Nedern Brook Wetland SSSI Phase 1 hydrological monitoring

Geology and Landscape Wales

Open Report OR/15/038

BRITISH GEOLOGICAL SURVEY

Geology and Landscape Wales

Open Report OR/15/038

Nedern Brook Wetland SSSI Phase 1 hydrological monitoring

Gareth Farr

with contributions from Luz Ramos Cabrera

Keywords

Groundwater Dependant Wetland, Wales, Carboniferous Limestone.

Front cover

Nedern Brook Wetland SSSI in flood P83234

Bibliographical reference

FARR, G. 2016. Nedern Brook Wetland SSSI Phase 1 hydrological monitoring. *British Geological Survey Internal Report*, OR/15/038. 41pp.

British Geological Survey, Cardiff 2016

BRITISH GEOLOGICAL SURVEY

The full range of our publications is available from BGS shops at Nottingham, Edinburgh, London and Cardiff (Welsh publications only) see contact details below or shop online at www.geologyshop.com

The London Information Office also maintains a reference collection of BGS publications, including maps, for consultation.

We publish an annual catalogue of our maps and other publications; this catalogue is available online or from any of the BGS shops.

The British Geological Survey carries out the geological survey of Great Britain and Northern Ireland (the latter as an agency service for the government of Northern Ireland), and of the surrounding continental shelf, as well as basic research projects. It also undertakes programmes of technical aid in geology in developing countries.

The British Geological Survey is a component body of the Natural Environment Research Council.

British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Environmental Science Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488

email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683

email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270

Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501

www.nerc.ac.uk

Website www.bgs.ac.uk

Shop online at www.geologyshop.com

Foreword

This report contains a description of a hydrological study undertaken by the British Geological Survey (BGS) for Natural Resources Wales at the Nedern Brook Wetland SSSI, South Wales. The primary objective was to characterise one flood cycle at the Nedern Brook Wetland SSSI and answer selected recommendations made by Haskoning UK Ltd (2013).

Acknowledgements

We would like to thank the following landowners for access during the study: Mr Broome (Broome & Co), Mr DJ & R Bennett, Mr Stone, Mr TJ & GE Price, the estate of Mr Heaven and Monmouthshire County Council who part own the SSSI. David Samuel, Network Rail is thanked for provision of pumping data from the Great Spring. Dr Rob Low Rigare Ltd is thanked for provision of data and Michael Booth, Caldicot Castle for access and parking during the survey. Numerous staff at Natural Resources Wales are thanked including; Catrin Grimstead (project manager), Robert Bacon, Paul Griffiths, John Evans, Ross Adamson, Kris Tomsett, Rachel Breen, David A Jones and Richard Facey.

Contents

FIGURES

TABLES

APPENDICIES

1 Photographs of monitoring points

2 Elevation survey data

3 Field water chemistry

4 Borehole logs

5 Field maps showing extent of flooding

CD APPENDICIES

1 Hydrometric data (surface water and groundwater)

2 Elevation survey data

3 Geovisionary Landscape Visualization Video

4 Digital photographs and videos

Summary

This report provides a description of the first targeted hydrological and hydrogeological investigation at the Nedern Brook Wetland SSSI (described as ‘the wetland’) South Wales. The wetland is designated for its importance for overwintering and wading birds. The Nedern Brook – the water course that flows through the wetland from north to south is classified as a main river, however it has been heavily modified in its lower reaches. Historical alterations to the Nedern Brook, such as straightening and over deepening, have resulted in a ‘Poor’ ecological and hydrological status classification for the Water Framework Directive (WFD). This investigation collects data that has previously been absent from other studies and will support decision making in terms of management and potential restoration of the Nedern Brook to meet WFD targets.

The hydrology of the wetland and the brook are interlinked and both are heavily influenced by changing groundwater levels within the underlying aquifers. In the summer, water is only visible in the over-deepened Nedern Brook channel that flows through the wetland. In the winter, flooding from groundwater discharge along the floodplains and discrete springs and seepages contributes to the formation of a freshwater lake approximately 1.5 km in length, 1.5 m in depth, covering an area of over 30 ha.

Flooding in the Nedern Brook starts with groundwater discharge onto the floodplains rather than over-bank fluvial flooding from the Nedern Brook. The Nedern Brook is over-deepened and acts primarily as a drain, directing water away from the floodplains. During the study there was no evidence that fluvial flooding, from overtopping of the Nedern Brook, was the initial cause of flooding.

During the study there was no evidence that flow within the Nedern Brook, especially downstream of the wetland, was inhibited and on all site visits visible flow was reported from Caldicot Castle to the mouth of the brook in the estuary.

Water levels were recorded during one ‘fill and empty’ cycle between September 2014 and May 2015. Monthly field observations and detailed elevation surveys were undertaken to improve the understanding of the flooding mechanisms in the wetland and to identify areas where groundwater discharge enters the wetland, contributing to flooding.

Spot gauging to calculate flow within the Nedern brook was undertaken both above and below the SSSI. The flow measurements show that there is a greater volume of water in the Nedern Brook downstream of the wetland (outflow) than there is upstream of the wetland (inflow). This difference, which can be as much as 225 l/s in January 2015, can be attributed mainly to groundwater discharge into the wetland area, although direct rainfall and other surface water inputs are likely to contribute to the flood waters. Further work is needed to translate existing river stage data and spot gauging data into stage discharge curves.

Further north of the wetland the Nedern Brook loses its water both to a discrete sink at a location called the ‘Cwm’ and it continues to do so along its course towards the M48 road bridge. The concrete lined channel installed by Victorian engineers, in an attempt to reduce water inflow into the Severn Tunnel, is reported to be in poor condition and ineffective in retaining water in the brook.

1 Introduction

The Nedern Brook Wetlands Site of Special Scientific Interest (SSSI), referred to from here on as 'the wetland' to avoid confusion with the Nedern Brook water course, was first notified in 1988 and covers 44.5 ha of the lower Nedern Brook and its adjacent floodplain. It is owned by both private land owners and Monmouthshire County Council. The wetland was designated as a SSSI for its importance to wading and overwintering birds including redshank, wigeon, and Bewicks swan. There are also populations of breeding birds including lapwing, shelduck and yellow wagtail (Countryside Council for Wales, 1988).

Although the site is designated for its bird interest, the hydrology is just as important as the wetland is subject to seasonally controlled groundwater flooding, creating a temporary freshwater lake about 1.5 km long. The bird populations are only supported when there are flood waters in the wetland, thus understanding of the mechanisms of flooding will enable better management of overwintering wading bird populations.

The Nedern Brook is a complex and heavily modified channel, which has been straightened and over-deepened along its course, however some remnant meanders can still be seen in the floodplain (River Restoration Centre, 2012). Natural Resources Wales (NRW) has identified the lower Nedern Brook as a main river that has poor water quality, ecology and hydrology in terms of its Water Framework Directive (WFD) classification. When a main river is considered at poor status, NRW are required to investigate options to improve the water course.

The Nedern Brook is classified as a main river however it has no permanent gauging stations or historic spot gauging data from which to characterize its flow. The lack of hydrological data coupled with the extensive and complex flooding regime have historically led to uncertainties in terms of flood prediction and modelling (Atkins, 2012) and options for river restoration (River Restoration Centre (2012) and Haskoning UK Ltd (2013).

The wetland is not always in a state of flood and thus understanding the mechanisms and duration of flooding and influence of groundwater are vital to support future management decisions. This may include a better understanding of the duration that the wetland can support wading bird populations based on the known flood duration of the wetland.

The wetland also lies within the Source Protection Zone (SPZ) for the 'Great Spring' (Lawrence et al 2013). The Great Spring is the name given to the large dewatering operation for the Severn Railway Tunnel (see Walker, 1888). Since 1887 groundwater has been continually pumped out of the underlying Carboniferous Limestone aquifer to reduce the risk of flooding within the Severn Tunnel. The wider impact of the dewatering and resultant lowering of the groundwater table is unknown as is its effect on the flow regime within the Nedern Brook. Connections with water loss from the Nedern Brook and the Great Spring have been known since the 1880's and in a desperate bid to reduce the amount of water entering the tunnel during construction Walker ordered his men to concrete 4 km of the Nedern Brook, large sections of which are still visible today. Drew et al (1970) proved this connection using tracers injected at a known sink located on the Castrogi Brook called the 'Cwm' and detecting them again at the Great Spring.

This report represents the first attempt to characterise the hydrology of this wetland using new surface water and groundwater data.

2 Scope of project

This project aims to provide hydrological and hydrogeological monitoring data to address some key recommendations from Haskoning UK Ltd (2013). In black are the proposed actions and in red the work undertaken.

- Set up two monitoring locations on the Nedern Brook for collection of stream stage (level) and flow data; one in the vicinity of the Tyne Cottage observation borehole and another downstream of Caldicot Castle, potentially within the country park. This would enable surface water flows through the study area to be recorded, providing a key data input for the scheme design. Positioning of the gauges in proximity to existing groundwater observation boreholes will enable interactions between groundwater and surface water to be quantified.

  New water level data has been collected from three stilling wells in the Nedern Brook. Groundwater level data collected from one piezometer and collated from NRW boreholes and the Great Spring. Gauging has been undertaken in the Nedern Brook to allow stage-discharge calculations to be calculated in the future.

- Undertake site visits to survey water levels and undertake groundwater and surface water monitoring.

  Monthly monitoring visits between November 2014 and May 2015 were used to observe the flooding regime, check monitoring equipment, undertake repeat photography of key areas, field water chemistry readings and survey of water levels to maOD (or manual reading of groundwater levels using a 'dip' tape). A sketch map of the extent of flooding was made during each field visit.

- Flow within the Nedern Brook to be visually checked from the Castrogi Brook at the Cwm (north of Caerwent ST 45875 92739) to the mouth of the Nedern (ST 48985 87258).

  Flow within the Nedern Brook was observed during each site visit.

- Undertake a site walkover along the reach of the Nedern Brook that was lined with concrete, noting the condition of the concrete and areas where cracks are visible or the concrete is missing.

  Details are provided from a recent survey undertaken in 2012 for Environment Agency Wales.

- Creation of a 3D Visualization of the Nedern Brook to be used as a tool to engage landowners and members of the public with the monitoring work and flood pattern of the Nedern SSSI. Create 2D flood depth maps to illustrate the maximum and mean flood conditions.

- Provision of scanned field notes and Survey data in Appendix
- Provision of all hydrological data in excel format
- Provision of all digital photographs and videos

  Provided in the CD appendix

3 Monitoring

Monthly monitoring visits were undertaken between October 2014 and May 2015. Observations on the brook and the wetlands were made from the ‘Cwm’ in the north to its mouth in the Bristol Channel (Figure 2). Information on the location of key groundwater discharge areas was also collected. Detailed survey elevations were collected from repeatable locations near all water level data loggers in both the dipwells and the stilling wells in the brook (Appendix 2).

3.1 SURFACE WATER

Spot flow gauging was undertaken by Paul Griffiths, John Evans, Ross Adamson and Kris Tomsett staff from Natural Resources Wales’ Hydrometry & Telemetry Team, South East Wales. Spot flow gauging was undertaken at three sites on the Nedern Brook (Table 1, Figure 2, Figure 3) during low, medium and high flow conditions using a Sontek M9 ADCP (Figure 1). The sites represent inflow to the top of the SSSI (‘Nedern Brook at Tyne Cottages’) and outflow (Nedern DS and Nedern Castle Car Park).

Stilling wells were installed at the start of the project at two locations called Nedern Brook US and DS (Figure 2). Later on, in January 2015, an additional stilling well was installed further up the Nedern Brook underneath the bridge near Tyne Cottages to complement the spot gauging and to allow for stage-discharge relationships to be calculated in the future. Due to this stilling well being installed part way through the project the data from this site only covers part of the study period.

Surface water gauging was also attempted within the SSSI boundary at the small tributary (ST 48654 89452) and at the ‘Nedern US’ monitoring point (ST 48427 89489). However both were ruled out for further monitoring due to access. Both sites can be entirely flooded and conversely experience extremely low flow velocities during dry periods.

Visual observations of surface water flow were undertaken during the monthly monitoring visits, starting upstream on the Castrogi Brook ‘Cwm’ where the surface water is known to sink and has been traced to the Great Spring (Drew et al 1970, Clarke & Aldous, 1987 and Lawrence et al, 2013). The Nedern Brook was observed throughout the SSSI section and then south through the industrial estate to the outflow.

3.2 GROUNDWATER

Groundwater levels in the bedrock Carboniferous Limestone aquifer are monitored at boreholes installed by Natural Resources Wales at Caldicot Castle Car Park, Tyne Cottages, Five Lanes and Dewstone Road (Figure 2, Table 1, Appendix 4). Each borehole is instrumented with a vented pressure transducer recording changes in groundwater levels every 30 minutes with the data corrected to maOD. To complement the groundwater level data within the Carboniferous Limestone aquifer a non-vented Solinst Level logger™ with a 10 m range was installed in Piezometer P3 monitoring the shallow clays and peats within the wetland (Figure 2, Figure 3). It was not possible to dip P3 during the majority of the study as it was fully submerged by flood waters.

3.3 PRECIPITATION

Precipitation data on a 15 minute basis was provided by Natural Resources Wales from weather stations at Collister Pill and Llanvaches, the data was then converted to daily total (mm).

3.4 ELEVATION SURVEY AND FLOOD MAP

Dipwells, piezometers and stilling wells were surveyed to maOD using a Leica Smart Rover CS10/CS15 & GS 14 Sensors, capable of surveying elevation to an accuracy of <5 cm. Flood levels of the Nedern Brook were also surveyed on a monthly basis to allow for corrections of the water level data loggers installed within the flooded area (Nedern US, Nedern P3 and to a lesser extent Nedern DS). The survey data is included in Appendix 2. The water level data and survey data were combined, and the maximum and mean flood values were input into ArcView, with the 1m LIDAR data for the area. The LIDAR was 'flooded' in order to create two flood maps.

3.5 WATER CHEMSITRY

Water chemistry sampling was undertaken in Dec 2015, with samples collected from the Nedern Brook and flood waters. The samples were analysed at the Environment Agency National Labs. Due to the flood levels it was not possible to sample groundwater directly from the Piezometers, or from discharge from the Whirly Holes, both of which were under water. Field observations of temperature, pH and electrical conductivity were collected during site visits on the 18th December 2014 and 16th January 2015 using a Hannah HI98312 hand held temperature and electrical conductivity meter with an accuracy of ±2% for electrical conductivity and ±.5ºC for temperature. Results for the field parameters are presented in Appendix 3, and the ion analysis in Table 3.

3.6 GENERAL OBSERVATIONS

During each site visit a sketch map was made of the extent of flooding (Appendix 5). Observations on the flow of water in the Nedern Brook were made from the Castrogi Brook 'Cwm' monitoring point upstream to the outflow into the Bristol Channel.

Figure 1 Flow gauging at 'Nedern DS' using a Sontek M9 ADCP view south (Photograph with permission of Hydrometry & Telemetry Team South East Wales, Natural Resources Wales)

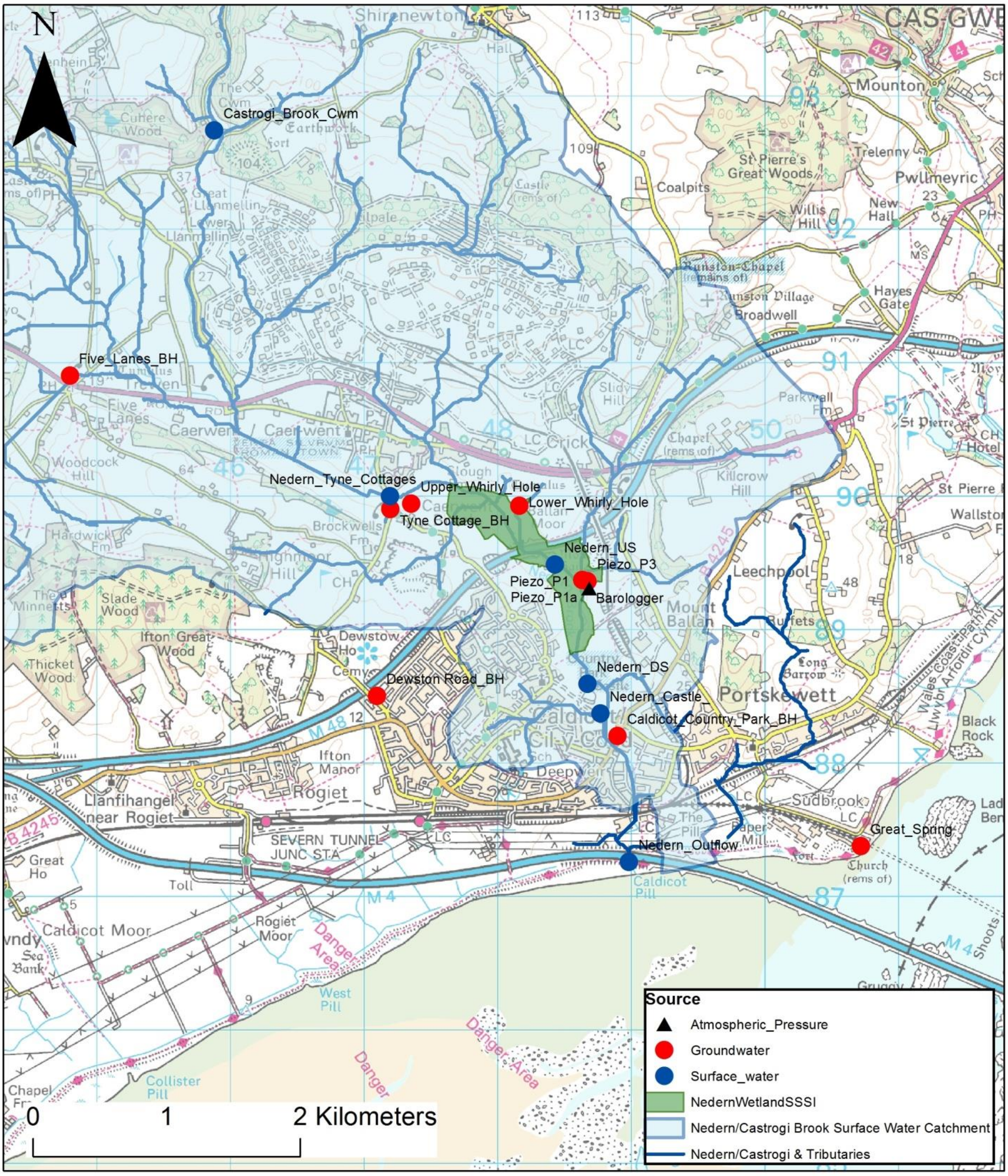


Figure 2 Hydrometric Monitoring Locations within the Nedern Brook catchment. Contains Ordnance Survey data © Crown Copyright and database rights 2015.

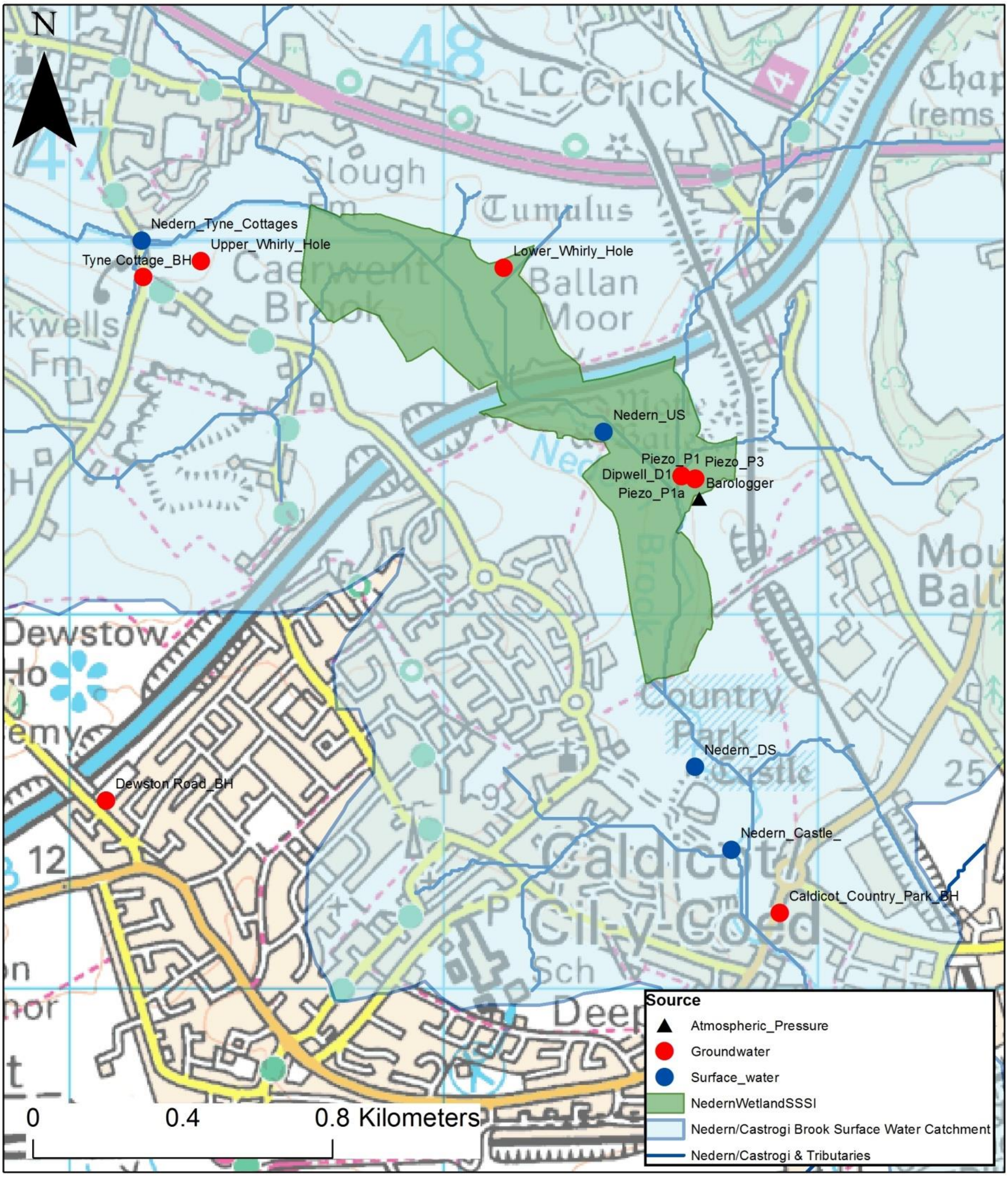


Figure 3 Hydrometric Monitoring Locations within the Nedern Brook Wetland SSSI catchment. Contains Ordnance Survey data © Crown Copyright and database rights 2015.

Monitoring Point	Source	Type	Method	Depth (mbgl)	Response Zone (mbgl)	Frequency	Easting	Northing
Dipwell DW2	Groundwater	Dipwell	Manual Dip	0.86	0-0.86	60 minutes	348674	189360
Piezo P3	Groundwater	Piezometer	Data logger	1.78	1.815-2.115	Monthly	348675	189361
Dipwell D1	Groundwater	Dipwell	Manual Dip	0.76	0-0.76	Monthly	348638	189368
Piezo P1a	Groundwater	Piezometer	Manual Dip	2.265	1.965-2.265	Monthly	348638	189368
Piezo P1	Groundwater	Piezometer	Manual Dip	3.07	2.77-3.07	Monthly	348638	189369
Barologger	Atmospheric Pressure	Barologger	Data logger	n/a	n/a	30 Minutes	348685	189307
Nedern US	Surface water	Surface water	Data logger	n/a	n/a	30 Minutes	348430	189486
Lower Whirly Hole	Groundwater	Spring / rising	Visual	n/a	n/a	Monthly	348163	189925
Upper Whirly Hole	Groundwater	Spring / rising	Visual	n/a	n/a	Monthly	347354	189943
Caldicot Country Park BH	Groundwater	NRW Observation Borehole	Data logger	70	56-70	30 Minutes	348900	188200
Five Lanes BH	Groundwater	NRW Observation Borehole	Data logger	55	22-55	30 Minutes	344800	190900
Tyne Cottage BH	Groundwater	NRW Observation Borehole	Data logger	65	17-65	30 Minutes	347200	189900
Dewston Road BH	Groundwater	NRW Observation Borehole	Data logger	60	5.1-60	30 Minutes	347100	188500
Great Spring	Groundwater	Abstraction Monitored by Network Rail	Abstraction Monitored by Network Rail		n/a	Daily	350721	187374
Nedern at Tyne Cottages	Surface water	Nedern Brook	NRW Spot Gauging and Data logger	n/a	n/a	30 Minutes	347195	189997
Nedern DS	Surface water	Nedern Brook	NRW Spot Gauging and Data logger	n/a	n/a	30 Minutes	348674	188591
Nedern Castle Car Park	Surface water	Nedern Brook	NRW Spot Gauging and Data logger	n/a	n/a	30 Minutes	348771	188369
Nedern Outflow	Surface water	Nedern Brook	Visual	n/a	n/a	Monthly	348985	187258
Castrogi Brook Sink at the ‘Cwm’	Surface water	Castrogi Brook	Visual	n/a	n/a	Monthly	345879	192739

Table 1 Monitoring points and monitoring frequency

4 Results and discussion

4.1 SURFACE WATER AND GROUNDWATER

Prior to this study the absence of hydrometric data, including flow and flood levels, for the Nedern Brook had resulted in uncertainties for, flood prediction and modelling (Atkins, 2012) and potential options for river restoration Haskoning UK Ltd (2013). The paucity of hydrometric data was highlighted as the **'most significant data gap'** by Haskoning UK Ltd (2013). It is this lack of data on the Nedern Brook that data within this survey is hoping to address.

4.1.1 Surface water spot gauging

Spot gauging results (Table 1 Table 2Table 2 Flow gauging in the Nedern Brook) show that temporal variations in flow can range from 0.086 to 0.256 m^3/s (Nedern at Tyne Cottages Bridge upstream of the wetland) to 0.151to 0.481 m^3/s downstream of the wetland (Nedern DS). The difference between the upstream (Nedern at Tyne Cottages) and downstream monitoring points (Nedern DS) can reach 0.255m^3/s (31st Jan 2015). The difference in flow is related to additional discharge into the wetland from either groundwater discharge onto the floodplain, baseflow to the brook, surface water from small tributaries, field/surface drains and direct precipitation. It is proposed that the majority of this additional flow originates from groundwater that discharges into the wetland from discrete inflows such as the Upper and Lower Whirly Hole or across more diffuse areas where groundwater upwells onto the floodplain or where it can be seen discharging from bedrock outcrop. To better understand the additional contribution into the wetland area future work should focus on forming a stage discharge relationship between the stage at the DS gauging station spot gauging in the brook.

SITE	NGR	Date	Time	Flow m^3s^{-1} (cumecs)	Date	Time	Flow m^3s^{-1} (cumecs)	Date	Time	Flow m^3s^{-1} (cumecs)
Nedern at Tyne Cottages Bridge	ST 47199 89998	30/11/2014	10:10	0.193	06/12/2014	10:10	0.086	31/01/2015	10:34	0.256
Nedern US	ST 48427 89489	30/11/2014	11:15	not possible	06/12/2014	11:15	0.083	not possible	n/a	n/a
Small trib	ST 48654 89452	30/11/2014	11:55	not possible	06/12/2014	11:55	0.042	not possible	n/a	n/a
Nedern DS	ST 48676 88593	30/11/2014	12:30	0.289	06/12/2014	12:30	0.151	31/01/2015	12:30	0.481
Nedern Castle Car Park	ST 48771 88369	30/11/2014	13:40	0.319	06/12/2014	13:40	0.138	31/01/2015	12:50	0.473

Table 2 Flow gauging in the Nedern Brook

4.1.2 Base flow index

Base flow is the percentage of water in a stream or river that is not derived from surface runoff, and high base flow values indicate a strong groundwater control. A modelling exercise (Atkins, 2012) estimated BFI-HOST (base flow index values using the HOST soil classification) values of between 0.677 and 0.739% suggesting that flow within the Nedern comprises of 68 – 74% baseflow from discharging groundwater. Although there was no hydrometric data to base this upon the assumption that BFI is high is not disputed and could provide an explanation for the observed increase in flow upstream and downstream of the Nedern SSSI.

4.1.3 Precipitation

Rainfall data was supplied from NRWs monitoring points at Collister Pill and Llanvaches as 15 minute data converted into daily totals. No on site data was collected as part of this project.

4.1.4 Observations on the influence of the Nedern Brook during flood events

During each site visit observations were made on both water levels in the wetland and in the Nedern Brook. The key observation is that the over deepened Nedern Brook acts as a drain, taking flood waters away from the adjacent floodplain. Flooding does not appear to be of ‘fluvial flooding’ type and does not initiate from over topping of the Nedern Brook. Evidence for this can be seen in numerous locations, throughout the wetland, both above and below the M48 road bridge. Drains installed into the river banks (Figure 4) to take water from the floodplains into the brook, were further evidence that flooding initially occurs on the floodplain and then drains into the Nedern Brook.

The second key observation was that, during the flood period, flow was observed in the Nedern Brook below the wetland area all the way to its mouth in the Bristol Channel. This flow observed in the brook is evidence that during this study, water was actively draining from the wetland area, and was not impeded. The monitoring period could be considered relatively dry and 2014-2015 was certainly not a winter of excessive rainfall when compared the stormy weather of the previous winter (MetOffice Winter 2014/15 summary). Flow conditions and the likelihood of impeded flow within the Nedern Brook have not been observed during more prolonged wet periods.

Figure 4 Flooding initiated on the banks and floodplains drains into the Nedern Brook (P915242) © BGS NERC.

4.1.5 Observations on groundwater discharge

During the walk over surveys it was possible to observe areas where groundwater was discharging into the wetland, the key areas are illustrated on Figure 5. The Lower Whirly Hole was actively discharging groundwater for most of the monitoring period and during recession other small seepages and springs appeared nearby. The electrical conductivity of the spring water was 580 - 670 µs/cm, indicative of groundwater. A large spring head/seepage area can be found in a woodland area just to the north of the Lower Whirly Hole however it was only actively discharging water during very high flood levels, remaining dry for the majority of the monitoring period.

The Upper Whirly Hole remained dry for the majority of the monitoring period only becoming flooded during January-February 2015. It is associated with a spring head, near the large Oak Tree and is also in very close proximity to the Tyne Cottages NRW monitoring borehole. On a previous visit in 2012 groundwater could be seen seeping upwards through the very sandy soil near the Upper Whirly Hole.

To the south of the M48 road bridge an outcrop of Carboniferous Limestone occurs between ST 48365 89487 and ST 48211 89555. This appears to be an important area for groundwater discharge into the wetland (see video in Appendix). The electrical conductivity of the water was measured at 740 µscm, indicative of groundwater from the Carboniferous Limestone. Flow across this area was estimated in a small channel draining into the Nedern Brook at 10 l/s (18.3.2015) however the true volume of groundwater seepage across this area is likely to be much greater. Eventually the water is intercepted by the channelised Nedern Brook to the east flowing through the remainder of the wetland.

Diffuse areas of groundwater discharge occur across the floodplains of the wetland and are most notable to the north of the M48 road bridge near ST 4787 8989 but also occur south of the bridge in areas centred at ST 4844 8952, ST 4872 8940 and ST 4829 8953.

4.1.6 Groundwater and flood levels in the Nedern Brook Wetland

Groundwater in the underlying Carboniferous Limestone aquifer is monitored by NRW as part of routine monitoring within the Great Spring Source Protection Zone (SPZ). The general overall trend of groundwater levels (Figure 6) within the limestone aquifer is very similar. There is a significant groundwater abstraction at the ‘Great Spring’, located about 2 km to the south east. The Great Spring is a dewatering operation to keep the Severn Tunnel from flooding. It is monitored by Network Rail (Figure 6). Pumping at the Great Spring has to respond to increasing groundwater levels in order to maintain groundwater at a set level within the tunnel and thus also shows a similar trend to the groundwater hydrographs. Figure 6-A illustrates groundwater levels in the Caldicot Country Park borehole, during September when groundwater levels are <0 maOD. Groundwater levels would not normally be <0 maOD under natural conditions and it is prosed this is a dewatering effect of the Great Spring. Small changes in the same hydrograph (Figure 6-B) are also possible responses to pumping at the Great Spring. The Tyne Cottages borehole, Figure 6 C, is geographically closest to the wetland and has a range of nearly 6 m.

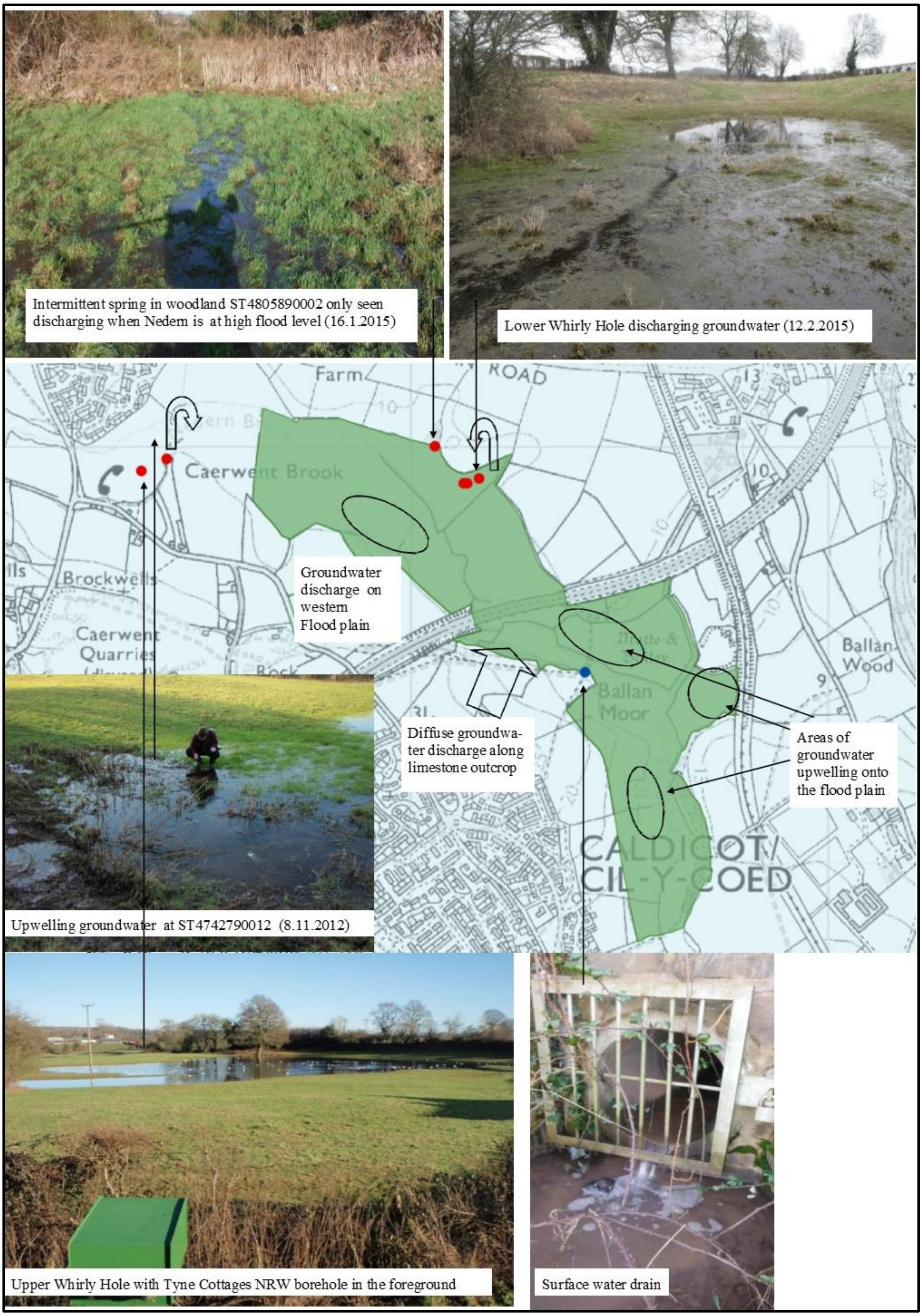


Figure 5 Key groundwater and surface water discharges in the Nedern SSSI (P502171, P915237, P915234, P915243). © BGS NERC.

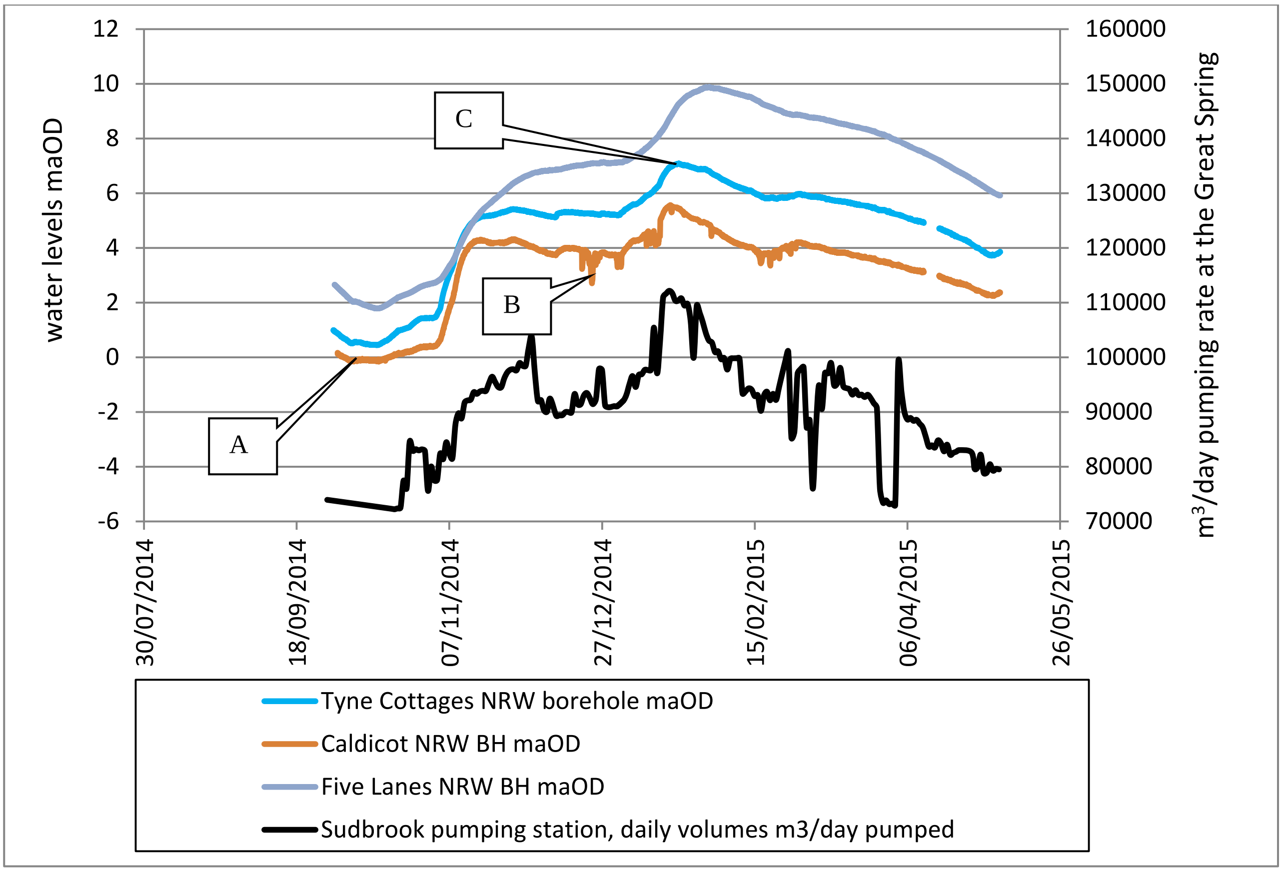


Figure 6 Groundwater levels in the Carboniferous Limestone aquifer compared to pumping rates at the Great Spring

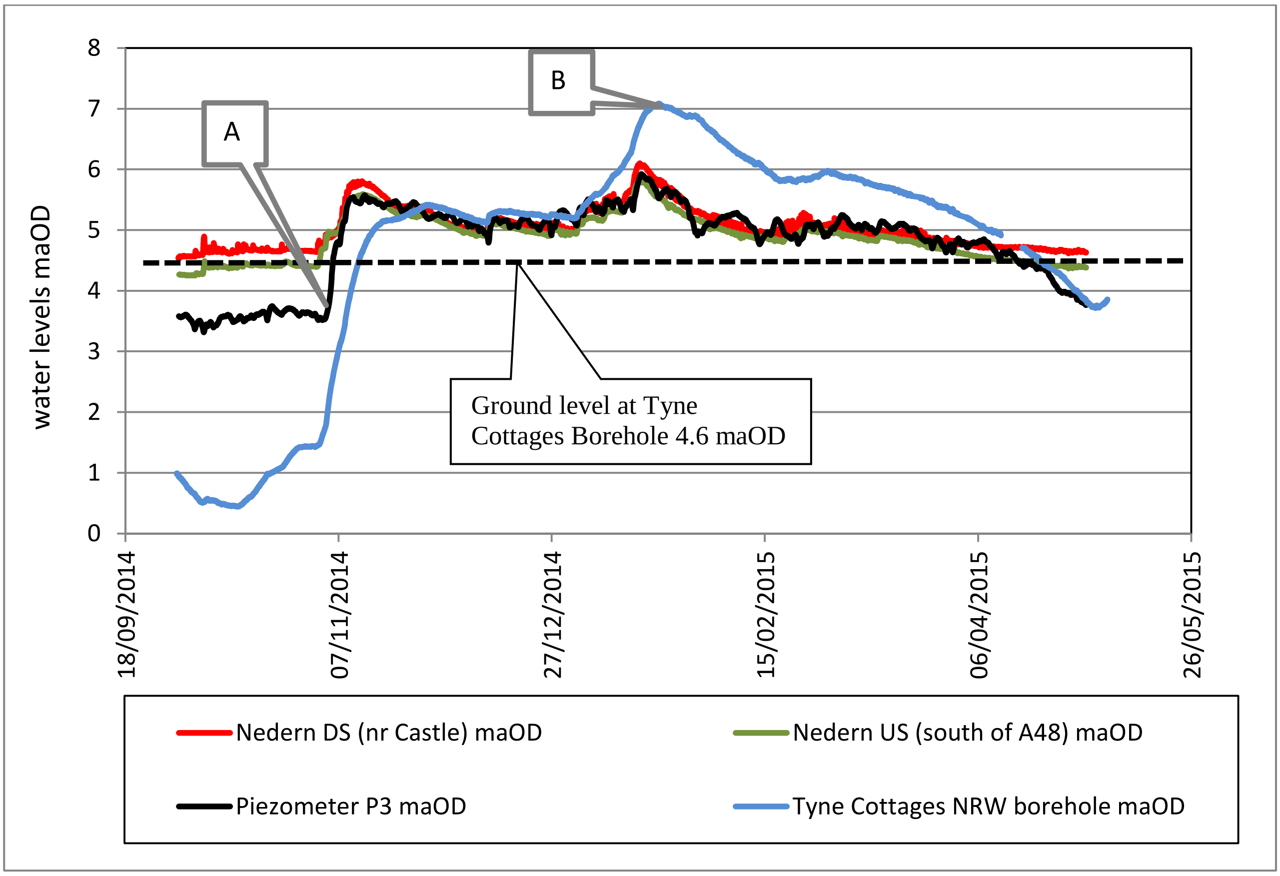


Figure 7 Groundwater and surface water levels in the wetland.

Groundwater levels recorded from a piezometer 'P3' located within the wetland are plotted against surface water levels collected from the stilling wells on the Nedern Brook and groundwater levels from the NRW Tyne Cottages borehole(Figure 7). Tyne Cottages is the closet bedrock borehole to the wetland that monitors the underlying Carboniferous Limestone aquifer (Figure 7). The ground level near the dipwells and piezometers, approximately 4.6 maOD, is marked by the black dashed line (Figure 7 and Figure 8). The rapid rise in groundwater levels within the limestone aquifer, in response to precipitation, is reflected by a rise in Piezometer P3 (Figure 7 A) and also the stage readings within the Nedern Brook US and DS monitoring points. During the flooding period the piezometric head in the limestone aquifer (Tyne Cottages borehole) is lower than that of the flood water in the wetland suggesting that there is a limited vertical movement of groundwater from the limestone during the initial flooding period. This could highlight that springs and seepage from shallower sources such as the River Terrace Gravels (which are not instrumented) are in part responsible for initial flooding within the wetland. However in late November the piezometric head in the limestone aquifer reaches 7 maOD (Figure 7 B), higher than the ground level within the wetland and greater than the flood waters within the wetland, suggesting that vertical flow of water upwards into the wetland might be possible if a low permeability pathway (such as a sand or gravel horizon) exists. The flood depth reaches about 1.5 m in the vicinity of the dipwell and piezometer nests and covers an area of over 30 ha (see Appendix 5 field maps for the 1st January 2015).

Precipitation at Collister Pill gauging station is compared to groundwater levels in the Carboniferous Limestone (Tyne Cottages Borehole) and flood levels in the Nedern wetland, Piezometer P3 (Figure 8). The black dashed line represents ground level within the wetland next to the peizometer, and not at the Tyne Cottage borehole. It is clear that flooding in the Nedern Wetland occurs before the piezometric head in the limestone aquifer is great enough to cause surface flooding (Figure 8 A), suggesting either an input from another source such as the overlying river terrace gravels or impediment of downwards flow by low permeability infill within the Nedern Brook Wetland.

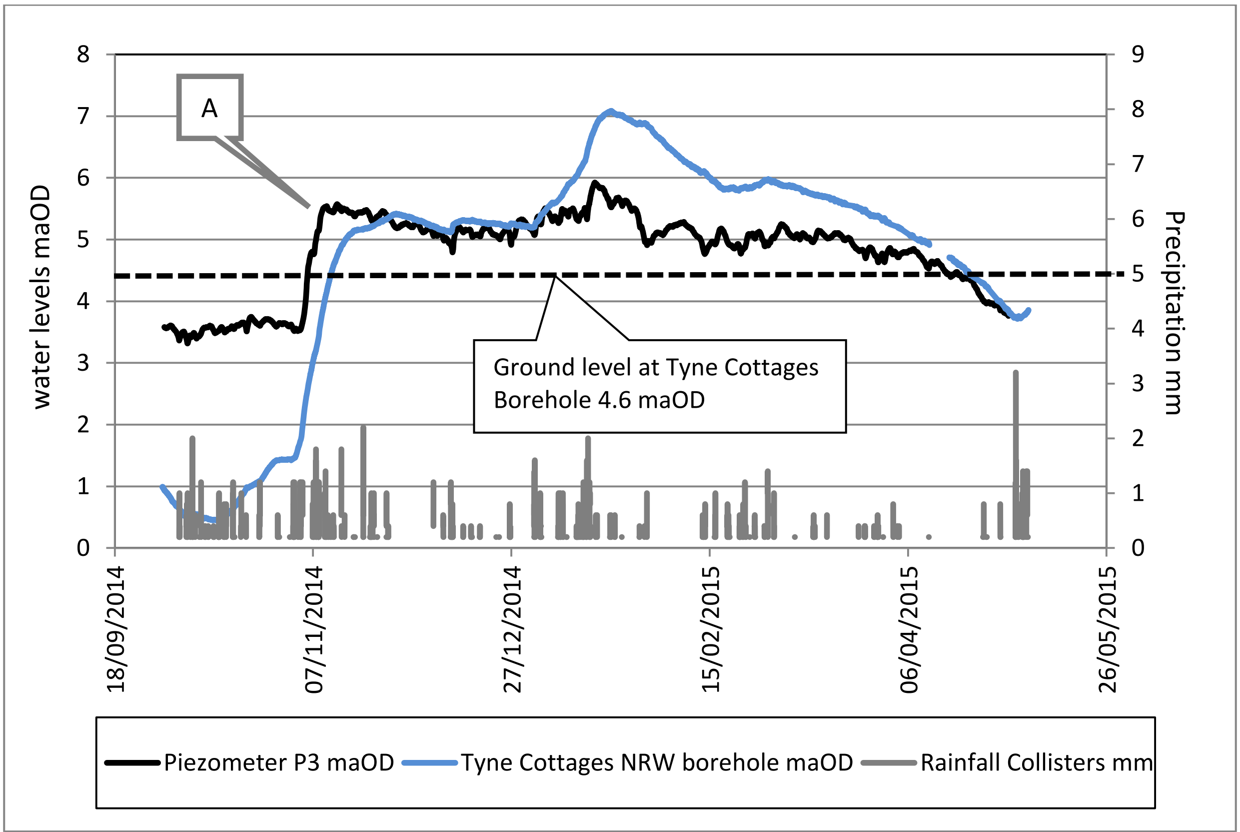


Figure 8 Rainfall compared to flood depth in the wetland (P3) and groundwater levels in the Carboniferous Limestone (Tyne Cottages).

4.1.7 Flood depth maps

The following flood depth maps were produced to illustrate the maximum and mean flood depths during the monitoring period (Figure 9; Figure 10). The existing and historic meanders of the Nedern Brook are clearly visible, the deeper areas tend to be those that flood first and retain water longest.

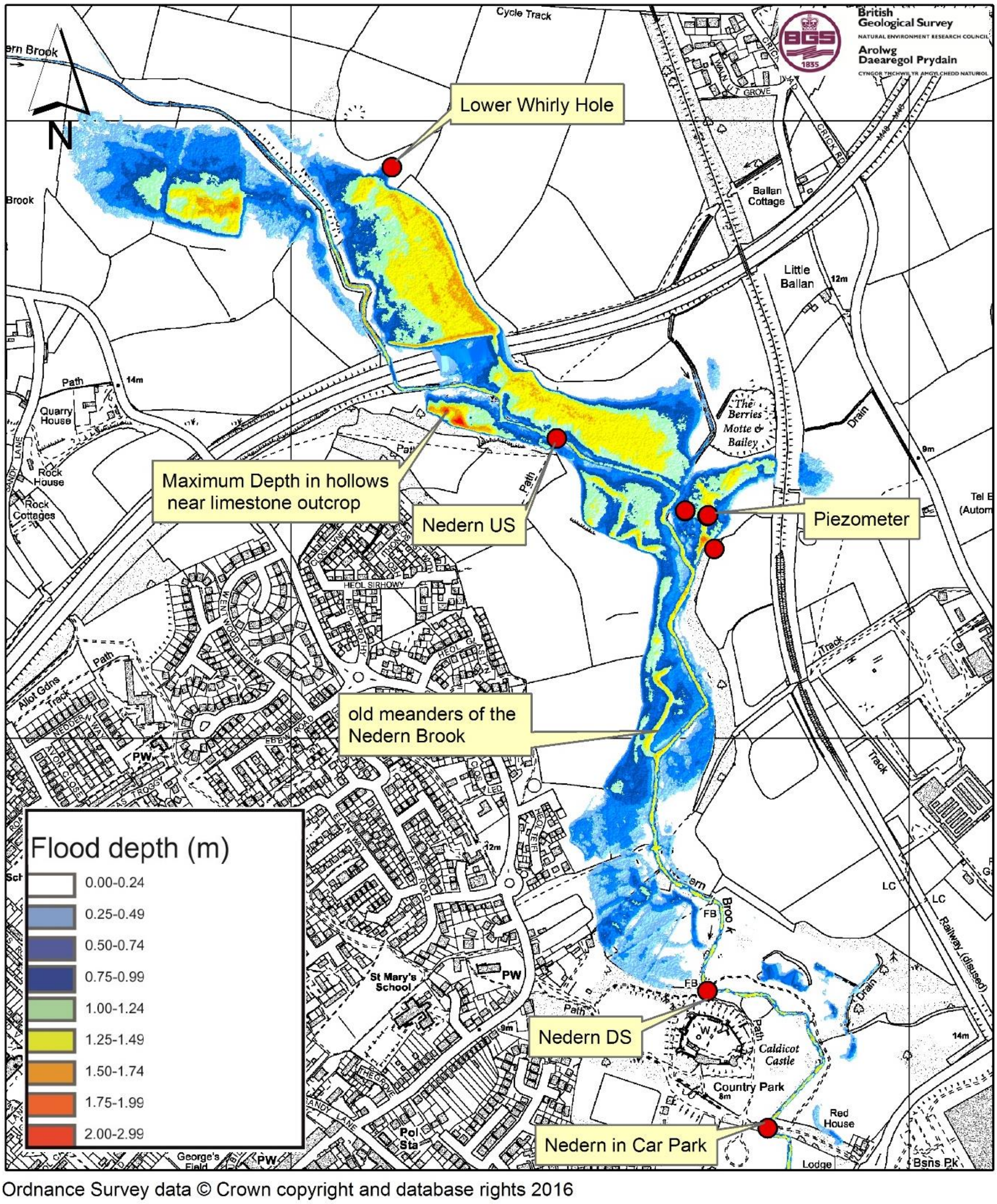


Figure 9 Maximum Flood levels based on 5.92maOD elevation of maximum flood depth between 30/09/2014 and 1/05/2015

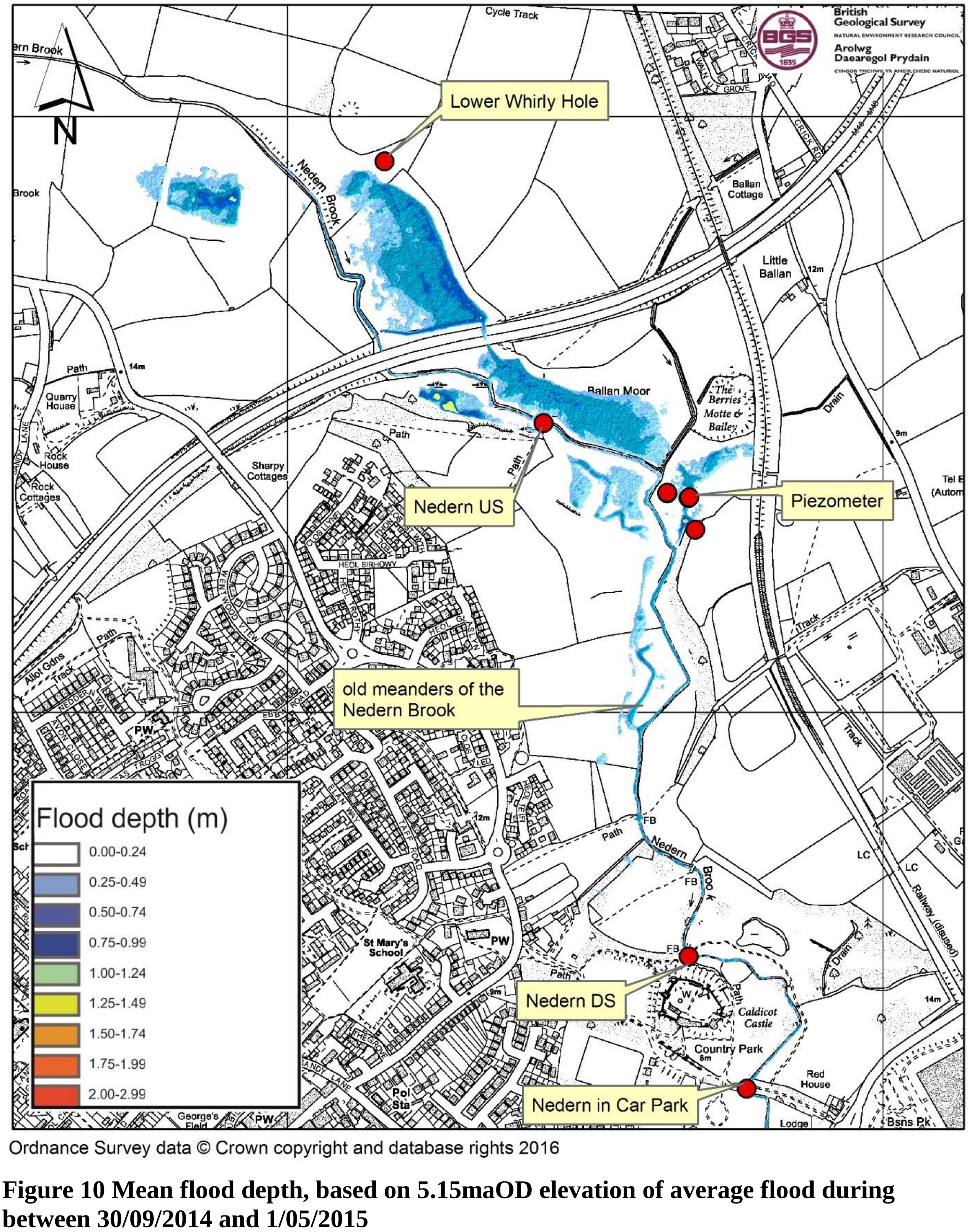


Figure 10 Mean flood depth, based on 5.15maOD elevation of average flood during between 30/09/2014 and 1/05/2015

4.1.8 Groundwater chemistry

The groundwater chemistry provides only a snapshot of the ionic composition of the water in the brook and in the flood waters during December 2015. Due to the flood waters it was not possible to sample directly from the piezometers or dipwells, nor from the discharge from the Whirly Holes. Samples from the Great Spring abstraction are provided, to illustrate the composition of groundwater from the Carboniferous Limestone aquifer (Table 3 Figure 11).

Calcium bicarbonate dominates the water types, however the Great Spring outflow, that represent groundwater from the Carboniferous Limestone aquifer, has higher levels of sulphate especially when sampled at the outflow to the River Severn. The groundwater from the Great Spring is more mineralised that the waters in the Nedern Brook and the wetland, however this could representative of a longer residence time of groundwater within the Carboniferous Limestone aquifer before it reaches the Great Spring. In the upper part of the Nedern Brook (nr Caldicot Castle) nitrate (5.45mg/l) concentrations reflect that of local groundwater in the Great Spring (5.61mg/l), which may reflect the high amount of baseflow that the upper course of the brook receives from the underlying limestone aquifer. The effects of dilution, from direct precipitation or from groundwater from the river terrace gravels are not understood.

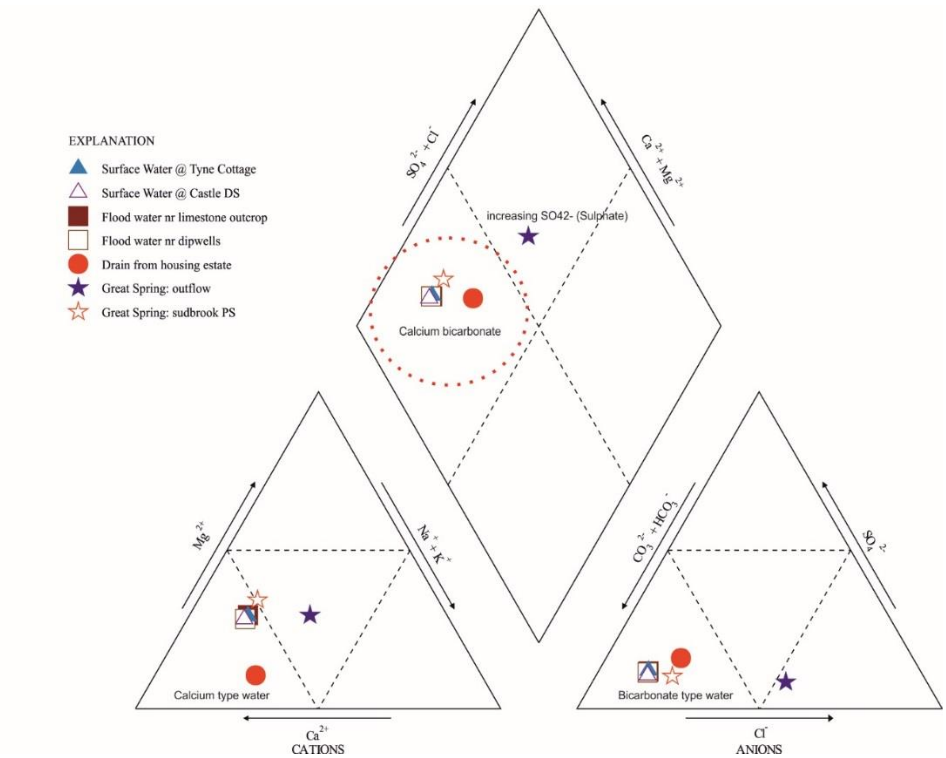


Figure 11 Major ions of water samples taken from Table 1, shown in a 'Piper Trilinear Diagram'. Most samples are of $CaHCO_3$ type as highlighted by the red dashed circle in the upper triangle.

Location		Nedern Brook at Tyne Cottage	Nedern Brook nr Castle	Flood water nr limestone outcrop	Flood water near dipwells	Surface drain from housing estate	Great Spring: Outflow	Great Spring: Sudbrook Pumping Station
Date		10-Dec-2015	10-Dec-2015	10-Dec-2015	10-Dec-2015	10-Dec-2015	30-Sep-2014	22-Oct -2014
Time		12:42	10:48	12:03	10:24	11:47	12:12	15:45:00
Type		Surface water	Surface water	Flood water	Flood water	Drain	Groundwater	Groundwater
NRW 'WIMS' Code		660078	660078	660078	660078	660078	51260	48420
E		347190	348674	348293	348658	348415	350838	350701
N		190000	188592	189500	189270	189460	187472	187431
Temp	oC	9.9	8.6	9.3	8.6	11.2	13.4	11
EC @25oC	uS/cm	236.2	255.3	236.8	273.8	178.9	1177	825
Ammoniacal Nitrogen as N	mg/l	<0.03	0.04	0.07	0.039	<0.03	<0.03	<0.03
Nitrogen Total Oxidised as N	mg/l	2.42	5.47	1.70	2.04	0.80	5.61	5.50
Nitrate as N	mg/l	2.42	5.45	1.69	2.02	0.78	5.61	5.50
Nitrite as N	mg/l	<0.004	0.017	0.009	0.016	0.027	0.004	<0.004
Hardness as CaCO3	mg/l	103	114	103	124	52.8	403	374
Alkalinity as CaCO3	mg/l	89.8	97.7	89.1	106	46.5	290	282
Chloride	mg/l	11.8	12.6	11.8	13.8	10.6	283	61
Orthophosphate reactive as P	mg/l	0.021	0.07	0.029	0.104	0.12	0.039	<0.0.2
Sulphate as SO4	mg/l	13.7	14.3	13.8	14.2	11.2	60.1	41
Phosphate TIP	mg/l	0.0339	0.0807	0.0418	0.123	NR	NR	32
Sodium	mg/l	7.76	8.23	7.72	8.72	7.73	90.5	32.0
Potassium	mg/l	2.02	2.61	2.19	3.08	2.5	4.88	2.6
Magnesium	mg/l	8.77	9.36	8.75	10.1	1.85	44.1	37.1
Calcium	mg/l	26.7	30.3	26.9	32.9	18.1	92.2	88.1
pH in Situ	pH	7.93	7.31	7.54		7.67	7.58	7.5
Manganese	ug/l	22.2	11.6	<10	14.5	33.2	<10	<10
Iron	ug/l	117	116	72	189	66.4	34.6	<30
Manganese Dissolved	ug/l	<10	<10	<10	<10	24.8	<10	<10
Iron Dissolved	ug/l	<30	51.6	<30	75.1	<30	<30	<30
Ionic balance	%	-2.85	-5.04	-1.38	-0.324	-2.13	-11.3	1.7
Bicarbonate as HCO3	mg/l	110	119	109	129	56.7	354	344
Oxygen Dissolved %	%	106	89.9	72.8	84.7	92.8	104.5	90.8
Oxygen Dissolved as O2mg/l	mg/l	12	10.5	8.34	9.87	10.2	10.9	<0.02

Table 3 Water chemistry analysis from the Nedern Brook SSSI (wetland), Nedern Brook (surface water) and the Great Spring (groundwater). All data stored and accessible on the Natural Resources Wales 'WIMS' database.

4.2 SITE WALKOVER OF THE NEDERN BROOK CONCRETE LINED CHANNEL

The concrete river channel was installed to minimise water loss to ground and to reduce flow to the Great Spring. It was constructed in just a few months between August and October 1883, (Walker, 1888). The channel was constructed on the upper part of the Nedern Brook from the Cwm (ST4591093175) and Rodge Farm (ST4609509461) for a distance of 3 km. There are no concrete sections within the wetland SSSI boundary. Haskoning UK Ltd (2013) recommended that a survey was undertaken to assess the state of the concrete channel. Although this was not done during this project a similar survey had been undertaken for Environment Agency Wales as part of the Great Spring work (Lawrence et al 2013). The survey showed that the concrete channel was still visible over much of the original 3 km reach however the concrete bed 'is now in a poor state of repair and it is considered unlikely to prevent recharge to the aquifer from the Castrogi or Nedern Brooks'(Lawrence et al 2013). The Nedern Brook is known to have a discrete sink at the 'Cwm' (Figure 12) and will also dry up along much of its lower reach (Figure 13).

Figure 12 Nedern Brook sinking to the base of the river, at the Cwm (1.5.2015). The concrete river channel is still visible however it does not restrict the water from sinking to ground. (P915235) © BGS NERC.

Figure 13 Nedern Brook (dry) looking south towards the M48 road bridge 1st May 2015. © BGS NERC. P917085.

4.3 CLASSIFIACATION

The classification of the Nedern Brook Wetlands SSSI is not the main purpose of this study however it is worth some consideration in light of the information collected. This study has shown that the wetland is ephemeral, fed by springs and groundwater seepages and that it responds to changes in groundwater levels in the underlying aquifers. The wetland should be considered to be a 'Groundwater Dependent Terrestrial Ecosystem' (GWDTE). The current SSSI Citation (CCW, 1998) does correctly note that groundwater levels control the flooding regime, however the site is only classed as 'productive meadows'.

One possibility is that the Nedern Brook SSSI could fit the description of the Priority Habitat '**aquifer fed naturally fluctuating water body'** (UKBAP, 2008), however additional data would be needed to confirm that the vegetation displayed the characteristic zonation of these habitats. Aquifer fed naturally fluctuating water bodies are rare in the UK with only 10 ha in Northern Ireland, 1 ha in Wales and 20 ha in England (UKBAP, 2008). In comparison the Nedern Brook Wetland when flooded covers an area over 30 ha. Currently the wetland fits some, but not all, of the classification criteria leaving several grey areas in terms of any potential future re-classification.

The Nedern Brook SSSI fits the UKBAP priority habitat criteria including:

- Natural water body that has an intrinsic regime of extreme fluctuations
- Periods of complete or almost complete drying out occur
- Water flooding exceeds 0.5m depth

However it does not fit the following criteria:

- The wetland should not have an inflow and outflow stream
- Aquatic vegetation should not be present

The following criteria need further data collection to allow reassessment:

- It is unknown if specialist semi-aquatic bryophytes capable of withstanding fluctuating water levels are present (survey required)
- There is no NVC map and concentric zonation of vegetation (if any) has not yet been identified
- The aquatic fauna is currently unknown and the wetland may not include any key species often associated with the priority habitat
- Nutrient status reflects that of local groundwater (requires more detailed sampling and analysis)

In conclusion the Nedern Brook Wetlands SSSI has several key features that are similar to the UKBAP Priority habitat 'aquifer fed naturally fluctuating water body' and also several features that remain unassessed due to the lack of information, thus is it not currently clear if the wetland fits the UKBAP description for this habitat. Consideration of these features could be beneficial should the classification of the wetland be updated in the future as and when information become available.

5 Recommendations

The current study has helped to answer some recommendations from Haskoning UK Ltd (2013) regarding the hydrology of the Nedern SSSI / Nedern Brook, however it is acknowledged that the scope was limited and did not cover water balance, geological investigations or water chemistry.

1. **Hydrological monitoring**

   There is still a lack of long term water level data in the Nedrn Brook and extreme events such as drought or flood have not been characterized, thus the limits of flooding and flood duration are poorly understood. The lack of spot gauging within the Nedern Brook also limits the calculation of a stage discharge relationship for flow within the brook. This data is very important to underpin future river restoration plans. There is no groundwater monitoring within the River Terrace Gravel deposits, and thus the role of gravels in groundwater supply to the wetland is not known.

   It is proposed that monitoring of groundwater and surface water levels should continue in the Nedern Brook to better characterise the hydrology of the area. Surface water spot gauging during high flow and low flow should be repeated upstream at Tyne Cottages and downstream (Nedern DS) to allow a stage discharge relationship to be formed. This data, which can be back calculated for the monitoring period, will address the key knowledge gap of understanding flow within the Nedern Brook.

   Should funding become available then borehole/s drilled into the River Terrace Deposits should be instrumented with data loggers to help better understand the role of the river terrace deposits on groundwater supply to the wetland. On site precipitation data is preferable but not necessary as existing NRW stations at Llanvaches and Collister Pill can be used.

2. **Water balance**

   Currently there is no water balance for the Nedern brook wetland. Without this we cannot quantify inflows and outflows of water into the wetland, or design appropriate river restoration plans. An initial water balance should be possible once stage discharge relationships for flow are calculated as described in recommendation 1. This would require flow volumes in the Nedern Brook both upstream and downstream of the wetland (as detailed in recommendation 1), rainfall and evapotranspiration (from existing stations), ground and surface water abstraction returns (NRW database) and flow from direct inputs such as drains. An initial water balance would directly benefit the understanding of how the site works, underpinning future management or restoration options.

3. **Geological properties**

There is a lack of information on the superficial deposits within the wetland area. It is likely that the superficial deposits will be heterogeneous, some areas being highly permeable – allowing the movement of groundwater and others less so resulting in the impediment or retention of water. The implication is that different areas within the wetland will function differently dependent upon their geology.

The recommendation from Haskoning UK Ltd (2013) to ‘Undertake an investigation to determine the thickness, spatial extent and permeability of the alluvium and river terrace gravels within the study area’ remains however should only be undertaken if river restoration plans are to go ahead. Geological mapping by the BGS see Lawrence et al (2013) could be built upon with a series of small boreholes across the site and lab testing required.

6 Conclusions

For the first time a complete flood cycle has been characterised at the Nedern Brook Wetland SSSI. A hydrological monitoring network of stilling wells, piezometers, boreholes were instrumented with data collected every 30 minutes.

- The Nedern Brook has been heavily modified in the past. It has been straightened and over deepened and acts primarily as a drain for groundwater that discharges onto its floodplains.

- The Nedern Brook was not seen to be ‘overtopping’ or causing fluvial flooding during the study, but only acting as a drain taking water away from the wetland.

- Surface water gauging both upstream and downstream of the wetland proved that flow within the Nedern Brook can be highly variable. Flow downstream of the wetland is often much greater than the flow recorded upstream of the wetland. This difference (up to 225 l/s in January 2015) is attributed principally to groundwater discharge into the wetland.

- A walkover of the Nedern and Castrogi Brook showed that the Victorian concrete lined channel was in a poor state of repair and is very unlikely to prevent surface water loss into the aquifer.

- The wetland can flood to a depth of 1.5 m (based on depth near piezometer P3) and flooding can cover an area nearly 1.5 km in length and cover an area greater than 30 ha.

- Groundwater plays a principal role in the flood regime of the Nedern Brook Wetland and it should be classified as a Groundwater Dependent Terrestrial Ecosystem (GWDTE).

- Key discrete groundwater discharges were identified namely the Upper and Lower Whirly Holes an area of discharge from the limestone outcrop south of the M48 and an unnamed spring that only flows when groundwater levels are high.

- Larger diffuse areas of groundwater discharge on the floodplains were identified within the wetland.

- It is possible that the Nedern Brook Wetland should be reclassified as the UKBAP Priority Habitat ‘aquifer fed naturally fluctuating wetland’ however further information, especially about vegetation zonation, is required.

Glossary

BFI	Baseflow Index
BGS	British Geological Survey
GWDTE	Groundwater Dependant Terrestrial Ecosystem
maOD	meters above Ordnance datum (sea level)
NRW	Natural Resources Wales
SPZ	Source Protection Zone
SSSI	Site of Special Scientific Interest
UKBAP	UK Biodiversity Action Plan
WFD	Water Framework Directive

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

ATKINS, 2012. Nedern Brook, Caldicot Catchment Study Summary Report. March 2012. For Environment Agency Wales.

CLARKE, L & ALDOUS, P.J. 1987. Hydrogeological investigations in the Chepstow Block, Gwent: Summary report. WRc Environment for the Welsh Office: restricted report CO1469-M/EV 8390.

COUNTRYSIDE COUNCIL FOR WALES, 1988. Nedern Brook Wetlands SSSI Citation http://www.ccgc.gov.uk/landscape--wildlife/protecting-our-landscape/special-landscapes--sites/protected-landscape/sssis/sssi-sites/nedern-brook-wetlands.aspx

DREW D P, NEWSON, M D AND SMITH D I. 1970. Water-tracing of the Severn Tunnel Great Spring. Proc Univ. Bristol Spelaeol Soc. **12**, 203-212.

HASKONING UK LTD, 2013. Nedern Brook River Restoration Option Summary Report. Final Draft Report for Environment Agency Wales. Reference 9Y0437/R/303693/Soli.

LAWRENCE, D.J.D, FARR G.J, WHITBREAD, K AND KENDALL, R. 2013. The geology, hydrogeology and vulnerability of the Great Spring Source Protection Zone. Commissioned Report CF/12/024 for Environment Agency Wales. Confidential Report.

RIGARE, 2014. Report on a pumping test to inform determination of an application to increase the licensed groundwater abstraction rate at Mount Ballan Manor, Caldicot. 1496_r1, November 2014.

RIVER RESTORATION CENTRE,2012. Nedern Brook, Monmouthshire, options for river restoration. The River Restoration Centre for Environment Agency Wales.

UKBAP, 2008. Aquifer fed naturally fluctuating water bodies. From UK Biodiversity Action Plan; Priority Habitat Descriptions. http://jncc.defra.gov.uk/Docs/UKBAP_BAPHabitats-01-AqFedWaterBodies.doc

WALKER, T.A.1888. The Severn Tunnel - Its construction and difficulties (1872 - 1887). London, Richard Bentley and Son. http://archive.org/stream/severntunnelits01walkgoog#page/n12/mode/2up

APPENDIX 1

Photographs of monitoring sites

Figure 14 Nedern Brook DS Monitoring Point under variable flow conditions © BGS NERC.

27.11.2014 (top), 16.1.2015(middle) & 18.3.2015 (bottom)

BGS Photograph Numbers top to bottom; P917083, P917084, P917082.

Figure 15 Nedern Brook US Monitoring Point under variable flow conditions © BGS NERC.

30.09.2014 (top: dry), 27.11.14 (middle: dry view north towards the road bridge), 16.1.15 (bottom: wet view east).

BGS Photograph Numbers top to bottom; P917088, P917089, P917087

Figure 16 Dipwells and Piezometers (P3) in dry and flood conditions © BGS NERC.

30.09.2014 (top: dry install and survey view north towards M48) and 16.01.2015 (bottom: wet similar view)

BGS Photograph Numbers top to bottom; P915233, P915230.

Figure 17 Lower Whirly Hole in variable flood conditions © BGS NERC.

30.09.2014 (top), 18.12.2014 (middle), 27.11.2014 (bottom)

(BGS Photograph Numbers top to bottom; P915232, P502178 and P915228)

Figure 18 Nedern Brook at Tyne Cottages in variable flow conditions © BGS NERC.

27.11.2014 (top) and 1.05.2015 (below)

BGS Photograph Numbers top to bottom; P917086, P915238.

APPENDIX 2

Elevation Survey Data

Survey	Easting	Northing	Z	Z accuracy (m)	Comments	Date
3	348674	189360	4.547	0.016	Dipwell DW2 toc . Water level 0.9mbtoc = 3.647maOD - toc height above groundlevel 0.179m = 3.468maOD water level)	30.09.2014
4	348675	189361	4.626	0.017	Piezometer P3 toc. Water level 0.96mbtoc = 3.66maod - toc height above GL 0.22m = 3.446maOD water level. Water level logger installed at 1.5mbtoc = 3.126 datum for logger in P3	30.09.2014
7	348638	189368	5.033	0.14	Dipwell D1 toc .Water level 0.95mbtoc = 4.083 - toc height above GL 0.321 = 3.762moAD water level.	30.09.2014
8	348638	189368	4.968	0.015	Piezometer P1a. Water level 0.97mbtoc = 3.998mbtoc - toc height above GL 0.256 = 3.742maOD water level.	30.09.2014
9	348638	189369	4.832	0.014	Piezometer P1 toc (water level 0.82mbtoc = 4.012 -toc height above GL 0.12m = 3.892maOD water level.	30.09.2014
10	348638	189369	4.712	0.017	Ground level near P1, D1 and P1a0	30.09.2014
11	348612	189364	5.563	0.016	Bank Near the Nedern and dipwells and piezometers (groundlevel)	30.09.2014
12	348607	189364	4.499	0.016	Nedern Brook near survey 11 (no flow in Nedern at this point)	30.09.2014
13	348685	189307	na	na	Barologger Location (on fence post)	30.09.2014
14	348430	189486	5.66	0.018	US Monitoring Point (logger suspended 1.63m of wire thus datum 4.03maOD. Dip at time of installation was 1.17m or 4.49maOD rest water level in Brook. (water level)	30.09.2014
15	348163	189925	4.771	0.014	Lower Whirly Hole (near centre and base of depression whilst dry)	30.09.2014
20	348846	188400	5.621	0.02	Palaeochannel south of SSSI near castle car park (water level)	27.11.2014
20	348846	188400	6.52	0.029	DS Monitoring Point (datum on bridge). At time logger suspended 2.08m below datum thus logger datum is 4.43maOD. Rest water level at the time of installation was 2.01mb or 4.51maOD rest water level. No flow in Nedern at this point. (water level)	30.09.2014
21	348674	188591	5.08	0.048	DS Nedern Monitoring Point (water level)	27.11.2014
22	348685	188740	5.507	0.397	Nedern Brook level by bridge (water level)	27.11.2014
23	348601	188825	5.287	0.213	Nedern Brook level by bridge on Mr Brooms Land (water level)	27.11.2014
24	348655	189272	6.187	0.052	Dipwell /Piezometer water level correction point (about 50m south of dipwells) (water level)	27.11.2014
25	347387	190052	6.158	0.018	Nedern Brook on Slough Farm Mr Bennett (water level)	27.11.2014
26	347944	189919	5.307	0.008	Nedrn Brook on Slough Farm Mr Bennett - recorded to compare to flooded area adjacent but not connected to Nedern see survey 27	27.11.2014
27	348032	189922	5.221	0.03	Flood to east of Nedern Brook (Survey 26) taken just to compare elevation. Nedern Brook is slightly higher in this area. (water level)	27.11.2014
28	348166	189918	5.253	0.012	Lower Whirly Hole (water level)	27.11.2014
29	348431	189487	5.473	0.021	US Nedern Monitoring Point (water level)	27.11.2014
32	348844	188396	5.5.8	0.018	Palaeochannel south of SSSI near castle car park (water level)	18.12.2014
33	348674	188592	5.071	0.028	DS Nedern Monitoring Point (water level)	18.12.2014
35	348686	188740	5.102	0.052	Stone Bridge (water level)	18.12.2014
36	348597	188825	5.057	0.022	Small wooden footbridge (water level)	18.12.2014
37	348654	189275	5.249	0.013	Dipwell /Piezometer water level correction point (about 50m south of dipwells) (water level)	18.12.2014
38	348431	189487	5.25	0.04	US Nedern Monitoring Point (water level)	18.12.2014
39	348012	189901	5.33	0.196	Nedern by small culvert (water level)	18.12.2014
40	348166	189918	5.162	0.178	Lower Whirly Hole (water level)	18.12.2014
42	348985	187260	7.182	0.013	Nedern outflow (survey point is the concrete structure below the yellow winch box) (water level)	18.12.2014
42	348985	187260	3.623		Outflow of Nedern : water level (measured down from the datum point) (water level)	18.12.2014
43	348854	188509	5.96	0.021	Gate on Mr Brooms land East side of Nedern (water level)	16.1.2015
44	348674	188591	5.983	0.033	DS Nedern Monitoring Point (water level)	16.1.2015
45	348720	188704	5.927	0.025	Small section poss part of palaeochannel ? (water level)	16.1.2015

Survey	Easting	Northing	Z	Z accuracy (m)	Comments	Date
46	348686	188740	6.09	0.067	Stone Bridge _ levels very high and water blocking up against it and flowing overland (water level)	16.1.2015
47	348622	188821	6.055	0.023	Small wooden footbridge (water level)	16.1.2015
48	348644	188908	6.029	0.027	Flood level next to footpath leading up to Mr Brooms main fields	16.1.2015
49	348684	189062		bad	Gate on Mr Brooms land East side of Nedern (water level)	16.1.2015
51	348655	189272	6.116	0.018	Dipwell /Piezometer water level correction point (about 50m south of dipwells) (water level)	16.1.2015
52	348846	188400	5.883	0.016	Palaeochannel south of SSSI near castle car park (water level)	16.1.2015
53	348780	188391	5.901	0.02	Nedern at Bridge by carpark - good flow (water level)	16.1.2015
54	348431	189487	6.062	0.028	US Nedern Monitoring Point (water level)	16.1.2015
55	348417	189460	6.996	0.018	Storm Drain flow about1.5-2 l / s (location)	16.1.2015
56	347711	190079	6.359	0.018	Flooded land on Slade Farm (water level)	16.1.2015
57	347708	190069	6.289	0.019	Adjacent to Point 56 River Nedern (water level)	16.1.2015
58	347339	190038	6.774	0.027	Nedern Adjacent to upper whirly hole (water level)	16.1.2015
59	347808	189993	6.045	0.019	Flood on land adjacent to point 58 (water level)	16.1.2015
60	347949	189965	6.082	0.017	Nedern on slough Farm where it joins flooding (water level)	16.1.2015
61	347961	189984	6.033	0.018	Flood opposite point 60 (water level)	16.1.2015
62	348058	190002	6.317	0.015	SPRING. Not recorded before - seepage across about 5m of fence line into Nedern (location)	16.1.2015
63	348166	189918	6.042	0.015	Lower Whirly Hole (water level)	16.1.2015
64	348834	188127	5.888	0.036	Nedern at main road flowing out of Country park - good flow no obstructions no ponding of water (water level)	16.1.2015
65	347192	189995	7.65	0.041	Nedern at Tyne Cottages (concrete lip in channel)	27.1.2015
66	347192	189995	7.511	0.041	Nedern at Tyne Cottages WATER LEVEL use this to correct stilling well data (INSTALL date)	27.1.2015
67	34192	18995	7.37	0.041	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
68	347192	18995	7.261	0.046	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
69	347192	189996	7.16	0.038	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
70	347192	189996	7.194	0.056	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
71	347192	189997	7.064	0.029	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
72	347192	189997	7.347	0.083	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
73	347192	189998	7.255	0.027	Nedern at Tyne Cottages (river bed profile left to right)	27.1.2015
84	348781	188390	5.276	0.023	Nedern at Bridge by carpark - good flow (water level)	27.1.2015
85	349030	187690	5.217	0.024	Nedern in Industrial Estate good flow (water level)	27.1.2015
86	348983	187257	5.143	0.017	Nedern outflow - measure of water level - however tide was in so level is reflection of sea level.	27.1.2015
89	348781	188390	5.023	0.076	Nedern at Bridge by carpark - good flow (water level)	12.2.2015
90	348846	188400	5.619	0.051	Palaeochannel south of SSSI near castle car park (water level)	12.2.2015
91	348674	188591	4.916	0.041	DS Nedern Monitoring Point (water level)	12.2.2015
92	348622	188821	4.94	0.019	Small wooden footbridge (water level)	12.2.2015
93	348684	189062	5.16	0.041	Gate on Mr Brooms land East side of Nedern (water level)	12.2.2015
94	348655	189272	5.207	0.037	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	12.2.2015
95	348431	189487	5.095	0.016	US Nedern Monitoring Point (water level)	12.2.2015
98	347799	189979	5.04	0.024	Slough Farm Upper Flood Limit of Nedern (water level)	12.2.2015
99	348166	189918	5.246	0.022	Lower Whirly Hole (water level)	12.2.2015
100	348135	189913	5.267	0.027	small seepage (observed only as Nedern Recedes)	12.2.2015
101	348127	189913	5.186	0.051	small seepage (observed only as Nedern recedes)	12.2.2015
102	348781	188390	4.853	0.02	Nedern at Castle Car Park (flow visible) (water level)	18.3.2015

Survey	Easting	Northing	Z	Z accuracy (m)	Comments	Date
103	348846	188400	5.5	0.016	Palaeochannel south of SSSI near castle car park (water level)	18.3.2015
104	348674	188591	5.036	0.035	DS Nedern Monitoring Point (water level)	18.3.2015
105	348686	188740	4.93	0.014	Stone Bridge (water level)	18.3.2015
106	348622	188821	4.954	0.01	Wood bridge (water level)	18.3.2015
107	348684	189062	5.043	0.014	Gate on Mr Brooms land East side of Nedern (water level)	18.3.2015
108	348655	189272	5.043	0.014	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	18.3.2015
110	348431	189487	5.001	0.046	US Nedern Monitoring Point (water level)	18.3.2015
112	347192	189995	8.329	0.056	Nedern at Tyne Cottages (flow) (water level)	18.3.2015
113	347795	189937	5.359	0.033	Slough Farm top of flooded extent (water level)	18.3.2015
114	348166	189918	5.207	0.019	Lower Whirly Hole (wet with discharge visible) (water level)	18.3.2015
115	348007	189905	5.163	0.023	Nedern adjacent to drain on Slough Farm (water level)	18.3.2015
116	348781	188390	4.643	0.039	Nedern at Castle Car Park (flow visible) (water level)	01.5.2015
117	348674	188591	4.575	0.021	DS Nedern Monitoring Point (water level)	01.5.2015
118	348686	188740	4.763	0.073	Stone Bridge (water level)	01.5.2015
119	348622	188821	4.614	0.014	Wood bridge (water level)	01.5.2015
121	348431	189487	4.632	0.014	US Nedern Monitoring Point	01.5.2015
123	348254	189529	3.856	0.02	residual pool in small hollow (water level)	01.5.2015
124	348275	189509	3.902	0.03	residual pool in small hollow (water level)	01.5.2015

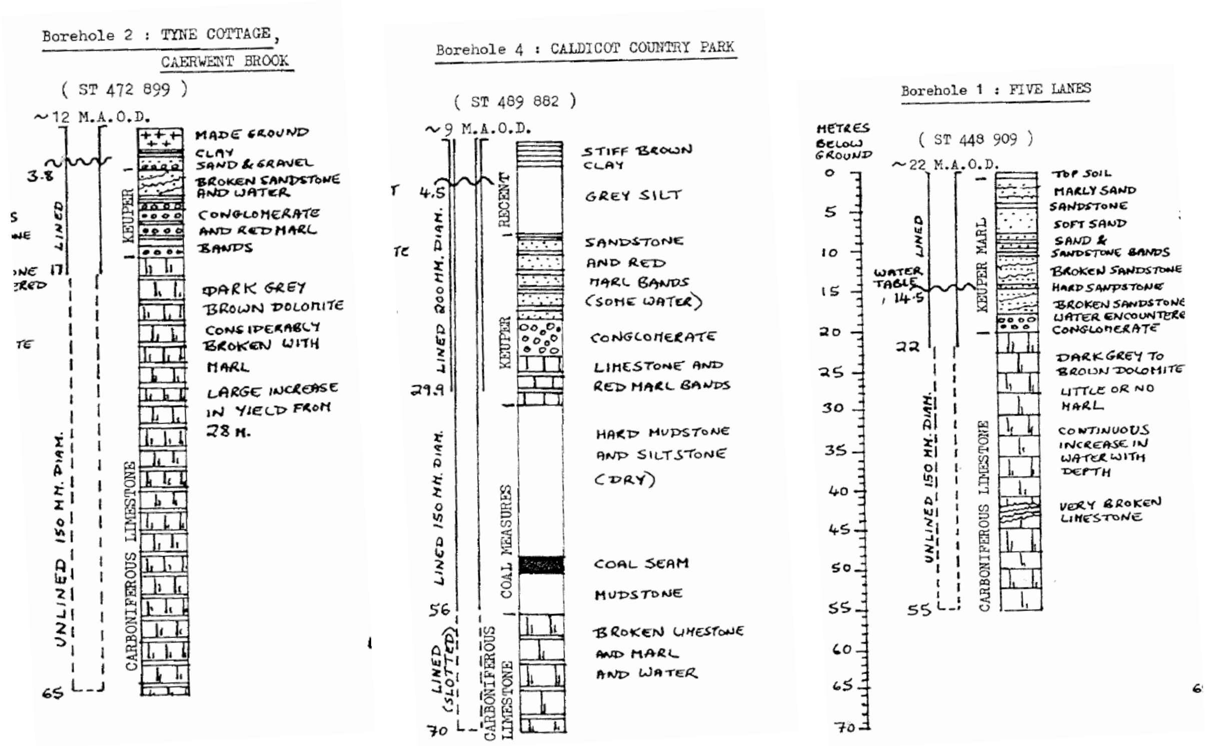
APPENDIX 3

Field water chemistry

Survey	E	N	Comments	Type	Date	EC us/cm	Temp °C
51	348655	189272	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	Flood water	16.1.2015	290	5.8
37	348654	189275	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	Flood water	18.12.2014	330	10
104	348674	188591	DS Nedern Monitoring Point	Nedern Brook	18.3.2015	453	6.8
44	348674	188591	DS Nedern Monitoring Point	Nedern Brook	16.1.2015	290	4
33	348674	188592	DS Nedern Monitoring Point about 9am	Nedern Brook	18.12.2014	300	10.3
48	348644	188908	Flood level next to footpath leading up to Mr Brooms main fields	Flood water	16.1.2015	280	4
61	347961	189984	Flood opposite point 60	Flood water	16.1.2015	240	7.7
43	348854	188509	Gate on Mr Brooms land East side of Nedern	Flood water	16.1.2015	300	4
49	348684	189062	Gate on Mr Brooms land East side of Nedern	Flood water	16.1.2015	310	4.1
107	348684	189062	Gate on Mr Brooms land East side of Nedern	Flood water	18.3.2015	452	6.2
63	348166	189918	Lower Whirly Hole	Groundwater	16.1.2015	290	9
40	348166	189918	Lower Whirly Hole	Groundwater	18.12.2014	580	n/a
114	348166	189918	Lower Whirly Hole (wet with discharge visible)	Groundwater	18.3.2015	670	12.9
102	348781	188390	Nedern at Castle Car Park (flow visible)	Nedern Brook	18.3.2015	448	7.1
112	347192	189995	Nedern at Tyne Cottages (flow)	Nedern Brook	18.3.2015	350	8.2
39	348012	189901	Nedern by small culvert	Nedern Brook	18.12.2014	230	10
60	347949	189965	Nedern on slough Farm where it joins flooding	Nedern Brook	16.1.2015	180	9
52	348846	188400	Palaeochannel south of SSSI near castle car park	Flood water	16.1.2015	370	3.2
32	348844	188396	Palaeochannel south of SSSI near castle car park	Flood water	18.12.2014	640	9.5
103	348846	188400	Palaeochannel south of SSSI near castle car park	Flood water	18.3.2015	661	3.6
113	347795	189937	Slough Farm top of flooded extent	Flood water	18.3.2015	440	14.3
36	348597	188825	Small wooden footbridge	Nedern Brook	18.12.2014	290	10.1
47	348622	188821	Small wooden footbridge	Nedern Brook	16.1.2015	300	3.9
62	348058	190002	SPRING seepage across about 5m of fence line into Nedern Brook	Groundwater	16.1.2015	340	6
105	348686	188740	Stone Bridge	Nedern Brook	18.3.2015	450	6.9
46	348686	188740	Stone Bridge _ levels very high and water blocking up against it and flowing overland	Nedern Brook	16.1.2015	310	3.1
55	348417	189460	Storm Drain flow about1.5-2 l / s	Storm Drain	16.1.2015	140	7.5
38	348431	189487	US Nedern Monitoring Point	Nedern Brook	18.12.2014	240	n/a
54	348431	189487	US Nedern Monitoring Point	Nedern Brook	16.1.2015	270	7.7
110	348431	189487	US Nedern Monitoring Point	Nedern Brook	18.3.2015	404	7.1
106	348622	188821	Wood bridge	Nedern Brook	18.3.2015	451	6.7
n/a	348405	189488	Groundwater discharge from limestone outcrop	Groundwater	18.3.2015	740	9.4
n/a	348339	189512	Groundwater discharge from limestone outcrop (est 10 l/s)	Groundwater	18.3.2015	710	9.7

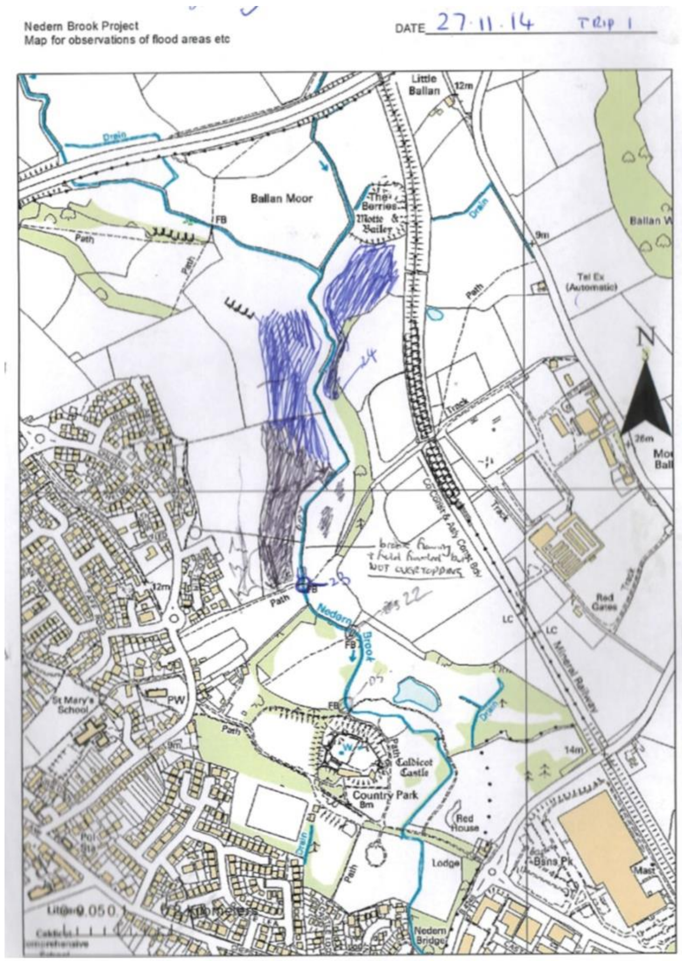
APPENDIX 4

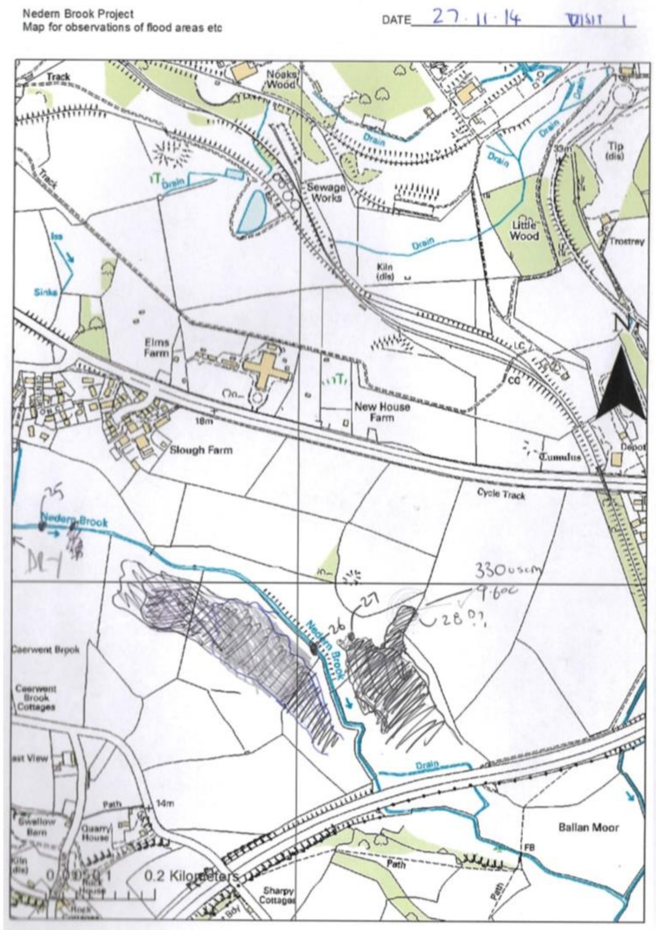
Borehole Logs

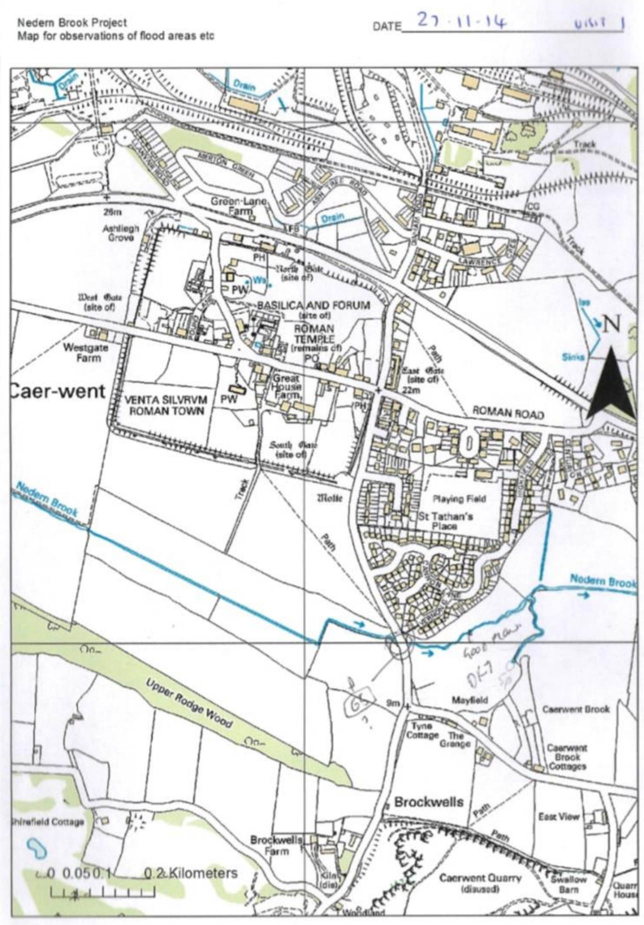

Borehole 2 : TYNE COTTAGE, CAERWENT BROOK
(ST 472 899)
~12 M.A.O.D.
MADE GROUND
CLAY
SAND & GRAVEL
BROKEN SANDSTONE AND WATER
CONGLOMERATE AND RED MARL BANDS
DARK GREY BROWN DOLOMITE CONSIDERABLY BROKEN WITH MARL
LARGE INCREASE IN YIELD FROM 28 M.
KEUPER
CARBONIFEROUS LIMESTONE
LINED
UNLINED 150 MM. DIAM.
Borehole 4 : CALDICOT COUNTRY PARK
(ST 489 882)
~9 M.A.O.D.
STIFF BROWN CLAY
GREY SILT
SANDSTONE AND RED MARL BANDS (SOME WATER)
CONGLOMERATE
LIMESTONE AND RED MARL BANDS
HARD MUDSTONE AND SILTSTONE (DRY)
COAL SEAM
MUDSTONE
BROKEN LIMESTONE AND MARL AND WATER
RECENT
KEUPER
COAL MEASURES
CARBONIFEROUS LIMESTONE
LINED 200 MM. DIAM.
LINED 150 MM. DIAM.
LINED (SLOTTED)
Borehole 1 : FIVE LANES
(ST 448 909)
~22 M.A.O.D.
METRES BELOW GROUND
TOP SOIL
MARLY SAND
SANDSTONE
SOFT SAND
SAND & SANDSTONE BANDS
BROKEN SANDSTONE
HARD SANDSTONE
BROKEN SANDSTONE WATER ENCOUNTERED
CONGLOMERATE
DARK GREY TO BROWN DOLOMITE
LITTLE OR NO MARL
CONTINUOUS INCREASE IN WATER WITH DEPTH
VERY BROKEN LIMESTONE
WATER TABLE 14.5
KEUPER MARL
CARBONIFEROUS LIMESTONE
LINED
UNLINED 150 MM. DIAM.

APPENDIX 5

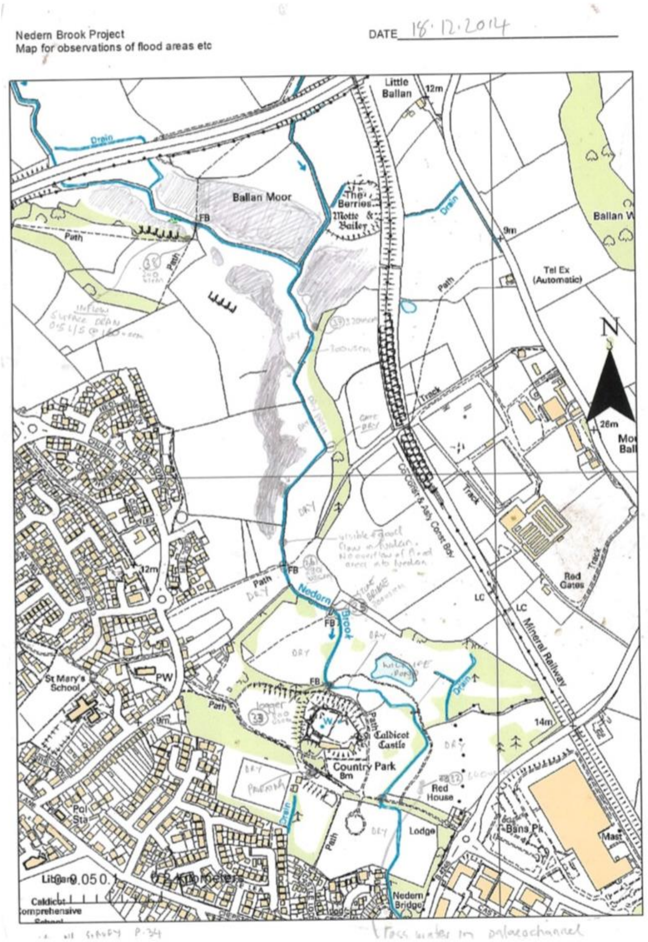
Field maps with sketches of flood extent

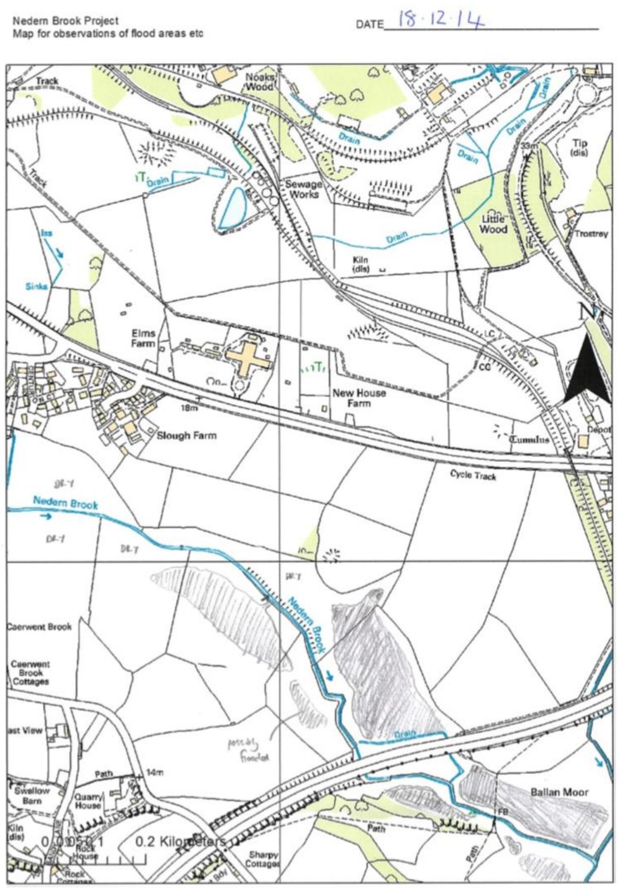


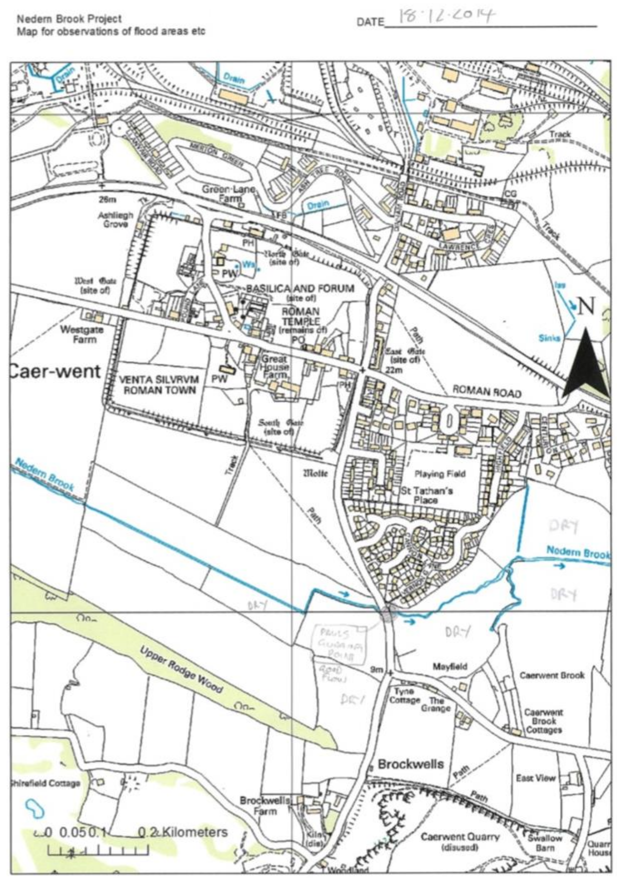




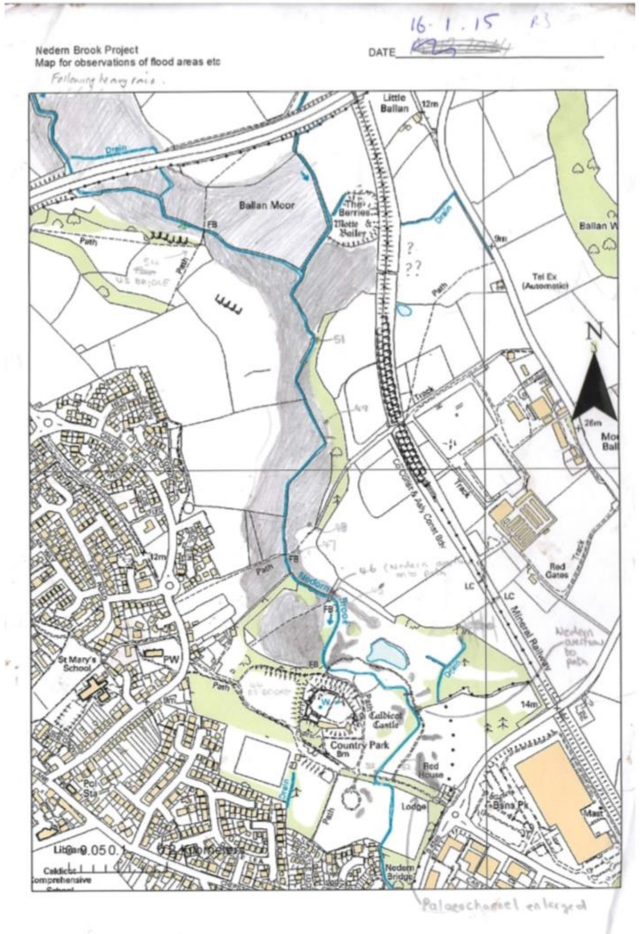
Contains OS data © Crown Copyright and database right [2015]

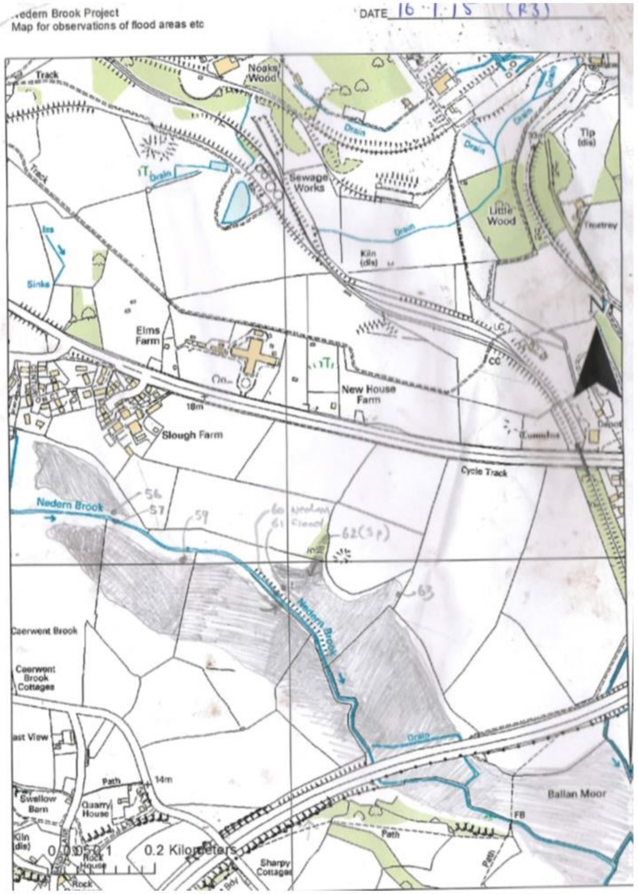


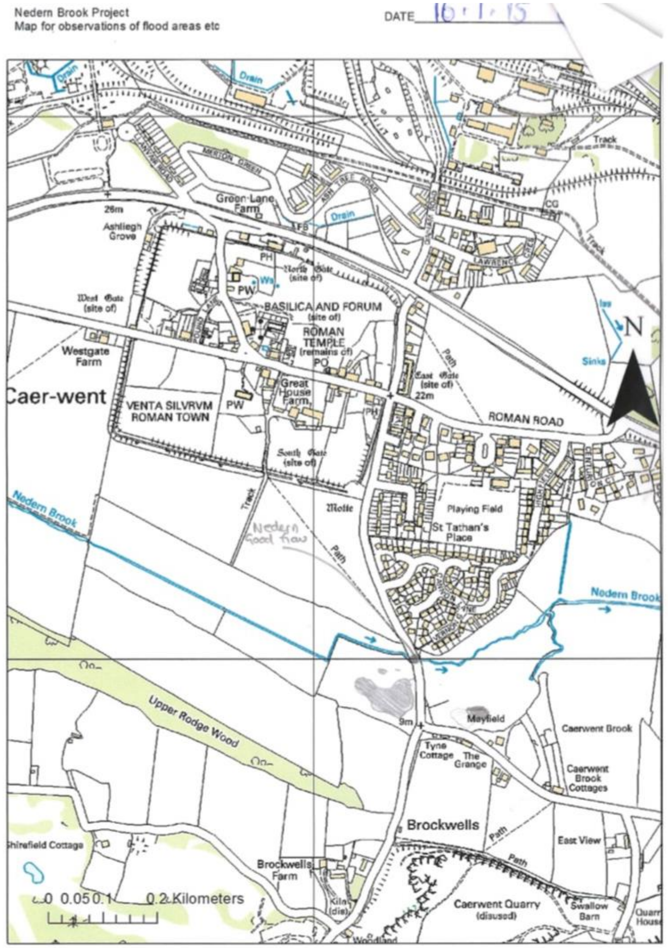




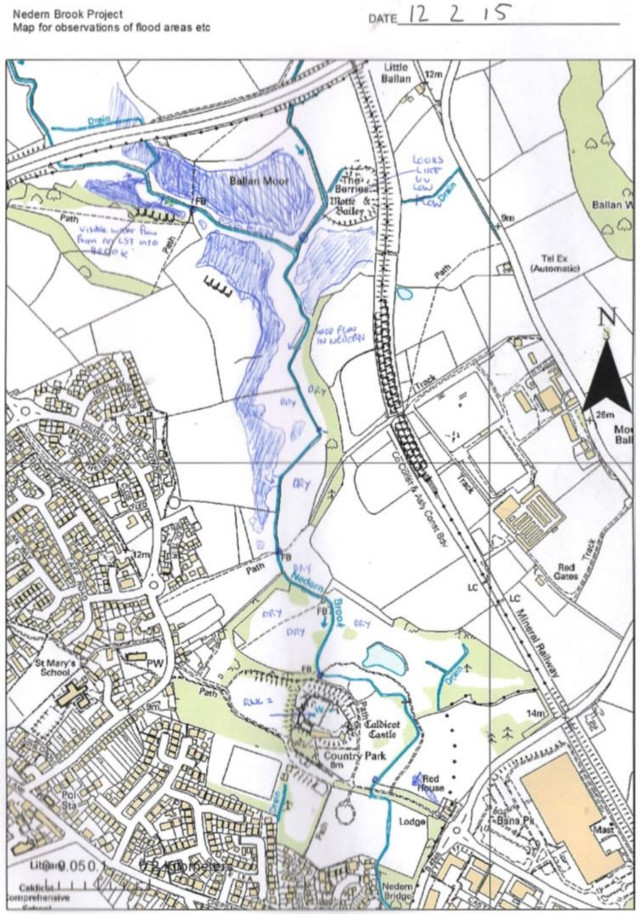
Contains OS data © Crown Copyright and database right [2015]

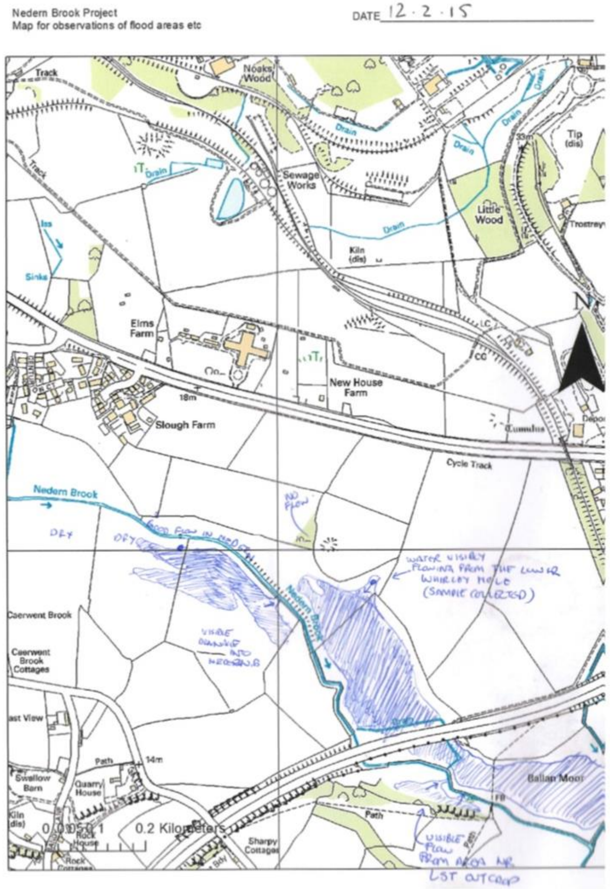


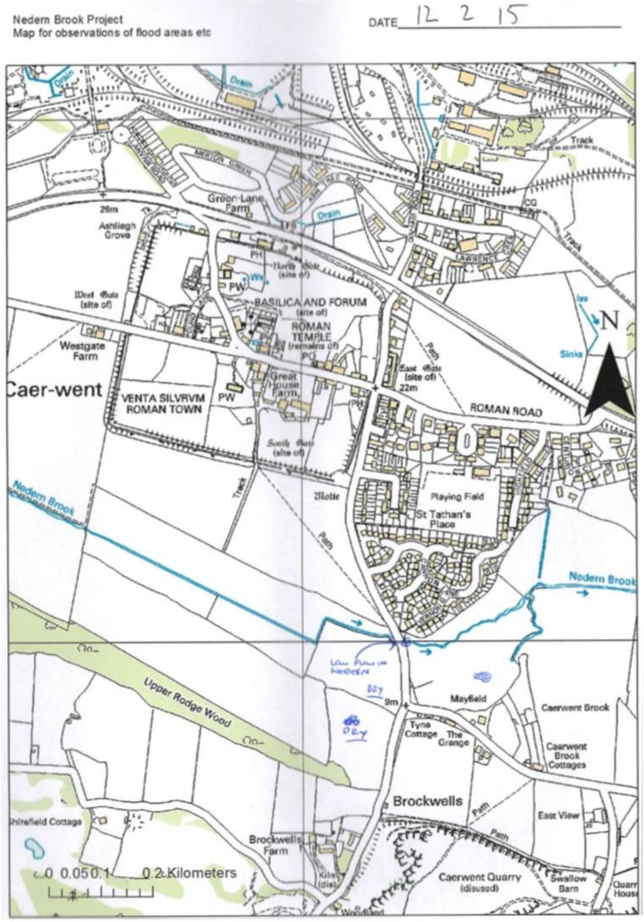




Contains OS data © Crown Copyright and database right [2015]



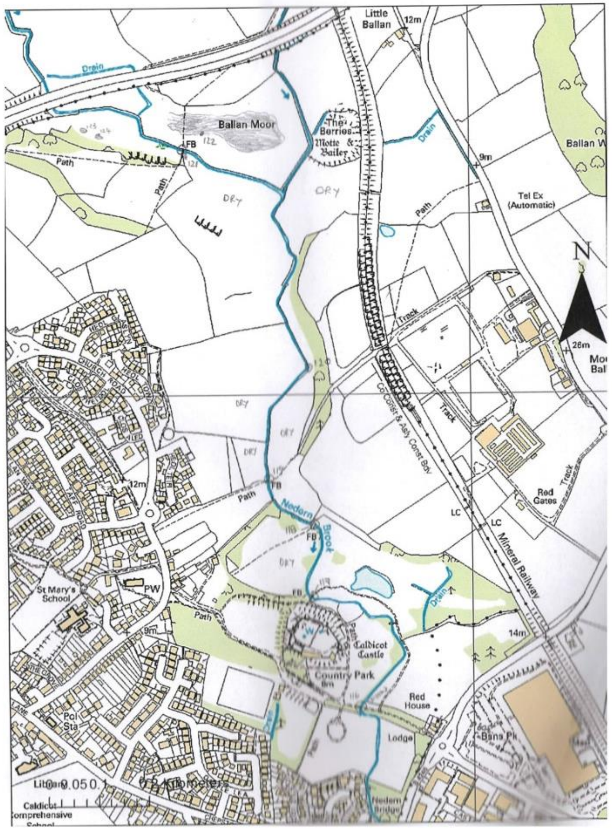




Contains OS data © Crown Copyright and database right [2015]

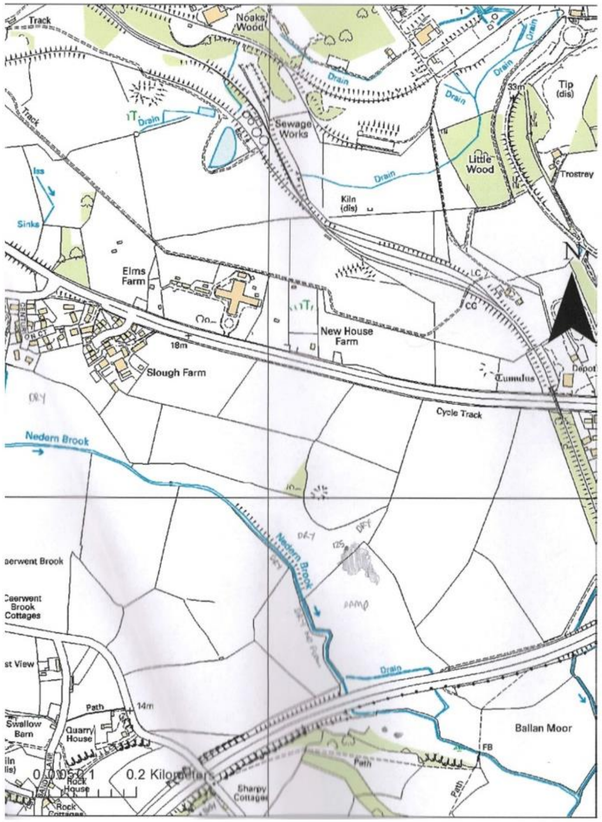
Nedern Brook Project
Map for observations of flood areas etc

DATE 1st MAY 2015



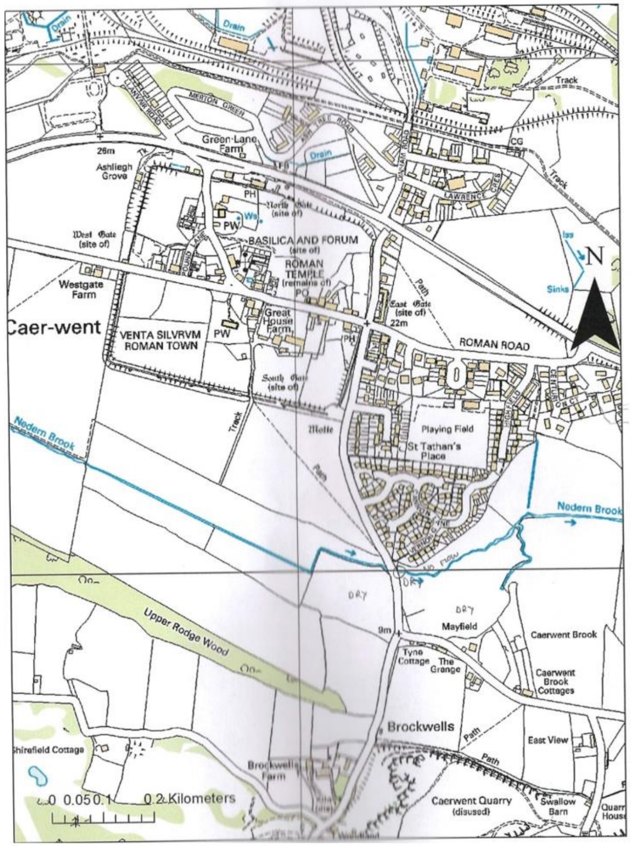
Nedern Brook Project
Map for observations of flood areas etc

DATE 1st May 2015



Nedern Brook Project
Map for observations of flood areas etc

DATE 1st MAY 2015



Contains OS data © Crown Copyright and database right [2015]