groundwater springs/seepages emerging from around the periphery of the site at the boundary of the edge of the Head deposits. The land area covered during the field survey was limited due to time and inaccessibility but it is expected that there are more groundwater springs/seepages around the site boundary.
- Areas of wet, boggy land are found on the site, shown by a star on Figure 6. These are likely to be areas where surface flow collects in slight topographic hollows as it flows across the site.

- The fields to the northwest of the site were visited and there was not found to be any ditches or visible flow pathways onto the site. Furthermore, there was no evidence of overland runoff from these fields onto the site. The absence of drainage ditches suggests the ground is relatively free draining and surface water tends to infiltrate. The primary source of water from these fields is considered to be infiltration of rainfall and surface runoff into the substrate and not direct surface water runoff.
- With the exception of the North field, which is slightly drier and supports Wet Heath and Humid Heath communities, the ground character of the site is very different to the surrounding fields, being predominantly wet with impeded drainage.

3.2 Water Chemistry

Field measurements were made of pH and Electrical Conductivity using handheld meters. The results of the field measurements are shown in Table 2 below, and the locations are shown Figure 5.

Before discussing the results of the field water chemistry, it is important to note that these are a snap-shot of the water chemistry on 11th and 12th December 2018 and may not be representative of water chemistry through the seasons.

Table 2 Results of the field water chemistry

Survey point	Grid ref Easting, Northing	pH	Electrical Conductivity (µS/cm)
C1 (SP4)	140900, 033355	5.3	84
C2 (SP6)	140856, 033261	5.8	75
C3	140856, 033282	5.7	80
C4	140910, 033359	5.6	83
C5 (SP7)	140877, 033362	5.7	78
C6 (SP2)	140899, 033530	6.5	79
C7 (SP3)	140894, 033459	5.5	83
C8 (SP16)	140963, 033431	5.8	79
C9 (SP5)	140912, 033379	5.6	82
C10 (SP10)	140615, 033355	5.9	73
C11 (SP9)	140547, 033363	5.7	66
C12 (SP13)	140283, 033325	4.3	120

Table 2 shows the pH is between 4.3 – 6.5 with a median of 5.7. The conductivity is between 66 and 120 µS/cm which is low and indicates a low mineral content.

The BGS's Baseline Report Series (Smedley and Allen, 2004) states that the Lands End granite has a pH between 4.8 – 6.8 with a median of 5.8. Due to the groundwater circulating at shallow depths, it is soft (due to an absence of carbonate minerals in the granite), acidic, and unmineralised. The pH and conductivity measurements taken on site concur with the literature, implying that the groundwater at Boswens behaves in the same way.

The pH of a fen is used to determine whether the fen type is base-poor, with a pH of 5.5 or less; or base-rich with pH of 5.5 or above (McBride *et al.*, 2011). The recorded pH of 4.3 – 6.5 as well as the NVC mire communities found at the site indicate this to be at the high end of base-poor fen.

3.3 Peat Depth

Peat depths were taken along five transects using a fibreglass rod which was pushed into the ground until the underlying substrate was encountered. The transects were paced and a measurement was taken roughly every 20 m. The results of the transects are presented on Figure 6.

No peat is mapped underlying the site, but peaty soils between 0.1 – 1.4 m in depth were found underlying the majority of the site. In general, peat was absent at the edges of the site, but became deeper towards the centre. This area of the site was seen to be wet and supporting wetland forming vegetation including Sphagnum mosses and it is considered that the vegetation is still peat forming.

3.4 Wetland Supply Mechanisms (WETMECs)

The findings of the field survey have been presented above and in this section are discussed to determine the water supply mechanisms (WETMECs). The WETMECs are part of the Wetland Framework (Wheeler *et al*, 2009) which identifies the main wetland habitats that occur in lowland wetlands in England and Wales. It focusses primarily on mires (fens, bogs and swamps) and in particular to the relationships between wetland topography, hydrology, hydrogeology, hydrochemistry and the ecological and biological characteristics of the site.

The site and the catchment are underlain by granite, the upper 30 – 40 m of which is weathered and is classified as an aquifer. The aquifer is unconfined, except beneath the site, and groundwater flow follows the topographic contours from the higher ground to the northwest (Chun Downs) and the southwest (Air Traffic Control Station). The site itself has a very shallow gradient down to the east, therefore, as groundwater from the higher ground reaches the site flow is slowed and water tends to collect within the site.

At the site, the granite bedrock is overlain by clayey, silty Head deposits which have collected in the valley. The thickness of this deposit is expected to be more than 2 m deep. This low permeability Head acts to locally confine the underlying aquifer beneath the site and results in the piezometric surface being above ground level.

> ***Piezometric surface:*** *Where an aquifer is confined and there is a high hydraulic head the groundwater in the confined aquifer is under pressure. The piezometric surface is the level to which groundwater would rise in a borehole penetrating the aquifer.*

The survey found that all four of the site streams are fed by groundwater springs/seepages. There was also a groundwater spring/seepage found on adjacent land to the south of the site feeding Stream 5. These springs/seepages emerge around the periphery of the site at the edge of the Head deposits as shown on Figure 5.

This setting is consistent with the WETMEC Group of Seepage Slopes: Outflows of groundwater, typically on slopes but occasionally on more or less flat ground where there is water outflow. The high water table is maintained in what is essentially an unfavourable topographical context (sloping) by high

rates of groundwater outflow (they are soligenous systems). Within this group the WETMEC 10: Permanent Seepage Slopes best describes the water source.

Moving away from the site periphery there is a transition to the WETMEC Group of Seepage Basins and Bottoms: Rheo-topogenous (topogenous flow) seepage systems developed in various topographical contexts, usually with lateral water flow, probably mainly through the surface layer. Within this group the WETMEC 14: Seepage Percolation Troughs best describes the centre of the site: Peat-filled troughs, more or less flat to gently sloping, fed by groundwater outflow directly from underlying deposits or flanking slopes.

4 Ecohydrological Conceptual Model

The ecohydrological conceptual model for the site is presented on Figure 7 and described as follows:

- The site has an approximate area of 8.6 ha and sits in a relatively flat valley that slopes gently down to the east. Chun Downs hill is to the northwest and the Air Traffic Control Station hill is to the southwest.
- The bedrock geology underlying the site is part of the Land's End Intrusion, of Carboniferous age, and consists of fine-grained biotite granite. The bedrock is overlain by shallow superficial Head deposits between 0.5 – 2 m thick, consisting of a heterogeneous mixture of local rock in a matrix of fine sand, silt and clay. Greater accumulations of Head deposits are found in valleys and basins and the site is mapped as overlying a deeper valley deposit of Head.
- The granite bedrock is classified by the Environment Agency as a Secondary A aquifer. The aquifer is 30 – 40 m thick as a result of the fracture network which diminishes with depth. Groundwater flow and storage are predominantly within the fracture network. The granite is overlain by up to 2 m of Head deposit which is in connectivity with the granite aquifer and allows recharge. Therefore, over most of the area the aquifer is unconfined.
- Due to the mainly unconfined nature of the aquifer and the connectivity with the superficial deposits it is considered that the groundwater catchment for the site is coincident with the surface water catchment.
- Where thicker deposits of Head occur at the site these act locally to confine the aquifer, which offers resistance to upwards flow, and groundwater pressure in the bedrock is likely to be artesian beneath the site resulting in the piezometric surface being above ground level.
- Recharge into the granite aquifer will occur on the higher ground to the northwest and southwest of the site where the Head is thinner and surface water infiltrates into the aquifer. Groundwater flow within the aquifer follows the relatively steep topographic and hydraulic gradient down towards the site. Flow is then significantly reduced in the valley bottom at the site due to the very shallow gradient of the site and upwards hydraulic gradients and groundwater discharge will dominate.
- The primary water source for the site is groundwater springs/seepages which emerge around the periphery of the site at the edge of the Head deposits. These groundwater springs/seepages support the soligenous ecology found within the site.
- Direct rainfall is also a source of water for the wetland habitats within the site.
- Streams 1 – 3 rise on the site and are fed by groundwater springs/seepages. The historic mapping shows that the streams have been present for over 100 years. However, the location of the streams along the site boundary to capture and drain spring water from the site suggests that the streams are likely to be historic man-made water features. The streams do not appear to have been maintained for a number of years. There is no evidence that the streams have been recently deepened or straightened but historically these streams could have been aligned with field boundaries.

- Stream 4 flows east across the centre of the site through the NVC mapped band of scrub (W1) and is considered to be a naturally formed stream
- Stream 5 rises just to the south of the site from a groundwater spring/seepage and is channelled along the field boundary to the east, where it is used to provide water for horses. It is possible that in the past this water source would have flowed north onto the site.
- All the streams are fed by groundwater springs/seepages, but the water is then confined into the stream channels and flows away from the site. Therefore, these springs do not provide the main water source for the wetland habitat. It is considered that there are more springs/seepages around the periphery of the site which were not found during the survey and are the water source for the wetland habitat.
- The recorded pH of 4.3 – 6.5 and the NVC mire communities found at the site indicate this to be at the high end of base-poor fen.
- The dominant WETMEC within the site is WETMEC 10: Permanent Seepage Slopes. These occur around the periphery of the site where the groundwater table intersects the ground surface and springs arise. Moving away from the site periphery there is a transition to WETMEC 14: Seepage Percolation Troughs which occur on more or less flat to gently sloping ground, fed by groundwater outflow from underlying deposits or flanking slopes.
- The fields to the northwest of the site are relatively free draining and surface water tends to infiltrate. The primary source of water from these fields is considered to be infiltration of rainfall and surface runoff into the substrate and not direct surface water runoff.
- Peaty soils between 0.1 – 1.4 m in depth were found underlying the majority of the site with the deepest peat towards the centre. This area of the site was seen to be wet and supporting wetland forming vegetation including Sphagnum mosses and it is considered that the vegetation is still peat forming.

5 Conclusions: Definition of the hydrological unit for Boswens

A baseline review of the geology and hydrogeology of Boswens has been completed and the NVC survey (Hewins Ecology, 2014) has also been reviewed. A two day ecohydrological survey of Boswens was carried out in December 2018 and the results of the above have been used to develop the ecohydrological conceptual model of the site (Figure 7).

The ecohydrological conceptual model has shown that the site is fed by groundwater seepages/springs emerging from the underlying granite aquifer, which have allowed base-poor soligenous wetlands to become established. Therefore, under the JNCC fen and bog SSSI selection guidelines (JNCC, 2013), the groundwater catchment upgradient of the site has been included within the hydrological unit. Due to the hydrogeological characteristics of the site, the groundwater catchment is co-incident with the surface water catchment.

The ecohydrological survey found no evidence of overland surface runoff onto the site, instead it is considered that the soils are relatively free draining and surface water tends to infiltrate.

The hydrological unit for Boswens is shown on Figure 8 and includes both the surface water and groundwater catchments which are co-incident.

Streams and ditches downstream of the areas of wetland habitat have not been included in the hydrological unit; it is considered that management of these watercourses within reasonable bounds will have little influence on the hydrology of the wetland habitats.

6 Future considerations for Boswens, Boswarva and Bussow

A set of three reports have been prepared which present the results of site ecohydrological investigations, conceptual models and the hydrological units for Boswens, Boswarva and Bussow. Boswens and Boswarva are located within 1 km of each other, around 4.5 km northeast of St Just, and Bussow Moor is 10 km northeast, around 2 km inland from St Ives.

These three sites all contain valley mire habitat and the conceptual models have shown the ecohydrological regimes for the three sites to be similar. The primary water source is groundwater and the dominant WETMEC is Permanent Seepage Slopes (10). For each site the hydrological unit has been defined which includes the groundwater and surface water catchments which are coincident.

Due to the similarity of the ecohydrological regimes at the three sites, potential considerations and issues for the sites are similar and are discussed generically. Where there are site specific considerations, they are listed at the end of the individual reports.

The hydrological units include a significant area of farmland. The hydrology of the farmland is that the ground is relatively free draining and surface water tends to infiltrate into the subsurface and the underlying aquifer. Groundwater flow in the aquifer is generally through fractures and weathering in the upper bedrock and groundwater residence time is relatively short.

It is expected that within the hydrological units there will be a range of different land management practices which could have the potential to pollute the sites though changes to water quality and in particular to increase the risk of nutrient enrichment to groundwater which is the dominant site water source. The inclusion of this farmland within the hydrological units would allow potential risks to groundwater quality to be managed through the SSSI management practices.

Site specific considerations for Boswens

Stream 5 rises on neighbouring land to the south of the site, has been channelled to the east and currently provides water for horses on the neighbouring land. It is possible that historically this stream could have flowed north into the site. It would be worth considering, with agreement from the landowner, whether re-routed this stream into the north of the site could benefit the site.

Streams 1 – 3 are all close to the eastern site border and may have been historically built to capture and drain spring water from the site. Future consideration could be given as to whether the water within these streams could be better used within the site.

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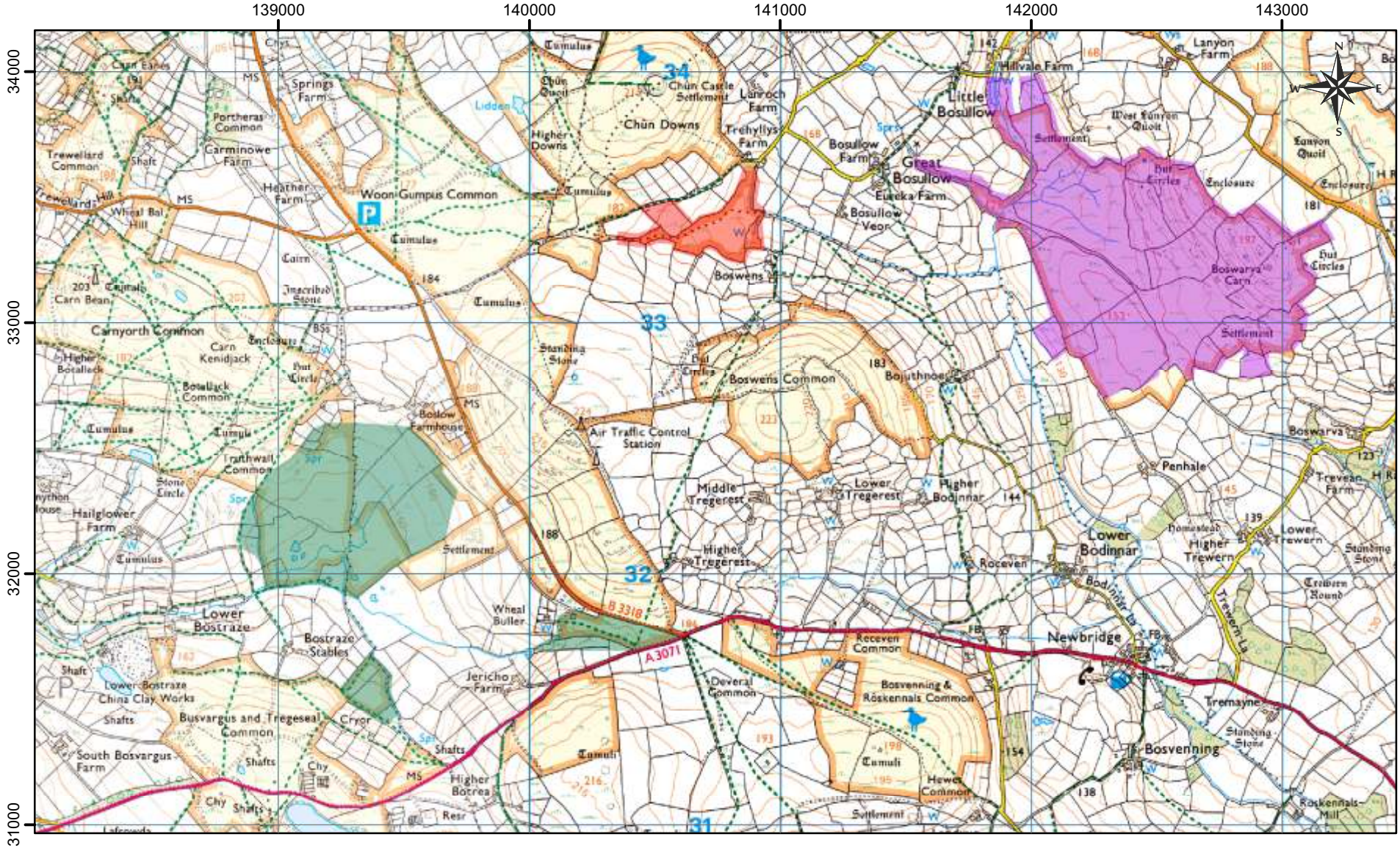
Figures



KEY

Boswens

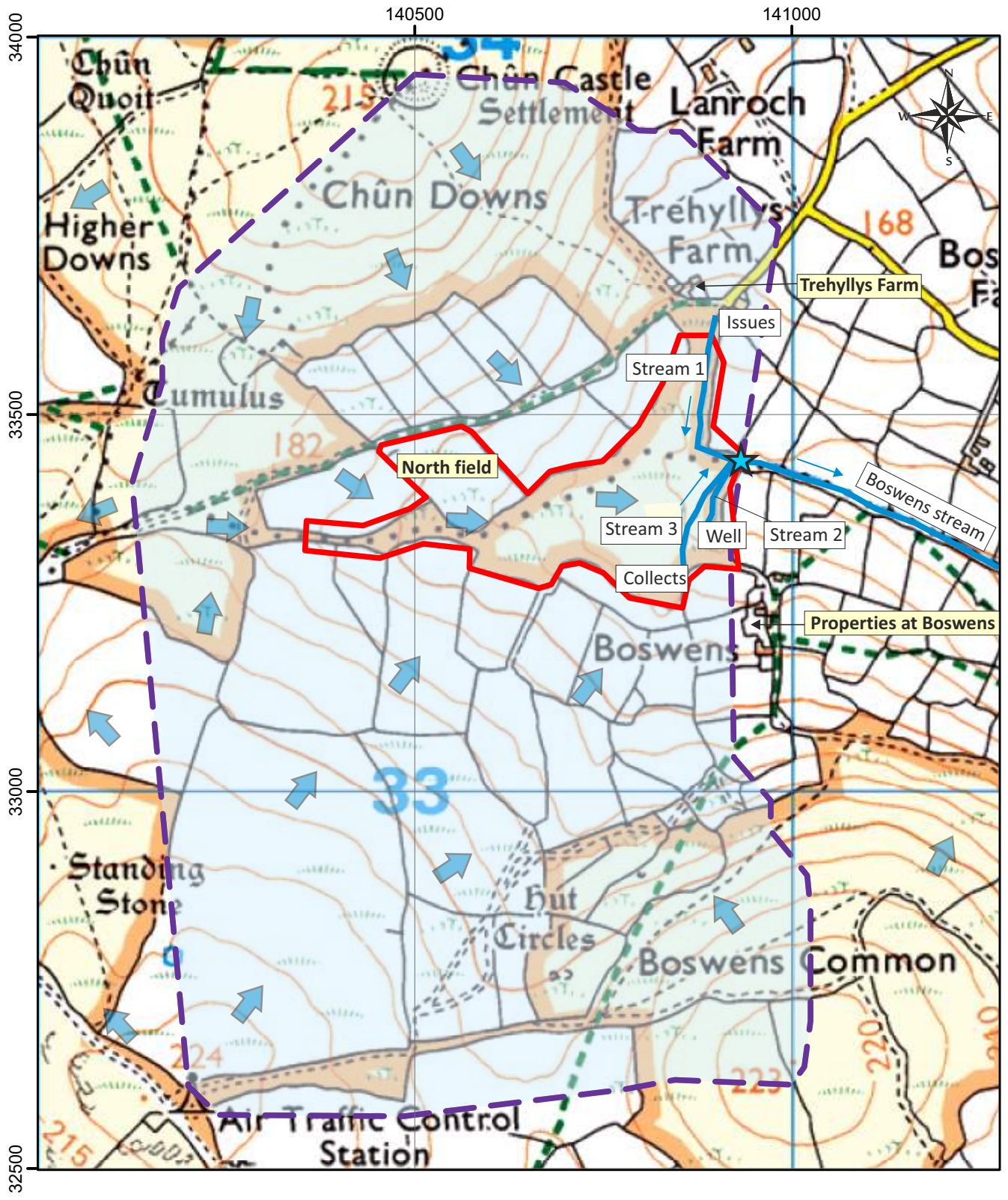
Boswarva

Bostraze

Figure 1 Site location
Boswens, West Penwith

Date: 22/02/2019
Prepared By: Pendleton Hydro Ltd.

PH



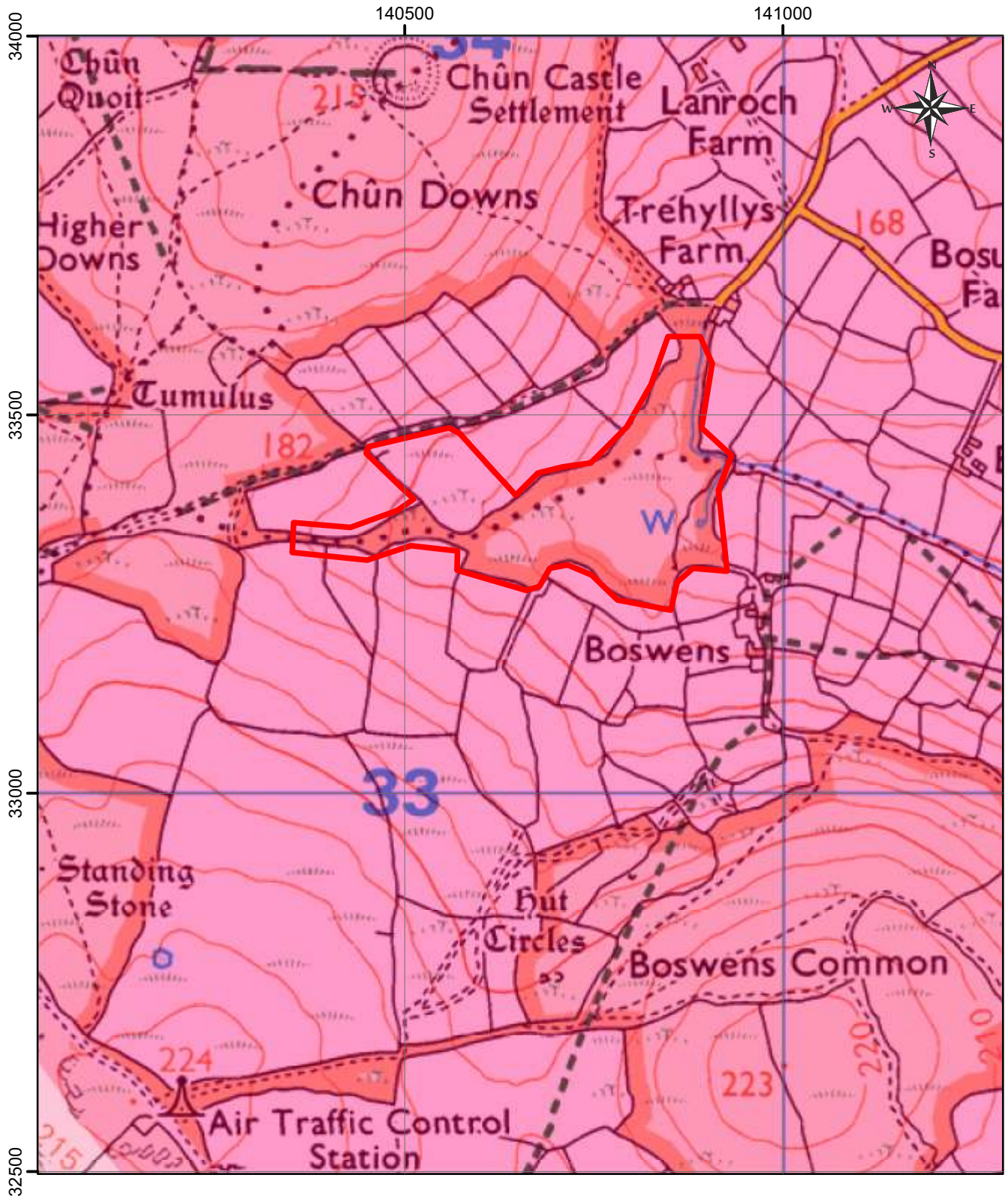
KEY

- Site boundary
- Catchment to the outflow point
- Outflow point
- Watercourse
- Watercourse flow direction
- Surface runoff direction

Figure 2 Hydrological catchment & mapped water features
Boswens, West Penwith

Date: 14/01/2019
Prepared By: Pendleton Hydro Ltd.

PH



KEY

Bedrock Geology

Site boundary

Land's End Intrusion - Microgranite

Figure 3 Bedrock geology
Boswens, West Penwith

Date: 18/02/2019
Prepared By: Pendleton Hydro Ltd.

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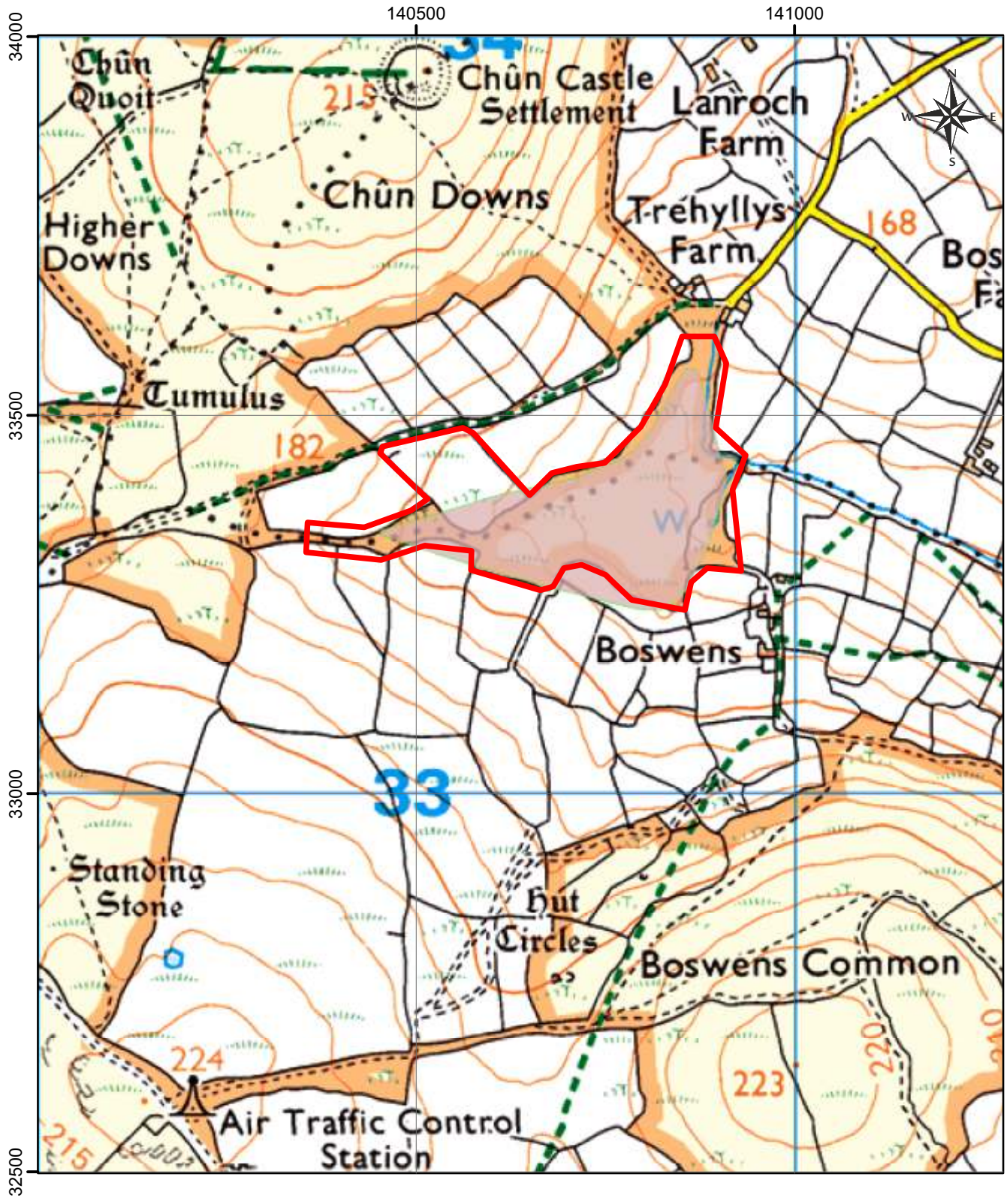


KEY

Site boundary

Superficial Geology

Head - clay, silt, sand and gravel

Figure 4 Superficial geology
Boswens, West Penwith

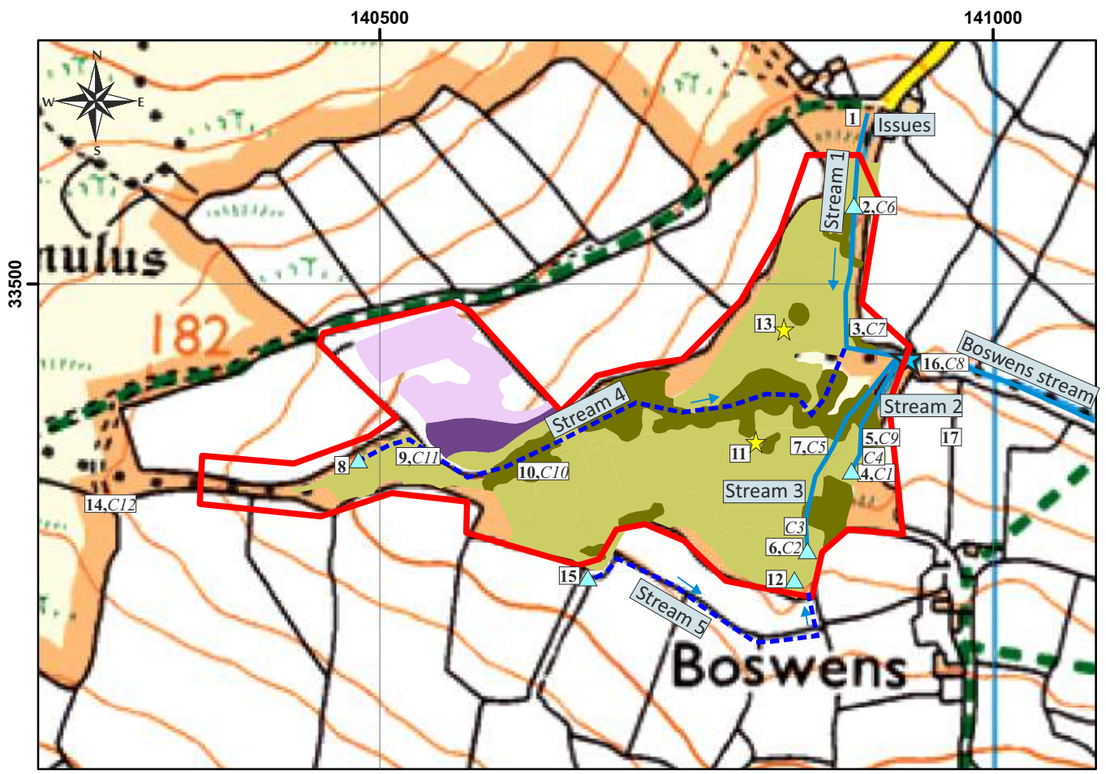
Date: 22/02/2019
Prepared By: Pendleton Hydro Ltd.

PH

(SP2) Stream 1, increased flow moving south

(SP4) The 'Butterhouse', spring water source marked as Well on the OS map

(SP5) Stream 2, flows north, heavily vegetated



KEY

Site boundary	
Outflow point	
Mapped watercourse	
Watercourse flow direction	
Unmapped watercourse	
1 Survey point	
9,C11 Survey point, water chemistry measurement	
Groundwater spring/seepage	
Very wet, boggy ground	

NVC type

Humid heath (H4)	
Wet heath (M16b)	
Mire (M23, M25)	
Scrub (W1)	

(SP6) Stream 3, flows north

(SP8) Seepage forms the headwaters of Stream 4, flows east

(SP11) Very wet ground and a series of small streams flowing north

Figure 5 Ecohydrological survey
Boswens, West Penwith

Date: 22/01/2019
Prepared By: Pendleton Hydro Ltd.

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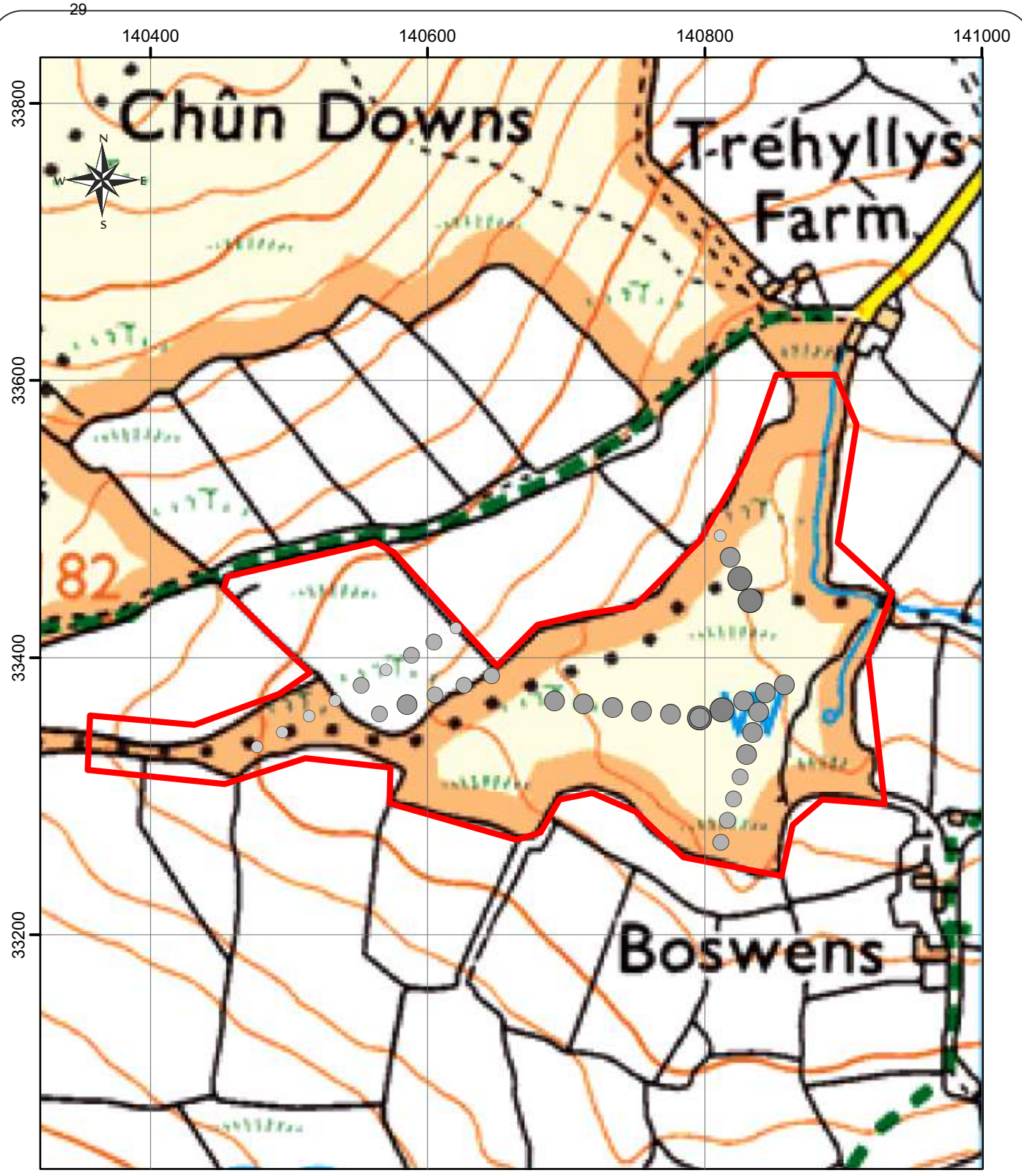

KEY

Site boundary

Peat Depth (cm)

- 0-25
- 25-50
- 50-100
- 100-150
- 150-200

Figure 6 Peat depth
Boswens, West Penwith

Date: 22/02/2019
Prepared By: Pendleton Hydro Ltd.

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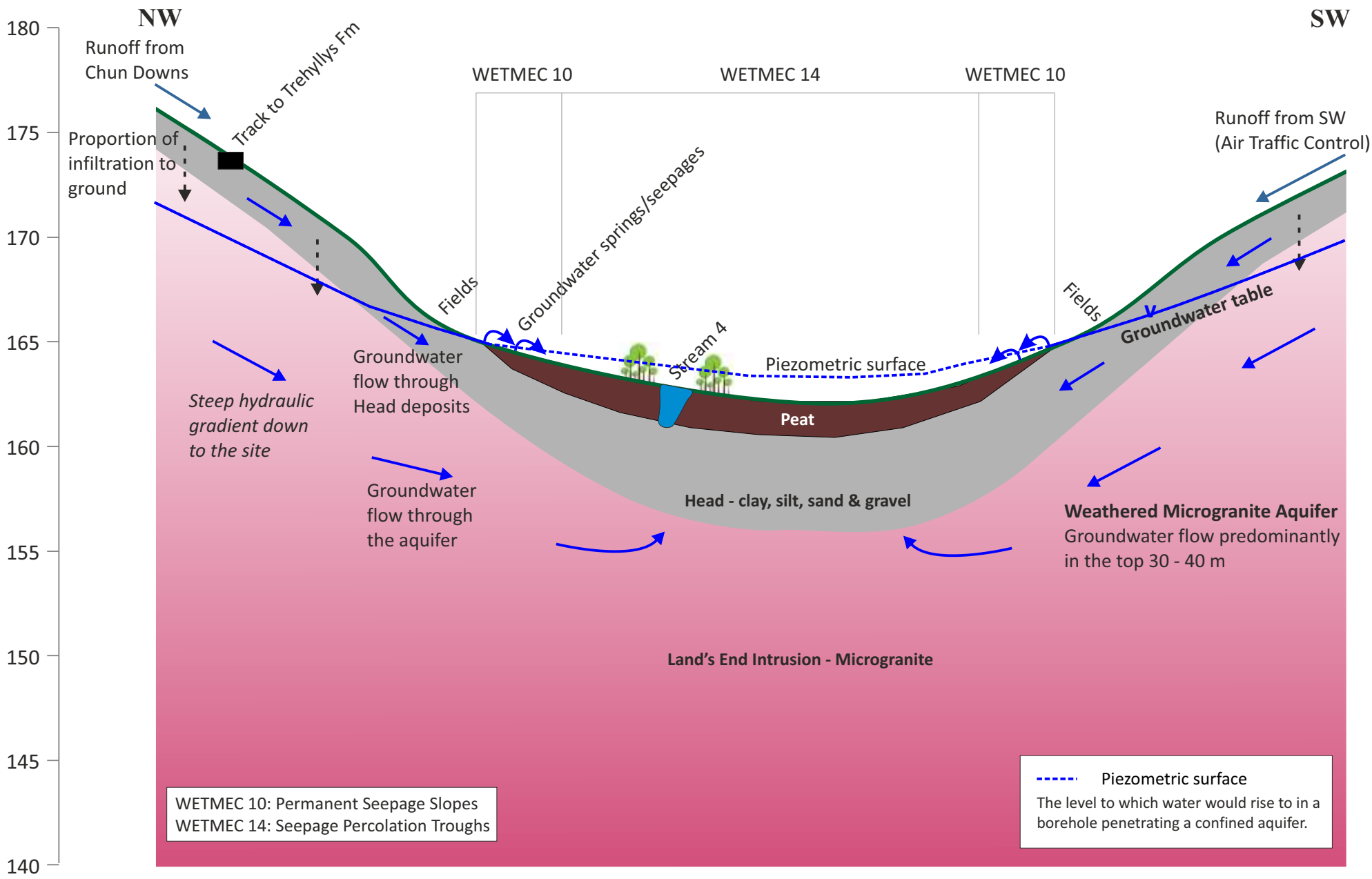

Figure 8 Ecohydrological conceptual model
Boswens, West Penwith

Date: 18/01/2019
Prepared By: Pendleton Hydro Ltd.

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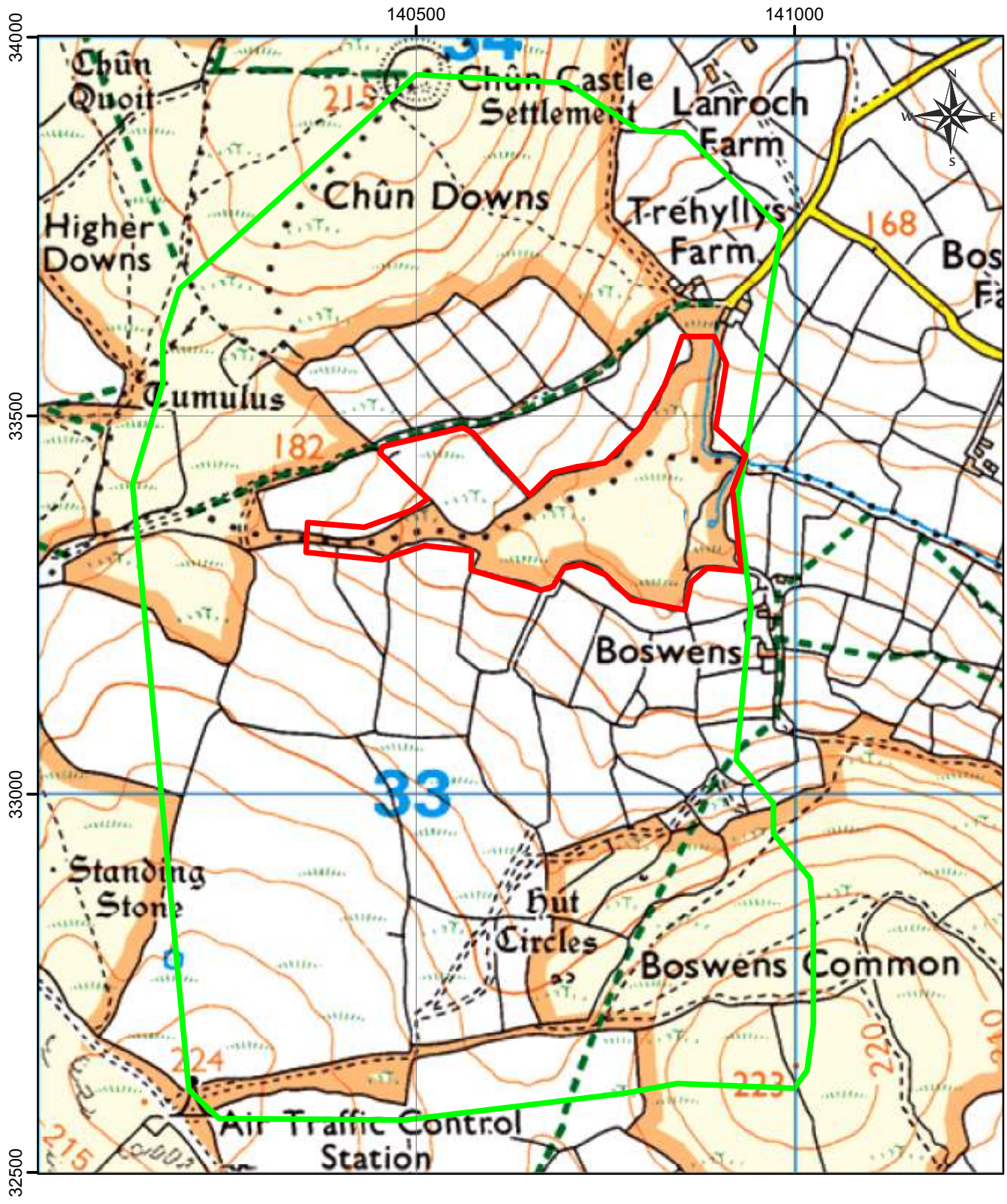

KEY

Site boundary

Hydrological unit for Boswens
(Groundwater and surface water catchments)

Figure 8 Definition of the hydrological unit for Boswens
Boswens, West Penwith

Date: 25/02/2019
Prepared By: Pendleton Hydro Ltd.

PH

Ecohydrological Investigation and Characterisation of three proposed SSSI Units – Report 2 of 3: Boswarva North, West Penwith, Cornwall

Report:

West Penwith - Boswarva - Report 2 of 3 Final.docx
March 2019

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Appendices

1 Introduction

1.1 Background

Penwith Downs Moors and Heaths in west Cornwall has been submitted for possible SSSI designation. The potential SSSI site consists of 55 units and Natural England has gathered much supporting evidence for the proposed designation. One of the key features is valley mires and further hydrological information is required for three of the potential units that contain valley mire habitat: Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54). In addition to these three proposed valley mire units a further unit named Bostraze Bog was hydrologically surveyed by Rigare Ltd (2018).

The results of the site ecohydrological investigations are presented as a set of three reports, the second being this one for Boswarva (the 'site'). Boswens (Report 1 of 3) and Boswarva (Report 2 of 3) are located within 1 km of each other, around 4.5 km northeast of St Just, and Bostraze Bog (Rigare, 2018) is approximately 2 km southwest of Boswens. The locations of these three units are shown on Figure 1. Bussow Moor is 10 km northeast of Boswens and Boswarva and is 2 km inland from St Ives.

In order to progress with the designation of the valley mire SSSI units Natural England require further investigation and assessment of the ecohydrology. The existing Natural England fen and bog SSSI selection guidelines advise that sufficient land should be included within the SSSI boundary to protect the interest feature and its hydrology. The guidance for determining boundaries for valley mire features states:

> *Wetlands in basins and valley bottoms can be supplied with water from various sources including surface run-off from within the catchment, groundwater seepage and direct rainfall. The site boundary of these wetlands should encompass the following:*
>
> - *all influencing slopes;*
> - *all springs, flushes and seepages that supply the wetland;*
> - *all ditches, channels and peripheral drains that influence site hydrology;*
> - *depending on the ecohydrology of the site and landscape setting, it may be necessary to include whole fields above the slope as well in order to protect the wetland feature from nutrient-enriched run-off and sub-surface flow e.g. through sandy soils;*
> - *the outflow stream for some distance to prevent lowering of the stream bed which would lower the water level in the wetland.*

The area including all of the above features can be considered as that in which land use, management and activities can influence hydrological supporting conditions for interest features within the proposed SSSI.

1.2 Scope of work

Natural England requested an ecohydrological survey and suitably tailored hydrological and hydrogeological surveys of the surface water and groundwater catchments for Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54).

The objectives of the ecohydrological survey are as follows:

- Identify, describe, and map all site water features including streams, ditches, seepages, flushes. Flow rates in watercourses will be estimated.
- Identify, describe, and map off-site water features identified during the desk study phase, as land access allows. Flow rates in watercourses will be estimated.
- Visual assessment of field drains based on the findings of the desk study and information provided by Natural England.
- Take field measurements of pH and Electrical Conductivity.
- Undertake a peat depth survey along transects through the site. The locations of 3 to 4 transects will be discussed with and agreed with Natural England during the desk study phase.

The findings from the ecohydrological field survey and a desk study will be used to develop a conceptual model for the site. The conceptual model will provide a visual representation of the ecohydrological functioning of the site and will include:

- the hydrological processes (WETMECS, Wheeler *et al*, 2009) that provide the necessary supporting conditions for the wetland vegetation
- identify the principal water sources and characterise the hydrological regime of the site, including surface and groundwater flow directions
- characterise the water chemistry of the site based on the pH and Electrical Conductivity measurements

The conceptual model, in conjunction with existing vegetation data and information derived from the ecohydrological survey and peat depth measurements will be used to define the ecohydrological boundary of each of the three proposed SSSI units.

The ecohydrological survey was undertaken between 10 – 13 December 2018 and 4 – 5 February 2019.

1.3 Data sources

The following data sources were used in the investigation:

- Ordnance Survey mapping
- Historic mapping available online
- Aerial photography provided by Natural England
- Online soil type data available at the LandIS Soilscapes website, developed by Cranfield University
- British Geological Survey mapping and geological data
- NVC survey of the site (Hewins Ecology, 2014)

2 Site Setting

2.1 Location

The site has an approximate area of 88.7 ha and is located on the Lands End Peninsula, Cornwall, at grid reference SW 42434 33344 (approximate site centre). It is 5.8 km northeast of St Just and 5.4 km northwest of Penzance. Although inland, the Peninsula is relatively narrow and the site is only 3.2 km from the coast. The site lies to the south of the B3306 that runs northwest to the village of Morvah.

2.2 Topography

The site is situated within the rolling hills and fields of the Land's End Peninsula. The dominant landscape feature of the site is Boswarva Carn, a hill in the east of the site which rises to 197 mAOD. A second summit (152 mAOD) is 500 m southwest of Boswarva Carn and a shallow, broad-bottomed valley slopes gently down to the northwest between these two hills at a lower elevation of ~130 mAOD.

In the north of the site, the topography is defined by the valley of the Newlyn River which flows south along the west site boundary.

The 'Western Finger' of the site is indicated on Figure 2 and sits in a narrow valley with a moderate gradient sloping down to the southeast towards Newlyn River.

2.3 Land use

The site is located in a rural setting, with the surrounding land predominantly semi-improved grassland used for pastoral farming. The site itself is used recreationally by walkers, and grazed by horses, and on the days of the site visit there was evidence that horses are kept in the fields to the north of Boswarva Carn, as shown on Figure 2.

The closest residential dwellings are located immediately to the northwest of the site in the hamlets of Great Bosullow and Little Bosullow.

Hillvale Farm is located immediately north of the site. Personal communication with Mrs Rowe, landowner, identified a discrepancy on the OS mapping. The farm is actually named Millvale Farm and not Hillvale Farm as on the OS mapping. However, for clarity with the OS mapping it will be referred to as Hillvale Farm for the rest of the report.

A review of historic maps of the site has been undertaken using maps available at www.old-maps.co.uk (accessed 14/01/2019). The earliest map is the 1878 OS County series for Cornwall and Isle of Scilly which shows the following site features indicated on Figure 2: Lanyon Mill, historic village and a historic quarry. In addition, there is a disused tin mine named Ding Dong mine approximately 1.5 km northeast of the site (Figure 2).

2.4 Ecology

An NVC survey of the site was carried in 2013, and also in July 2014. The results are summarised on Figure 3 with respect to the valley mire/wetland communities. Summary descriptions of the communities have been taken from the NVC field guides (JNCC, 2001 and JNCC, 2004):

Humid heath (H4, H8): Humid heath is found on the slopes of Boswarva Carn and the second summit to the southeast.

H4 is *Ulex gallii – Agrostis curtisii* heath. This community is confined to the warm oceanic parts of southwest Britain where it occurs on a variety of moist, acid soils. Occurs on acid soils that are too moist for dry heath but not so consistently waterlogged as to be able to sustain wet heath.

H8 is *Calluna vulgaris – Ulex gallii* heath. This community can be found over a wide range of acid igneous and metamorphic rocks as well as on silty and sandy superficials like loess and aeolian sands. The superficial pH underneath this community is usually from 3.5 to 4.5.

Mire (M23, M25): The M25 community is mapped in the lower central north of the site. The M23 community is mapped along the Western Finger.

M25 is *Molinia caerulea – Potentilla erecta* mire and is found on moist, but well-aerated, acid to neutral peats and peaty mineral soils in the wet and cool western lowlands of Britain. It occurs over gently-sloping ground, marking out seepage zones and flushed margins of sluggish streams, water-tracks and topogenous mires, but also extends onto the fringes of ombrogenous mires. Soil and drainage conditions of this community have similarities to those of M23.

M23 is *Juncus effusus/acutiflorus – Galium palustre* rush-pasture. It occurs over a variety of moist, moderately acid to neutral (pH 4 – 6), peaty and mineral soils in the cool and rainy lowlands of western Britain. It is found on gently-sloping ground, often around the margins of soligenous flushes, as a zone around topogenous mires and wet heaths, and especially widespread in wet, comparatively semi-natural pasture.

The mire communities occur on wet acid soils and can be found in a range of locations including topogenous mires and soligenous flushes. We can therefore conclude that these communities are water dependent, but are they ground water dependent?

The UKTAG[1] guidance on the identification and risk assessment of groundwater dependent terrestrial ecosystems (GWDTE), (2004), provides a groundwater dependency score for the mire and woodland NVC communities as follows:

- M23 and M25. Low groundwater dependency (score = 3). This means that sites including these habitats should only be included in risk assessments under the GWDTE test of the Water Framework Directive if they are found to be coincident with a groundwater body with high surface interaction.

[1] The UK Technical Advisory Group on the Water Framework Directive

2.5 Soils

The soil type has been taken from the *LandIS Soilscapes* website, developed by Cranfield University. The soil type underlying the site and the surrounding surface water catchment is classified as: "Very acid loamy upland soils with a wet peaty surface". Smedley and Allen (2004) describe the soils in the region as thin, well-drained and representative of the bedrock of the local geology. Peaty soils are also seen in some upland areas.

2.6 Geology

The regional geology of the site has been taken from the British Geological Survey (BGS) 1:50,000 scale sheet Penzance (351 & 358) and associated memoirs. The bedrock and superficial geology are presented in Figures 4 and 5. The following review is taken from the BGS (Sheet 351, Penzance, BGS, 1989), Smedley and Allen (2004) and Jones *et al* (2000).

2.6.1 Bedrock and structural geology

The site and its surface water catchment is underlain by a medium- and coarse-grained biotite granite bedrock, which is part of the Land's End granite pluton, a body of magma that intruded into the area about 280 million years ago and slowly cooled. The Land's End granite is an offshoot from the Cornubian batholith, which is a much larger mass of cooled magma.

A series of faults run in a roughly southeasterly direction from the coast to the site. The faults represent the boundary between the medium- to course- grained granite and an area of microgranite that lies predominantly to the west of the site boundary. One of these faults extends beneath the Western Finger into the site shown on Figure 4.

2.6.2 Superficial geology

The Newlyn River is underlain by Alluvium consisting of silt, sand and gravel. Head deposits are mapped in the north of the site. The Head deposits are described as a heterogeneous mixture of local rock in a matrix of fine sand, silt and clay that were formed through the reworking of earlier weathering products by peri-glacial processes. The BGS mapping notes that only deeper Head deposits are shown on the map for clarity, but that the area is generally underlain by shallow Head deposits between 0.5 – 2 m thick.

2.7 Hydrogeology

The granite underlying the site is classified by the Environment Agency as a Secondary A aquifer capable of supporting small abstractions and providing baseflow to groundwater-supported surface water features.

Groundwater storage and flow within the granite occurs entirely within fractures in the upper weathered bedrock. Fractures decrease with depth and the base of the aquifer is generally considered to be 30 - 40 m below ground level. There is little literature data regarding the Land's End Granite. However, studies have been carried out on the nearby Carnmenellis Granite (around 30 km to the east, between Cambourne and Falmouth) which is considered to be comparable (Jones et al., 2000).

The BGS maintains a database of water wells and boreholes, and three boreholes near the site have been reviewed. The borehole logs record that the boreholes penetrate the granite and borehole depths are 29 – 41 m which supports the base of the aquifer to be between 30 – 40 m.

Across the region, the granite is overlain by up to 2 m of Head deposit which is in connectivity with the granite aquifer and allows recharge. Therefore, over most of the area the aquifer is unconfined. The water table is generally less than 10 m below ground and tends to follow the topography. Due to the low permeability of the granite and the topography, the hydraulic gradient can be steep (BGS, 1989).

Where thicker deposits of Head occur in valleys and basins, as in the north of the site, these tend to locally confine the aquifer. This is due both to the silty, clayey nature and the thickness of the deposits.

Recharge into the granite aquifer will occur on the higher ground at Boswarva Carn in the southeast and the second summit to the southwest where the Head is thinner and surface water infiltrates into the aquifer.

Due to the mainly unconfined nature of the aquifer and the connectivity with the superficial deposits it is considered that the groundwater catchment for the site will be coincident with the surface water catchment.

One other factor that has the potential to influence the hydrogeology is historic mine workings. The historic Ding Dong Mine is 1.5 km northeast and upgradient of the site. Any direct influence on the site would potentially be through minewater discharge through adits into surface water courses. Due to the distance from the site this is not considered to be a significant risk. There is the potential that the historical mining has altered groundwater geochemistry, however the mine closed in 1877 and any residual risks are considered to be low.

2.8 Hydrology

The site is located within the Newlyn River catchment and the River Newlyn flows south along the west site boundary. The river rises approximately 1.5 km northeast of the site at an approximate elevation of 200 mAOD and flows south down to an elevation of ~130 mAOD where it leaves the site at the outflow point. Figure 6 shows the Newlyn River catchment which contributes to the outflow point from the site.

The OS 1:25,000 mapping shows the following water features on and in close vicinity to the site, and shown on Figure 7:

- Stream 1 flows southeast along the Western Finger into the outflow point of the Newlyn River.
- Spring 1 is approximately 100 m north of the start of Stream 1 and has an approximate elevation of 150 mAOD.
- Stream 2 is fed by a network of tributaries that flow in a westerly direction from the eastern site boundary and Boswarva Carn into the Newlyn River.
- Stream 3 rises approximately 200 m north of the site, to the east of Hillvale Farm and flows south towards Ponds 1 & 2.
- Ponds 1 & 2: The OS 1, 25,000 map shows a single pond, but a review of the 1,10,000 mapping has shown that there are two separate ponds.
- Well 1 is 130 m north of Spring 1 at an elevation of 155 mAOD.
- Well 2 is in close vicinity to Hillvale Farm at an elevation of 135 mAOD.
- Well 3 is 300 m northeast of the site at an elevation of 150 mAOD.

A review of historic maps of the site has been undertaken using maps available at www.old-maps.co.uk (accessed 14/01/2019). The earliest map is the 1878 OS County series for Cornwall and Isle of Scilly.

It shows all of the streams as they are currently marked and Well 1 to the north of the site and Spring 1 to the west of the Western Finger. It also shows an additional spring where the current OS mapping shows the head of Stream 1. A later 1908 map shows three ponds in the south of the site (Ponds 3 & 4 on Figure 7).

The annual average rainfall for the region is around 1,000 mm/yr based on the Met Office annual average data from the Camborne and Culdrose weather stations, around 25km east-north-east and east of the site respectively.

3 Ecohydrological Survey

The ecohydrological survey was undertaken between 10 – 13 December 2018 and 4 – 5 February 2019. There had been a heavy storm two days before the site visit in December, and rain on the night of the 11 December. There was heavy rain the night of the 4 February and persistent fog during the day on 5 February.

The site can be accessed through gates and paths which are used by local walkers. The site was observed to be grazed by horses/ponies and narrow trails crisscross the site. The surrounding fields are semi-improved grassland managed by local farmers and support pastoral farming (cattle and horses).

The site has a long history and is home to the old Lanyon Mill (closed around 50 years ago) as well as a historical track from Bosullow to Newlyn. Well 2 in the north of the site is no longer flowing, but historically provided water to the village of Bosullow (personal communication, Mrs Rowe, landowner).

3.1 Site Survey

Key features were identified during the desk study and visited during the ecohydrological and walkover survey. Survey points were recorded using a handheld Garmin GPS accurate to approximately 5 m. During the survey, field measurements were made of pH and Electrical Conductivity for water samples around the site, which are presented in Section 3.2. The results of the hydrological survey are presented on Figure 8 (surveyed water features) and Figure 9 (survey photos). Full field notes and stream dimensions are provided in Appendix A.

Newlyn River

Where the Newlyn River passes into and through the west of the site, it is a wide, shallow, fast-flowing stream with clear water, a mineral bottom and has a partially vegetated channel (Photo 1, Figure 9). Through this section of the site, the stream channel sits in a narrow valley and for the majority of the channel the banks are high and densely vegetated with bracken and brambles.

Due to the well contained channel characteristics of the stream, it is considered unlikely that the Newlyn River provides a source of surface water to the site via flooding.

Road drains

Upgradient (north) of the site there are a series of road drains (Figure 8) that capture surface water runoff from Bosullow Common to the north. Runoff is collected in a road drain that runs northwest along the B3306. This is then directed under the B3306 and emerges into two ditches on the east and west side of the road. The ditch on the west side of the road (Photo 2, Figure 9) is serially culverted under the road to allow water to discharge to the east. It was not possible to see the final discharge from these drains but it is assumed that they flow into Newlyn River.

These drains do not provide a water source to the site.

This system of road drains means that surface runoff from Bosullow Common does not flow over the fields north of Hillvale Farm, which helps surface water management and water quality (personal communication, Mrs Rowe).

Stream 1

Stream 1 rises to the west of the Western Finger at Spring 1. Spring 1 itself could not be accessed. Stream 1 flows southeast in a narrow, moderately sloping valley. The vegetation in the valley bottom is predominantly brambles and scrub, and the channel is not always clearly defined (Photo 3, Figure 9). Over its course, Stream 1 can be seen to gain; this may be due to a second spring along its length. A second spring is marked on the historical maps, but was not seen during the site visit. The water is clear, with a moderate to fast flow. Stream 1 flows into the Newlyn River.

Reviewing the location of Spring 1 with the bedrock geology shows that Spring 1 overlies a geological fault (Figure 8) and suggests this is a groundwater spring fed through the fault.

Stream 2

Stream 2 is fed by six stream tributaries that flow west across the site from the eastern boundary and Boswarva Carn. They meet at a single point before flowing into the Newlyn River. Five of the heads of the six tributaries were visited and all were found to originate from springs/seepages.

- 2A is located in an inaccessible area of molinia and wet woodland. The surrounding area was wet with standing water
- 2B is a seepage in a large area of quaking bog and standing water (Photo 4, Figure 9).
- 2C was inaccessible
- 2D is a seepage within a wet area of molinia and cotton grass
- 2E rises in inaccessible wet woodland. The surrounding area was very boggy with lots of standing water. The vegetation is that of a blanket type bog with sphagnum in hollows and hummocks of cotton grass and heather.
- The seepage source of 2F is indicated on Figure 8 and is approx. 200 m upgradient of where it is marked on the OS map. The approximate elevation of this seepage is 160 mAOD.

The tributary channels generally follow the site topography and are considered to be natural. The channels are generally not well-defined and were seen to weave through dense vegetation often dominated by molinia (Photo 5, Figure 9). Where the channels were visible they have a mineral bottom with clear water and no vegetation.

Stream 2 and the six tributaries are fed by groundwater springs and are the main water source for the wetland communities in the north of the site. The springs rise from the granite aquifer at the edge of the valley Head deposits between the 130 – 150 mAOD contours on the east of the site.

Stream 3

The source of Stream 3 is a spring/seepage. Water flows south in a ditch, is piped under the road and flows south to Ponds 1 & 2. For this reason Stream 3 is not a water source for the wetland communities in the north of the site.

Ponds 1 & 2

Ponds 1 & 2 (Photo 6, Figure 9) are connected by a pipe and fed by Stream 3 which flows into Pond 1 (north). The ponds are not fed from Newlyn River, but there is an overflow from Pond 2 (south) that allows the ponds to overflow and discharge into Newlyn River. The ponds were built for recreation

and no longer hold a significant amount of water following an earthquake around 20 years ago (personal communication, Mrs Rowe, landowner).

There is no surface water outflow from Ponds 1 & 2 into the site and they do not provide a direct water source to the site. Surface water entering the ponds is likely to provide some infiltration into the underlying aquifer and may be an indirect source of water to the site.

Stream 4 and Ditch 1

Stream 4 is not indicated on the current 1:25,000 OS mapping. It was found to flow south in a ditch from an area of woodland in the north of the site (Photo 7, Figure 9) but it was not possible to follow the course of the ditch. Ditch 1 follows an ancient field boundary, there was some standing water but no visible flow. It is likely that there are a number of similar features along old field boundaries throughout the site.

Ponds 3 & 4

Ponds 3 & 4 are marked on historic maps but not on the current OS map. Both ponds were seen during the survey. Pond 3 (Photo 8, Figure 9) is approximately 15 m by 10 m and appears to be relatively shallow (<30cm). The base of the pond was seen to be vegetated beneath the waterline which suggests that the pond is not permanently wet. The ground surrounding the ponds was wet, with vegetation typically associated with wet conditions including Sphagnum mosses. Pond 4 is 10m to the north, slightly larger with similar features and vegetation.

Small ponds

A series of small, shallow manmade ponds have historically been dug around the ancient Settlement marked on the OS map.

Wells

Well 1 was visited and was seen to be covered by a manhole and is assumed to sill be in use. Well 2 in the north of the site is no longer flowing, but historically provided water to the village of Bosullow (personal communication, Mrs Rowe, landowner). It was thought to have dried up following an earthquake 20 years ago.

Boundaries

The boundaries of fields to the north of Boswarva Carn site are traditional Cornish hedges.

Summary

The main findings of the ecohydrological survey are summarised as follows:

- Stream 2 and the six groundwater spring fed tributaries are the main water source for the wetland communities in the north of the site. The springs rise on the east of the site and Boswarva Carn between the 130 – 150 mAOD contours. The springs originate from the granite aquifer at the edge of the valley Head deposits. The tributary channels generally follow the site topography and are considered to be natural.
- Stream 1 is the main water source for the Western Finger and flows southeast through a narrow, moderately sloping valley. The vegetation in the valley bottom is predominantly brambles and scrub. The spring source of Stream 1 was found to be further northwest than indicated on the OS mapping. Spring 1 is a groundwater spring fed by groundwater from an underlying geological fault.
- The Newlyn River is a wide, shallow, fast-flowing stream with clear water, a mineral bottom, that flows along the west boundary of the site. Due to the well contained channel characteristics of the stream, it is considered unlikely that the Newlyn River provides a source of surface water to the site via flooding.
- Ponds 1 & 2 are manmade water features built for recreation which no longer hold a significant amount of water. There is no surface water outflow from Ponds 1 & 2 into the site and they do not provide a direct water source to the site. Surface water entering the ponds is likely to provide some infiltration into the underlying aquifer and may be an indirect source of water to the site.
- Road drains to the north of the site capture surface runoff which is routed into the Newlyn River. These drains do not provide a water source for the site.
- The site includes various historic features including old field ditches, ponds and boundary hedges, which will act to have local perturbations on surface water flows.

3.2 Water Chemistry

Field measurements were made of pH and Electrical Conductivity using handheld meters. The results of the field measurements are shown in Table 1 below, and the locations are shown on Figure 10. Before discussing the results of the field water chemistry, it is important to note that these are a snap-shot of the water chemistry during the field visits and may not be representative of water chemistry through the seasons.

Table 1 Results of the field water chemistry

Survey point	Grid ref Easting, Northing	pH	Electrical Conductivity (µS/cm)
C1 (SP1)	141939, 034127	5.9	141
C2 (SP2)	141919, 034103	6.0	122
C3 (SP3)	142013, 033624	6.3	159
C4 (SP5)	141854, 033369	5.7	164
C5 (SP8)	141913, 034149	5.7	156

C6 (SP10)	141500, 033723	6.2	251
C7 (SP11)	141544, 033647	6.4	240
C8 (SP12)	142848, 032996	6.1	220
C9 (SP13)	142118, 033599	5.6	160
C10 (SP14)	142195, 033638	5.5	178
C11	142264, 033522	5.9	169
C12 (SP17)	142571, 033329	4.6	72
C13 (SP18)	142070, 033538	6.2	188
C14	142011, 033482	6.2	158
C15 (SP20)	141867, 034079	5.7	166
C16	141853, 033908	6.2	211
C17 (SP21)	142015, 033770	4.3	172
C18 (SP24)	142582, 032841	4.8	92
C19	142594, 032871	4.7	90
C20 (SP26)	142059, 033611	Not collected	154
C21 (SP27)	142830, 033028	4.4	112
C22	142926, 033260	4.6	41

Table 1 shows the pH is between 4.3 and 6.4 with a median of 5.7. The conductivity is between 41 and 251 µS/cm which is low and indicates a low mineral content.

The BGS's Baseline Report Series (Smedley and Allen, 2004) states that the Lands End granite has a pH between 4.8 - 6.8 with a median of 5.8. Due to the groundwater circulating at shallow depths, it is soft (due to an absence of carbonate minerals in the granite), acidic, and unmineralised. The pH and conductivity measurements taken on site concur with the literature, implying that the groundwater at Boswarva behaves in the same way.

The highest pH values of greater than 6.0 were found at Stream 1 (C6, C7), Stream 2 (C13, C14), and the Newyln River (C3) and are considered to represent the pH of the underlying granite fed groundwater. With respect to the mire communities found in the north of the site, that are fed by Stream 2, a pH of 6.0 is at the top end of that expected for the M23 community and indicates the fen to be at the high end of a base-poor fen.

Low pH values are found at C21 and C22 on Boswarva Carn and may reflect the short residence time of groundwater due to the steep topography. These lower pH values are within the pH range of 3.5 – 4.5 expected for humid heath (H8).

3.3 Soils and peat

Peat depths were taken along two main transects using a fibreglass rod which was pushed into the ground until the underlying substrate was encountered. The transects were paced and a measurement was taken roughly every 20 m. The results are presented on Figure 11. It was not possible to walk all of the transects identified during the desk study due to accessibility constraints, and so where transects were not possible, the transect lines were roughly followed in the field and GPS points were recorded.

The peat measurements found peat to be between 0.1 – 1.9 m in depth, with the deepest peat being at the lower end of Stream 2. This area of the site was seen to be wet and supporting wetland forming vegetation including Sphagnum mosses and it is considered that the vegetation is still peat forming.

A soil sample was dug out to investigate the underlying substrate. The sample was a dark peaty, humus-rich topsoil overlaying a silty substrate, which at the sample location was ~0.2 m below ground level. The substrate is considered to be the Head deposit and was a buff-coloured silt/clay with course, angular granules and small pebbles.

3.4 Wetland Supply Mechanisms (WETMECs)

The findings of the field survey have been presented above and in this section are discussed to determine the water supply mechanisms (WETMECs). The WETMECs are part of the Wetland Framework (Wheeler *et al*, 2009) which identifies the main wetland habitats that occur in lowland wetlands in England and Wales. It focusses primarily on mires (fens, bogs and swamps) and in particular to the relationships between wetland topography, hydrology, hydrogeology, hydrochemistry and the ecological and biological characteristics of the site.

The site and the catchment are underlain by granite, the upper 30 – 40 m of which is weathered and classified as an aquifer. Across the catchment the aquifer is overlain by weathered granite Head deposits that are in connectivity with the granite aquifer and allow recharge through infiltration of rainfall and surface water. Therefore, over most of the area the aquifer is unconfined.

In the north of the site the BGS mapping shows deeper deposits of Head which are expected to be greater than 2 m deep. These have collected in the lower lying valley in the north of the site and act to locally confine the underlying aquifer. NVC mire communities are found in this area of the site.

Where the aquifer is locally confined the piezometric surface has the potential to rise above ground level.

> ***Piezometric surface:*** *Where an aquifer is confined and there is a high hydraulic head then the groundwater in the confined aquifer is under pressure. The piezometric surface is the level to which groundwater would rise in a borehole penetrating the aquifer.*

The survey found the dominant water source for the mire communities in the north of the site is Stream 2 and the six tributaries (2A – 2F, Figure 8). The tributaries are fed by groundwater springs/seepages emerging from the granite aquifer on the east of the site at the break of slope before the aquifer becomes confined by deeper Head deposits.

This setting is consistent with the WETMEC Group of Seepage Slopes: Outflows of groundwater, typically on slopes, where a high water table is maintained in what is essentially an unfavourable

topographical context (sloping) by high rates of groundwater outflow (they are soligenous systems). At the site, this is consistent with groundwater flow through the weathered Head deposits and the granite aquifer from the higher ground of Boswarva Carn.

Within this group of seepage slopes, WETMEC 10: Permanent Seepage Slopes best describes the water source for the north of the site. These Permanent Seepage Slopes stretch from an upwards limit where the lowest (usually late summer) water table intersects the ground surface, to much lower down the slope to the north where the valley gradient becomes much shallower. WETMEC 11; Intermittent Seepage Slopes extend from the upper limit of WETMEC 10, upwards to where the highest (usually late spring) water table intersects the ground surface. This was observed at tributary 2F (Figure 8) where the groundwater source spring/seepage was seen to emerge from a seepage slope upgradient of where the stream was marked on the OS map.

In the shallow gradient north of the site, conditions become rheo-topogenous (topogenous flow) with water flowing from the periphery towards this lower part of the site. WETMEC 13: Seepage Percolation Basins is descriptive of this water source.

4 Ecohydrological Conceptual Model

The ecohydrological conceptual model for the site is presented on Figure 12 and described as follows:

- The site has an approximate area of 88.7 ha. The dominant landscape feature of the site is Boswarva Carn, a hill in the east of the site which rises to 197 mAOD. A second summit (152 mAOD) is 500 m southwest of Boswarva Carn and a shallow, broad-bottomed valley slopes gently down to the northwest between these two hills at a lower elevation of ~130 mAOD. The Western Finger of the site sits in a narrow valley with a moderate gradient sloping down to the southeast.
- The bedrock geology underlying the site is part of the Land's End Intrusion, of Carboniferous age, and consists of medium- and coarse-grained biotite granite. A series of faults run in a roughly southeasterly direction from the coast to the site, one of which extends beneath the Western Finger.
- Across the catchment, the bedrock is overlain by shallow superficial Head deposits between 0.5 – 2 m thick, consisting of a heterogeneous mixture of local rock in a matrix of fine sand, silt and clay. Greater accumulations of Head deposits are found in valleys and the BGS maps these thicker deposits beneath the north of the site. The Newlyn River is underlain by Alluvium consisting of silt, sand and gravel.
- The granite bedrock is classified by the Environment Agency as a Secondary A aquifer. The aquifer is 30 – 40 m thick as a result of the fracture network which diminishes with depth. Groundwater flow and storage are predominantly within the fracture network. The granite is overlain by up to 2 m of Head deposit which is in connectivity with the granite aquifer and allows recharge. Therefore, over most of the area the aquifer is unconfined.
- Due to the mainly unconfined nature of the aquifer and the connectivity with the superficial deposits it is considered that the groundwater catchment for the site is coincident with the surface water catchment.
- Where thicker deposits of Head occur beneath the north of the site these act locally to confine the aquifer, which offers resistance to upwards flow, and groundwater pressure in the bedrock is likely to be artesian resulting in the piezometric surface being above ground level.
- Recharge into the granite aquifer will occur on the higher ground at Boswarva Carn in the southeast and the second summit to the southwest where the Head is thinner and surface water infiltrates into the aquifer.
- The primary water source for the mire communities in the north of the site are six groundwater spring fed tributaries that flow into Stream 2. The springs rise on the east of the site and Boswarva Carn between the 130 – 150 mAOD contours. The springs originate from the granite aquifer at the edge of the valley Head deposits. The tributary channels generally follow the site topography and are considered to be natural.
- Stream 1 is the main water source for the Western Finger and flows southeast through a narrow, moderately sloping valley. Spring 1 is the source of Stream 1 and is a groundwater spring fed by groundwater from an underlying geological fault.
- Direct rainfall is also a source of water for the wetland habitats within the site.

- The Newlyn River is a wide, shallow, fast-flowing stream with clear water and a mineral bottom, that flows along the west boundary of the site. Due to the well contained channel characteristics of the stream, it is considered unlikely that the Newlyn River provides a source of surface water to the site via flooding.
- The fields around the site are relatively free draining and surface water tends to infiltrate. The primary source of water from these fields is considered to be infiltration of rainfall and surface runoff into the substrate and not direct surface water runoff.
- The recorded pH of circa 6.0 in the north of the site is at the top end of that expected for the M23 community found there, and indicates the fen to be at the high end of a base-poor fen. Low pH values of circa 4.5 are found on Boswarva Carn and are within the pH range of 3.5 – 4.5 expected for the humid heath (H8) found in that area.
- The dominant WETMEC within the site is WETMEC 10: Permanent Seepage Slopes. WETMEC 11; Intermittent Seepage Slopes extend from the upper limit of WETMEC 10, upwards to where the highest (usually late spring) water table intersects the ground surface. In the shallow gradient north of the site, conditions become rheo-topogenous (topogenous flow) with water flowing from the periphery towards this lower part of the site. WETMEC 13: Seepage Percolation Basins is descriptive of this water source.
- The peat depth is between 0.1 – 1.9 m, with the deepest peat being at the lower end of Stream 2. This area of the site was seen to be wet and supporting wetland forming vegetation including Sphagnum mosses and it is considered that the vegetation is still peat forming.

5 Conclusions: Definition of the hydrological unit for Boswarva

A baseline review of the geology and hydrogeology of Boswarva has been completed and the NVC survey (Hewins Ecology, 2014) has also been reviewed. An ecohydrological survey of Boswarva has been undertaken and the results of the above have been used to develop the ecohydrological conceptual model of the site (Figure 12).

The ecohydrological conceptual model has shown that the primary water source for the mire communities in the north of the site are six groundwater spring fed tributaries that flow into Stream 2. In the Western Finger, the primary water source is Spring 1, a groundwater spring fed by groundwater from an underlying geological fault, that flows into Stream 1.

The wetland communities at Boswarva are fed by groundwater seepages/springs emerging from the underlying granite aquifer, which have allowed base-poor soligenous wetlands to become established. Therefore, under the natural England fen and bog SSSI selection guidelines, the groundwater catchment upgradient of the site has been included within the hydrological unit. Due to the hydrogeological characteristics of the site, the groundwater catchment is co-incident with the surface water catchment.

The hydrological unit for Boswarva is shown on Figure 13 and is defined by the groundwater and surface water catchments for Stream 1 and Stream 2 which are the primary site water sources. For clarity, Figure 13 outlines the Stream 1 and Stream 2 catchments. The Stream 1 catchment extends over an approximate area of 74 ha from the higher ground to the northwest and is predominantly farmland. The Stream 2 catchment covers an approximate area of 104 ha to the east of the site where surface water will infiltrate into the granite aquifer. This land is also predominantly farmland.

The ecohydrological survey found no evidence of overland surface runoff onto the site, instead it is considered that the soils are relatively free draining and surface water tends to infiltrate.

The catchment of the Newlyn River has not been included in the hydrological unit because based on the findings of the field survey, surface water flooding from the river onto the site is not a source of water for the site.

Streams and ditches downstream of the areas of wetland habitat have not been included in the hydrological unit; it is considered that management of these watercourses within reasonable bounds will have little influence on the hydrology of the wetland habitats.

It is worth noting that there will almost certainly be small-scale differences between surface runoff and topographic catchments, caused primarily by anthropic influences such as roads and tracks which divert surface runoff into or out of a topographic catchment. Characterisation of these differences would require significant fieldwork time, and it has not been attempted here.

6 Future considerations for Boswens, Boswarva and Bussow

A set of three reports have been prepared which present the results of site ecohydrological investigations, conceptual models and the hydrological units for Boswens, Boswarva and Bussow. Boswens and Boswarva are located within 1 km of each other, around 4.5 km northeast of St Just, and Bussow Moor is 10 km northeast, around 2 km inland from St Ives.

These three sites all contain valley mire habitat and the conceptual models have shown the ecohydrological regimes for the three sites to be similar. The primary water source is groundwater and the dominant WETMEC is Permanent Seepage Slopes (10). For each site the hydrological unit has been defined which includes the groundwater and surface water catchments which are coincident.

Due to the similarity of the ecohydrological regimes at the three sites, potential considerations and issues for the sites are similar and are discussed generically. Where there are site specific considerations, they are listed at the end of the individual reports.

The hydrological units include a significant area of farmland. The hydrology of the farmland is that the ground is relatively free draining and surface water tends to infiltrate into the subsurface and the underlying aquifer. Groundwater flow in the aquifer is generally through fractures and weathering in the upper bedrock and groundwater residence time is relatively short.

It is expected that within the hydrological units there will be a range of different land management practices which could have the potential to pollute the sites though changes to water quality and in particular to increase the risk of nutrient enrichment to groundwater which is the dominant site water source. The inclusion of this farmland within the hydrological units would allow potential risks to groundwater quality to be managed through the SSSI management practices.

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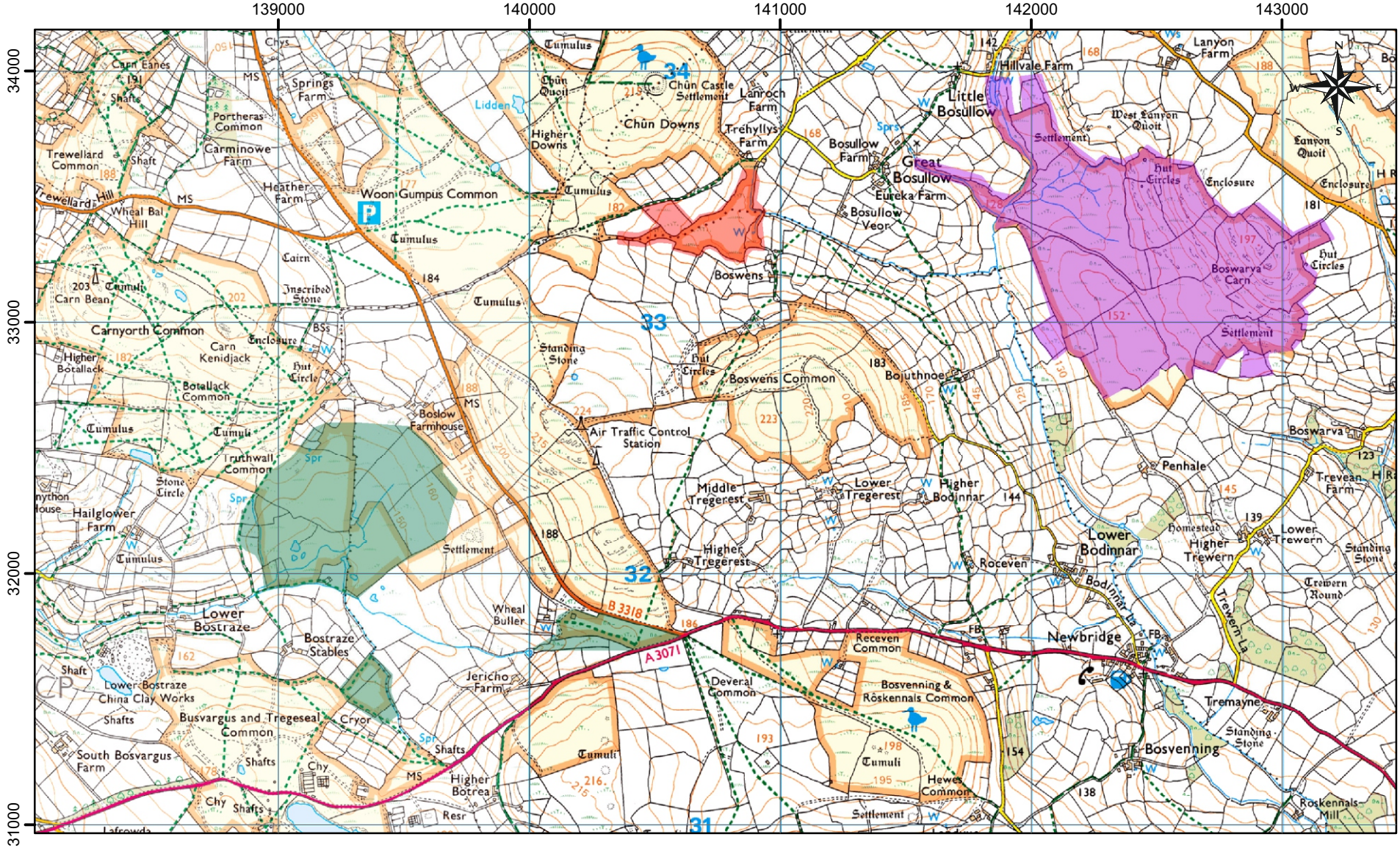
Figures



KEY

Boswens

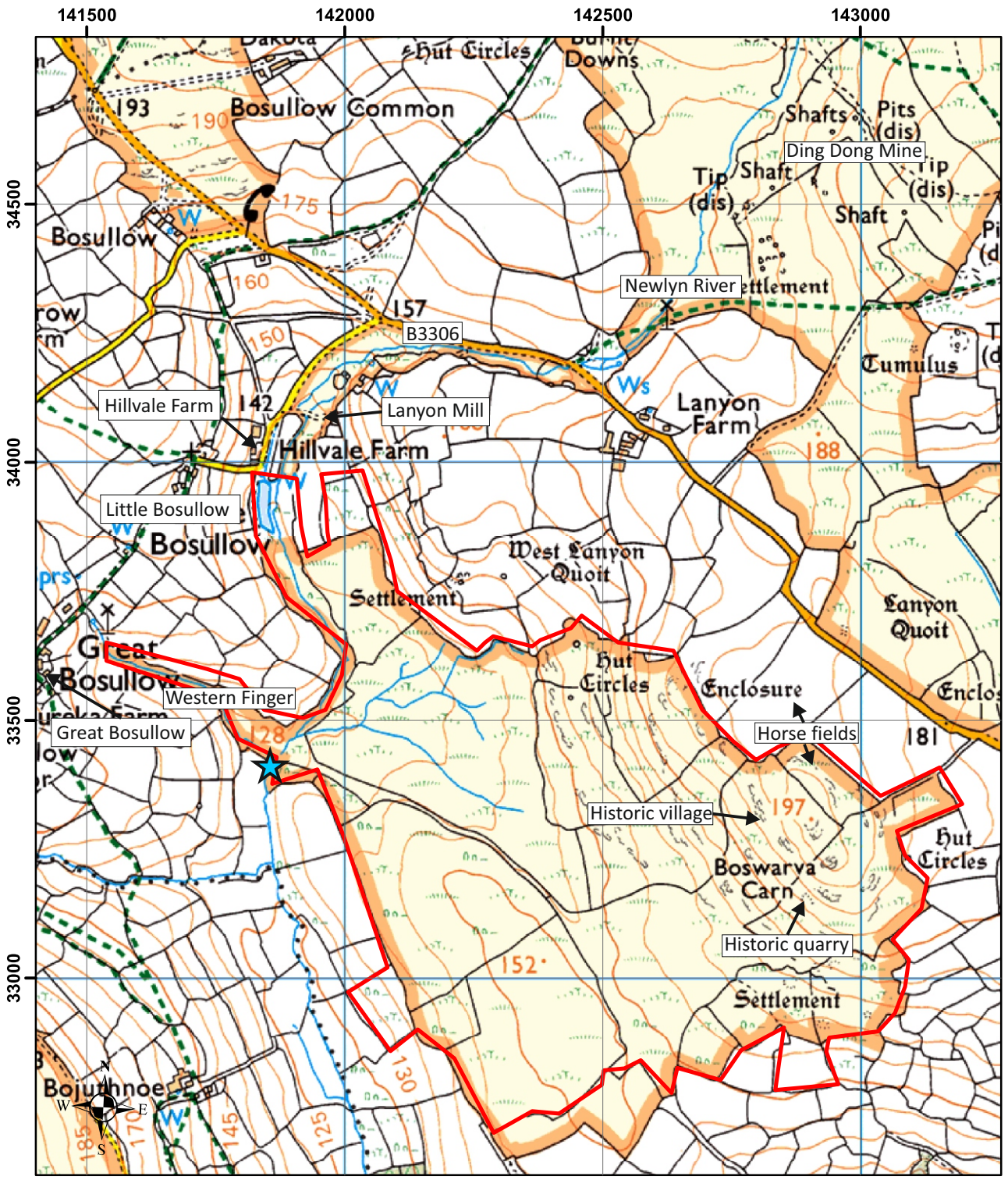
Boswarva

Bostraze

Figure 1 Site location
Boswarva, West Penwith

Date: 22/02/2019
Prepared By: Pendleton Hydro Ltd.

PH



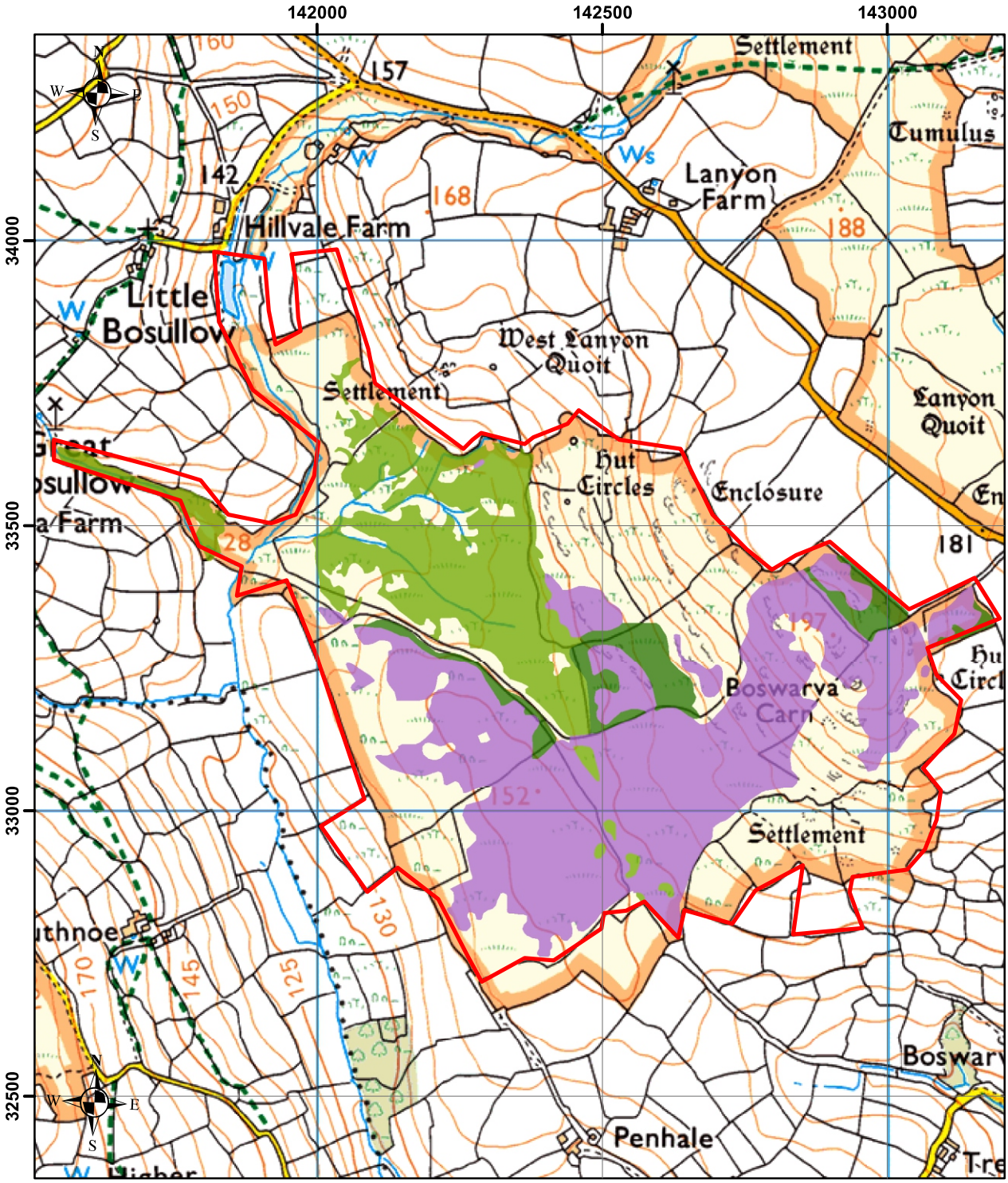
KEY

- Site boundary
- Outflow point
- Watercourse

Figure 2 Site features
Boswarva, West Penwith

Date: 27/02/2019
Prepared By: Pendleton Hydro Ltd.

PH



KEY

- Humid heath communities (H4, H8)
- Mire communities (M23, M25)
- Molinia-Pteridium
- Site boundary

Figure 3 NVC survey summary
Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

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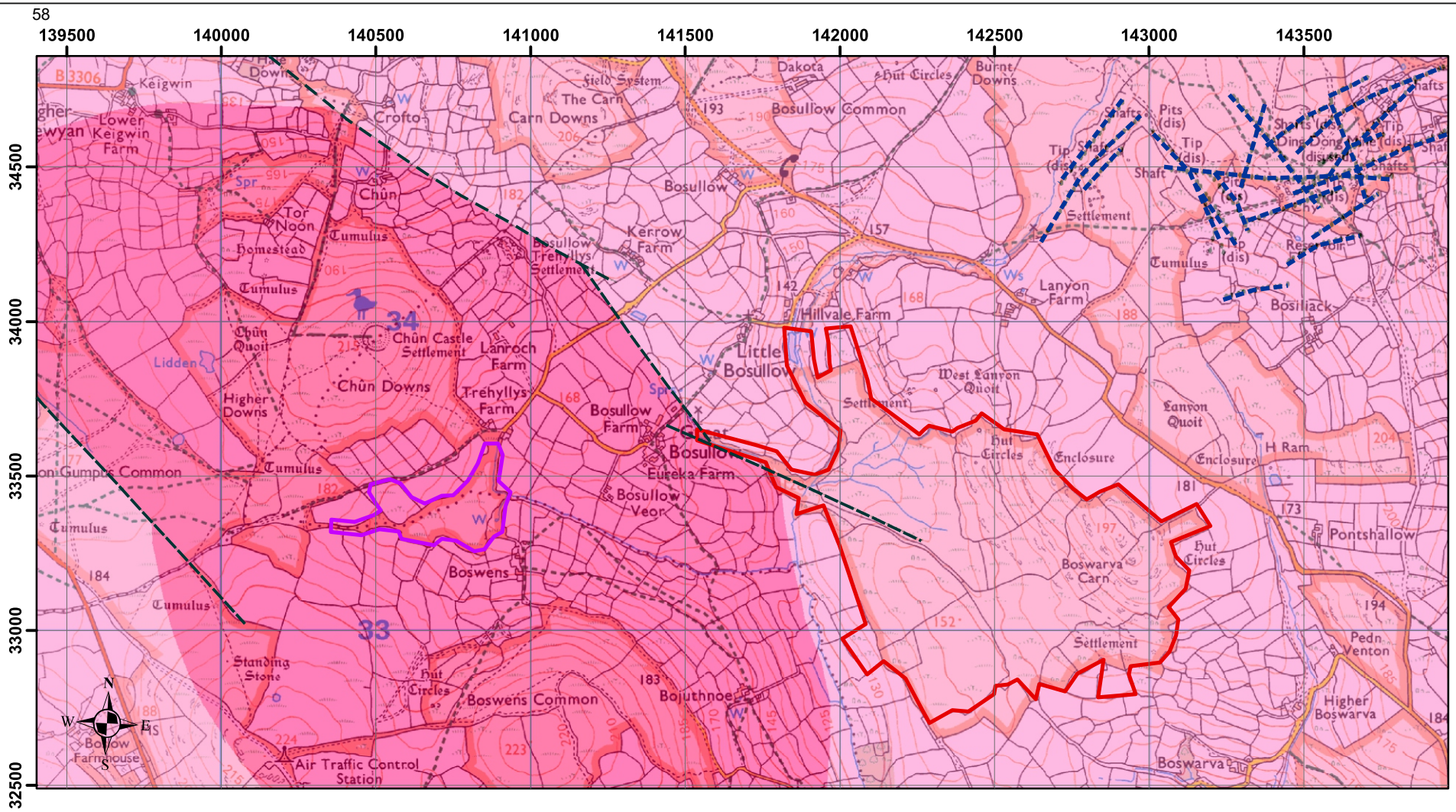

KEY

Boswarva site boundary

Boswens site boundary

Bedrock Geology

Land's End Intrusion - Granite

Land's End Intrusion - Microgranite

Fault

Mineral vein associated with Ding Dong mine

Figure 4 Bedrock geology
Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

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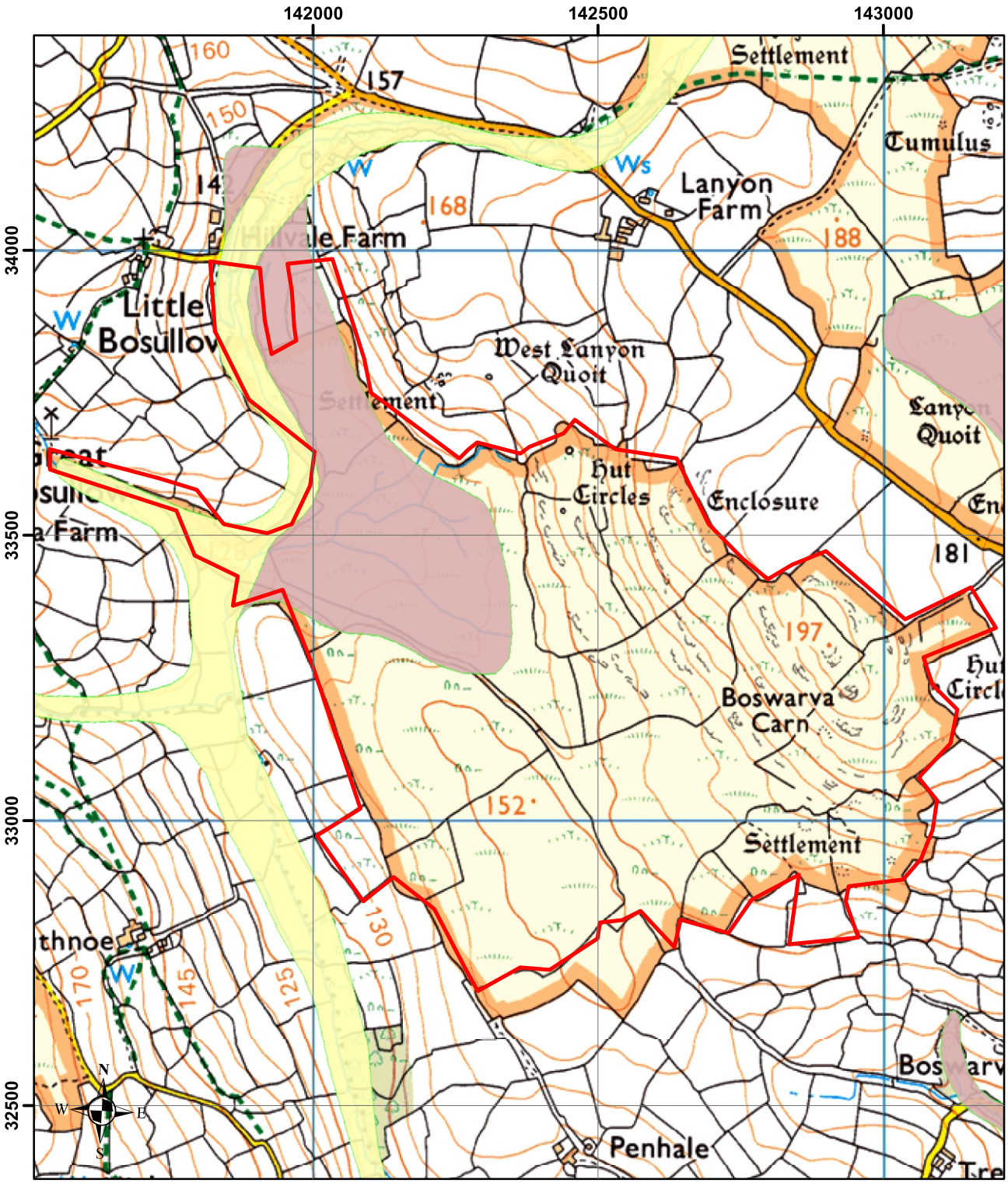

KEY

Site boundary

Superficial Geology

Alluvium - clay, silt, sand and gravel

Head - clay, silt, sand and gravel

Figure 5 Superficial geology
Boswarva, West Penwith

Date: 25/02/2019
Prepared By: Pendleton Hydro Ltd.

PH

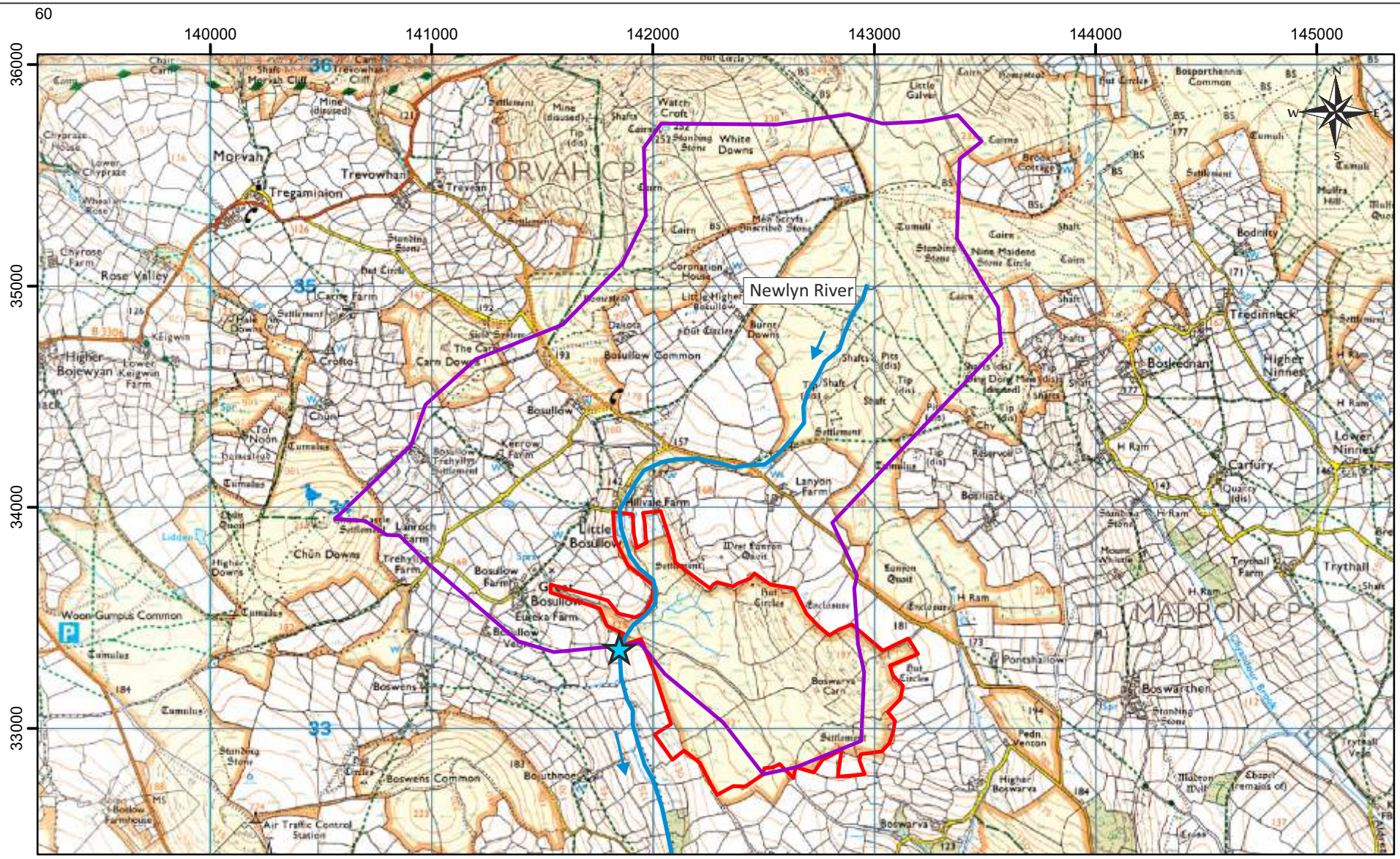

Figure 6 Newlyn River Catchment
Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

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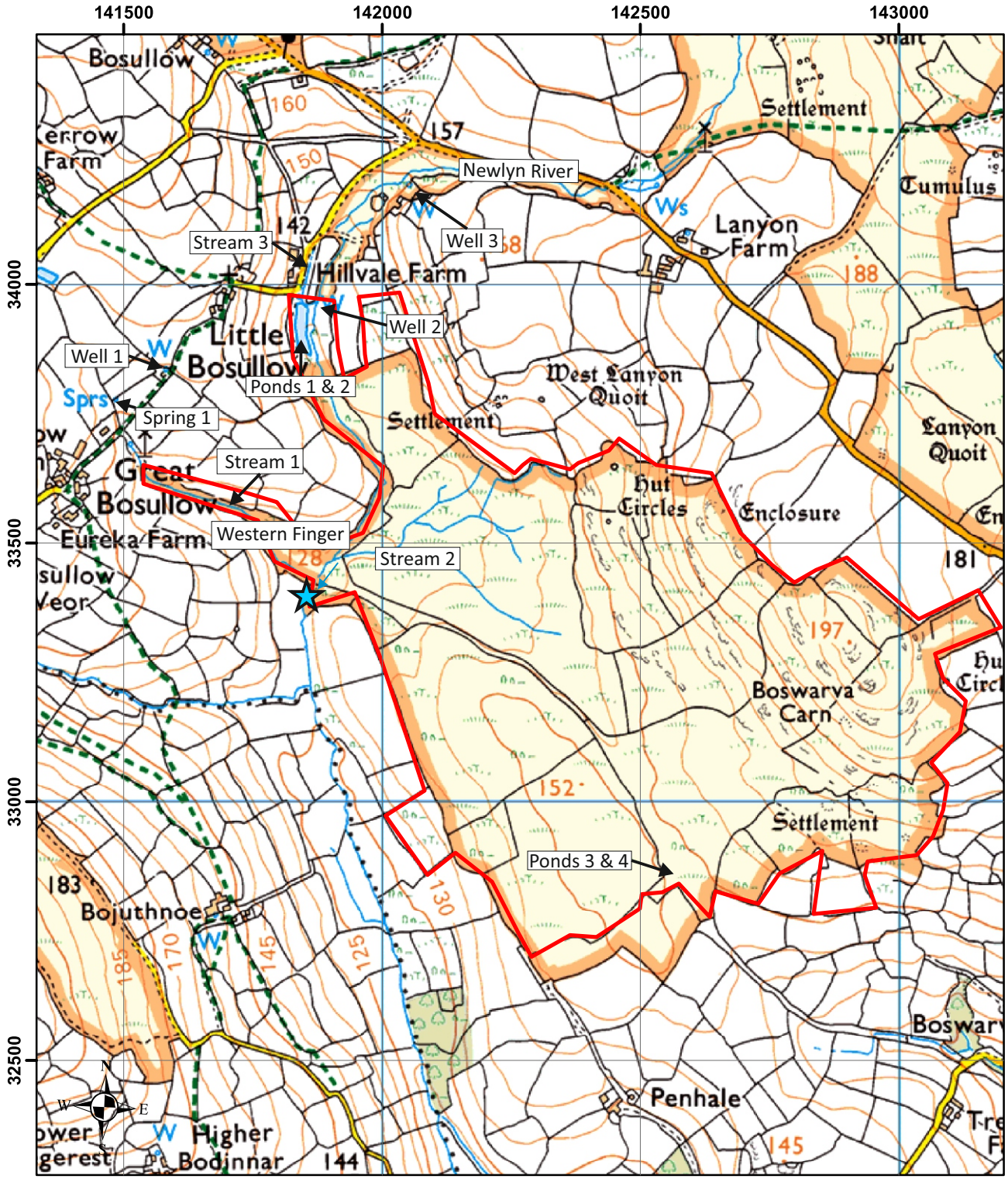

KEY

- Site boundary
- Outflow point
- Watercourse

Figure 7 Site water features indicated on OS mapping Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

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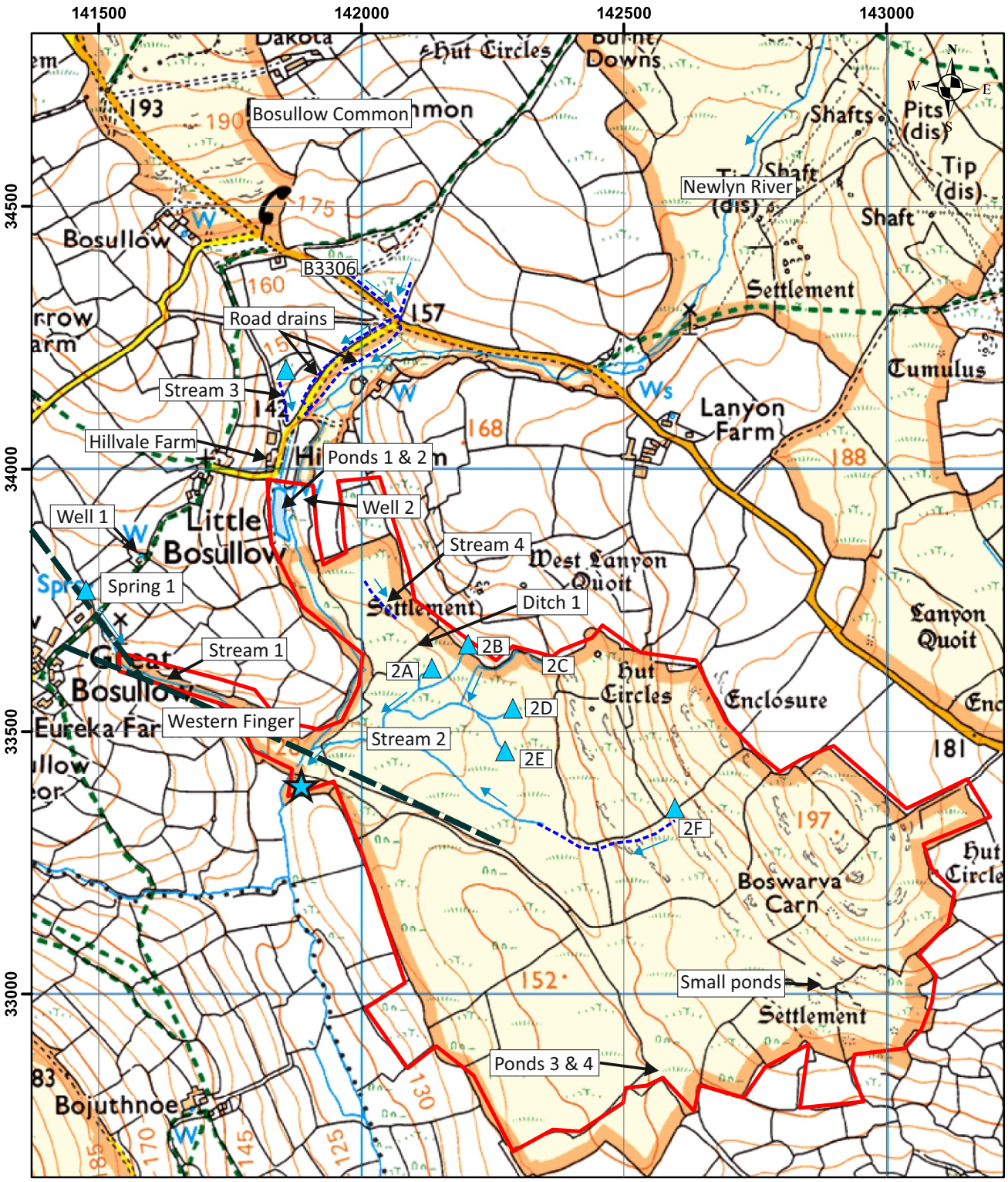

KEY

- Site boundary
- Spring/seepage
- Outflow point
- Watercourse
- Direction of flow
- Unmapped watercourse
- Fault

Figure 8 Surveyed water features
Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

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Photo 1: Newlyn River, fast-flowing with well-vegetated steep banks

Photo 2: Road ditch, looking northeast away from Hillvale Farm

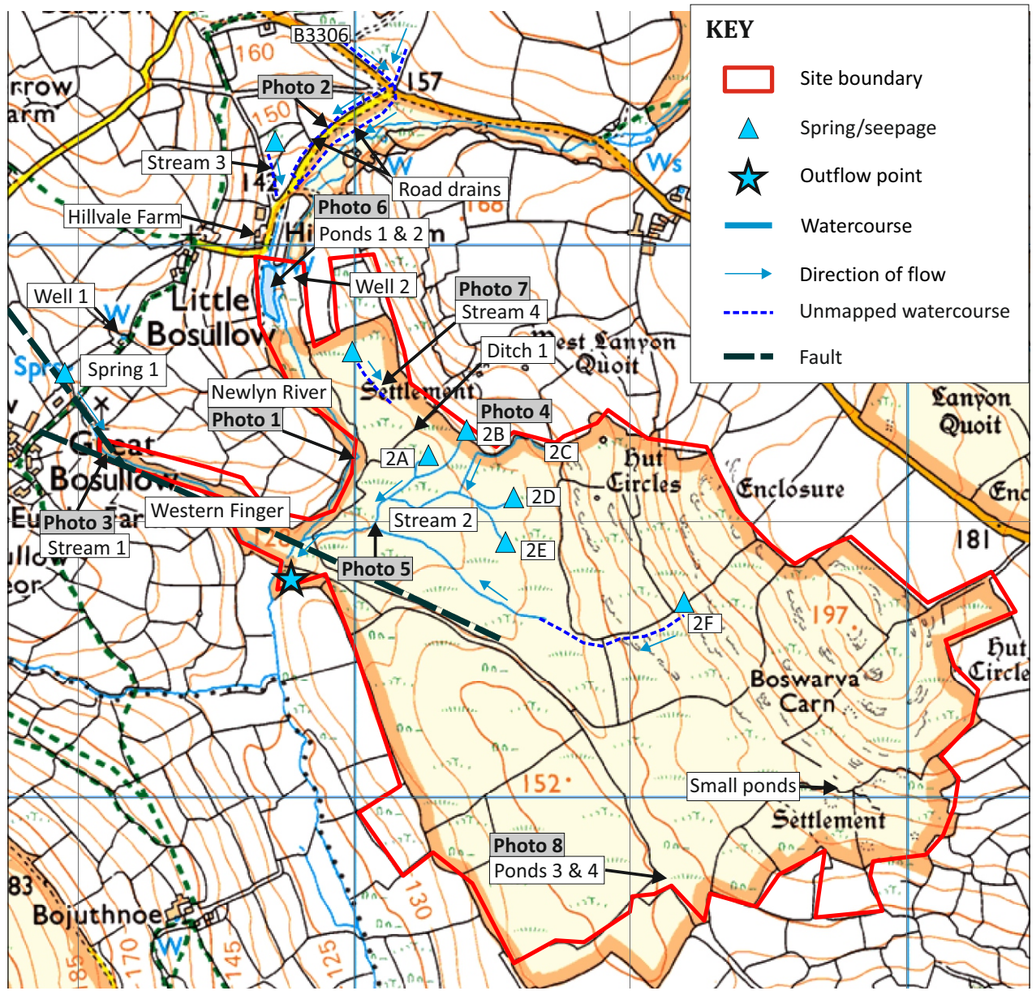


Photo 8: Pond 3, marked on historical maps

Photo 7: Stream 4, flows south from wet woodland along a ditch

Photo 3: Stream 1, flows southeast into wet woodland

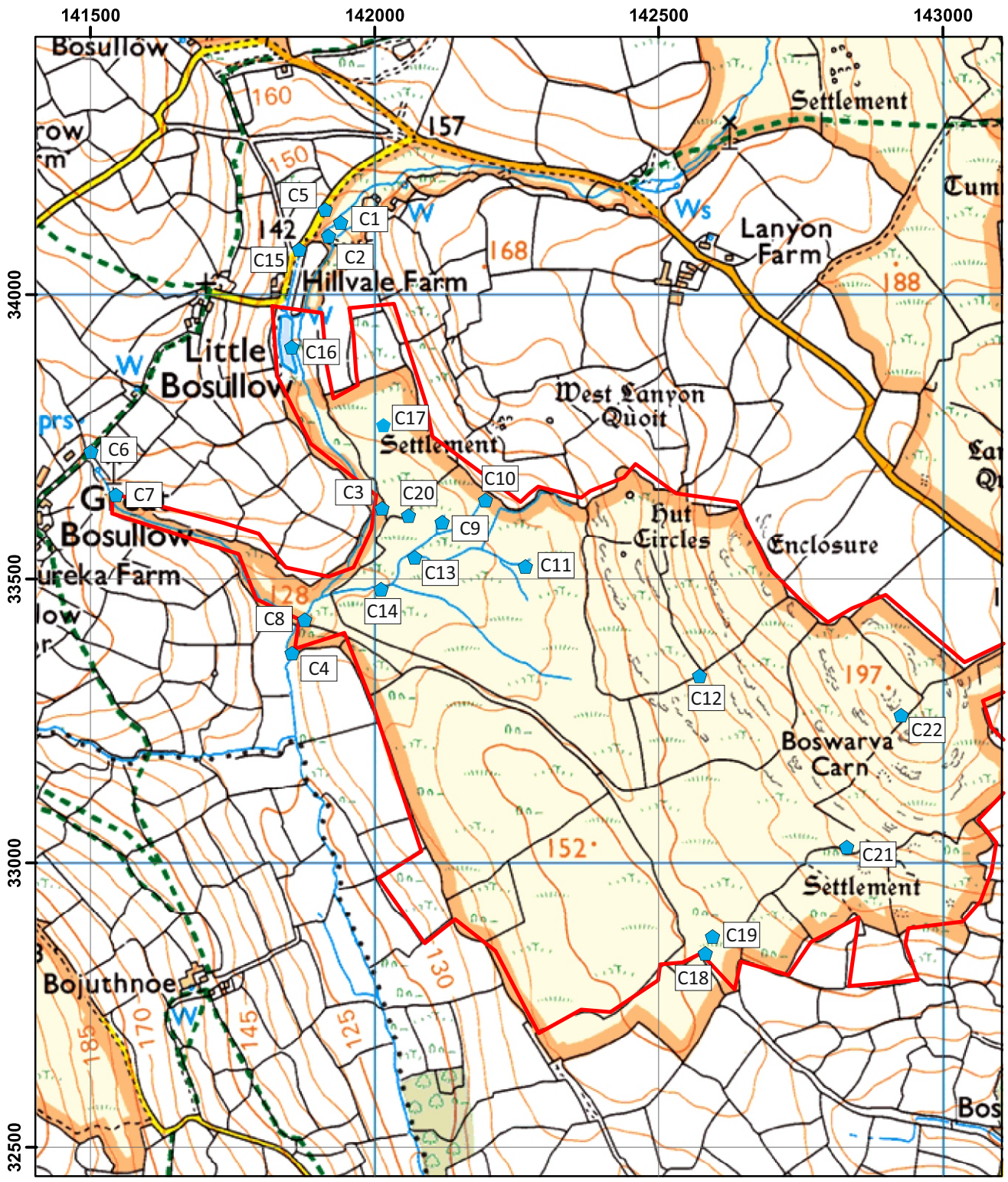
Photo 4: Stream 2 (2B) seepage forming the stream head

Photo 5: Stream 2, channel can be hard to define

Photo 6: Ponds 1 & 2, not holding water

Figure 9 Survey photos
Boswarva, West Penwith

Date: 24/02/2019
Prepared By: Pendleton Hydro Ltd.



KEY

Chemistry

Site boundary

Sample points

Figure 10 Map of water chemistry measurements
Boswarva, West Penwith

Date: 25/02/2019
Prepared By: Pendleton Hydro Ltd.

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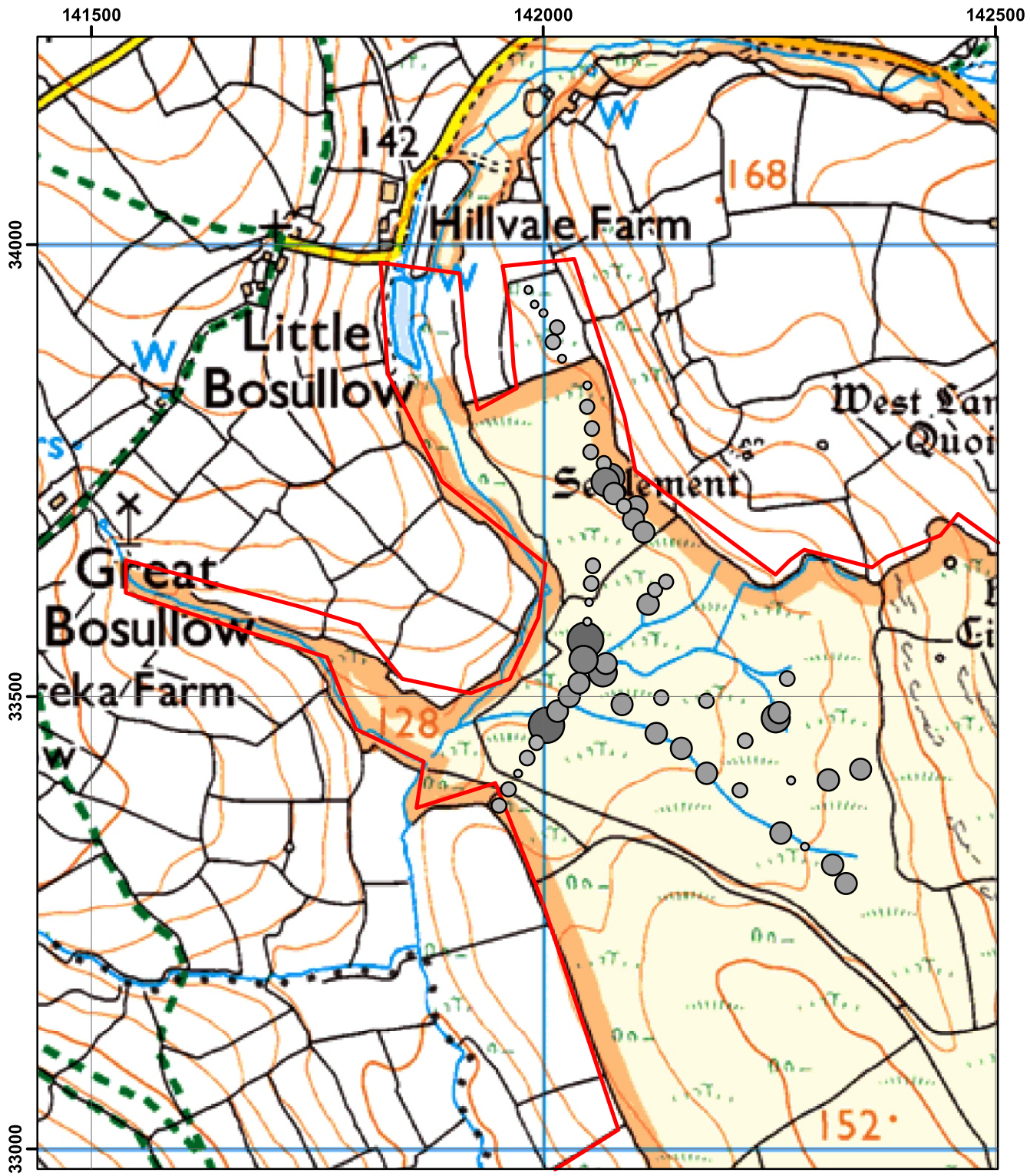

KEY

Site boundary

Peat Depth (cm)

- 0-25
- 25-50
- 50-100
- 100-150
- 150-200

Figure 11 Peat depth
Boswarva, West Penwith

Date: 25/02/2019
Prepared By: Pendleton Hydro Ltd.

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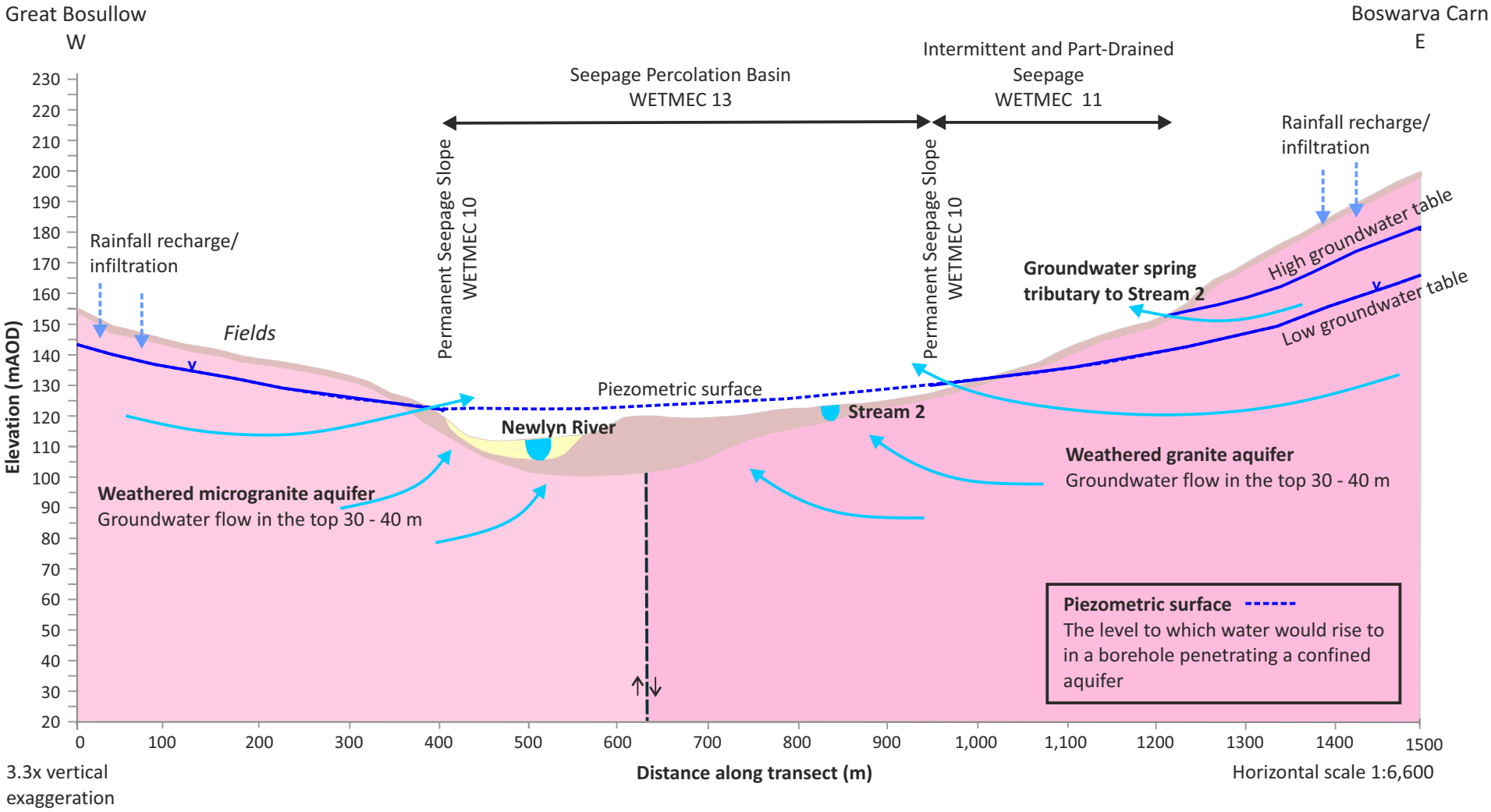
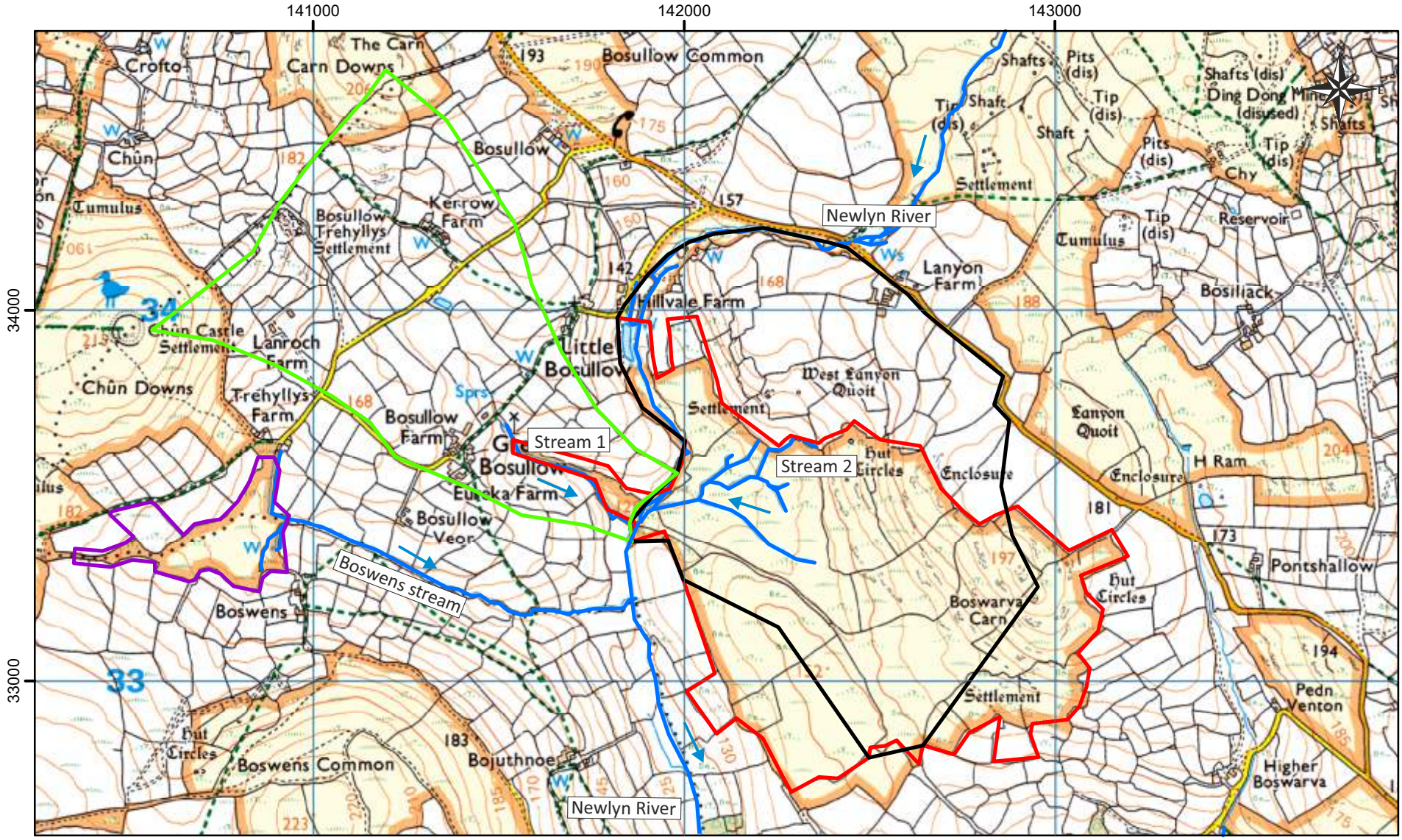


Figure 12 Ecohydrological conceptual model
Boswarva, West Penwith

Date: 09/03/2019
Prepared By: Pendleton Hydro Ltd.

PH



KEY

Site boundary | Boswens site | Steam 1 catchment | Stream 2 catchment | Watercourse | Watercourse flow direction

Figure 13 Definition of the hydrological unit for Boswarva
Boswarva, West Penwith

Date: 08/03/2019
Prepared By: Pendleton Hydro Ltd.

PH

Appendices

Appendix A

Ecohydrological survey field notes

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
Newlyn River			Yes	Yes – but limited
SP 1	141939, 034127	SP1 is located 170 m before the Newlyn River enters the site. Water is clear, channel is partially vegetated. Width of channel: 130 cm, Depth of channel: 50 cm, Depth of water: 20 cm Vigorous flow		
SP2	141919, 034103	SP2 is located on an earth bridge leading to the ruins of Lanyon Mill, 140 m before the Newlyn River enters the site. After the bridge, the river flows east for 25 m, then south, bypassing Ponds 1&2. At SP2, the Newlyn River is known to flood after prolonged periods of rain, but soon dissipates (personal communication, Mrs Rowe). Apart from this instance of localised flooding, Mrs Rowe had never witnessed the river flood onto the site. Width of channel: 280 cm, Depth of channel: 40 cm, Height of water: 20 cm Fast flow		
SP3	142013, 033624	SP3 is representative of the majority of the Newlyn River's channel through the site. The water is clear and relatively fast-flowing in a narrow channel with a mineral bottom and highly vegetated banks of bracken and brambles. No floodplain is present. Width of channel: 200 cm, Depth of water: 50 cm Fast flow		
SP4	141905, 033459	At SP4 the water is clear and the channel is partially vegetated. Width of channel: 175 cm, Depth of water: 65 cm Fast flow		
SP5	141854, 033369	SP5 is where the Newlyn River exits the site. The channel has widened and is shallower, but still has relatively high banks which would prevent flooding. The water is clear and fast-flowing. There is a potential floodplain on fields to the west of river. Width of channel: 250 cm, Depth of water: 25 cm Fast flow		

Road Drains			No	Limited – the drains flow into the Newlyn River
SP6	142053, 034279	At SP6, road drains running along the B3306 collect surface water running off of the hills to the north of the site. The drains were built to stop water running over fields (personal communication, Mrs Rowe). At the junction of the road leading to Hillvale Farm, the water flows south under the road and emerges to both the east and west of the raod leading to Hillvale Farm. The eastern ditch runs south, and it is presumed it either joins the Newlyn River or flows into Ponds 1 and 2. The western ditch runs along the road and continues to collect water from fields to the west before flowing under the road at SP7 and SP8 (below), where it is presumed water in the ditches then either flows into the Newlyn River or Ponds 1 and 2.		
SP8	141913, 034149	At SP8 the road drain ends and runs under the road and into dense scrub. Width of channel: 55 cm, Depth of channel: 40 cm, Height of water: 10 cm Medium flow		
SP9	141922, 034134	At SP9, water from SP8 is seen to flow into a stream. The stream is punctuated by pools of water and has a very low flow. The channel does not have any clearly defined banks and is surrounded by scrub. The area would be likely to flood in times of high rainfall. The main channel of the Newlyn River is 15 m to the southeast. Width of channel: 15 m, Height of channel: negligible, Height of water: 15 cm		
Stream 1				
SP10	141500, 033723	At SP10 a stream crosses the road and flows into the site. The stream is considered to originate from Spring 1. Width of channel: 100 cm, Depth of water: 35 cm Moderate flow	Yes	Yes – but limited to the western 'finger' of the site
SP11	141544, 033647	Stream 1 flows southeast into the site with a moderate flow. It is surrounded by grass and brambles. Width of channel: 70cm, Depth of water: 15cm Moderate flow		
SP12	141871, 033416	Stream 1 joins the River Newlyn at SP12. The water is clear and the channel is partially vegetated. Flow has increased. The channel is surrounded by grass, bracken and brambles.		

		Width of channel: 150 cm, Depth of water: 40 cm Moderate-fast flow		
Stream 2		Stream 2 is fed by a six small spring-fed tributaries. All the streams meet at a single point before flowing into the Newlyn River. Five of the heads of the Stream 2 were visited when on site (SP13 – 17). They are described below.	Yes	Yes
SP13	142118, 033599	SP13 is located in an inaccessible area of molinia and wet woodland. The surrounding area was wet with standing water.		
SP14	142195, 033638	SP14 is a large area of quaking bog and standing water. Two channels drained the area – one that follows the mapped watercourse, and a second, smaller channel that ran towards SP13. Channel c.10m southwest of stream head: Width of channel: 200 cm, Depth of channel: 50 cm, Depth of water: 10 cm Low-medium flow		
SP15	142281, 033531	SP15 is in an area of molinia and cotton grass. The precise location of the stream head could not be identified due to dense vegetation, but the area was very wet with water trickling through the vegetation. Approximately 15 m southwest of SP15 a number of additional flows of water join the stream. The channel is not clearly defined, with no banks.		
SP16	142283, 033456	The ground at SP16 was wet with standing water. Blanket bog vegetation is found in the area with sphagnum in hollows and hummocks of cotton grass and heather. The stream rises in an area of wet woodland that cannot be accessed.		
SP17	142571, 033329	SP17 marks the beginning of the southern-most tributary of Stream 2. After locating the head of the stream as marked on the OS map, the flow of water was followed up-slope until it stopped. At SP17, the water was seeping from the ground. The seepage part of a large area of wet ground.		
SP18	142070, 033538	At SP18, Stream 2 has a mineral bottom, with no vegetation in the channel. Width of channel: 95 cm, Depth of channel: 90 cm, Depth of water: 5 cm Medium flow		

SP19	142011, 033482	At SP19 the channel is hard to define as it is surrounded by molinia and brambles and the water is weaving through the vegetation. The channel was often undefined upstream of SP19 towards SP17. With of channel: 110 cm, Depth of water: 55 cm Slow to medium flow		
Stream 3 SP20	141867, 034079	At SP20 water from an unmapped stream flows under the road. The source of the stream is a spring 25 m to the north-west (personal communication, Mrs Rowe). Stream 3 was not followed, but it is considered that it then follows the watercourse marked on the OS map and into Ponds 1 &2. Run-off from the road is also captured at SP20.	Partially	No
Stream 4 SP21	142015, 033770	At SP21 an unmapped stream is flowing out of wet woodland. It is then channelled along a ditch that appears to be man-made. The ditch is filled with rush and brambles and runs in roughly a southerly direction.	No	Yes
Well 2 SP22	141849, 033972	The spring feeding Well 2 used to be prolific, and at one time is thought to have provided water to all of Bosullow (personal communication, Mrs Rowe). The pumping house (no longer in use) is 12m to the west. Following an earthquake c. 20 years ago, Well 2 is thought to have dried up (personal communication, Mrs Rowe).	Yes	No
Ponds 1 and 2 SP23	141829, 033908	SP23 is located between Ponds 1&2. The ponds are connected and fed by water from Stream 3 and surface run off. The ponds are not fed by the Newlyn River, but overflow from the southern pond (Pond 2) does discharge into the Newlyn River. The ponds were built for recreation but no longer hold a significant amount of water following an earthquake around 20 years ago (personal communication, Mrs Rowe).	Yes	Yes – but only during times of flood
Ponds 3 and 4		Ponds marked on historic maps but not on the current OS map.	No	Yes

SP24	142582, 032841	Pond 3 at SP24 is approximately 15 m by 10 m but appears relatively shallow (<30cm) with a completely vegetated bottom. It is unlikely to be a permanent feature. The surrounding vegetation is typically associated with wet conditions, with rushes and Sphagnum mosses. Pond 4 is 10m to the north of Pond 3 and is slightly larger with similar features and vegetation. A small scrape is found 60m east of Pond 3. These three water features are likely to provide water to ponies/horses on site (significant amounts of horse dung surround the area). The scrape is deeper than the two ponds and it is possible it continues to provide water during drier periods.		
Ditch 1 SP25	142117, 033675	At SP25 a ditch can be seen along an ancient field boundary. There is some standing water but no visible flow. It is possible that during periods of wet weather, there would be periodic flow along the ditch into some small ponds found 85 m southwest. It is likely that there are a number of similar features along old field boundaries throughout the site. These will act to locally channel flow.	No	Yes
Small ponds SP26	142830, 033028	At SP26 there are a series of ponds, in an area about 50 m^2. The ponds are shallow, and occupy hollows with no inflow of water. They appear to correlate with an ancient Settlement marked on the OS map.	No	Yes
Boundaries SP27	142727, 033489	The land outside the boundary of the site at SP27 is semi-improved grassland. Traditional Cornish hedges border the fields which would significantly reduce any overland flow from the fields into the site.	Yes	Yes

Ecohydrological Investigation and Characterisation of three proposed SSSI Units – Report 3 of 3: Bussow Moor, West Penwith, Cornwall

Report:

West Penwith - Bussow Moor - Report 3 of 3 Final.docx
March 2019

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1 Introduction

1.1 Background

Penwith Downs Moors and Heaths in west Cornwall has been submitted for possible SSSI designation. Natural England has gathered much supporting evidence for the proposed designation, and as part of this 55 sites have been surveyed. One of the key features is valley mires and further hydrological information is required for three of the survey sites that contain valley mire habitat: Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54). In addition to these three proposed valley mire units a further survey site named Bostraze Bog was hydrologically surveyed by Rigare Ltd (2018).

The results of the ecohydrological investigations are presented as a set of three reports, the third being this one for Bussow Moor (the 'site'). The location of Bussow Moor (Report 3 of 3) is on Figure 1. It is 2 km inland from St Ives and 10 km northeast of Boswens (Report 1 of 3) and Boswarva (Report 2 of 3).

In order to progress with the designation of the valley mire SSSI units Natural England require further investigation and assessment of the ecohydrology. The existing Natural England fen and bog SSSI selection guidelines advise that sufficient land should be included within the SSSI boundary to protect the interest feature and its hydrology. The guidance for determining boundaries for valley mire features states:

> *Wetlands in basins and valley bottoms can be supplied with water from various sources including surface run-off from within the catchment, groundwater seepage and direct rainfall. The site boundary of these wetlands should encompass the following:*
>
> - *all influencing slopes;*
> - *all springs, flushes and seepages that supply the wetland;*
> - *all ditches, channels and peripheral drains that influence site hydrology;*
> - *depending on the ecohydrology of the site and landscape setting, it may be necessary to include whole fields above the slope as well in order to protect the wetland feature from nutrient-enriched run-off and sub-surface flow e.g. through sandy soils;*
> - *the outflow stream for some distance to prevent lowering of the stream bed which would lower the water level in the wetland.*

The area including all of the above features can be considered as that in which land use, management and activities can influence hydrological supporting conditions for interest features within the proposed SSSI.

1.2 Scope of work

Natural England requested an ecohydrological survey and suitably tailored hydrological and hydrogeological surveys of the surface water and groundwater catchments for Boswens North (survey site 24), Boswarva Carn to Great Bosullow (survey site 28), and Bussow Moor (survey site 54).

The objectives of the ecohydrological survey are as follows:

- Identify, describe, and map all site water features including streams, ditches, seepages, flushes. Flow rates in watercourses will be estimated.

- Identify, describe, and map off-site water features identified during the desk study phase, as land access allows. Flow rates in watercourses will be estimated.
- Visual assessment of hydrological pathways, including modified pathways such as field drains based on the findings of the desk study and information provided by Natural England.
- Take field measurements of pH and Electrical Conductivity.

The findings from the ecohydrological field survey and a desk study will be used to develop a conceptual model for the site. The conceptual model will provide a visual representation of the ecohydrological functioning of the site and will include:

- the hydrological processes (WETMECS, Wheeler *et al*, 2009) that provide the necessary supporting conditions for the wetland vegetation
- the principal water sources and characterising the hydrological regime of the site, including surface and groundwater flow directions
- characterising the water chemistry of the site based on the pH and Electrical Conductivity measurements.

The conceptual model, in conjunction with existing vegetation data and information derived from the ecohydrological survey will be used to define the ecohydrological boundary of each of the three proposed SSSI units.

The ecohydrological survey of Bussow Moor was undertaken on 14 December 2018, and 6 – 7 February 2019.

1.3 Data sources

The following data sources were used in the investigation:

- Ordnance Survey mapping
- Historic mapping available online
- Aerial photography provided by Natural England
- Online soil type data available at the LandIS Soilscapes website, developed by Cranfield University
- British Geological Survey mapping and geological data
- NVC survey of the site (Hewins Ecology, 2013)

2 Site Setting

2.1 Location

The site has an approximate area of 21.5 ha and is located on the Land's End Peninsula, Cornwall, at grid reference SW 50155 38807 (approximate site centre). It is 2 km southwest of St Ives and 2 km south of the coast (Figure 1).

2.2 Site description and topography

The site is oriented north-south in a shallow valley bottom that slopes gently down from 135 m AOD in the south to 125 mAOD in the north. The site is bordered on the west and south by hills. To the west, Rosewall Hill dominates the landscape, rising steeply to 227 mAOD from the valley floor. From Rosewall Hill a ridge extends to the south. To the southeast, the land gently rises before steepening to Trink Hill (212 mAOD).

Immediately to the east of the site there is a second shallow second valley trending northwest – southeast. This second valley has a very shallow gradient sloping down to the southeast. The village of Halsetown sits on the southwest slope of this shallow valley.

The main site features are shown in Figure 2.

2.3 Land use

The site is located in a semi-rural area and there are a number of farms and small holdings that manage the surrounding land. The closest of these are dwellings at Bussow Farm and Higher Bussow Farm, as shown on Figure 2. Small fields are found on the valley sides surrounding the site which appear to be predominantly used to graze cattle/horses/ponies. Apple trees are also being grown to the southeast of the site.

On the site itself, the open areas of the valley are grazed by horses/ponies and there was evidence that the southern woodland is being managed for game birds.

Bussow Reservoir is immediately to the north of the site, and is owned by South West Water and managed as a coarse fishery by the South West Lakes Trust. The reservoir is no longer operated as a supply reservoir but may still be used for water in extreme circumstances.

Disused mine shafts are marked on the OS map to the east of the site at Rosewall Hill and to the south of Higher Bussow Farm as shown on Figure 2.

2.4 Hydrology

The site lies within the catchment of the Stennack River which flows north and then east before being culverted and flowing into the sea at St Ives. Figure 3 shows the Stennack River catchment which contributes to the outflow point from the site.

The OS 1:25,000 mapping shows the following water features on, and in close vicinity to the site. These are shown on Figure 3:

- The Stennack River flows north through the site.

- A series of ditches rise on the land to the south of the site (D2, D4, D5, D6, D7), flow north through the site and into the Stennack River. Ditch D8 rises in the southern woodland and flows northwest into the Stennack River.
- Ditches D9 and D10 are two straight parallel watercourses approximately 750 m long which flow northwest towards Bussow reservoir. Ditches D9 and D10 have a sub-catchment which contributes to the larger Stennack River catchment and is shown on Figure 3.
- Bussow Reservoir is immediately north of the site. The OS mapping shows an outflow from the reservoir into Stennack River from the north side of the reservoir.

The 1:10,000 mapping also shows the following:

- Ponds 1 and 2 are located in the northern woodland.
- Pond 3 is not mapped but was found during the survey and is discussed in Section 3.1.5.
- Ponds 4 and 5 are located in the southern woodland and surrounding fields.
- Streams 1 and 2 flow west through the central belt into the Stennack River.
- A Sink which is mapped at the northwest end of Ditches D9 and D10.

A review of historic maps of the site has been undertaken using maps available at www.old-maps.co.uk (accessed 26/02/2019). The earliest map is the 1887 OS County series for Cornwall and Isle of Scilly.

- Ditches D2, D4, D5, D6, D7 and D8 in the southern woodland are mapped on the 1887 version of the map
- Ditches D9 and D10, the Sink, and Bussow Reservoir are not mapped until 1963.

The annual average rainfall for the region is around 1000 mm/yr based on the Met Office annual average data from the Camborne and Culdrose weather stations, around 15 km east and 22 km southeast of the site respectively.

2.5 Ecology

An NVC survey of the site was carried out by Hewins Ecology in September 2013 and the results are summarised on Figure 4. The survey found the main wetland community of interest is mire and there are two bands of mire mapped on either side of Stennack River.

The NVC survey also mapped two areas of Salix woodland, which is non-NVC, but can form a wet woodland. The survey carried out by Hewins Ecology noted that wet woodland field layer species were scarce and that from what could be seen, the community was not a true wet woodland community. The areas of Salix woodland are indicated as the northern and southern woodlands on Figure 4.

The following mire summary description is taken from the NVC field guides (JNCC, 2001 and JNCC, 2004):

Mire (M23, M25): M25 is *Molinia caerulea – Potentilla erecta* mire and is found on moist, but well-aerated, acid to neutral peats and peaty mineral soils in the wet and cool western lowlands of Britain. It occurs over gently-sloping ground, marking out seepage zones and flushed margins of sluggish streams, water-tracks and topogenous mires, but also extends onto the fringes of

ombrogenous mires. Soil and drainage conditions of this community have similarities to those of M23.

M23 is *Juncus effusus/acutiflorus – Galium palustre* rush-pasture. It occurs over a variety of moist, moderately acid to neutral (pH 4 – 6), peaty and mineral soils in the cool and rainy lowlands of western Britain. It is found on gently-sloping ground, often around the margins of soligenous flushes, as a zone around topogenous mires and wet heaths, and especially widespread in wet, comparatively semi-natural pasture.

The mire communities occur on wet acid soils and can be found in a range of locations including topogenous mires and soligenous flushes. We can therefore conclude that these communities are water dependent, but are they ground water dependent?

The UKTAG[1] guidance on the identification and risk assessment of groundwater dependent terrestrial ecosystems (GWDTE), (2004), provides a groundwater dependency score for the mire and woodland NVC communities as follows:

- M23 and M25. Low groundwater dependency (score = 3). This means that sites including these habitats should only be included in risk assessments under the GWDTE test of the Water Framework Directive if they are found to be coincident with a groundwater body with high surface interaction.

2.6 Soils

The soil type has been taken from the *LandIS Soilscapes* website, developed by Cranfield University. The soil type underlying the site and the surrounding surface water catchment is classified as: “Freely draining acid loamy soils over rock”. Smedley and Allen (2004) describe the soils in the region as thin, well-drained and representative of the bedrock of the local geology.

2.7 Geology

The regional geology of the site has been taken from the British Geological Survey (BGS) 1:50,000 scale sheet Penzance (351 & 358) and associated memoirs. The bedrock and superficial geology are presented in Figures 5 and 6. The following review is taken from the BGS (Sheet 351, Penzance), BGS (1989), Smedley and Allen (2004) and Jones *et al* (2000).

2.7.1 Bedrock and structural geology

The site and its surface water catchment is underlain by a medium- and coarse-grained biotite granite bedrock, which is part of the Land’s End granite pluton, a body of magma that intruded into the area about 280 million years ago and slowly cooled. The Land’s End granite is an offshoot from the Cornubian batholith, which is a much larger mass of cooled magma.

A geological fault runs south-south-east from the coast to cut through the north east corner of the site. The fault continues through the shallow valley to the east of the site as shown on Figure 5.

[1] The UK Technical Advisory Group on the Water Framework Directive

A series of mineral veins are mapped near Higher Bussow Farm. The veins are between 175 m and 500 m long and run in a northeast – southwest direction. The veins are likely to have been either explored or mined as there are three shafts marked on the 1:25,000 OS map in the same area.

One mineral vein is mapped on the southeast slopes of Rosewall Hill. This vein corresponds to tip, quarry and shafts (all disused) marked on the OS 1:25,000 mapping.

2.7.2 Superficial geology

Across the site, the granite bedrock is overlain by Alluvium that was deposited in the Quaternary. The Alluvium consist of silty, clayey deposits with lenses of sand, peat and gravel, that underly the valley of the Stennack River and tributary watercourses.

For reasons of clarity, the BGS mapping does not show any superficial deposits surrounding the site. However, it is noted that superficial Head deposits are expected to cover much of the Land's End Peninsula at a thickness of between 0.5 – 2 m. These superficial Head deposits, described as a heterogeneous mixture of local rock in a matrix of fine sand, silt and clay, are likely to be found on the hills surrounding the site.

2.8 Hydrogeology

The granite underlying the site is classified by the Environment Agency as a Secondary A aquifer capable of supporting small abstractions and providing baseflow to groundwater supported surface water features.

Groundwater storage and flow within the granite occurs entirely within fractures in the upper weathered bedrock. Fractures decrease with depth and the base of the aquifer is generally considered to be 30 - 40 m below ground level. There is little literature data regarding the Land's End Granite. However, studies have been carried out on the nearby Carnmenellis Granite (around 30 km to the east, between Cambourne and Falmouth) which is considered to be comparable (Jones et al., 2000).

Across the region, the granite is overlain by up to 2 m of Head deposit which is in connectivity with the granite aquifer and allows recharge. Therefore, over most of the area the aquifer is unconfined. The water table is generally less than 10 m below ground and tends to follow the topography. Due to the low permeability of the granite and the topography, the hydraulic gradient can be steep (BGS, 1989).

Due to the unconfined nature of the aquifer and the connectivity with the superficial Head deposits it is considered that the groundwater catchment for the site will be coincident with the surface water catchment. The surface water catchment is detailed in Section 2.4 and shown on Figure 3.

Recharge into the granite aquifer will occur on the higher ground to the east and south of the site.

The site itself is underlain by Alluvium which is a low permeability silty, clayey deposit that overlies the granite aquifer. The presence of the Alluvium beneath the site will act to locally confine the underlying granite aquifer and limit connectivity between surface water and groundwater.

One other factor that has the potential to influence the hydrogeology is historic mine workings. The OS mapping shows a series of mine shafts approximately 300 m southwest of the site and mine workings around Rosewall Hill, approximately 500 m northwest of the site. The mine workings are into the granite aquifer and upgradient of the site. There is the potential for these historic mineworks to change groundwater flow patterns and groundwater chemistry. There is also the potential for minewater discharge from adits into surface water upgradient of the site. However, due to the historical nature of the industry any residual risk to water chemistry is considered to be low.

3 Ecohydrological Survey

The ecohydrological survey was undertaken on 14 December 2018, and 6 – 7 February 2019. There had been rain the night of 13 December and 14 December was overcast with sporadic showers. There was rain in the days preceding the survey in February, it rained heavily on the night of 6 February, and periodically throughout the day on 7 February.

The site has a central belt of marshy ground supporting wetland mire communities with Salix woodland to the north and south. There is evidence that horses use the central belt of the site for grazing, although no horses were present on the days of the site visit. The southern woodland can be accessed by a number of private footpaths and there is evidence that it is managed for game birds.

The northern woodland surrounding Bussow Reservoir is mostly inaccessible. Scrub extends from the woodland into the site, occasionally making access through the central belt difficult.

Fields surrounding the site appear to be predominantly used for grazing cattle and horses. Apple trees are being grown on land to the east of the site.

3.1 Site Survey

Key features were identified during the desk study and visited during the ecohydrological and walkover survey. Survey points were recorded using a handheld Garmin GPS accurate to approximately 5 m. The surveyed water features described below are shown on Figure 7, and photos of the ecohydrological survey are presented on Figure 8. A detailed summary of the survey is included in Appendix 1.

During the survey, field measurements were made of pH and Electrical Conductivity for water samples around the site. Full field water chemistry results are presented in Section 3.2.

3.1.1 Ditches D1 – D8

Ditches D1 – D6 are located on the farmland and woodland to the south of the site and have been built to channel water from springs and seepages (presumably so that the land could be better farmed). As such, they directly influence the hydrology of the south of the site by quickly directing flow into the Stennack River.

Although the spring heads were often inaccessible due to dense vegetation or because they had been fenced off, the immediate land surrounding the spring heads was often wetter than other parts of the field, water was audible, and the flow in the ditches was seen to be gaining. Except in a few localised instances, flow was confined to the ditches, there was no significant overland flow, and the ditches were all carrying water over and above what would be expected from the wet weather. Except for one spring, which was reported to occasionally run dry during the summer months (personal communication, Mr Thomas, landowner) all the rest of the springs are considered to be permanent. The locations of the springs/seepages are shown by a blue triangle on Figure 7.

Ditches D1 – D8 were generally between 0.5 – 1.6 m wide (further ditch dimensions in Appendix A). Ditch channels were between 0.2 – 1.2 m deep, with shallow ditches predominantly seen at the spring heads and southern woodland. Flow through the ditches was slow to medium and the water was clear. Ditches running through the farmland to the south of the site had a mineral bottom;

those in the woodland were often filled with leaf litter. Photos 1 and 2 on Figure 8 show Ditches D4 and D8.

The walkover survey identified that the majority of the ditches that were mapped on the 1:25,000 OS map were in place. The following were found during the survey and are not on the OS mapping:

- Ditches D1 and D3, between 130 - 220 m south of the site as indicated on Figure 7.
- Ditch D2, which continued for 150 m upslope along field boundaries.
- Ditch D7, which was seen to continue west along a boundary track and join Ditch D5.

3.1.2 Surrounding Land

To the south and west of the site, the land slopes down towards the site and consists of small fields grazed by cattle and horses/ponies. No overland surface flow was seen, probably due to the nature of the Head deposit that allows infiltration. It was observed that Ditches D1 – D8 were carrying higher volumes of water after rain. This indicates that a proportion of rainfall does not infiltrate and instead forms overland surface flow which is captured by the ditches.

3.1.3 Stennack River

The Stennack River (Photo 3, Figure 8) is a stream that flows north through the site and on the day of the survey was medium to fast flowing. Where the river could be accessed in the central belt it was seen to follow a relatively straight channel approximately 1.5 m wide and less than 1 m deep with a mineral bottom and clear water. The channel was well confined. On the date of the second site visit (7 February) the water was discoloured due to heavy rainfall the previous night and the impact of surface run-off into the watercourse.

At the northern end of the central belt (by Ponds 1 and 2) the stream channel of Stennack River was much shallower (c. 5 m deep) and the stream was not well confined. This changed as Stennack River flowed into the northern woodland, where the channel again became well confined.

The Stennack River is fed by Ditches D1 –D8, which flow south from the southern woodland and surrounding fields.

Some sections of the river in the northern woodland had been artificially channeled and the river banks are constructed of concrete approaching Bussow Reservoir. In addition, within the northern woodland, a sluice gate/collection chamber exists at SP1 (Figure 7) and it is possible this outlet provides a supply of water to Bussow Reservoir. A second concrete channel and structure was seen at SP2 (Photo 4, Figure 8). Historically, this structure would have held a sluice gate. A short concrete channel directing water into the northern woodland is seen 2 m upstream of the structure at SP2.

Due to the man-made nature of the ditch system feeding Stennack River, and the man-made structures seen in the northern section of the river, it is probable that the course of the Stennack River has been heavily modified in its entirety.

3.1.4 Stream 1

Stream 1 (Photo 5, Figure 8) is fed by a large seepage around 50 m x 200 m (Seepage 1) on the eastern site boundary. Stream 1 flows northwest through the central belt and into Stennack River. The stream is seen to be gaining and the channel is clearly defined, but vegetated. The channel is around 1 m wide and 0.75 m deep. It was not possible to follow Stream 1 due to the vegetation but

it is considered that this is a natural stream. There is no evidence of maintenance and the stream channel does not appear to have been straightened.

3.1.5 Stream 2

The course of Stream 2 could not be followed due to dense vegetation, but it appears to drain the northeast of the central belt and flows west into Stennack River. Where it was measured, it was 40 cm wide, and 60 cm deep with very slow flow. It is not known if the channel is man-made, but it does help drain the site. It does not appear to be maintained.

3.1.6 Ponds

A number of ponds are found on the site and the surrounding area. Many of these appear to be man-made. They are fed by groundwater and overland flow, and most overflow into ditches that flow into the Stennack River.

Ponds 1 and 2 are 10 x 50 m and 10 x 20 m respectively. Pond 1 appears to have been relatively recently constructed, whereas Pond 2 is more established. They are fed by overland flow and groundwater from a seepage at Seepage 2. On the date of the site visit (7 February) Ponds 1 & 2 were overflowing into the Stennack River.

Pond 3 is not shown on the OS mapping. The area around Pond 3 is currently being landscaped and developed and the pond appears to be man-made.

Pond 4 is a relatively new man-made pond that was dug as part of an agri-environment scheme (personal communication, Mr Thomas, landowner). It overflows into Ditch D4. The superficial deposit of Alluvium is visible at the banks, and can be seen to consist of a poorly sorted, clayey silt with angular grit and pebbles. Pond 4 is illustrated in Photo 5, Figure 8.

Pond 5 is a man-made pond with an overflow into Ditch D5 in the northeast corner.

Pond 6 is not mapped. It is a man-made pond that appears to have been designed to provide a habitat for game birds. Pond 7 is also unmapped. It is 10 m to the west and appears to be a natural feature.

3.1.7 Ditches D9 and D10

The source of water for Ditch D9 could not be traced, but it is likely to be fed by a groundwater seepage/spring. The amount of flow in the ditch was seen to gain indicating groundwater flow because there was no evidence of overland flow and other inflows into the ditch.

For the majority of its length, the ditch was approximately 2 m wide and relatively shallow, no deeper than 0.5 m. It had a mineral bottom, but where the ditch was located in scrub, the channel was filled with leaf litter. The OS mapping indicates that Ditch D9 is not continuous along the length of the valley. Dense vegetation precluded a full investigation, but it is considered that the ditch is continuous and the estimated route of the ditch is shown on Figure 7.

It was impossible to follow most of the course of Ditch D9 into the northern woodland, but a ditch was located in the woodland that corresponds to the mapped course for Ditch D9. It was not possible to reach the northern end of Ditch D9, but it is assumed that it continues to the Sink marked on the OS mapping and shown on Figure 7.

Ditch D10 starts as a spring which rises beneath an old rope works building (personal communication, Mr Seaman, landowner). The rope works is now a cider factory. Ditch D10 follows a straight channel adjacent to a track through a wet and marshy area of land. The channel was not vegetated where it started by the cider factory, but in places downstream became highly vegetated. The channel of Ditch D10 has artificially high banks and is man-made.

The course of Ditch D10 could not be followed into the northern woodland, but as with Ditch D9 it is assumed to continue north to the Sink.

Ditches D9 and D10 are considered to be man-made. Although they do not provide water to the central marshy belt of land, they are a significant source of water to the northern woodland which is included in the proposed SSSI.

3.1.8 Sinks

The OS mapping shows that Ditch D9 and D10 flow north to a Sink. The survey found areas of pooled water in this area, specifically in two places 60 m apart immediately to the southeast of Bussow Reservoir (Photo 7, Figure 8). The location of the Sink itself and the course of water flowing into the Sink could not be identified as dense vegetation impeded access. One possibility is that the Sink is connected with the geological fault that runs through this part of the site and is discussed in Section 3.3; an alternative possibility is that there may be a sub-surface culvert.

3.1.9 Scrapes

A series of scrapes were found at SP3. These appear to have been recently dug, as the ground was disturbed and had not recovered. The scrapes were holding water.

3.1.10 Wet areas

The central belt consists of marshy ground, with numerous shallow pools of water (Photo 8, Figure 8). The standing water had no visible flow and was not connected to the Stennack River. Vegetation surrounding the pools was typical of a consistently wet area, with molinia, sphagnum mosses and rushes.

3.1.11 Summary

The main findings of the ecohydrological survey are summarised as follows:

- The Stennack River flows north through the centre of the site. It characterised as a medium-fast flowing stream that has a mineral base. The water is confined within the stream and does not spread out into the central belt. Therefore it is not a water source for the mire communities.
- At the northern tip of the central belt, it is possible that the Stennack River could flood onto the site. However, this flooding would be localised to the northern-most section of the central belt and the northern woodland, where flood waters have historically been diverted.
- It is probable that the Stennack River has been heavily modified in its entirety.
- Stream 1 is fed by a large seepage, almost 200 m in length, close to the east site boundary. The seepage is considered to be a groundwater seepage from the underlying granite aquifer. It is considered that Stream 2 is also fed by a similar groundwater seepage.
- Streams 1 and 2 provide the main water source for the mire communities of interest in the central belt. Flow in these streams is not always confined to the stream channel and spreads out across the ground to support the mire vegetation.
- Ditches D9 and D10 form a sub-catchment that flows into the northern woodland.
- Water from Ditches D9 and D10 flows into a Sink found in the northern woodland.
- Ditches D1 – D8 in the southern woodland are fed by groundwater springs. Water flowing from the springs is captured by the ditch channels and quickly flows into Stennack River. This drainage system provides a water source for the southern woodland and Stennack River.

3.2 Water Chemistry

Field measurements were made of pH and Electrical Conductivity using handheld meters. The results of the field measurements are shown in Table 1 below, and the locations are shown in Figure 9. The bracketed figures correspond to the survey points described in Appendix 1.

Before discussing the results of the field water chemistry, it is important to note that these are a snap-shot of the water chemistry on 14 December 2018, and 6 – 7 February 2019 and may not be representative of water chemistry through the seasons.

Table 1 Results of the field water chemistry

Survey point	Grid ref Easting, Northing	pH	Electrical Conductivity (µS/cm)
C1 (B1)	149661, 038507	6.1	197
C2 (B2)	149547, 038288	6.6	305
C3 (B3)	149661, 038507	6.2	250
C4 (B5)	149702, 038344	5.6	281
C5 (B7)	149956, 038438	6.2	234
C6 (B11)	150085, 038283	6.0	166

Survey point	Grid ref Easting, Northing	pH	Electrical Conductivity (µS/cm)
C7 (B12)	150101, 038371	6.2	183
C8 (B13)	150019, 038480	6.1	177
C9 (B15)	150576, 038367	6.4	233
C10 (B18)	150236, 038876	6.3	248
C11 (B20)	150458, 038700	6.5	263
C12 (B22)	150042, 038587	6.1	210
C13 (B25)	150051, 039039	6.6	220
C14 (B27)	150107, 039017	6.0	210
C15 (B28)	150141, 038684	6.2	190
C16 (B29)	150095, 038746	6.0	178
C17 (B30)	150118, 038805	6.1	219
C18 (B31)	150057, 038871	7.1	190
C19 (B33)	150065, 038870	6.8	175
C20 (B35)	149950, 038486	6.0	245
C21 (B39)	150007, 038614	5.1	146
C22	150171, 038958	5.3	150

Table 1 shows the pH is between 5.1 and 7.1 with a median of 6.1. The conductivity is between 150 and 305 µS/cm with a median of 210 µS/cm which is moderately low and indicates a low mineral content.

The BGS's Baseline Report Series (Smedley and Allen, 2004) states that the Lands End granite has a pH between 4.8 - 6.8 with a median of 5.8. Due to the groundwater circulating at shallow depths, it is soft (due to an absence of carbonate minerals in the granite), acidic, and unmineralised. The pH and conductivity measurements taken on site concur with the literature, implying that the groundwater at Bussow behaves in the same way.

The median pH is 6.1 with only three outliers. The three outliers (C13, C19 and C18) were all taken on the same day after heavy rain the previous night. The measurements taken at C19 (Seepage 2) and C18 (Pond 1) were both likely to have been influenced by overland flow as there was a lot of surface water flow between the seepage and into the ponds; this in turn is likely to have influenced C13 which is further downstream, and the only other downstream measurement taken that day. A pH of 6.0 is at the top end of that expected for the M23 community and indicates the fen to be at the high end of a base-poor fen.

3.3 Soils and peat

In West Cornwall, the majority of peat formation was during the Pleistocene and Holocene after the Head was deposited, but before the Alluvium deposits were laid down (BGS, 1984). Because of this, peat depth transects were not undertaken at Bussow because apart from in localised lenses, significant amounts of peat were not expected to be found overlying the Alluvium deposits. Ad hoc measurements were taken in the wetter areas of the site where the NVC mire communities are mapped which showed that the depth of peaty soils was less than 0.5 m deep.

3.4 Wetland Supply Mechanisms (WETMECs)

The findings of the field survey have been presented above and in this section are discussed to determine the water supply mechanisms (WETMECs). The WETMECs are part of the Wetland Framework (Wheeler *et al*, 2009) which identifies the main wetland habitats that occur in lowland wetlands in England and Wales. It focusses primarily on mires (fens, bogs and swamps) and in particular to the relationships between wetland topography, hydrology, hydrogeology, hydrochemistry and the ecological and biological characteristics of the site.

The catchment surrounding the site, including the hills to the east and the south are underlain by granite, the upper 30 – 40 m of which is weathered and is classified as an aquifer. The aquifer is unconfined, except beneath the site, and groundwater flow follows the topographic contours.

The site encompasses the river valley of Stennack River and is underlain by superficial deposits of low permeability clayey, silty, Alluvium that overly the granite aquifer. The presence of the Alluvium acts to confine the underlying granite aquifer and limit connectivity between surface water and groundwater. Where the aquifer is locally confined by the Alluvium, the piezometric surface has the potential to rise above ground level.

> ***Piezometric surface:*** *Where an aquifer is confined and there is a high hydraulic head the groundwater in the confined aquifer is under pressure. The piezometric surface is the level to which groundwater would rise in a borehole penetrating the aquifer.*

The NVC mire communities of interest at the site are located in two parallel bands on either side of Stennack River in the central belt of the site. The site survey found that the water source for these mire communities is a combination of surface water and groundwater.

Surface water runoff will flow towards the site from the hills to the west and south. Where rain falls onto the superficial Head deposits there will be some infiltration to groundwater, but it is expected that there will also be an element of overland flow due to the relatively steep slopes found to the west of the site. Overland flow can also increase where soils have been compacted, potentially due to the use of machinery of presence of grazing animals.

At the site, the Alluvium limits connectivity and infiltration to groundwater and surface flow will be overland and through the soils overlying the Alluvium, following the flat gradient of the site. Due to the shallow gradient of the valley and the clayey nature of the Alluvium, surface water will also collect in shallow topographic hollows on the site.

The site survey found that groundwater is a significant source of water for the mire communities. A number of springs/seepages rise around the periphery of the site from the underlying granite aquifer. A review of the location of these springs and the superficial deposits shows the springs to rise at the edge of the Alluvium deposits where the aquifer becomes confined. Water from these springs is seen to spread out across the site in places and provide a water source for the mire communities. The relationship between the Alluvium and springheads is shown on Figure 10.

Ditches D9 and D10 flow north into the northern woodland and provide the main water source for this Salix woodland. The spring that feeds Ditch D10 was found and it is likely that Ditch D9 is fed by a similar spring. A review of the geological fault at the site shows that the fault passes close to these

springs and therefore groundwater through the fault is the potential source of water to these springs. Ditches D9 and D10 flow north and disappear at a Sink. This Sink is also close to the geological fault which has the potential to impact the flow of water. The location of the geological fault is also shown on Figure 10.

The southern woodland is also a Salix woodland and the main watersource is Ditches D1 – D8 which are fed by a combination of surface water and groundwater springs.

This setting is consistent with the WETMEC Group of Seepage Slopes: Outflows of groundwater, typically on slopes but occasionally on more or less flat ground where there is water outflow. The high water table is maintained in what is essentially an unfavourable topographical context (sloping) by high rates of groundwater outflow (they are soligenous systems). Within this group the WETMEC 10: Permanent Seepage Slopes best describes the periphery of the site.

In the shallow gradient of the valley bottom, conditions become rheo-topogenous where the high water table is maintained by topographical hollows and by groundwater outflow (topogenous flow). This is consistent with the WETMEC group Seepage Basins and Bottoms, with WETMEC 13: Seepage Percolation Basins most descriptive of the conditions.

4 Ecohydrological Conceptual Model

The ecohydrological conceptual model for the site is presented on Figure 11 and described as follows:

- The site has an approximate area of 21.5 ha and is located in the valley of Stennack River, which flows north through the site.

- The site is oriented north-south in a shallow valley bottom that slopes gently down from 135 m AOD in the south to 125 mAOD in the north. The site is bordered on the west and south by hills. To the west, Rosewall Hill dominates the landscape, rising steeply to 227 mAOD from the valley floor. From Rosewall Hill a ridge extends to the south. To the southeast, the land gently rises before steepening to Trink Hill (212 mAOD).

- Immediately to the east of the site there is a second shallow second valley trending northwest – southeast. This second valley has a very shallow gradient sloping down to the southeast.

- The bedrock geology underlying the site is part of the Land's End Intrusion, of Carboniferous age, and consists of medium- and coarse-grained biotite granite. A geological fault runs north-north-west through the shallow valley to the east of the site.

- The granite bedrock is classified by the Environment Agency as a Secondary A aquifer. The aquifer is 30 – 40 m thick as a result of the fracture network which diminishes with depth. Groundwater flow and storage are predominantly within the fracture network.

- Superficial deposits of Head, up to 2 m thick overly the granite in the catchment surrounding the site. The Head deposits are in connectivity with the granite aquifer and surface water infiltrates to recharge the granite aquifer. Therefore, over most of the area the aquifer is unconfined. Recharge into the granite aquifer will occur on the higher ground to the east and south of the site.

- Due to the mainly unconfined nature of the aquifer in the catchment and the connectivity with the superficial Head deposits it is considered that the groundwater catchment for the site is coincident with the surface water catchment.

- The site itself is underlain by Alluvium which is a low permeability silty, clayey deposit that overlies the granite aquifer. The presence of the Alluvium beneath the site itself will act to confine the underlying granite aquifer and limit connectivity between surface water and groundwater.

- The wetland community of interest at the site are mire and there are two bands of mire mapped on either side of Stennack River.

- The recorded pH of circa 6.0 and the NVC mire communities found at the site indicate this to be at the high end of base-poor fen.

- The Stennack River flows north through the centre of the site. It characterised as a medium-fast flowing stream that has a mineral base. It is probable that the course of the Stennack River has been heavily modified in its entirety. The water is confined within the stream and does not spread out into the central belt. Therefore, it is not a water source for the mire communities.

- Streams 1 and 2 are fed by groundwater seepages from the underlying granite aquifer and provide the main water source for the mire communities of interest in the central belt. Flow in these streams is not always confined to the stream channel and spreads out across the ground to support the mire vegetation.

- Ditches D9 and D10 are fed by groundwater springs and form a sub-catchment that provides a water source for the northern woodland. Water from Ditches D9 and D10 flows into a Sink in the northern woodland.

- Ditches D1 – D8 in the southern woodland are fed by groundwater springs from the underlying granite aquifer. Water flowing from the springs is captured by the ditch channels and quickly flows into Stennack River. This drainage system provides a water source for the southern woodland and Stennack River.

- Direct rainfall is also a source of water for the wetland habitats within the site.

- The dominant WETMEC within the site is WETMEC 10: Permanent Seepage Slopes. These occur around the periphery of the site where the groundwater table intersects the ground surface and springs arise. In the shallow gradient of the valley bottom, conditions become rheo-topogenous where the high water table is maintained by topographical hollows and by groundwater outflow (topogenous flow). This is consistent with the WETMEC group Seepage Basins and Bottoms, with WETMEC 13: Seepage Percolation Basins most descriptive of the conditions.

- There is a proportion of surface water runoff from the fields to the west of the site and fields to the south.

5 Conclusions: Definition of the hydrological unit for Bussow Moor

A baseline review of the geology and hydrogeology of Bussow Moor has been completed and the NVC survey (Hewins Ecology, 2013) has also been reviewed. A two day ecohydrological survey of Bussow was carried out in December 2018 and February 2019 and the results of the above have been used to develop the ecohydrological conceptual model of the site (Figure 11).

The ecohydrological conceptual model has shown that the primary water source for the mire communities in the central belt are Streams 1 and 2 that rise on the east of the site and are fed by groundwater seepages from the granite aquifer. These seepages have allowed base-poor soligenous wetlands to become established. Therefore, under the Natural England fen and bog SSSI selection guidelines, the groundwater catchment upgradient of the site has been included within the hydrological unit. Due to the hydrogeological characteristics of the site, the groundwater catchment is co-incident with the surface water catchment.

The Stennack River flows north through the site and whilst not a primary water source for the mire communities, is a water source for the site. The Stennack River is fed by Ditches D1 – D8 that rise from groundwater springs. Therefore, the groundwater and surface water catchment of Stennack River is included in the hydrological unit.

Ditches D9 and D10 provide the main water source for the northern woodland. The Ditch D9 and D10 sub-catchment provides a water source for the northern woodland (Figure 12) and is included in the hydrological unit.

Streams and ditches downstream of the areas of wetland habitat have not been included in the hydrological unit; it is considered that management of these watercourses within reasonable bounds will have little influence on the hydrology of the wetland habitats.

6 Future considerations for Boswens, Boswarva and Bussow Moor

A set of three reports have been prepared which present the results of site ecohydrological investigations, conceptual models and the hydrological units for Boswens, Boswarva and Bussow. Boswens and Boswarva are located within 1 km of each other, around 4.5 km northeast of St Just, and Bussow Moor is 10 km northeast, around 2 km inland from St Ives.

These three sites all contain valley mire habitat and the conceptual models have shown the ecohydrological regimes for the three sites to be similar. The primary water source is groundwater and the dominant WETMEC is Permanent Seepage Slopes (10). For each site the hydrological unit has been defined which includes the groundwater and surface water catchments which are coincident.

Due to the similarity of the ecohydrological regimes at the three sites, potential considerations and issues for the sites are similar and are discussed generically. Where there are site specific considerations, they are listed at the end of the individual reports.

The hydrological units include a significant area of farmland. The hydrology of the farmland is that the ground is relatively free draining and surface water tends to infiltrate into the subsurface and the underlying aquifer. Groundwater flow in the aquifer is generally through fractures and weathering in the upper bedrock and groundwater residence time is relatively short.

It is expected that within the hydrological units there will be a range of different land management practices which could have the potential to pollute the sites though changes to water quality and in particular to increase the risk of nutrient enrichment to groundwater which is the dominant site water source. The inclusion of this farmland within the hydrological units would allow potential risks to groundwater quality to be managed through the SSSI management practices.

Site specific considerations for Bussow

Seepage 1 has the potential to re-wet the northeasten part of the central belt. It is therefore worth considering whether Streams 1 and 2 could be blocked to help flush groundwater across the ground surface and increase the area of mire vegetation in the valley bottom and central belt.

In the south of the central belt, it is possible that Ditch D2 could be modified/ redirected into the central belt to distribute water.

Apart from one section of D2, it is not recommended to block any of Ditches D1 – D8 draining the southern woodland because the woodland floor is very wet, and it is unlikely that blocking the ditches would significantly alter the dominant habitat.

7 References

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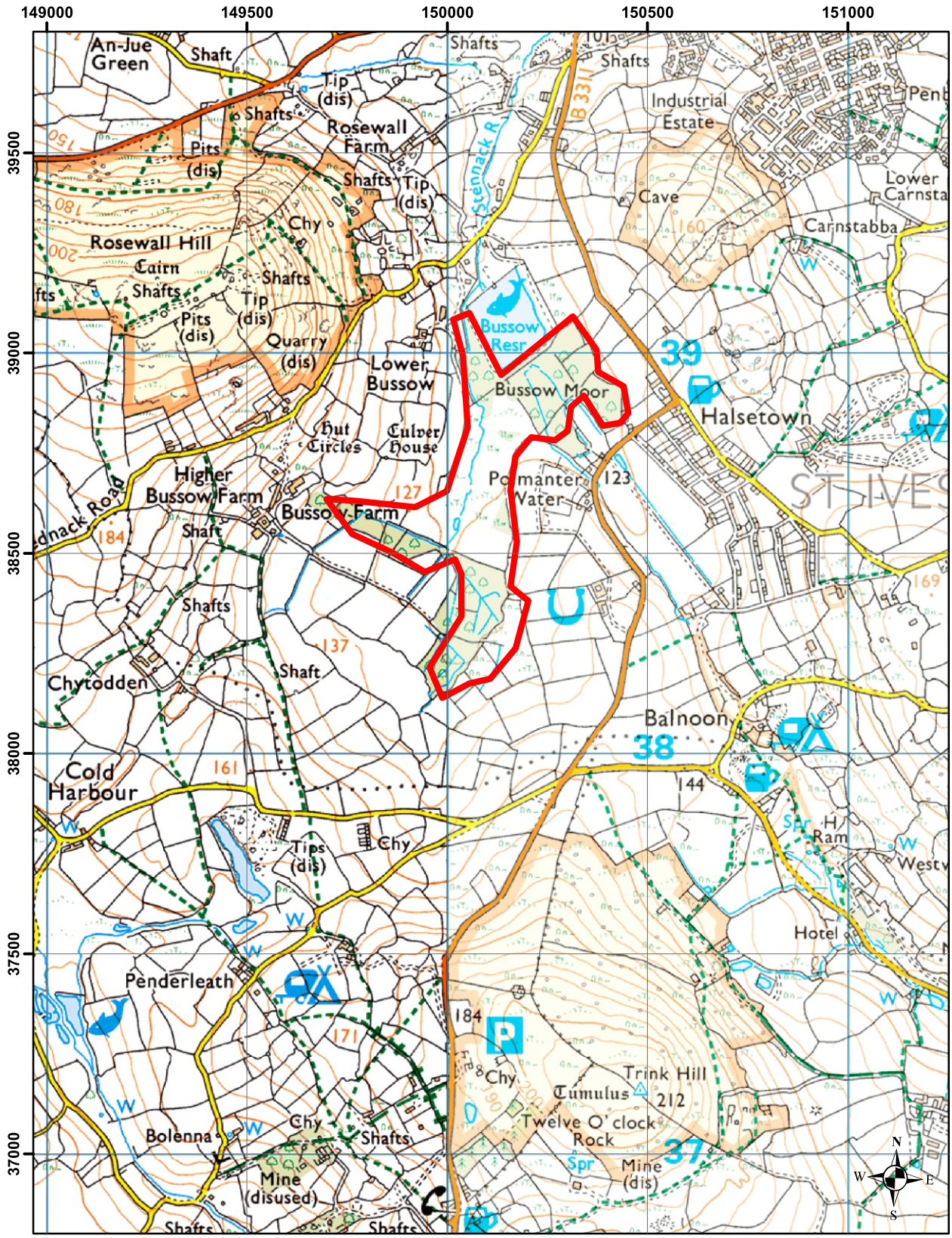
Figures



KEY

Bussow survey site boundary

Figure 1 Site location
Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.

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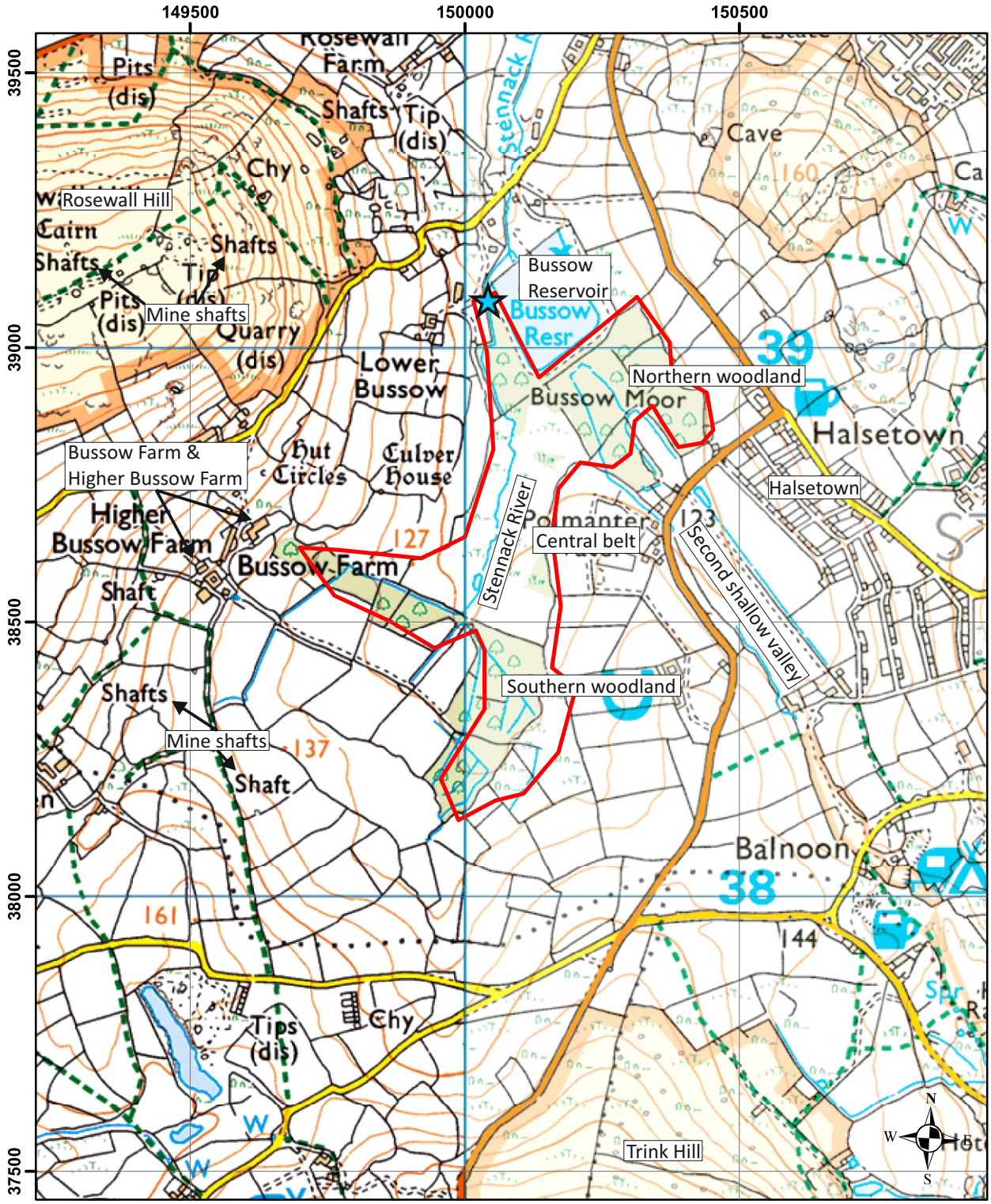

KEY

- Site boundary
- Outflow point
- Watercourse

Figure 2 Site features
Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.

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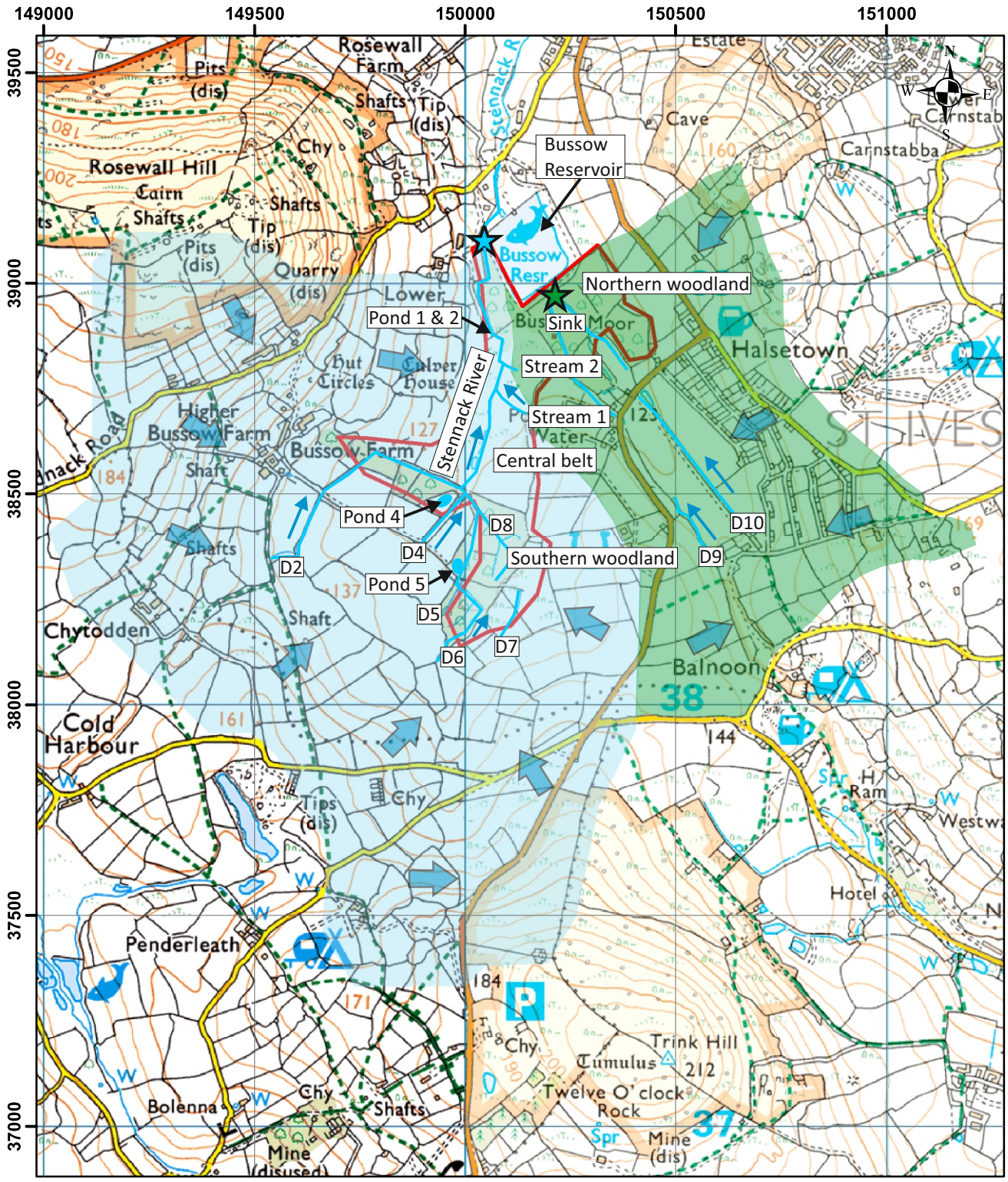


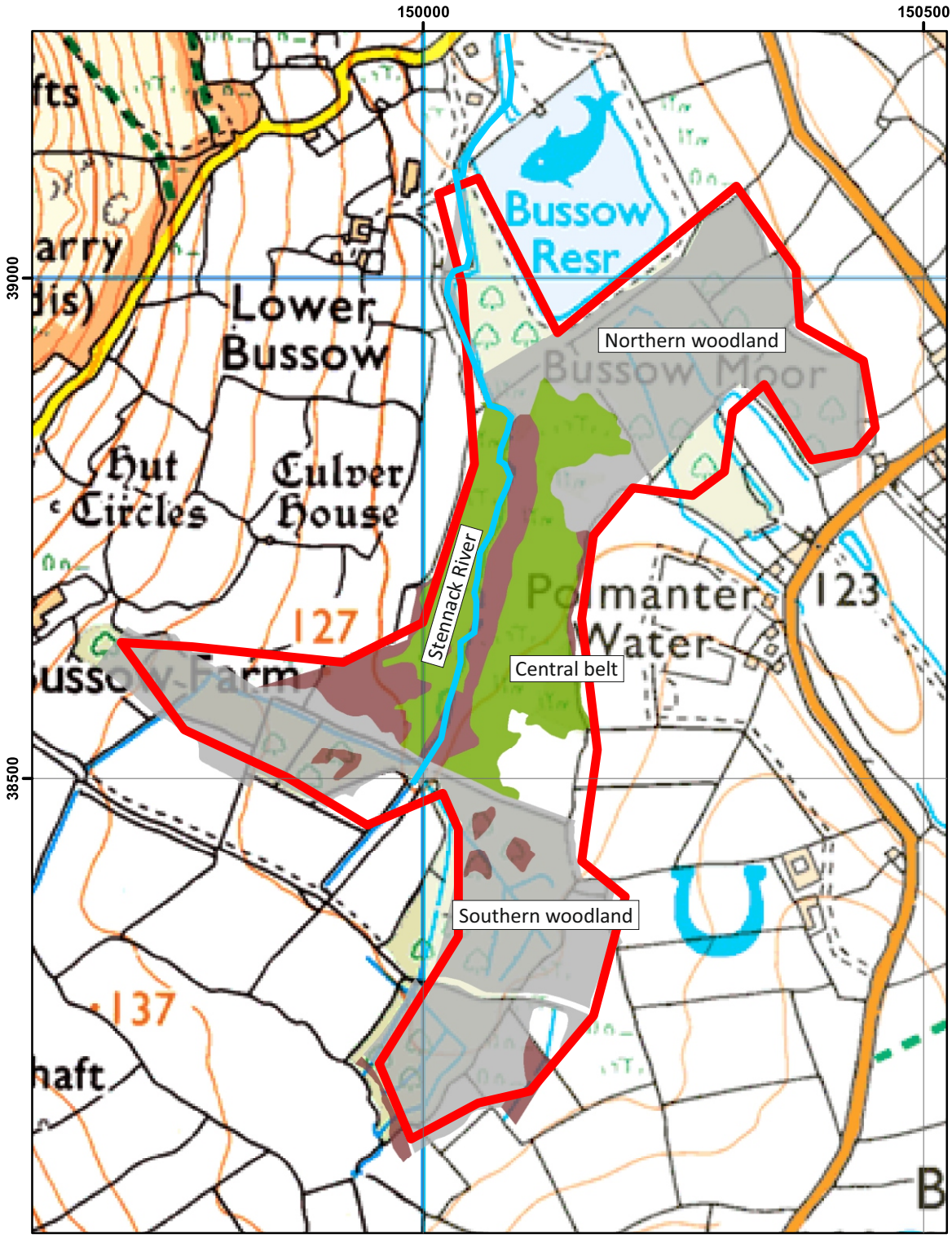
KEY

- Site boundary
- Stennack River catchment to outflow point
- Outflow point
- Catchment for D9 and D10
- Sink for D9 and D10
- Watercourse
- Watercourse flow direction
- Surface runoff direction

Figure 3 Site water features and hydrological catchment Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.

PH

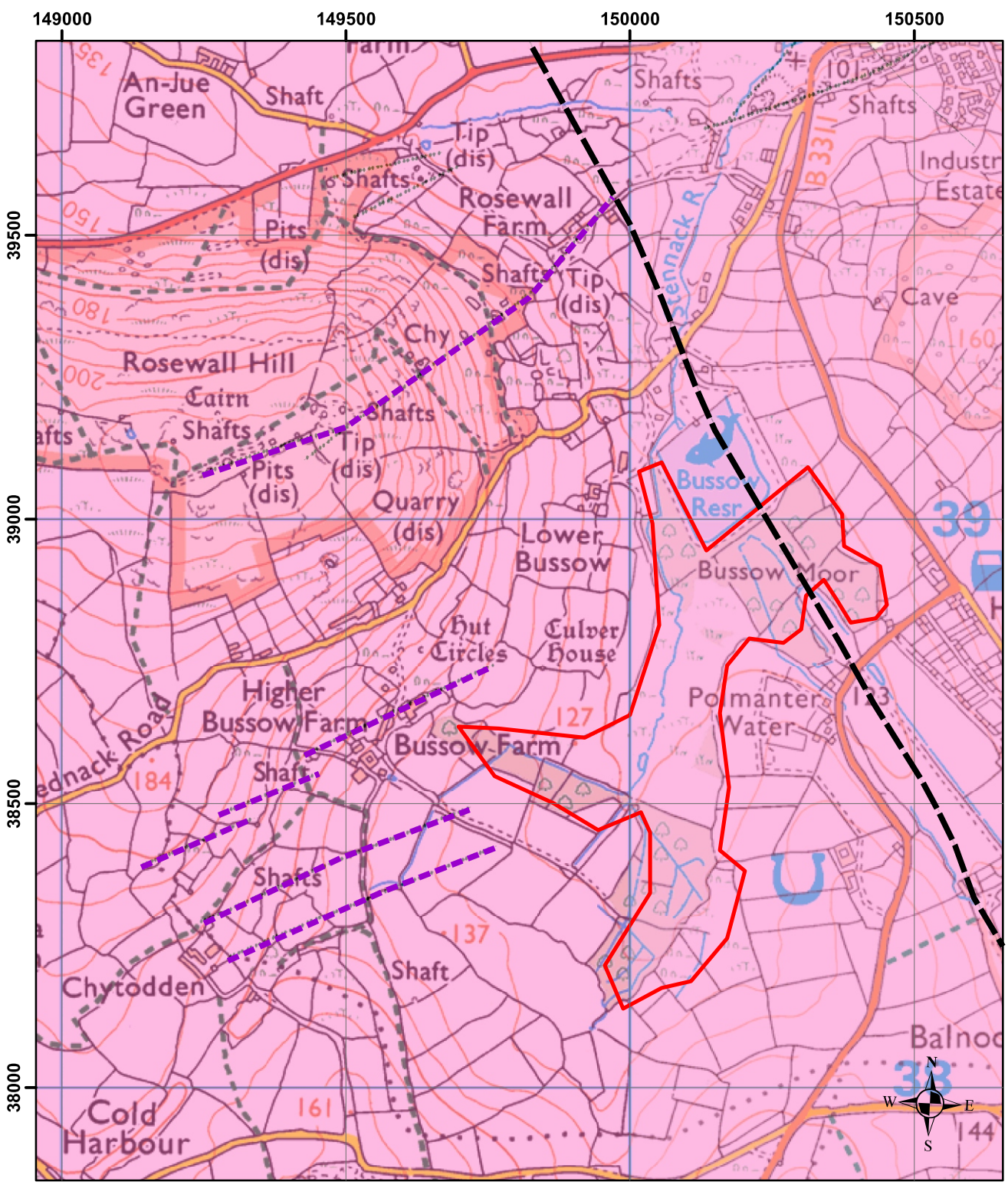


KEY

- Mire communities (M25 and M23)
- Scrub communities (W23 and W25b)
- Salix
- Site boundary

Figure 4 NVC communities
Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.



KEY

Bedrock Geology

- Site boundary
- Land's End Intrusion - Granite
- Mineral vein
- Fault

Figure 5 Bedrock geology
Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.

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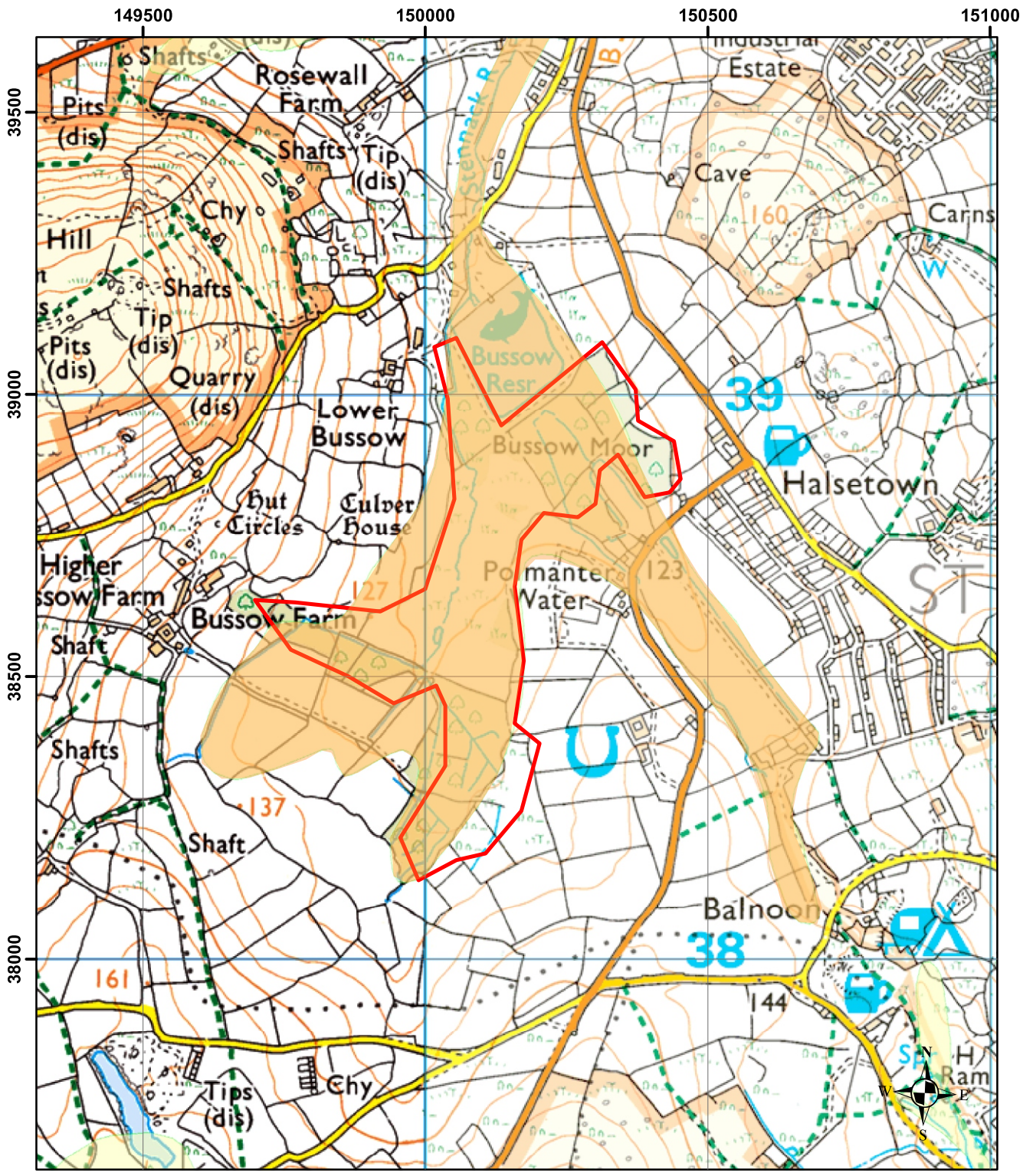

KEY

Site boundary

Superficial Geology

Alluvium

Figure 6 Superficial geology
Bussow, West Penwith

Date: 06/03/2019
Prepared By: Pendleton Hydro Ltd.

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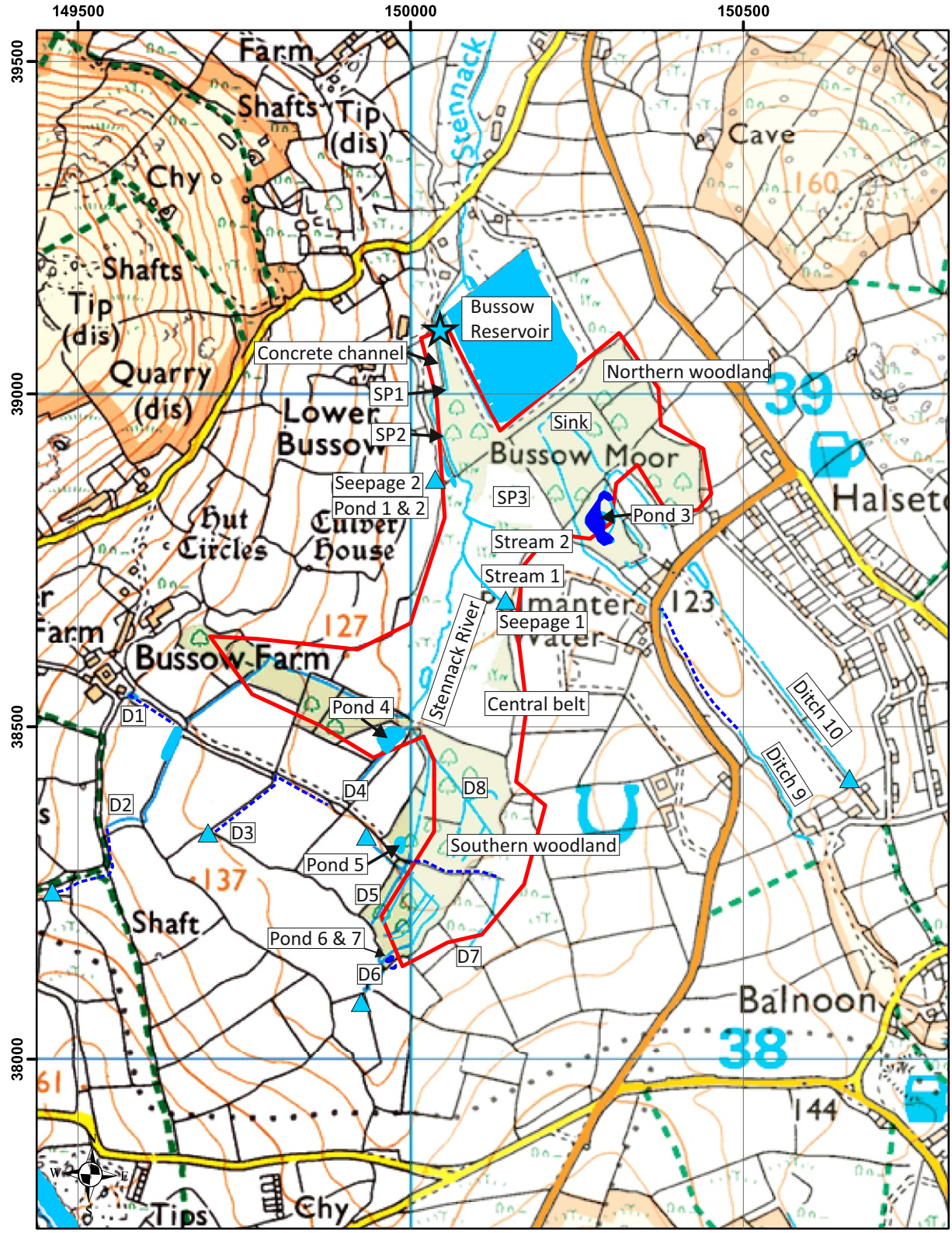


KEY

- Site boundary
- Outflow point
- Watercourse
- Unmapped watercourse
- Pond
- Unmapped pond
- Location with evidence of spring/seepage

Figure 7 Surveyed site water features
Bussow, West Penwith

Date: 15/03/2019
Prepared By: Pendleton Hydro Ltd.

PH

Photo 1: Ditch 4, spring fed, flowing north along field boundary

Photo 2: Ditch 8, flowing west through southern woodland

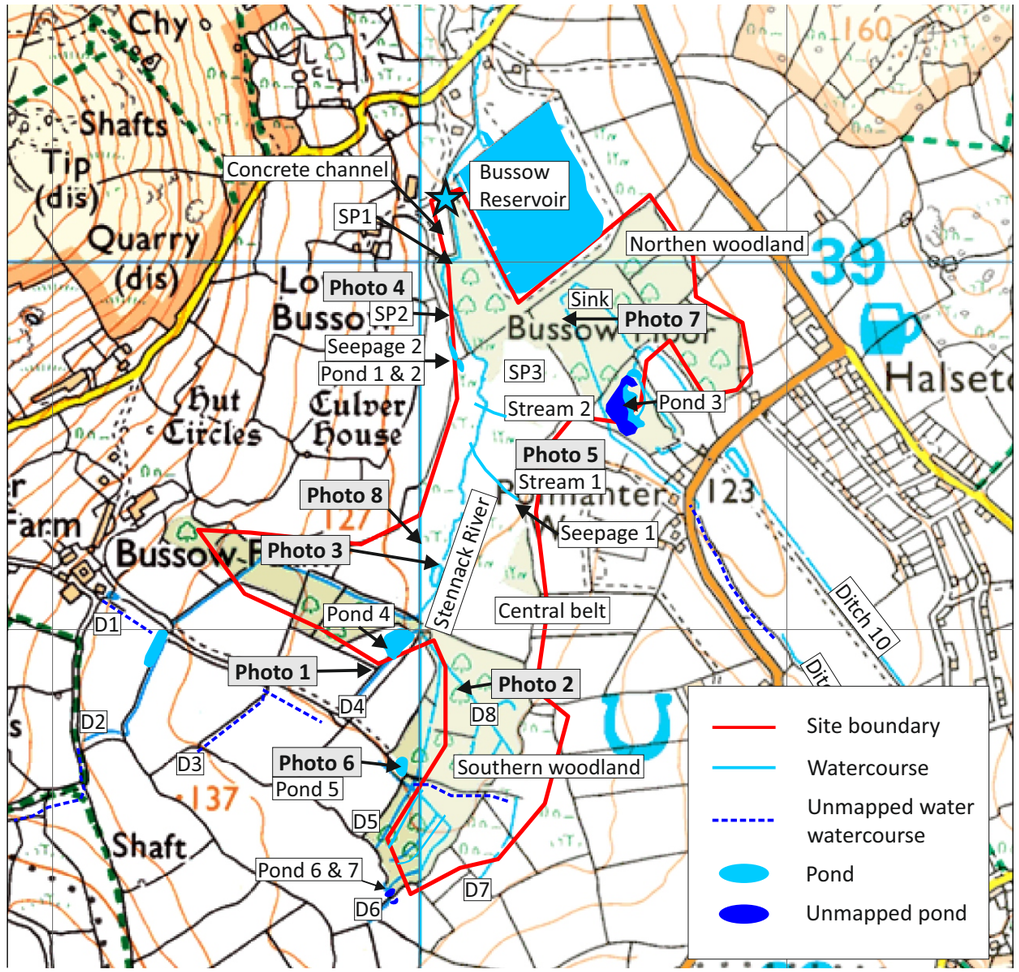


Photo 8: Example of pooled water on central belt

Photo 7: Sink, where Ditches 9 and 10 collect and dissipate

Photo 3: Stennack River in central belt, flowing north

Photo 4: SP2, showing concrete channel and historical sluice gate

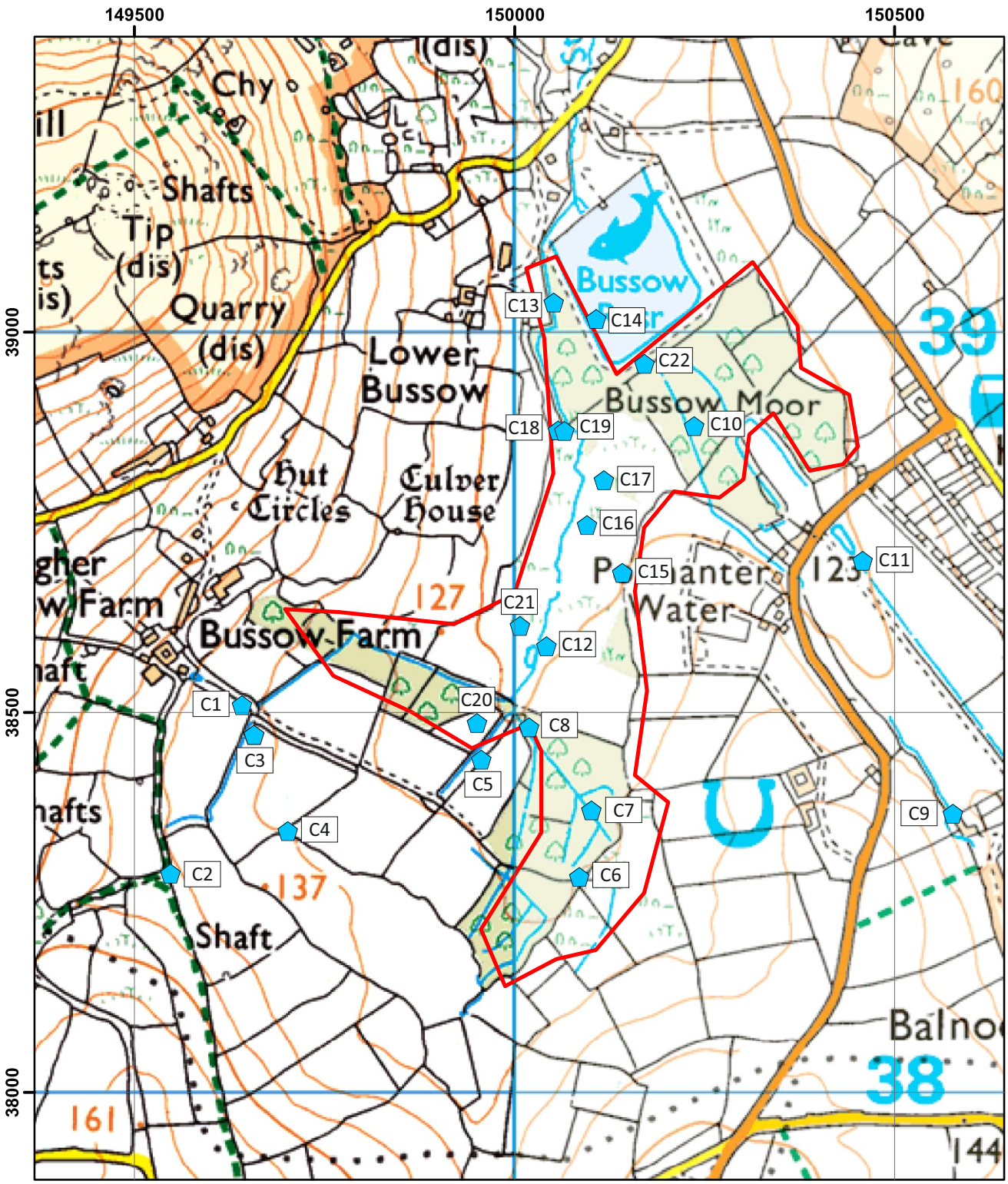
Photo 5: Stream 1, flowing northwest through dense vegetation

Photo 6: Pond 5, dug as part of an agri-environmental scheme

Figure 8 Ecohydrological survey photos
Bussow, West Penwith

Date: 06/03/2019
Prepared By: Pendleton Hydro Ltd.

PH



KEY

Chemistry

Site boundary

Sample points

Figure 9 Map of water chemistry measurements
Bussow, West Penwith

Date: 15/03/2019
Prepared By: Pendleton Hydro Ltd.

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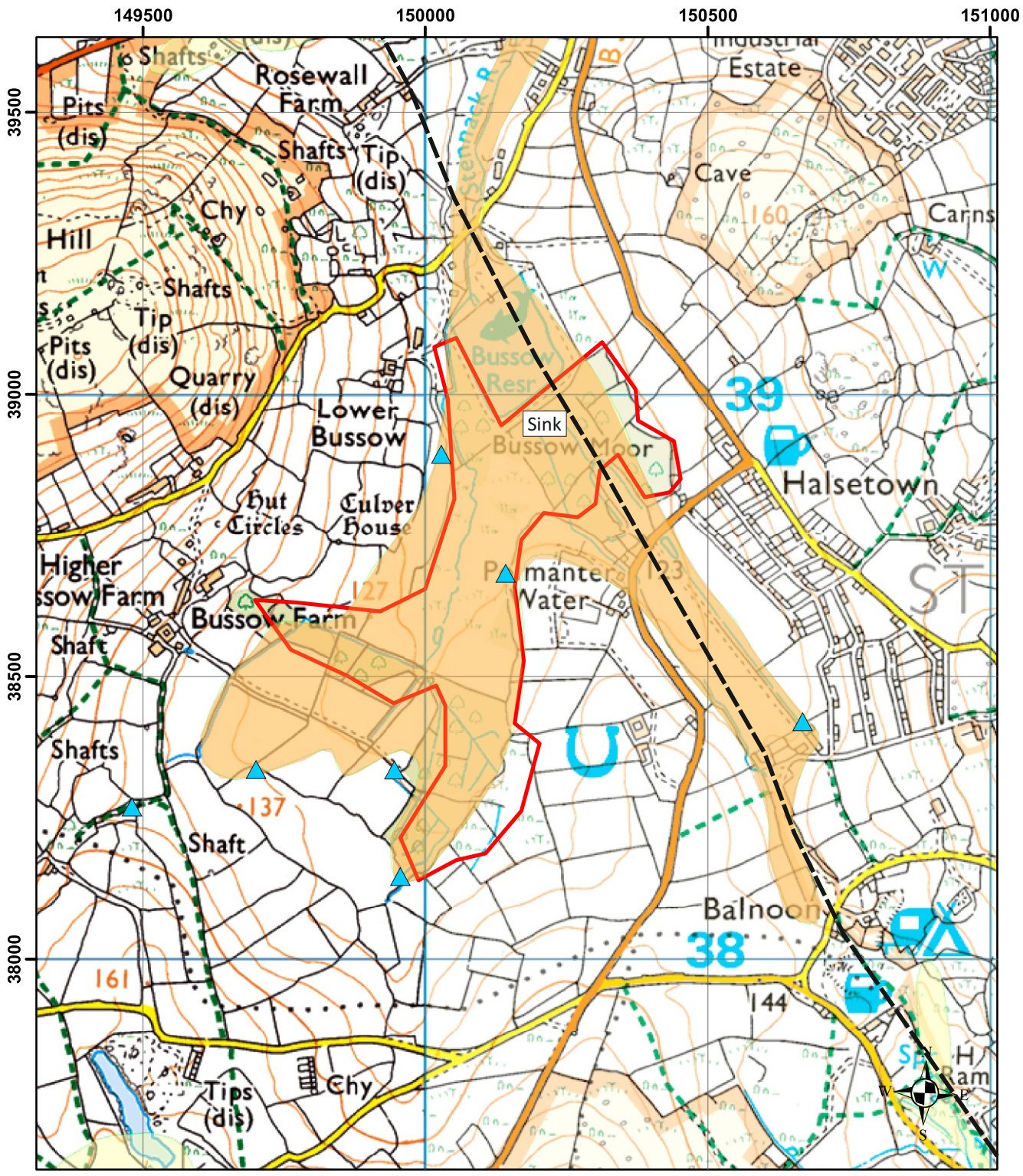

KEY

Site boundary

Superficial and structural geology

Alluvium

Fault

Evidence of springs/seepages

Figure 10 Geology and spring/seepages
Bussow, West Penwith

Date: 18/03/2019
Prepared By: Pendleton Hydro Ltd.

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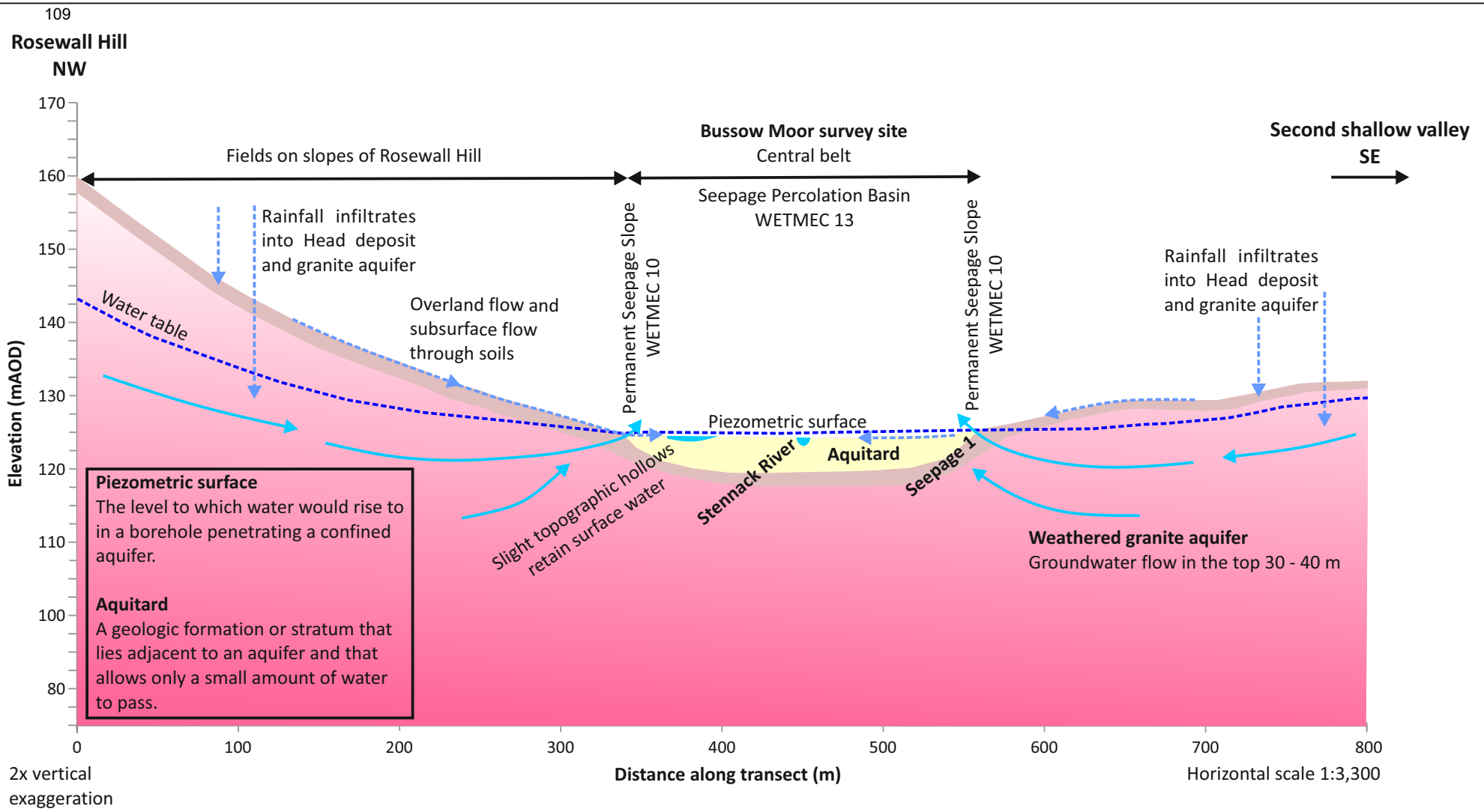

Figure 11 Hydrogeological cross section
Bussow, West Penwith

Date: 19/03/2019
Prepared By: Pendleton Hydro Ltd.

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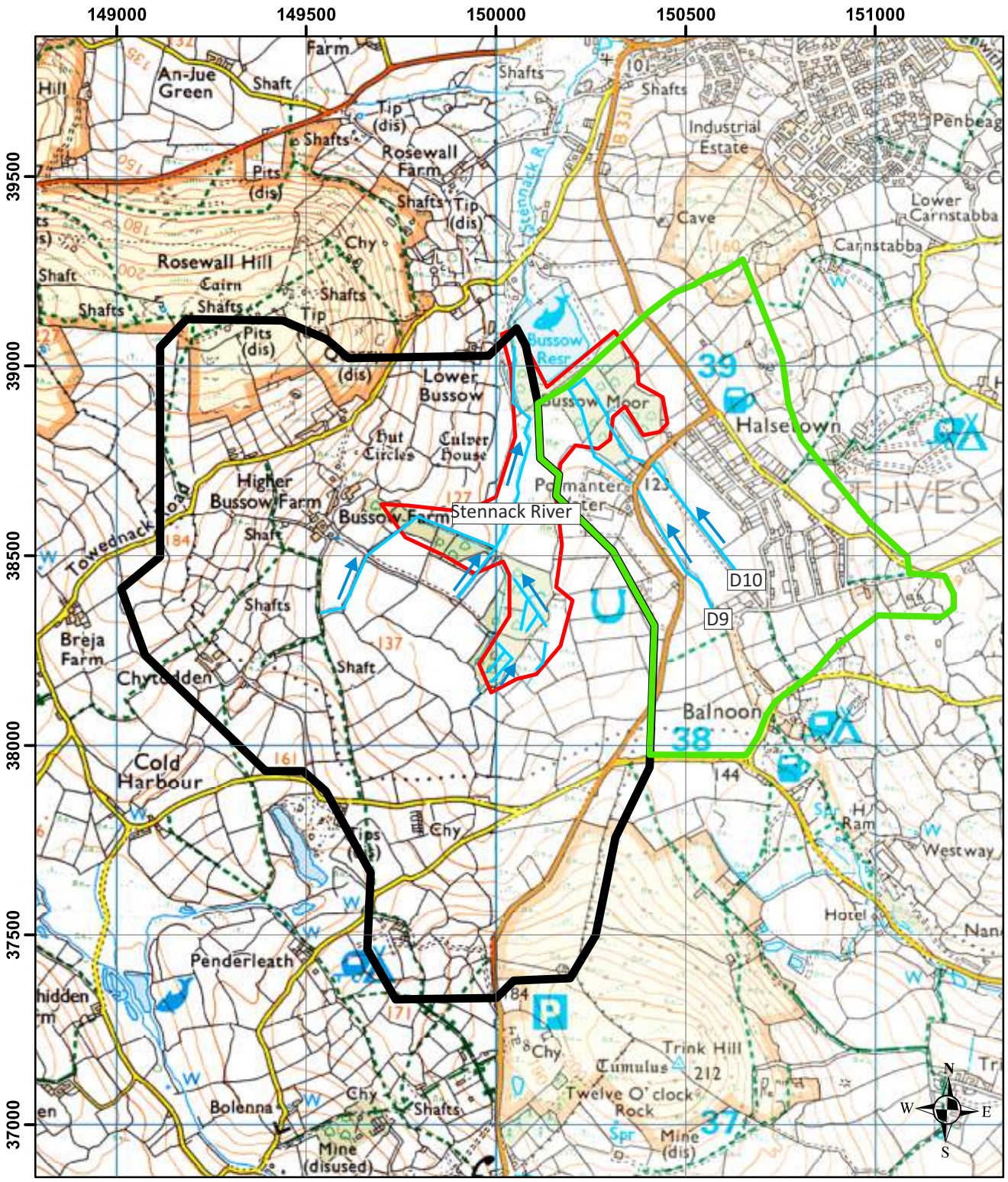

KEY

- Site boundary
- Watercourse
- Watercourse flow direction
- Stennack River catchment
- Catchment for Ditches D9 and D10

Figure 12 Definition of the hydrological unit for Bussow Bussow, West Penwith

Date: 19/03/2019
Prepared By: Pendleton Hydro Ltd.

PH

Appendices

Appendix A

Ecohydrological survey field notes

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
Ditch D1 B1	149661, 038507	At B1 an unmapped ditch is seen with water flowing southeast from Bussow Farm. It was not possible to follow the course of the stream. At B1, a pipe is also discharging water into Ditch D1 from an unknown source. Width of channel: 55 cm; Height of channel: 120 cm; Height of water: 10 cm Medium flow	No	Yes
Ditch D2 B2	149454, 038243	The head of Ditch D2 rises as a spring or seepage in inaccessible thick gorse and brambles. 80 m to the northeast, the stream can be accessed. Here the ditch has a mineralised bottom, and the channel is surrounded by thick vegetation including nettles, grass and dock leaves. Width of channel: 85 cm; Height of channel: 20 cm; Depth of water: 10 cm Medium flow	Yes	Yes
B3	149666, 038501	At B3 Ditch D1 joins Ditch D2 and flows through pipes under the track. It is unknown where the water exits as the water does not emerge the other side of the track. Width of channel: 45 cm; Height of channel: 35 cm; Depth of water: 15 cm Medium flow		
B4	149667, 038508	At B4, the corner of the field is wet and rushy and possibly represents a second seepage/spring that would flow into Ditch D2. It is fenced off. No water is flowing in the ditch visible from the track, but there is some standing water.		
Ditch D3 B5	149699, 038342	B5 marks the beginning of Ditch D3. The water in the ditch gains quickly, indicating that it is fed by groundwater. No spring/seepage could be seen, but the surrounding land was wet. The water was channelled in a ditch running along the field boundary. Width of channel: 80 cm; Height of channel: 40 cm;	No	Yes

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
		Depth of water: 10 cm Low-medium flow		
Ditch D4 B6 B7	 149899, 038363 149956, 038438	 Ditch D4 starts at B6. There is a very rushy patch in the corner of the field, surrounded by bracken and brambles. The area is inaccessible but flowing water is audible. At B7, the channel has a mineral bottom. A tributary ditch running northwest drains water from a wet/rushy patch in the corner of the field to the west. The tributary ditch is about 25 m long with slow flow. With of channel: 130 cm; Height of channel: 100 cm; Depth of water: 30 cm Medium-fast flow	Yes	Yes
Ditch D5 B8	 150010, 038299	 Ditch D5 can be seen passing under the track from the wooded area to the south. The channel is in dense scrub, but it appears to bypass Pond 4. Width of channel: 70 cm; Height of channel: 100 cm; Depth of water: unknown Medium flow	Yes	Yes
Ditch D6 B9	 149962, 038112	 The stream head of Ditch D6 rises in a very wet area of a field (inaccessible for further investigation). Water collects and runs northeast along field drains towards Ponds 6 and 7.	Yes	Yes
Ditch D7 B10 B11	 150116, 038284 150085, 038283	 At B10 a ditch can be seen flowing along the track. The fields surrounding the ditch are very wet, with standing water, grass and rushes. The water in the drain is slowly gaining. At B11, Ditch D7 flows in an east-west direction along the track and meets at B8. In several places, ditches/streams carrying water flow out of the woodland to the south and join Ditch D7. Width of channel: 120 cm; Height of channel: 95 cm; Depth of water: 15 cm Medium flow	Partially	Yes

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
Ditch D8			Yes	Yes
B12	150101, 038371	Ditch flowing through wet woodland. Surrounding vegetation includes sphagnum mosses. Width of channel: 160 cm; Height of channel: 25 cm; Depth of water: 15 cm Visible flow		
B13	150019, 038480	Flow remains sluggish. The ditch has been artificially created, with raised sides. Width of channel: 100 cm; Height of channel: 40 cm; Depth of water: 15 cm Slow flow		
Ditch D9			Yes, partially	Yes – limited to northern woodland
B14	150632, 038198	B14 marks the highest point of Ditch D9 that could be accessed. Ditch D9 continues up the field boundary trending north-south. Barbed wire on fences precludes following the ditch to the source of the water. Wet areas and standing water visible in adjacent fields. Estimated width of channel: 100 cm; Depth of channel: 100 cm; Height of water: unknown No visible flow		
B15	150576, 038367	At B15, Ditch D9 has mineral bed and is partially vegetated. Width of channel: 190 cm; Height of channel: 40 cm; Depth of water: 10 cm Slow flow		
B16	150404, 038630	Dense vegetation precludes following Ditch D9, but it appears to continue along the boundary from B15. The water in Ditch D9 appears to be gaining, and flow is increasing. Dense vegetation precludes investigating where the ditch exits under the road. Width of channel: 200 cm; Height of channel: 30 cm; Depth of water: 5 cm Slow-medium flow		
B17	150370, 038686	Water can be seen flowing from under the road into private land with ditches built to channel the water.		
B18	150236, 038876	Ditch D9 could not be followed as the land was inaccessible. However, a ditch was found in the northern woodland which is assumed to be a continuation of Ditch D9. Width of channel: 40 cm; Height of channel: 55 cm; Depth of water: 10 cm		

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
		Low flow		
Ditch D10 B19	150669, 038426	The water that feeds Ditch D10 is a spring that lies underneath the old ropework building (now a cider factory), personal communication Mr Seaman. Gutter water from the cider factory will also flow into the ditch at B19. Ditch could not be accessed, but approximately 50 cm wide and 100 cm high with slow-medium flow.	Yes	Yes – limited to northern woodland
B20	150458, 038700	At B20, Ditch D10 is surrounded by wet marshy vegetation. The ditch has artificially high banks and is man-made. Width of channel: 130 cm; Height of channel 70 cm; Depth of water: 25 cm Medium – fast flow		
B21	150407, 038752	Water from the ditch passes under the road, and follows an open ditch before being tunnelled under land to the north west.		
Stennack River B22	150042, 038587	Vegetation in the immediate vicinity of B22 is rushes and grasses, both showing evidence of grazing. Gorse and bracken is also found within the central belt of the site. At B22, an earth bridge connects the fields either side of the Stennack River. Width of channel: 170 cm; Height of channel: c.100 cm; Depth of water: 20 cm Fast flow	Yes	Yes
B22a	150078, 038863	At B22a, water from Ponds 1 and 2 overflows into the Stennack River. At this point, the channel is not clearly defined and shallow. Width of channel: c.100 cm; Depth of channel: c.50 cm		
B23	150049, 038945	At B23 there is a concrete channel that would have historically held a sluice gate. If in use, the sluice gate would hold back water from the Stennack River. A ditch upstream of the sluice gate channels water into the northern woodland. (B23 is SP2 in the main text).		
B24	150051, 039007	At B24 a closed sluice gate/collection chamber is in place. It is possible that water collected at this point		

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
		is channelled into Bussow Reservoir, at the pipe seen at B27. (Note: B24 is SP1 in the main text).		
B25	150051, 039039	At B25 the Stennack River flows down a concrete channel. The channel is not vegetated but the water is a discoloured. Width of channel: 150 cm; Height of channel: 140 cm; Depth of water: 20 cm Medium flow		
B26	150090, 039309	Stennack River flowing out of the site. Mineral bottom, no vegetation in channel, discoloured water. Width of channel: 100 cm; Height of channel: 140 cm; Depth of water 25 cm Fast flow		
Bussow Reservoir B27	150107, 039017	A pipe approximately 45 cm in diameter, issues fast-flowing water from the site into the reservoir. Uncertain where the water originates, but possibly from B24.	No	No
Stream 1 and Seepage 1 B28	150141, 038684	A seepage at B28 (Seepage 1) marks the head of Stream 1. The seepage is large (approximately 200 m x 50 m) with large pools of standing water between tussocks of molinia. There is some visible flow in places.	Yes	Yes
B29	150095, 038746	At B29 the flow of the stream has increased, and the channel is clearly defined but vegetated. It is unclear whether the channel is man-made, but it does not appear to be maintained. Width of channel: 120 cm; Height of channel: 75 cm; Depth of water: 50 cm Medium flow		
Stream 2 B30	150118, 038805	Stream 2 is a small stream. The surrounding vegetation consists of molinia, heather, hummock-forming sphagnum as well as gorse, bracken and brambles. The dense vegetation precludes following the course of the stream. It is unclear whether the channel is manmade, but it does not appear to be maintained. Width of channel: 40 cm; Height of channel: 60 cm;	Yes	Yes

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
		Depth of water: 10 cm Barely visible flow		
Seepage 2 B31	150057, 038871	A seepage is visible at the break of slope in the field. The seepage is flowing into Pond 1.	No	Yes
Sinks B32	150185, 038920	An area of standing water in the trees. Accessibility constrains mean that it is hard to determine the area of standing water, but a similar area was also found 60 m north of B32. It is considered that water from Ditch 9 and 10 flow into this extensive area of woodland and dissipate into large pools of standing water.	Yes	Yes
Pond 1&2 B33	150065, 38870	Two ponds are at B33. The northern pond (Pond1) is around 10 m x 50 m. The southern pond (Pond 2) is around 10 m x 20 m. Pond 1 appears to be man-made. Pond 2 appears to be more natural, perhaps established for longer. Chemistry results are taken from Pond 1. The ponds overflow into the Stennack River. At this point the Stennack River is in a shallow channel c.50 cm in height that is not well-confined.	Yes	Limited
Pond 3 B34	150266, 038771	Man-made pond possibly fed by Ditch D9. Area is currently being landscaped and developed. Plant/digger on site and some areas seem to have been raised. Unable to access.	No	Yes – limited to northern woodland
Pond 4 B35	149950, 038486	Man-made pond with a couple of islands in the middle. The pond was dug as part of an agri-environment scheme to attract more wildlife to the land (personal communication, Mr Thomas). Clayey/fine-grained alluvium visible at water edge. Overflow pipe visible, possibly connecting the pond with Ditch D4, although the pipe cannot be seen.	Yes	Limited
Pond 5 B36	149981, 38319	Man-made pond with overflow pipe in northeast corner. Gorse and rushes at the edges of the pond.	Yes	Limited
Pond 6&7			No	Limited

Survey point	Grid ref Easting, Northing	Description	Mapped	Influence on site
B37	149979, 038150	At B37, a man-made pond for game birds has been dug to the east of the track. A pond/collects that appears to be natural is seen to the west of the track.		
Scrape B38	150132, 038836	A series of scrapes were found at B38 (these are labelled as SP3 in the main text). These appear to have been recently dug, as the ground was disturbed and had not recovered. The scrapes were holding water.	No	Limited
Wet areas B39	150007, 038614	An example of marshy ground, with a shallow pool of standing water. The standing water had no visible flow and was not connected to the Stennack River. Vegetation surrounding the pools was typical of a consistently wet area, with molinia, sphagnum mosses and rushes.	Yes	Yes