Monmouthshire County Council

Flood and Water Management Act 2010

Section 19 Flood Investigation Report

Caldicot

February 2020

Version: Final

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Contents

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1. Executive Summary

In accordance with Section 19 of the Flood and Water Management Act 2010 Monmouthshire County Council (MCC) has a duty as Lead Local Flood Authority to investigate flooding within its area, insofar as it considers it necessary or appropriate. This report has been prepared specifically for the purpose of meeting the requirements of Section 19 and provides a factual account of the flood event that occurred on 29th February to 1st March 2020 at Caldicot, Monmouthshire.

On the 15th and 16th of February 2020, a period of heavy rain fell during Storm Dennis, causing wide spread flooding across the County. It remained a predominately wet period from the 16th to the 28th February, when on the 28th - 29th February, a further period of heavy rain fell during Storm Jorge on already saturated ground resulting in significant flooding in the town of Caldicot. Based on rain gauge data the rainfall commenced around 6.00am on Friday the 28th February through to approximately 6.00am on Saturday the 29th February, with up to 62mm of rainfall. From local reporting, flooding commenced in and around the areas of Caldicot Castle, Castle Lea, Jolyons Court, Castle Lodge Crescent and the Severn Bridge Industrial Estate, early in the morning of Saturday 29th February and continued to increase until late evening of Sunday 1st March, before mostly clearing by early morning of Monday the 2nd March.

It has been established that the primary mechanism of flooding was from the Neddern Brook and local surface water drainage systems which surcharged as they were unable to discharge into the watercourse whilst it was in spate. This investigation has identified that the large trash screen at the inlet to the M4 culvert downstream of the Severn Bridge Industrial Estate, became blocked and was unable to be immediately cleared by the asset owner Highways England, due to the level of debris and resultant pressure upon the screen. This, along with possible restrictions to flow along the channel of the Neddern Brook, were the primary causes of the backing up of flow, resulting in overtopping and backing up of connecting surface water systems. Widespread flooding occurred in and around the grounds of Caldicot Castle and the Severn Bridge Industrial Estate affecting numerous properties and business. In addition, a Welsh Water surface water sewer backed up and surcharged through a chamber cover within Castle Lea resulting in flooding to road networks as well as a number of residential properties and gardens.

Following the flood event Officers from MCC's Highways and Flood Risk Management Team visited the locations affected by flooding and collated information of the event from a number of residents and business owners to gain an understanding of the nature of the flooding. In addition and due to travel restrictions at the time, all affected properties and businesses within and adjacent to the flood extents were written to requesting information of the event. Further detail has been gathered from local Councillors/Elected Members, historic reports from previous flood events at the same location as well as from Natural Resources Wales, Welsh Water and Highways England who in addition to Monmouthshire County Council, are the Risk Management Authorities concerned. Additional supporting information of the weather patterns and rainfall at the time of the event has been gathered from the Met Office.

2. Introduction

2.1 Purpose of Investigation

On 28th & 29th February 2020 Monmouthshire was impacted by a significant weather event which resulted in heavy and prolonged rainfall across the county and upper catchments of many ordinary watercourses and main rivers, such as the Rivers Usk, Monnow and Wye, including the Neddern Brook at Caldicot.

The heavy rainfall event resulted in significant flooding in many areas across Monmouthshire, in particular the southern half of the county, where the town of Caldicot was badly affected. This report will focus on the flooding at Caldicot.

The reason behind Monmouthshire County Council's (MCC) investigation is in response to the duties of the local authority in regards to Section 19 of the Flood and Water Management Act 2010, which states:

(1) On becoming aware of a flood in its area, a Lead Local Flood Authority must, to the extent that it considers it necessary or appropriate, investigate:

    (a) Which risk management authorities have relevant flood risk management functions, and
    (b) Whether each of those risk management authorities has exercised, or is proposing to exercise, those functions in response to the flood.

(2) Where an authority carries out an investigation under subsection (1) it must:

    (a) Publish the results of its investigation, and
    (b) Notify any relevant risk management authorities.

2.2 Site Location

The town of Caldicot is located in the south-east of Monmouthshire and borders the Severn Estuary on its south, with Chepstow some 5 miles east. The town comprises a large residential population with a popular shopping centre and a commercial area to the south east. Caldicot is well located with the B4245 running through the town east to west and it is close to the A48, the M48 and M4 and has a railway station on the Newport – Chepstow line. Severn Tunnel Junction station is located some 2 miles west giving access by rail to Cardiff, Bristol and London. The population in the 2011 census was 11,200 and the 2018 population estimate was 11,636.

The Neddern Brook drains south to the Severn Estuary with its catchment north of Caldicot much of which is in the high ground known as Wentwood. As it heads south, it passes through the eastern side of Caldicot with the village of Portskewett just to the east. The main part of the town itself is located on the western side of the Neddern Brook, which is classified as a main river. The brook continues south to the Severn estuary where the Neddern Brook discharges via a culvert under the M4 Motorway. There is a trash screen on the upstream end of the culvert which can be lifted to clear debris and a sea door on the downstream side of the culvert (effectively a large tidal flap) which protects the brook from tidal inflows.

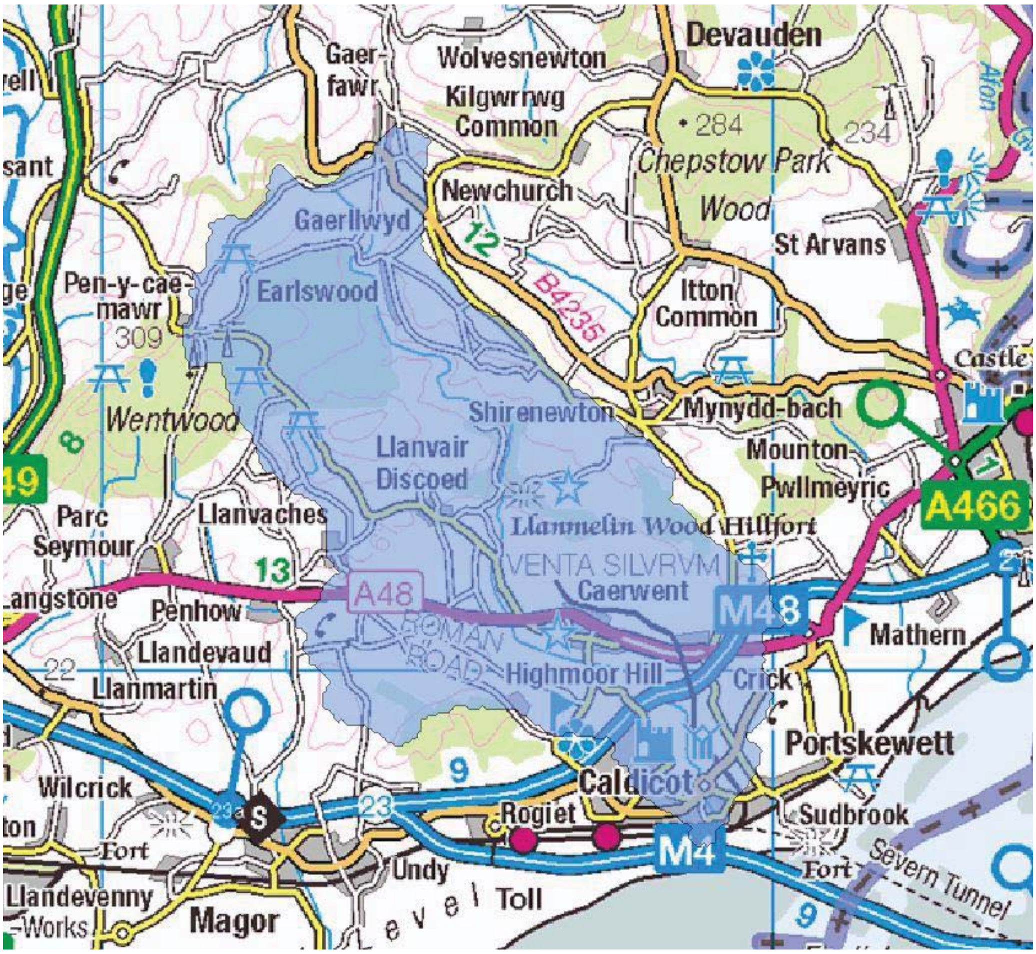


Figure 1: Location Plan (Neddern Brook Catchment shown in Blue)

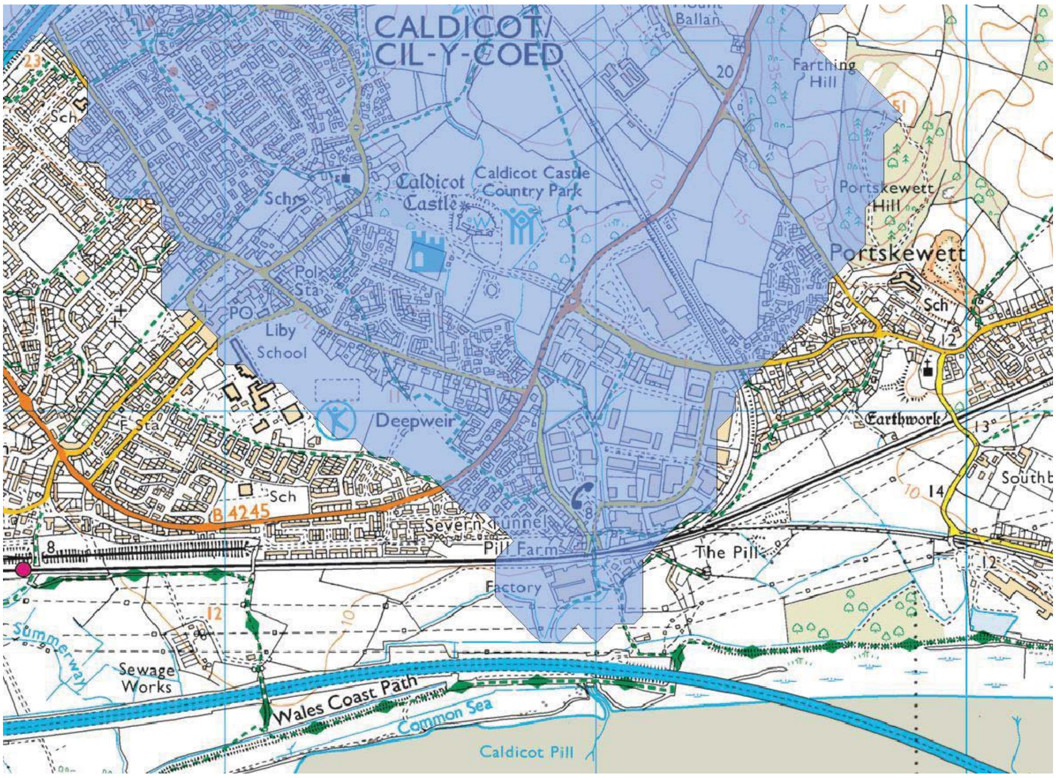


Figure 2: Caldicot Location Plan (Neddern Brook Catchment shown in Blue)

The Neddern Brook upstream of Caldicot has a catchment of approximately 46km² and is predominately rural in nature. The main flows rise in the Wentwood area north and north west of Caldicot, where the Castroggi Brook rises, known as the Caerwent Brook where it passes around Caerwent and then with another tributary from the north west becomes the Neddern Brook, collecting further small tributaries on the way. There is a Site of Special Scientific Interest (SSSI) to the north east of Caldicot known as the Caerwent SSSI. The M48 Motorway is carried over the Neddern Brook on a viaduct almost at the centre of the SSSI.

This SSSI is an area of water meadows and water levels here are managed to maintain the ecology of the site. The underlying limestone also has a number of swallow holes, locally named 'whirlpools' where in low summer flows the brook flows can drop down into fissures and may be connected to the flows of the great spring which is pumped out at Sudbrook to keep the Severn Rail Tunnel dry. In flood conditions the SSSI can act as a semi reservoir however, due to the very wet period in the weeks previous to the flood event little storage would have been available. The swallow holes can also discharge flows after significant rainfall adding to ground water flows which form much of the normal Neddern Brook flows.

Figure 3: Caerwent SSSI (Green Hatch)

There are two identified swallow holes, both along the northern edge of the SSSI. The OSGR of these are 348163/189925 and 347354/189943. A photo of one is shown below, courtesy of the British Geological Survey. Their study report from the winter of 2014/15 is available in Appendix D. Two extracts from the report are of interest here:

"*The Neddern 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.*"

"*Flooding in the Neddern Brook starts with groundwater discharge onto the floodplains rather than over-bank fluvial flooding from the Neddern Brook. The Neddern 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 Neddern Brook, was the initial cause of flooding.*" This flooding relates to the SSSI wetland area north and upstream of Caldicot Castle.

The Neddern Brook is a designated main river that falls within the Caldicot and Wentlooge Internal Drainage District (IDD) which is managed by Natural Resources Wales (NRW). The boundary of the IDD covers most of the area affected during this flooding event as shown in Figure 4 below. The section beneath the M4 Motorway is managed by Highways England as it falls with the boundary of the Second Severn Crossing, now known as the Prince of Wales Bridge.

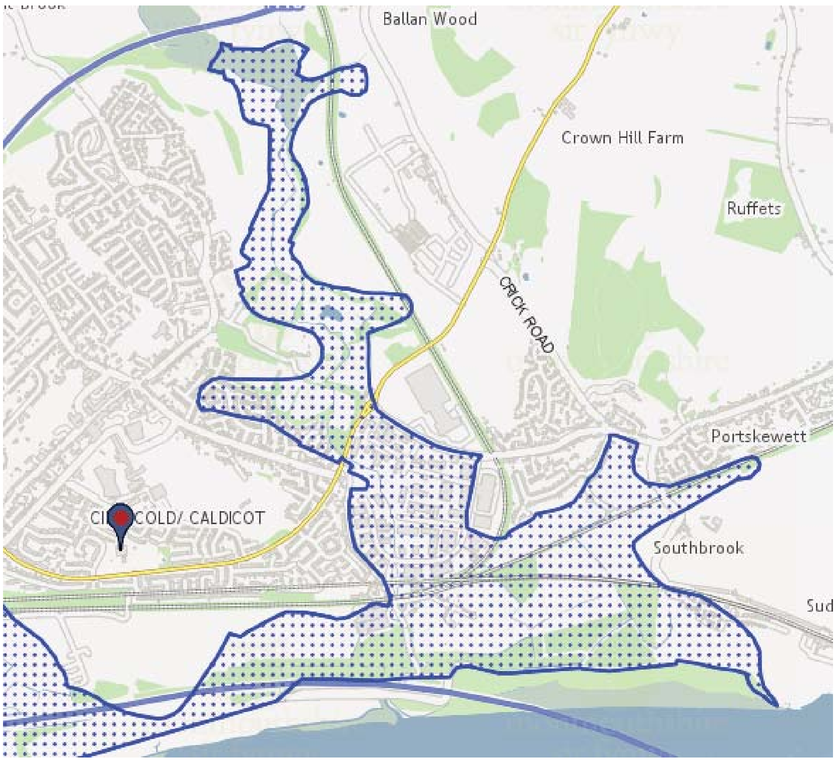


Figure 4: Location Plan (Caldicot & Wentlooge Internal Drainage District [IDD] area shown in Blue)

Figure 5: Aerial Photo of the Areas affected in the event

Natural Resources Wales (NRW) flood maps show the eastern part of Caldicot as being at a high risk of flooding from the Neddern Brook, and medium - high risk from surface water flooding as shown in Figures 5 and 6 below.

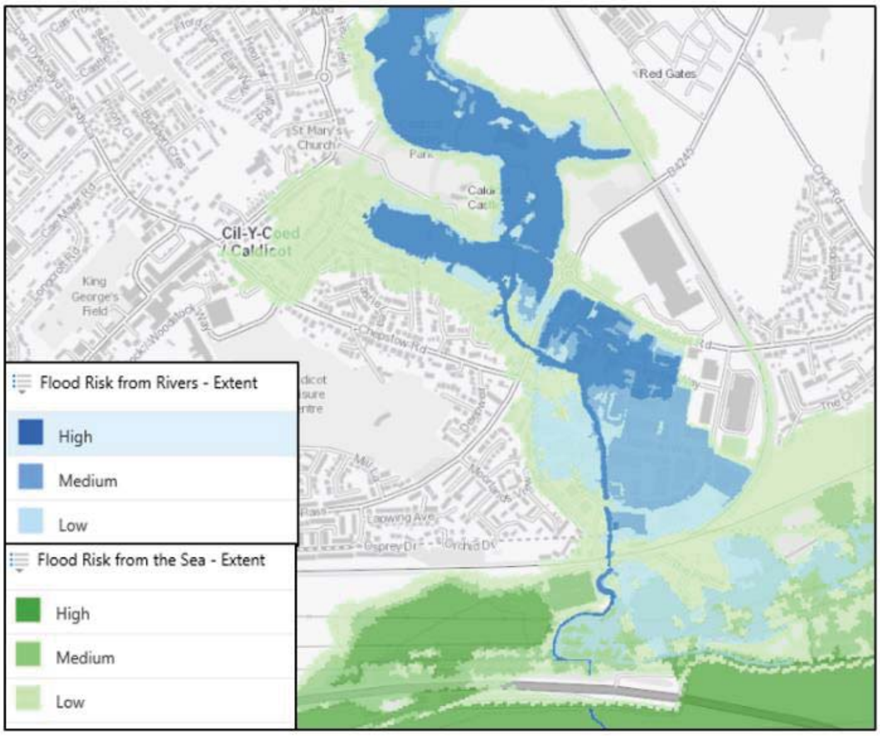


Figure 6: Extract from Natural Resources Wales Flood Map showing the Risk of Flooding from Rivers and the Sea

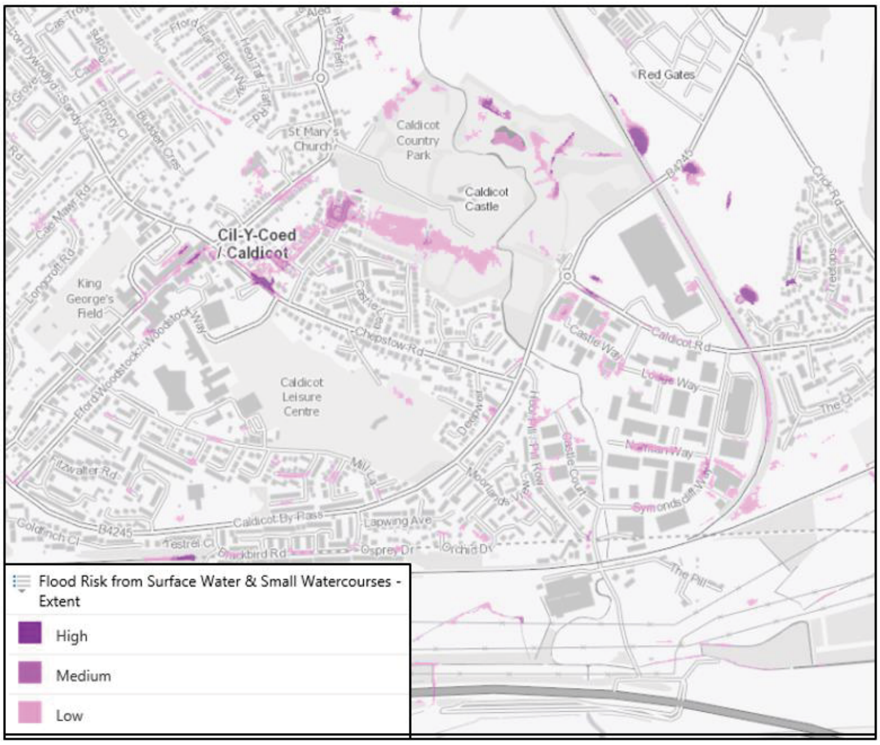


Figure 7: Extract from Natural Resources Wales Flood Map showing the Risk of Flooding from Surface Water

2.3 Investigation Evidence

To support the investigation a range of qualitative and quantitative evidence has been gathered from numerous sources, the summary of which is listed below:

- Residents, Business Owners & Local Councillors/Elected Members – photos, statements, written correspondence
- Surveys – drainage surveys and site inspections
- Met Office Data – Weather warnings and reviews
- Natural Resources Wales – rain gauges and previous study reports
- DCWW Welsh Water - actions
- Highways England – records, actions and attendance
- Monmouthshire County Council – rain gauges at Devauden and Penhow, asset database & Flood Risk Management Plan
- Historic reports relating to flooding at Caldicot, as shown in Section 3.1 below.

3. Flooding History

3.1 Previous Flood Incidents

There are a number previous flooding events which are relevant to the event covered by this report.

1. Various Recorded Events

From the sandbag request records held by MCC, there were flooding events in August 2006, June and July 2007, and August & September 2008. These fit with the comments from Environment Agency Wales in their report to Monmouthshire's Severnside Area Committee on 13 May 2011 which is referred to below.

2. Meeting with Environment Agency Wales 13 May 2011

Local County Councillors in the Caldicot Area had been concerned about pollution issues in the Neddern Brook in low summer flows and numerous flooding events affecting the Castle Lea estate. Following more recent flooding Welsh Water had proposed some new works they had planned to improve surface water drainage in the area. Much of the surface water system on the Castle Lea estate was private and inadequate to convey flows from upstream of the estate to the Neddern Brook. This new system would bypass the private systems serving the estate.

The Environment Agency Wales (now Natural Resources Wales - NRW) reported to MCC's Severnside Area Committee on 13th May 2011 and identified that there had been extensive flooding in the past affecting the east end of Castle Lea and Jolyons Court. This appeared to emanate from the road gullies which in turn connected to the Welsh Water drainage system which then discharges into the Neddern Brook. The planned works by Welsh Water were designed to remedy this issue. They also referred to a site meeting they had held with residents in August 2010. Environment Agency Wales also confirmed in their report that they carried out annual clearance of the Neddern Brook and had recently agreed to add a further 160m for maintenance to their annual programme.

3. Event on 22 July 2011

A significant flooding event occurred on 22 July 2011 when some 30 properties were affected in the Castle Lea estate, Chepstow Road and Castle Lodge Crescent. This event occurred after the major works carried out by Welsh Water to ease the flooding situation. Subsequently a meeting was held on 18th August 2011 between County Councillors, Welsh Water and Council Officers. Welsh Water explained that there were a number of factors causing the flooding, which were as follows:

a) that parts of the Welsh Water system had been partially blocked by fat and debris, which had since been cleared,

b) that parts of the Castle Lea drainage system were private and part of the major works had been to bypass this system and to take flows direct to the Neddern Brook,

c) residents affected by the flooding had called the Fire Brigade and they had set up to pump the water away by discharging the water into the drainage system, but in error had connected to the foul drainage system. This had caused an overload at the sewage pumping station, leading to backing up and surcharging the system causing foul sewage to mix with the flood water and aggravating the situation.

Welsh Water subsequently identified a particular manhole that the fire brigade could safely use in any future events and also agreed to carry out annual cleansing of the local system to minimise further backups.

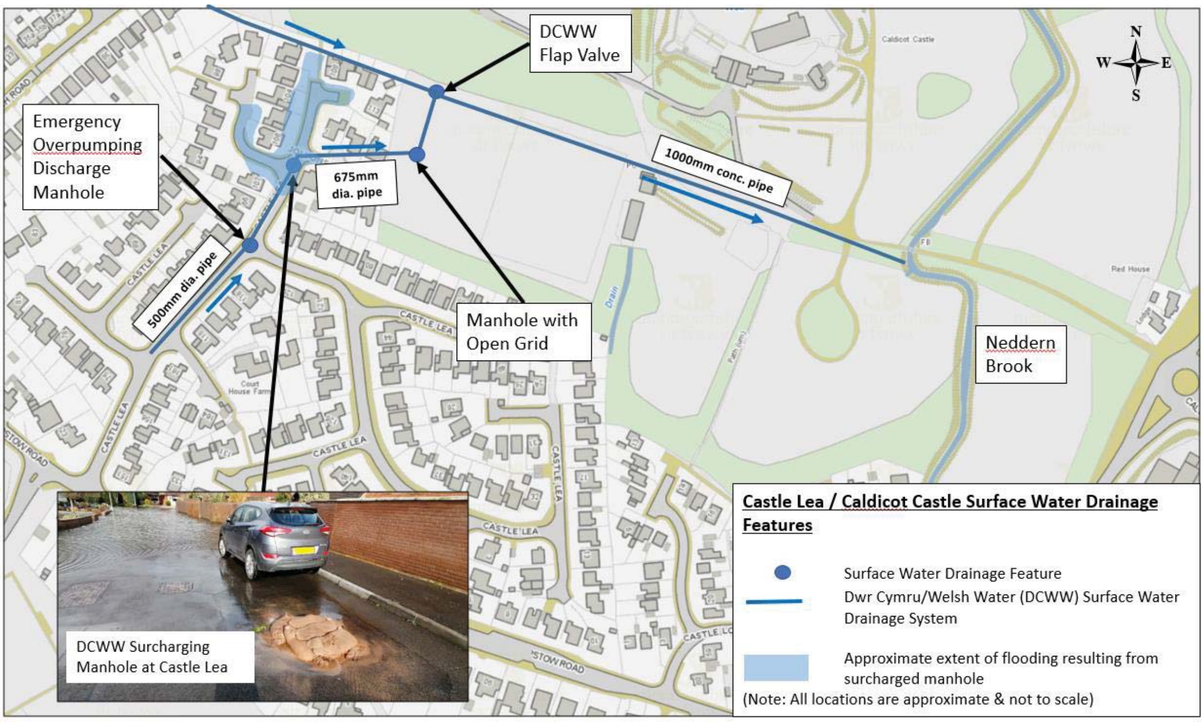


Figure 8: Surface Water Plan Showing Location of Manhole for Pumping

4. Event in December 2012

There was another significant event in the December of 2012 affecting parts of Castle Lea and most of the Country Park around the Castle – see Photo 1 below. It is understood that the flooding at Castle Lea was to gardens and outbuildings and not internal. Locally the cause was said to be linked to the sea door - that is the Neddern Brook's outfall into the Severn Estuary either not opening properly or jamming which created a substantial backup of water flooding in upstream areas, but this was never verified.

Photo 1: **Showing the Flood Extent in the Country Park December 2012**

3.2 Flood Incident

Following an extremely wet period from October 2019 to February 2020, Storm Dennis hit Monmouthshire on 15th and 16th of February causing wide spread flooding across the County. Some properties in the north end of Castle Lea were affected by flooding believed to be the same that flooded in the later incident covered by this report. On Friday 28th February the Met Office issued a Yellow Warning for heavy rain for most of Wales with an Amber warning covering parts of south Wales and the western edge of Monmouthshire.

Storm Jorge was identified and this landed on the 28th February adding a further tranche of heavy rainfall across Monmouthshire. From local rain gauges[1] rain commenced around 6.00am on Friday the 28th February and ceased around 6.00am on Saturday 29th February, with approximately 62mm falling over the 24 hour period. NRW's Collister rain gauge at near Undy recorded 41mm or rainfall during the same period. The surface water run-off and the streams which rise in the Wentwood area started to discharge and raised the water levels in the Neddern Brook, the major water way for this area which passes through Caldicot to discharge into the River Severn. Parts of the catchment also have a high groundwater component as they connect with the limestone layers below via swallow holes, the extent to which groundwater contributed to this flood event is uncertain. In dry periods flow may drop down into the limestone but in very wet periods flows can disgorge to the surface and add to flow levels. On Friday the 28th pallets of sandbags had been despatched to the MCC's Caldicot Depot in preparation of calls for assistance.

Although the rainfall ceased early on Saturday the 29th February flow continued and water levels in the Neddern Brook kept rising. On Saturday 29th February MCC's out of hours Duty Officer began to receive requests for sandbags throughout late morning, initially for Castle Lodge Crescent and then Castle Lea. At this stage the flooding at Castle Lodge Crescent was coming from the Neddern Brook. Resident's reports indicate flooding issues from 9.30am onwards. At Castle Lea flooding was coming from a surcharging surface water manhole and

[1] The data used has been taken from the nearest MCC rain gauges at Penhow and Devauden

residents here reported flooding issues from late afternoon onwards. Calls to MCC for assistance continued into the afternoon and evening of Saturday and the water levels continued to rise. At Castle Lea it was initially flooding estate roads but then creeping up into out-buildings and then by late evening, into properties. Despite attendance by MCC Officers with deliveries of sandbags and the South Wales Fire and Rescue Service, sandbag delivery comments indicate that it was not possible to prevent the continual flows from the surface water manhole near the junction of Jolyons Court and Castle Lea.

Photo 2: **Showing the Surcharging Surface Water Manhole at Castle Lea, taken on 1st March 2020**

South Wales Fire and Rescue Service were on site at Castle Lea, as was a local County Councillor until late into Saturday evening but accounts indicate that there was little those in attendance could do as the surcharging flows from the surface water systems continued. This arose as they could not discharge to the Neddern Brook due to its flood levels.

Photo 3: Showing the Flooding Extent at Castle Lea and Jolyons Court, taken on 1st March 2020.

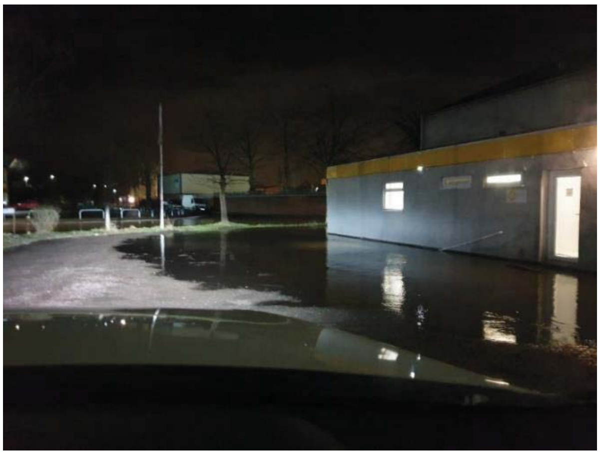
Photo 4: Showing the Flooding Extent at Castle Lea, taken on 1st March 2020.

Figure 9: Approximate flood extents based information provided to the LLFA

Calls for sandbags continued through Saturday night and into Sunday morning 1st March with deliveries and support being made from MCC's Caldicot Depot. Around 5.00am on Sunday 1st March further stocks of sandbags were delivered to Caldicot Depot to meet local needs.

On Sunday 1st March water levels remained high and parts of the Country Park and areas around the Castle were under water, in places over a metre deep. Officers and Councillors from MCC were on site to assist residents, together with other bodies including, Natural Resources Wales and South Wales Fire and Rescue, and later Highways England. Welsh Water were involved but did not attend the site.

MCC Officers spoke to flooded residents, provided advice and support where possible and took details of the flood extent, depths, etc. MCC Officers were able to establish that four properties at Castle Lea and one at Castle Lodge Crescent had internal flooding with a number of others having the gardens and outbuildings etc. under water. It was also established that six commercial properties suffered internal flooding on the Severn Bridge Industrial Estate which had come from the Neddern Brook as well as access roads being flooded. One commercial property was severely affected by the flooding with damage to machines and equipment. Flooding of the roads had affected access to Castle Way, parts of Norman Way, Lodge Way, Symondscliffe Way and an area at The Pill. There were also concerns around flood water mixed with oil in the Industrial estate.



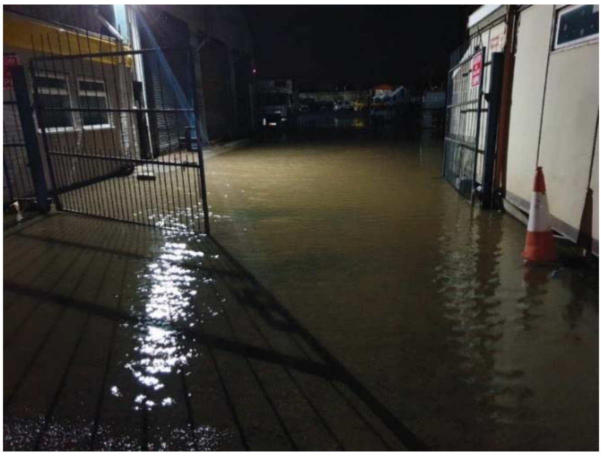


Photo 5: (Left) Shows Some of the Flooding in the Commercial Area on the Evening of 29th February 2020
Photo 6: (Right) Shows the Flooding in the Commercial Area on the Evening of 29th February 2020 Courtesy of Caldicot Recovery

Natural Resources Wales attended the site from around 10.15am on Sunday the 1st March and identified that the trash screen at the entrance to the culvert under the M4 Motorway was clogged with debris. They called Highways England at around 10.45am to attend to deal with the clogged trash screen. The trash screen, culvert and sea door are the responsibility of Highways England as they are associated with the Severn Second Crossing. Highways England (HE) report they received a call at around 11am and their Senior Operations Manager arrived at the site at midday, noting the screen was blocked by debris, mostly with reeds. He considered that the water in the reen was nothing out of the ordinary for this time of year but arranged for a team to attend and then left the site. No records of this team attending have been provided.

Figure 10: Aerial Photograph (2010) of the Culvert under the M4 Motorway

The Senior Operations Manager HE returned at 4pm and explained to several local representatives that were now on site that they were unable to lift the screen for clearing due to the water pressure on the flooded screen. They would need to wait for the next high tide to balance water pressures. Nonetheless the Senior Operations Manager called out a Chargehand / Rigger from HE to join him and they attempted to clear some of the debris manually to relieve the water pressure. An attempt to lift the screen at around 6.30pm failed as the power to the motor cut out. An Electrician from HE attended and restored power but could still not lift the screen and manual clearing continued to around 10pm. The HE staff on site then brought some manual pull lifts from their depot and around 1am on Monday 2nd March they were finally able to lift the screen and flood water dropped significantly. Having cleared the screen of debris it was put back in place. The screen again caught debris and the screen was lifted again, this time by motor about 1.30am on Monday 2nd March and cleared of debris.

From HE's Maintenance Records a full check on the screen and motor was carried out in January 2020 as part of their three monthly visits and all was satisfactory. A further visit was made on 3rd February and they noted that the reed clearing carried out by Natural Resources Wales had left the waterways clear and the screen was clear. There are no further records of attendance until the day of the floods.

Local reports state that the flooded areas had cleared by the early hours of Monday 2nd March, confirming the reports from HE.

In addition to the restriction of flow caused by the blockage at the HE screen, local reports have suggested that excessive vegetation and raised invert levels between the Castle grounds and the M4 culvert have reduced the channel's capacity over time and further restrict flow. Consideration should be given to undertaking a detailed assessment of the channel's capacity, invert levels and structures along its length to identify any significant restrictions to flow along this stretch of the Neddern Brook.

Photo 7: Showing the Flooding Extent at Castle Lea Looking South from Jolyons Court taken on 1st March 2020

Photo 8: Showing the Flooding Extent at Castle Lea Looking North from Jolyons Court, taken on 1st March 2020.

Subsequently MCC staff were on site to assist residents and commercial operators to remove damaged property for disposal and provide advice and guidance on how to proceed. MCC highways staff cleared roads and drains and cleared debris left from the floods. Some residents moved to alternative accommodation until their homes could be repaired.

Photo 9: Showing the Flooding Extent at Castle Lea Looking West, taken on 1st March 2020

Photo 10: Shows Flooding Levels on Sunday 1st March 2020 in the Commercial Area

Photo 11: Shows Flooding Levels on Sunday 1st March 2020 in the Commercial Area

Photo 12: Showing the flooded Neddern Brook looking North from near the Culvert under the M4.

Photo 13: Shows Water Level in Neddern Brook Looking North on Sunday 1st March 2020 Adjacent to Symondscliff Way

3.3 Rainfall Analysis

On the 15th and 16th of February 2020, a period of heavy rain fell during Storm Dennis, causing wide spread flooding across the County. It remained a predominately wet period from the 16th to the 28th February, when on the 28th - 29th February, a further period of heavy rain fell during Storm Jorge on already saturated ground resulting in significant flooding in the town of Caldicot. Based on rain gauge data the rainfall commenced around 6.00am on Friday the 28th February through to approximately 6.00am on Saturday the 29th February, with up to 62mm of rainfall, based on MCC gauges at Penhow and Devauden, the nearest to Caldicot. NRW's Collister rain gauge near Undy recorded 41mm or rainfall during the same period. From local reporting, flooding commenced in and around the areas of Caldicot Castle, Castle Lea, Jolyons Court, Castle Lodge Crescent and the Severn Bridge Industrial Estate, early in the morning of Saturday 29th February and continued to increase until late evening of Sunday 1st March, before mostly clearing by early morning of Monday the 2nd March.

Storm Jorge

Storm Jorge was the fifth named storm of the 2019/2010 season and occurred only two weeks after the heavy rainfall from Storm Dennis. Jorge was named by the Spanish meteorological service and brought strong winds and heavy rain across the UK from 28th February to 1st March.

Weather impacts from Storm Jorge were in general less severe than from storms Ciara and Dennis, but flooding problems continued in the aftermath of these earlier storms and as a result of further rain falling on already saturated ground. The railway line between Cardiff and Swansea was closed and there were reports of further localised flooding. The M4 in west Wales was closed due to strong winds. Flooding problems from the exceptionally wet February continued across parts of the UK.

A Met Office report on Storm Jorge can be found in Appendix A of this report.

Weather Data

The analysis chart at 18.00 UTC 29 February 2020 shows storm Jorge centred to the west of Scotland.

The chart below shows UK area-average rainfall totals for each day of winter 2020 (December 2019 to February 2020 inclusive), illustrating the persistently wet nature of the weather from early February onwards, with the three peaks associated with these three named storms.

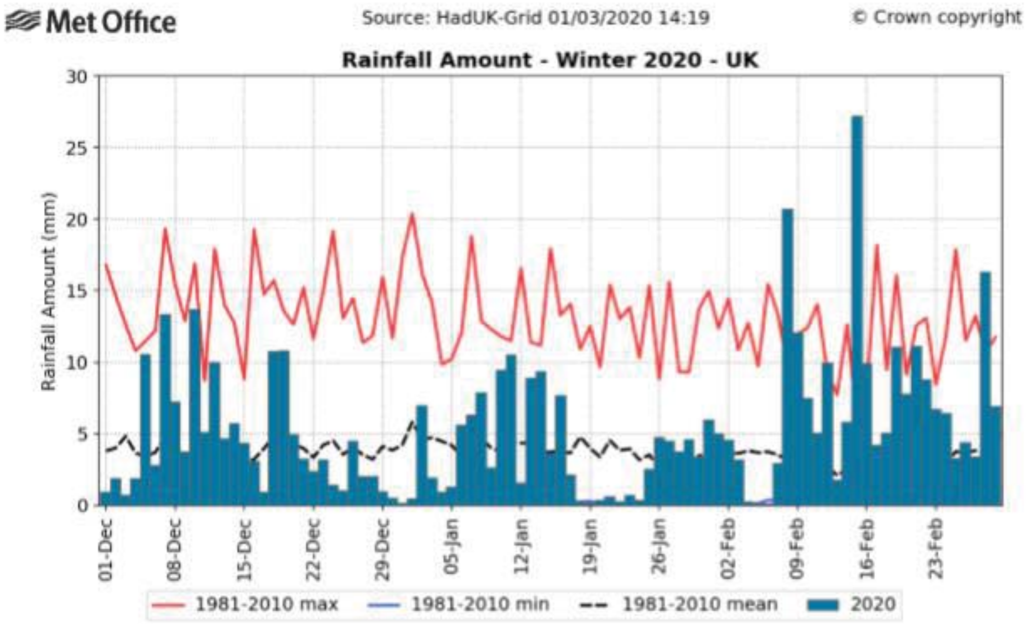


Figure 11: Met Office Rainfall Data December 2019 to February 2020. This also shows daily rainfall totals through February 2020, with particularly wet days from Ciara (8th), Dennis (15th) and Jorge (28th).

The rain-radar images at 0230 UTC 29 February 2020 shows heavy rain from fronts associated with Jorge sweeping across the UK ahead of the strongest winds, with the wettest weather across western upland areas of England and Wales and over 50 mm falling across these areas.

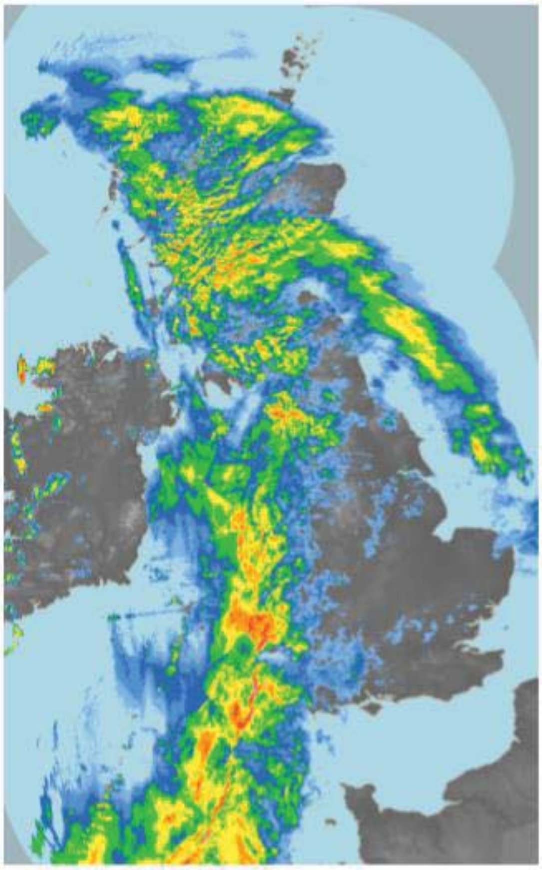


Figure 12: Rain Radar Image from Met Office

The provisional UK rainfall total for February 2020 was 209.1mm, 237% of the 1981-2010 average. This was the UK's wettest February and the fifth-wettest calendar month on record in a series from 1862. It was also the wettest February in the long-running England and Wales precipitation series from 1766. The map below shows UK rainfall totals for February 2020 as a percentage of the 1981-2010 February long-term average. Most of the UK received over twice the monthly average rainfall, with three times the average falling fairly widely and locally up to four times the average rainfall across parts of the south Pennines.

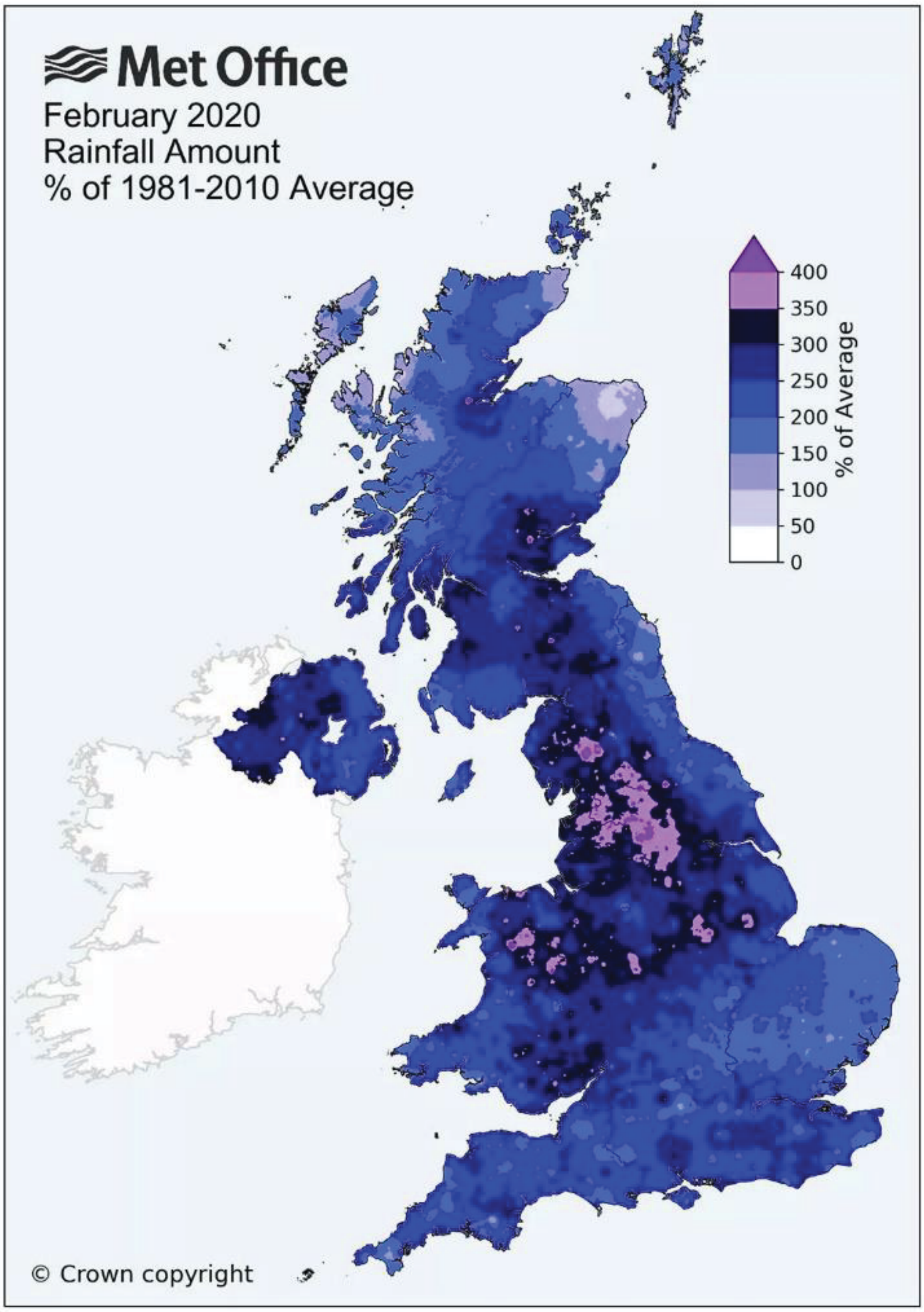


Figure 13: Shows the Total Rainfall for February 2020

4 Mechanisms of Flooding

4.1 Fluvial Flooding

The Neddern Brook upstream of Caldicot has a catchment of approximately 46km² and is predominately rural in nature. The main flows rise in the Wentwood area north and north west of Caldicot, where the Castroggi Brook rises. It is known as the Caerwent Brook where it passes around Caerwent and then joins with an unnamed tributary from the north west becomes the Neddern Brook, collecting further small tributaries on its way south.

As it heads south, it passes through the eastern side of the town with the village of Portskewett just to its east. The main part of the town itself is located on the western side of the Neddern Brook. The brook continues south to the River Severn estuary where the Neddern Brook discharges via a culvert under the M4 Motorway. There is a trash screen on the upstream end of the culvert which can be lifted to clear debris and a sea door (a large tidal flap) which prevents tidal flows back into the brook. The Neddern Brook is classed as a Main River and the responsibility of Natural Resources Wales. As the brook travels south it also enters the Caldicot and Wentlooge Internal Drainage District (IDD). Natural Resources Wales are now responsible for the IDD but managed with a Liaison Committee comprised of local Land Owners, Councillors and other relevant representatives.

The route of the brook runs along the east side of the Country Park close to the Castle, which is on higher ground, then turns close to the residential area of Castle Lodge Crescent, passing under several small bridges. It then travels via a culvert under the B4245 through the Severn Bridge Industrial Estate with a bridge where it passes under Symondscliffe Way to The Pill where it passes under the London to South Wales railway in a culvert and from there to the culvert beneath the M4 Motorway. In flood conditions the brook breaks its banks from north of the Castle and around the section through the low lying areas of the country park, including the playing field area adjacent to Castle Lea. Surface Water from the town and residential areas discharges into the Neddern brook at several locations, with the main surface water sewer outfalling into the Neddern Brook some 110 metres north of Castle Lodge Crescent at OSGR 34867/18860, adding to the catchment flows and increasing the flooding impact of the brook. As the discharge of the brook is to the River Severn, a tidal estuary here, tide levels can affect the discharges. The sea door, a large tidal flap, prevents reverse flows coming up the brook and in significant tidal levels will restrict discharges into the estuary, although this will only be for short periods. On this occasion high tide levels tides occurred at 10.20pm on Saturday 29th at 10.40am & 10.55pm on Sunday 1st March. Tide levels were several metres lower than the flood levels in the culvert upstream and it is considered that this would not have had a significant impact on flows.

A previous study by Atkins for Natural Resources Wales was carried out in 2012, but was limited. A further study would be extremely valuable to improve the understanding of the catchment, the impact of various structures along its route, the interaction with the tidal flows in the Severn Estuary, the surface water connections and any potential for reducing flow peaks including any natural flood management techniques.

Photo 14: The Neddern Brook in Flood taken Saturday 1st March 2020

Photos 15, 16 and 17: Shows Highways England staff at the Trash Screen in March 2020 also showing some of the Debris

Photo 18: Shows The Screen at the Entrance to the Culvert under the M4 Motorway, south of the Commercial Areas, taken Sunday 1st March 2020

4.2 Land Drainage

As mentioned previously, much of the Land Drainage is within the Caldicot and Wentlooge IDD, as show in Figure 4 above. Further North on the Neddern Brook is the Caerwent Site of Special Scientific Interest (SSSI) shown in Figure 3 above.

The SSSI is a substantial area to the north east of Caldicot known as the Caerwent SSSI which is on the Neddern Brook and also extends north and south of the M48 which is carried over the SSSI on a viaduct. This is an area of water meadows and water levels here are managed to maintain the ecology of the site. The underlying limestone also has a number of swallow holes, locally named 'whirlpools' where in low summer flows the brook flows can drop down into fissures and maybe connected to the flows of the great spring which is pumped out at Sudbrook to keep the Severn Rail Tunnel dry. In flood conditions the SSSI can act as a semi reservoir, however, due to the very wet period in the weeks previous to the flood event little storage would have been available. The swallow holes can also discharge flows after significant rainfall adding to ground water flows which form much of the normal Neddern Brook flows.

Other ditches and watercourses are the responsibility of the land owners to maintain and keep clear of debris.

A copy of the SSSI study by the British Geological Society is attached in Appendix C.

4.3 Surface Water Drainage

The Surface Water Drainage systems at Caldicot are a mix, mostly in the responsibility of Welsh Water but with some MCC highway drainage systems that connect to the Welsh Water system. There are also some private drainage systems at Castle Lea that also connect to the Welsh Water systems. Ultimately all the systems discharge into the Neddern Brook with the main outfall into the brook some 110 metres north of Castle Lodge Crescent at OSGR 34876/18836. Most of the outfalls have tide flaps to prevent back flows from the Brook. However once the systems cannot discharge they become tide locked and the systems will back up and surcharge. In the Playing Field part of the Country Park a manhole has been provided with a grid especially to allow surcharge at a location that reduces surcharging further back. During this event we know that much of the Country Park was under water so discharge from the surface water systems to the Neddern Brook would have ceased. The manhole identified in the playing field was itself under water so surcharging further back in the system would occur which accounts for the surcharging from the manhole at the junction of Jolyons Court and Castle Lea. It is important that all tide flaps be checked to ensure they are working as intended. There may be potential for further tide flaps to be installed in parts of the system but studies would be needed to ensure this did not cause problems elsewhere.

Similar arrangements are found on the Severn Bridge Industrial Estate with surface water systems discharging to the Neddern Brook. Based on the accounts from owners and visits by MCC Officers the systems worked well during the heavy rainfall without causing any direct flooding and the flooding of parts of the estate commenced over night of the 29th February to 1st March from the Neddern Brook.

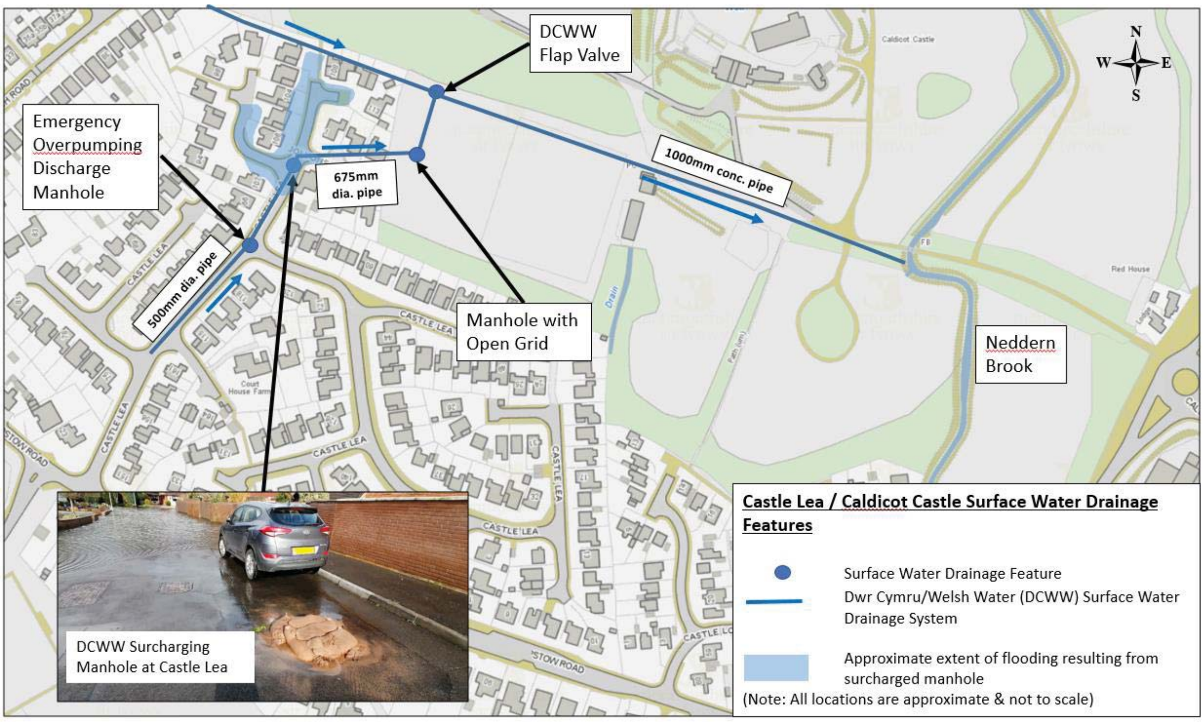


Figure 14: Caldicot - Welsh Water's Surface Water Drainage System at Castle Lea

5 Rights and Responsibilities of Risk Management Authorities

5.1 Lead Local Flood Authority

Under the Flood and Water Management Act 2010, Monmouthshire County Council (MCC) has been established as the Lead Local Flood Risk Authority (LLFA) for its administrative area.

As defined in the Flood and Water Management Act 2010, MCC is responsible for 'Managing' what is termed, its 'local flood risk'. This includes the risk of flooding from ordinary watercourses, surface runoff and groundwater.

Local Authorities have always had certain responsibilities in relation to ordinary watercourses, and in practice most Local Authorities took the lead in dealing with surface water flooding incidents prior to the changes contained within the Flood and Water Management 2010.

The Flood and Water Management Act 2010 places a number of statutory duties on Local Authorities in their new role as LLFAs including:

- The preparation of local flood risk management strategies;
- A duty to comply with the National Strategy;
- To co-operate with other authorities, including sharing data;
- A duty to investigate all flooding within its area, insofar as a LLFA consider it necessary or appropriate;
- A duty to maintain a register of structures and features likely to affect flood risk;
- A duty to contribute to sustainable development; and
- Consenting powers on ordinary watercourses.

In addition to these each LLFA has a number of what are called permissive powers. These are powers that allow them to do something, but do not compel them to and include:

- Powers to request information;
- Powers to designate certain structures or features that affect flood or coastal erosion risk;
- The expansion of powers to undertake works to include broader risk management actions; and
- The ability to cause flooding or coastal erosion under certain conditions.

LLFA's in Wales have also taken on the role of the SuDS Adopting and Approving Body in relation to sustainable drainage systems as of the 7th January 2019. In this role they are responsible for both approving the original design of the SuDS and adopting and maintaining the finished system in accordance with Welsh Government's National Standards for Sustainable Drainage.

The function of the LLFA during and after the flooding at Caldicot included a range of Response and Recovery functions:

- Officers investigated the initial flooding and wrote to all properties and businesses' adjacent to the Neddern Brook requesting information of the flood event. Responses and relevant information helped inform the investigation and this report which has been produced in line with the requirements of Section 19 FWMA 2010.
- Officers contacted residents affected by flooding to offer support and advice to assist in the recovery following the event.

- Officers coordinated the response to the flooding with Emergency Services.
- Asset information collected during the flood event has been incorporated into the LLFA Asset Register.

5.2 Natural Resources Wales

Under the Flood and Water Management Act 2010, NRW is responsible for managing flood risk from main rivers, reservoirs and the sea. They are also recognised as a coastal erosion risk management authority under the Coastal Protection Act 1949.

Their strategic oversight role is about having a Wales-wide understanding of all sources of flooding, coastal erosion and the risks associated with them, on a consistent basis across Wales to help inform the RMAs and the public.

Where present, NRW manage Internal Drainage Districts (IDDs) and are responsible for maintenance, improvement and operation of drainage systems and regulation of watercourses within the internal drainage district. Their main role is the close management of water levels in watercourses for the purpose of reducing the risk from flooding and for sustaining all land uses and the environment. A plan of the IDD can be seen in Figure 4 above.

As the Neddern Brook is classified as main river and falls within the IDD, Natural Resources Wales are the Risk Management Authority responsible for managing flood risk from this watercourse.

5.3 Water / Sewerage Company

Sewerage Undertakers are responsible for maintaining the public sewerage systems, including adopted sewers carrying surface water run-off.

In flood conditions, the sewer systems can often become overloaded with a mixture of floodwater and sewage leading to overflow and flooding. Where applicable, Sewerage Undertakers are responsible for the removal of surface water from impermeable surfaces through their sewerage system. Where there is frequent and severe sewer flooding, Sewerage Undertakers are required to address this through their capital investment plans which are regulated by Ofwat. To prevent further flooding, water and sewer companies have a responsibility to: monitor the levels; prevent overloading sewer systems; maintain and repair drainage pipes as necessary. This investigation has identified assets and infrastructure belonging to Dwr Cymru /Welsh Water that have contributed to the flood event through the surcharging of manholes at Castle Lea, potentially at Castle Lodge Crescent and on the Severn Bridge Industrial Estate. A plan of these assets is shown in Figure 14 above.

5.4 Network Rail

Network Rail has an operational responsibility as a riparian owner and is required to undertake regular maintenance of all assets that pose a risk to flooding. The Neddern Brook passes under the London to South Wales main line through a culvert at the Pill. There is no evidence or reports of any issues at this structure during the flood event covered by this report.

5.5 Highway Authorities

The Highway Authority is responsible for ensuring the highway is clear of obstructions and has a drainage system that controls the surface water that falls onto the highway.

Monmouthshire County Council is the Highways Authority for all highways in Monmouthshire apart from Trunk Roads and Motorways which are managed by the Welsh Government. The Severn Second Severn Crossing (now known as the Prince of Wales Bridge) is now the responsibility of Highways England. The extent of Highways England responsibility includes the Neddern Brook culvert, together with the upstream screen and downstream sea door. Highways Authorities are also Risk Management Authorities in their own right according to the Flood and Water Management Act 2010 and must adhere to all the responsibilities of Risk Management Authorities.

Under the Highways Act 1980, the Highways Authority has a duty to maintain the highway. This includes ensuring that highway surface water drainage systems are clear and free from blockages, including the extent of any watercourses and structures that pass under the Highway. There is no evidence or reports of any issues at any MCC structures during the flood event covered by this report.

5.6 Riparian Landowners

Riparian owners, householders and business owners are responsible for maintaining private drainage assets and these are usually minor drains, ditches, watercourses, pipes, culverts and bridges.

Riparian Landowners are legally responsible under common law for the maintenance of the land generally up to the centreline of any watercourse adjacent to their property. This includes the maintenance of the bed, banks and any boundary features e.g. vegetated strips such as hedging, with routine clearance of debris and/or blockages.

This does not mean that the owner must remove all debris from the watercourse, but it does require the owner to maintain as far as it does not pose a risk or 'nuisance' to a neighbour. Any works to modify the watercourse by the landowner must first be passed through the relevant Risk Management Authority, Lead Local Flood Authority (LLFA) or Natural Resources Wales (NRW).

Land owners are responsible for ditches and land drainage assets upon their land at Caldicot, with permissive powers and responsibility for those watercourses within the Internal Drainage District falling to NRW.

5.7 Residents and Property Owners

Residents and property owners are responsible for the maintenance and operation of drainage assets and connecting pipework falling within their ownership. They are also responsible for the protection of their own properties against flooding. Where safe to do so, they should take measures to protect themselves and their property from flooding. Residents and property owners have the right to defend their property as long as they do not subsequently increase the risk of flooding to other properties.

6 Permissive Powers of Risk Management Authorities

As Risk Management Authority for the main river Neddern Brook (Caldicot & Wentlooge Internal Drainage District), Natural Resources Wales have permissive powers under the Flood and Water Management Act 2010 and Land Drainage Act 1991. These powers include the right to undertake works to ensure watercourses are kept clear and free from impediments to flow, as well as promoting and implementing flood alleviation schemes

7 Flood Alleviation Scheme / Drainage Improvements

Caldicot is close to the Severn Estuary and the sea defences here are designed to cope with a 1:200 year coastal flood. The Severn Estuary Shoreline Management Plan identifies this section of coast as being under the policy “Hold the Line” which means to maintain the current position of defences.

The Neddern Brook has raised banks in some areas but there are no formal defences for flooding from the brook. Much of the Castle Lea estate, Castle Lodge Crescent, Industrial Estate and the Country Park are within Low – High Risk flood areas as shown on the NRW Flood Maps in Figures 6 & 7 above. With more intense rainfall and increased frequency of flood events expected brought about by climate change, it is recommended that consideration be given to undertaking an assessment of options to reduce flood risk to properties and businesses’ in the area.

As outlined in Section 3.1 above, Welsh Water have previously undertaken works to reduce flood risk in the Castle Lea area. However, the problem remains and further works should be considered to prevent flooding to residential properties in this area.

8 Conclusion

The investigation has identified the flooding that affected Caldicot on Saturday 29th February to Monday 2nd March was the result of a prolonged and significant rainfall event, with the largest accumulations of rain falling on already wet ground from around 6.00am on the 28th to about 6.00am on the 29th February as part of Storm Jorge.

The heavy rain fell on already saturated ground, with 62mm recorded in the 24hr period in parts of the Neddern Brook catchment. This resulted in a rapid rise in levels in the Neddern Brook and its tributaries from Friday 28th February to Sunday 1st March. There was also an element of flow from ground water sources which rise in the areas north of the town. This is where the underlying limestone acts as an aquifer storing water in low flow periods and discharging flows via swallow holes in flood periods.

It is with reasonable confidence to conclude that the blockage of the trash screen on the M4 culvert, along with possible restrictions to flow along the channel of the Neddern Brook were the primary causes of the flooding. This led to flooding parts of the Severn Bridge Industrial Estate, the Country Park and adjacent playing field areas. The surface water systems in the Castle Lea area, mostly within Welsh Water's responsibility discharge into the Neddern Brook, but as the water levels in the brook rose the discharges became unable to flow and became tide locked. This then created surcharging at various points in the surface water system, including a gridded manhole in the Playing field area of the Country Park. Most evident was a manhole within the Castle Lea estate near its junction with Jolyons Court which caused internal flooding to four adjacent residential properties. Further downstream the brook broke its banks causing internal flooding to a property in Castle Lodge Crescent and six commercial properties in the Severn Bridge Industrial Estate. Parts of the highways at Castle Lea, Castle Lodge Crescent, Norman Way, Castle Way, Lodge Way and Symondscliffe way were also flooded.

Whilst the groundwater element and surface water discharges to the Neddern Brook added to the flooding, the relative rapidity of the flood level reductions once the trash screen was lifted and cleared reinforce the conclusion that the clogged trash screen had a significant impact on the upstream levels. It is noted that there are no reported HE visits made between the 3rd February and the 1st March during which time there had been three major storms, with little doubt that each generated substantial debris which would have been caught by the trash screen.

The conclusions from this report have led to a list of recommended actions by the various Risk Management Authorities responsible, as listed below.

9 Recommendations

In accordance with Section 19 of the Flood and Water Management Act 2010, as Lead Local Flood Authority Monmouthshire County Council has investigated this flood event and identified which Risk Management Authorities have relevant flood risk management functions. As a result of the findings of this investigation and discussions with residents and other Authorities, the following recommendations have been made.

Reference	Recommendation	Responsible Risk Management Authority(s)
CA01 (Flood Risk)	Identify and implement any alterations that can be made to the trash screen on the Neddern Brook to ensure it can be immediately cleared at any time and without needing to await a High Tide or sourcing of additional lifting equipment from offsite. Consideration should be given to an automated screen or remote monitoring via a CCTV camera. Such changes may require approval from NRW (Flood Risk Activity Permit) and should be discussed with MCC as Lead Local Flood Authority.	Highways England
CA02 (Flood Risk)	That Highways England review their Maintenance Plan to ensure visits to check that the trash screen is clear during and following major flood warnings being issued and during and after any significant storm events.	Highways England
CA03 (Flood Risk)	Consider the viability of the addition of a gauge or gauge station on the Neddern Brook to aid forecasting and monitoring of water levels with a flood warning system.	NRW
CA04 (Local Protection)	Consider the requirement and location of a sandbag store within Caldicot that can be accessed during future flood events.	MCC
CA05 (Flood Risk)	Check that flap valves in the surface water systems are working as intended and consider whether additional tide flaps or other works could assist to avoid or reduce surcharging at Castle Lea.	DCWW
CA06 (Community Flood Plan)	Consider the requirement for a multi-agency Community Flood Plan to inform and aid the emergency response to future flood events.	NRW/MCC
CA07 (Flood Risk)	That NRW review their Flood Risk Maintenance Programme along the Neddern, to consider additional vegetation clearance work as reed growth and debris build up can be substantial over the spring and summer and that all debris and reed cuttings are removed from the vicinity of the brook.	NRW
CA08 (Flood Risk)	Consider undertaking an initial assessment of options to reduce flood risk from the Neddern Brook using current Welsh Government FCERM Business Case Guidance and updated hydraulic modelling. The assessment should consider the whole catchment and previous studies, as well as how the Neddern Brook (main river) impacts on local surface water systems during flood events. Natural flood management options should be considered as part of any future assessment.	NRW/MCC/DCWW
CA09 (Land Drainage and Surface Water)	Record detail, ownership and maintenance responsibility of all land drainage features and ensure such features are maintained to the required standards.	NRW/MCC/ Highways England
CA10 (Maintenance)	Review existing maintenance practices within the grounds of Caldicot Castle and Country Park and agree a suitable programme of works to ensure the Neddern Brook is free from any impediments to flow and to promote multiple benefits.	MCC/NRW

10 Useful Links and Contacts

- Monmouthshire County Council Flood Pages:
  www.monmouthshire.gov.uk/flood-risk-management
- Natural Resources Wales:
  www.naturalresources.wales/flooding
- Welsh Government:
  www.gov.wales/flooding-coastal-erosion
- Blue Pages
  www.bluepages.org.uk
- Flood Re (Insurance):
  www.floodre.co.uk

Appendix A – Met Office Report: Storm Jorge

Met Office

Storm Jorge

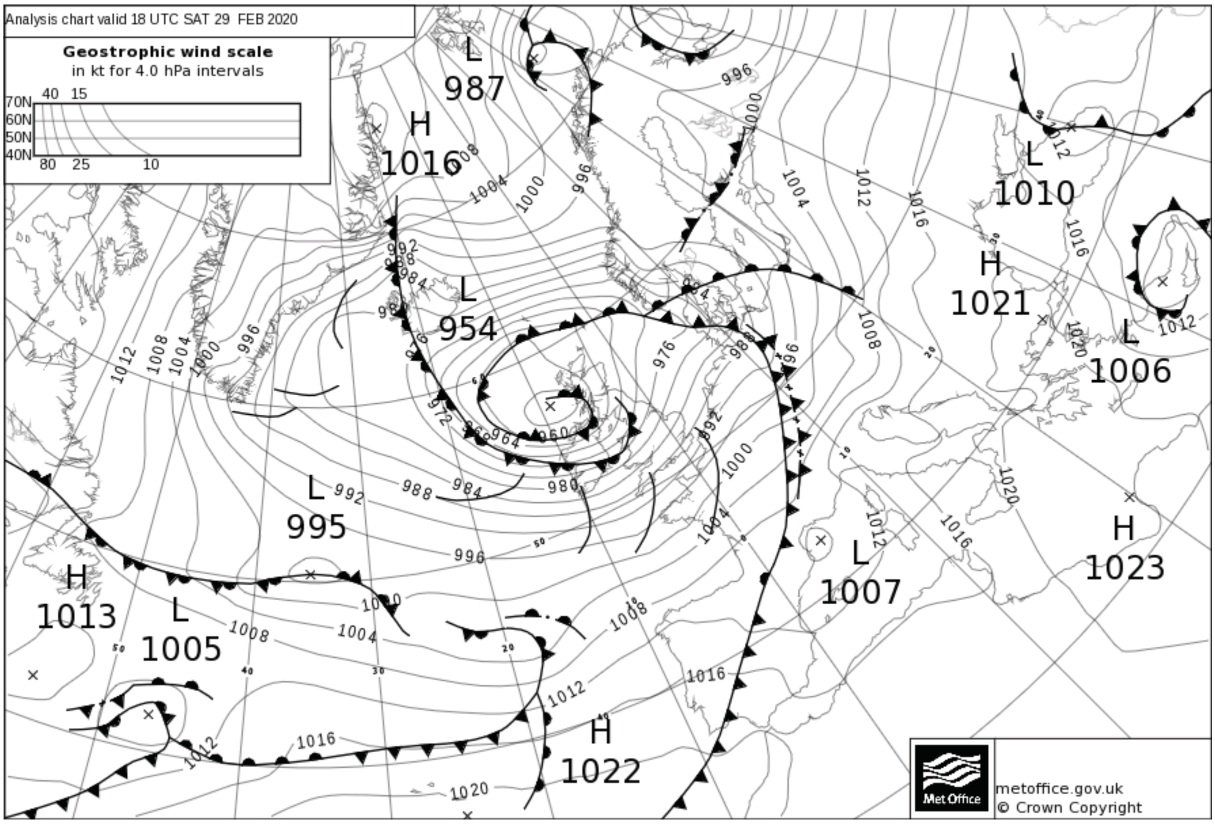
Storm Jorge was the fifth named storm of the 2019/2010 season. Jorge was named by the Spanish meteorological service and brought strong winds and heavy rain across the UK from 28 February to 1 March.

Impacts

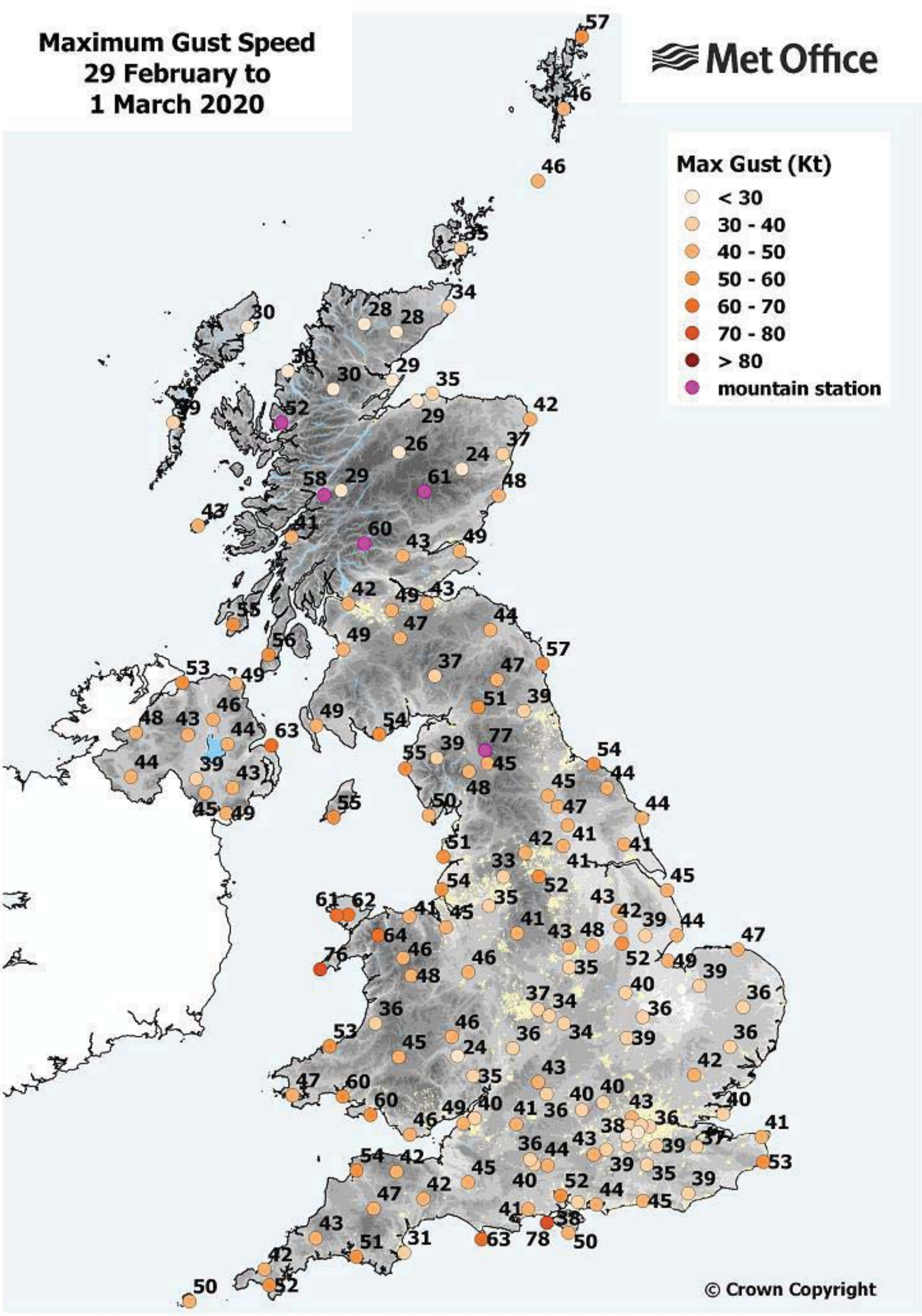
Weather impacts from storm Jorge were in general less severe than from storms Ciara and Dennis, but flooding problems continued in the aftermath of these earlier storms and as a result of further rain falling on already saturated ground. The railway line between Cardiff and Swansea as closed and there were reports of further localised flooding. The M4 in west Wales and was closed due to strong winds. Flooding problems from the exceptionally wet February continued across parts of Yorkshire.

Weather data

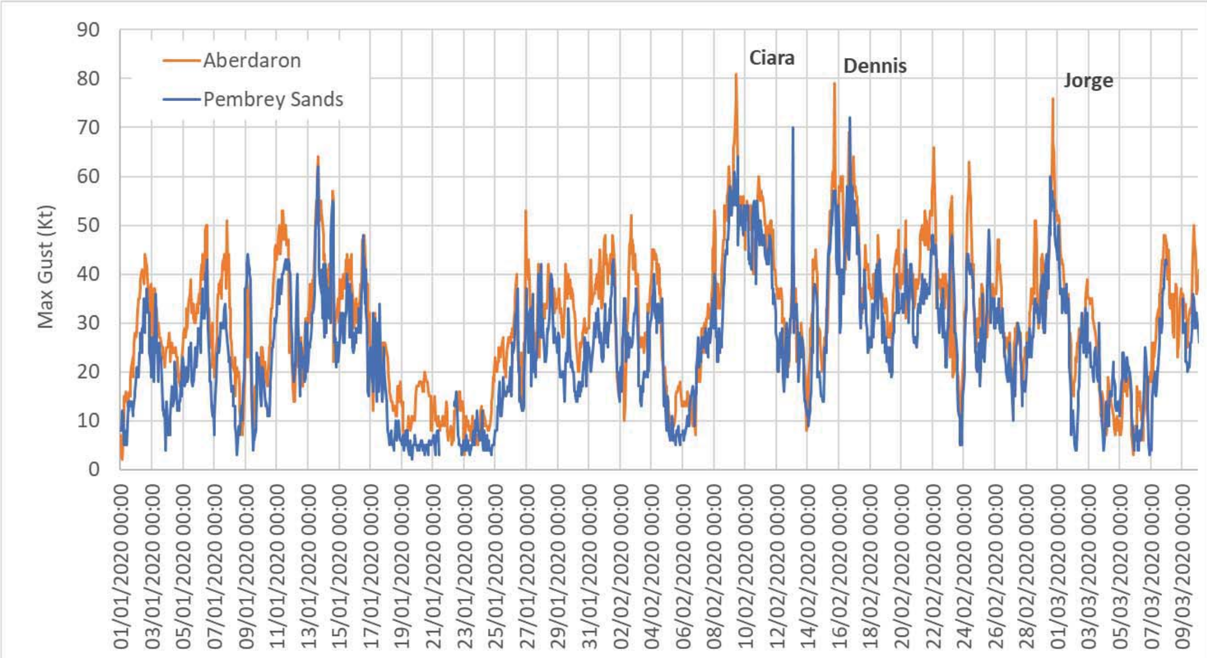
The analysis chart at 18 UTC 29 February 2020 shows storm Jorge centred to the west of Scotland.



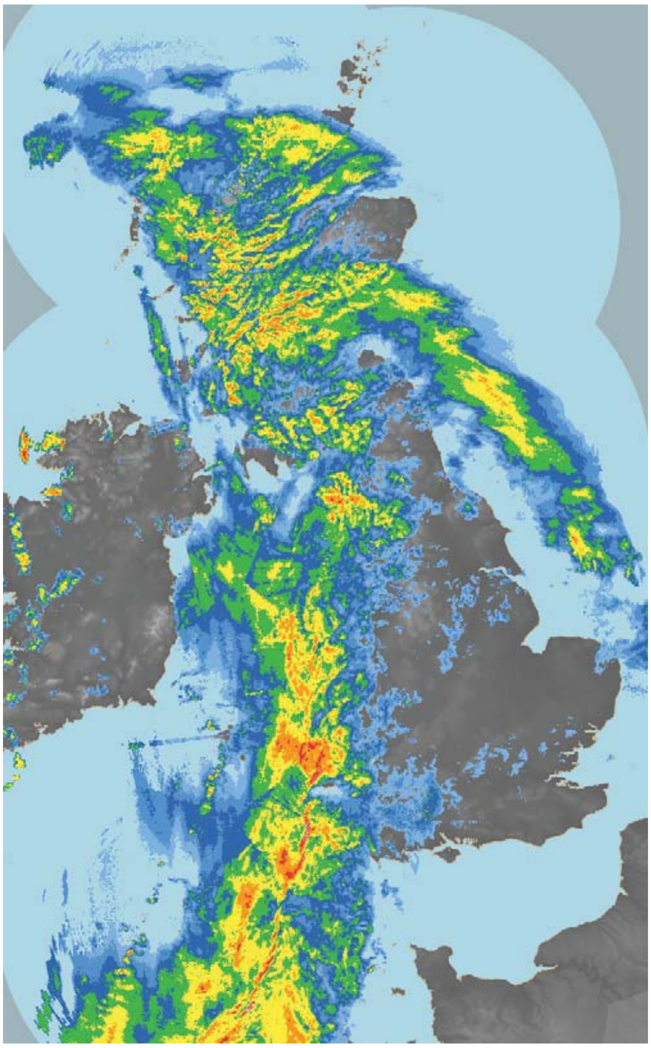
The map below shows maximum gust speeds from storm Jorge. Winds gusted at over 60 Kt (69 mph) around some exposed coastlines. The highest gusts were 78 Kt (90 mph) at Needles Old Battery, Isle of Wight, 76 Kt (87 mph) at Aberdaron, Lleyn Peninsula, 64 Kt (74 mph) at Capel Curig, Conwy and 63 Kt (72 mph) at Orlock Head, County Down and Isle of Portland, Dorset.



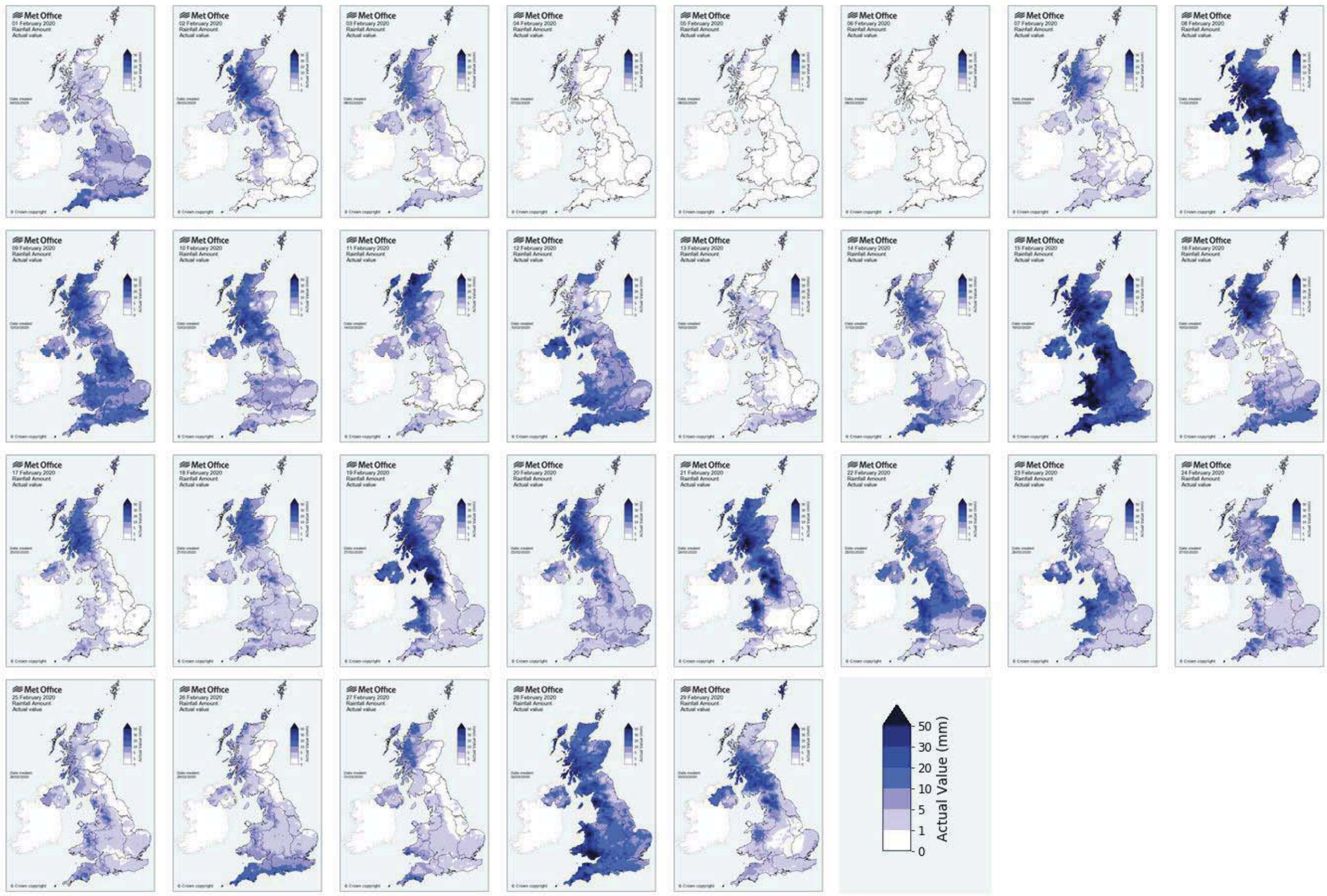
The chart below shows hourly maximum gust speeds for January, February and early March 2020 at Aberdaron, Lleyn Peninsula and Pembrey Sands, Dyfed, with the spikes in gust speeds at Aberdaron associated with storms Ciara, Dennis and Jorge. The chart also illustrates the persistently windy nature of the weather throughout much of February, associated with a powerful Atlantic jet stream and winds at these locations often gusting at 40 to 50 Kt or higher.



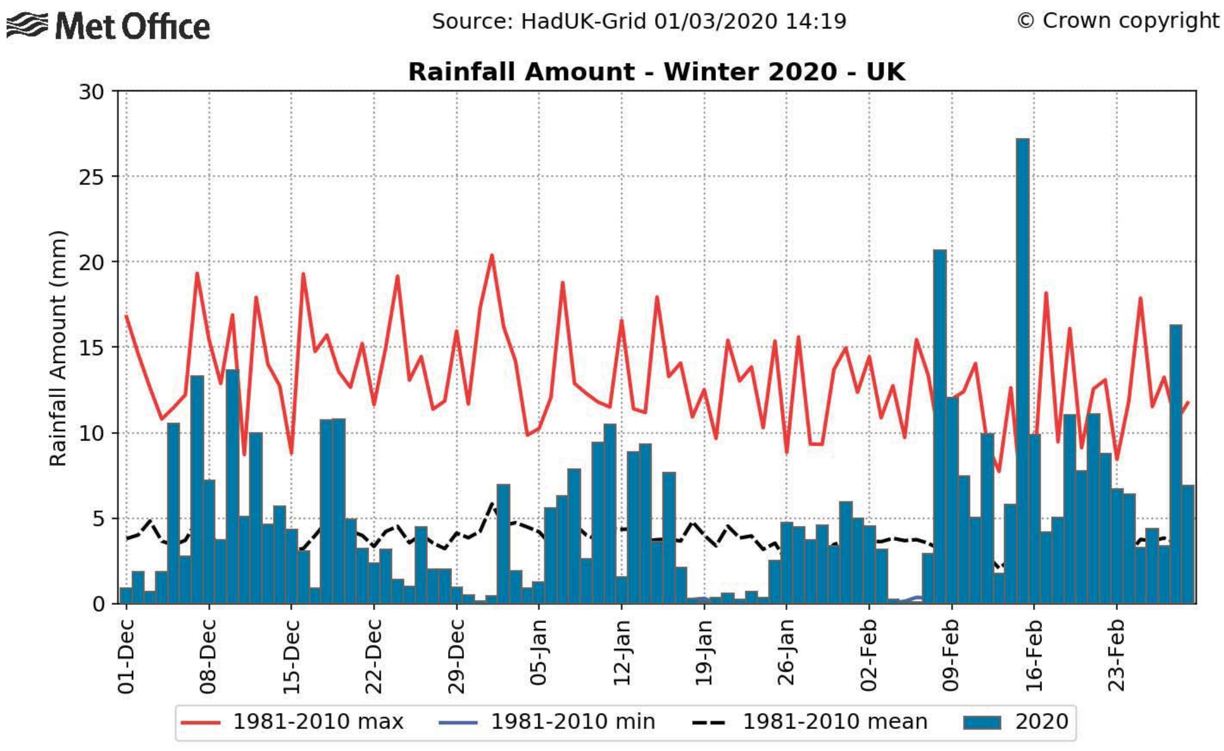
The rain-radar images at 0230 UTC 29 February 2020 shows heavy rain from fronts associated with Jorge sweeping across the UK ahead of the strongest winds, with the wettest weather across western upland areas of England and Wales and over 50 mm falling across these areas.



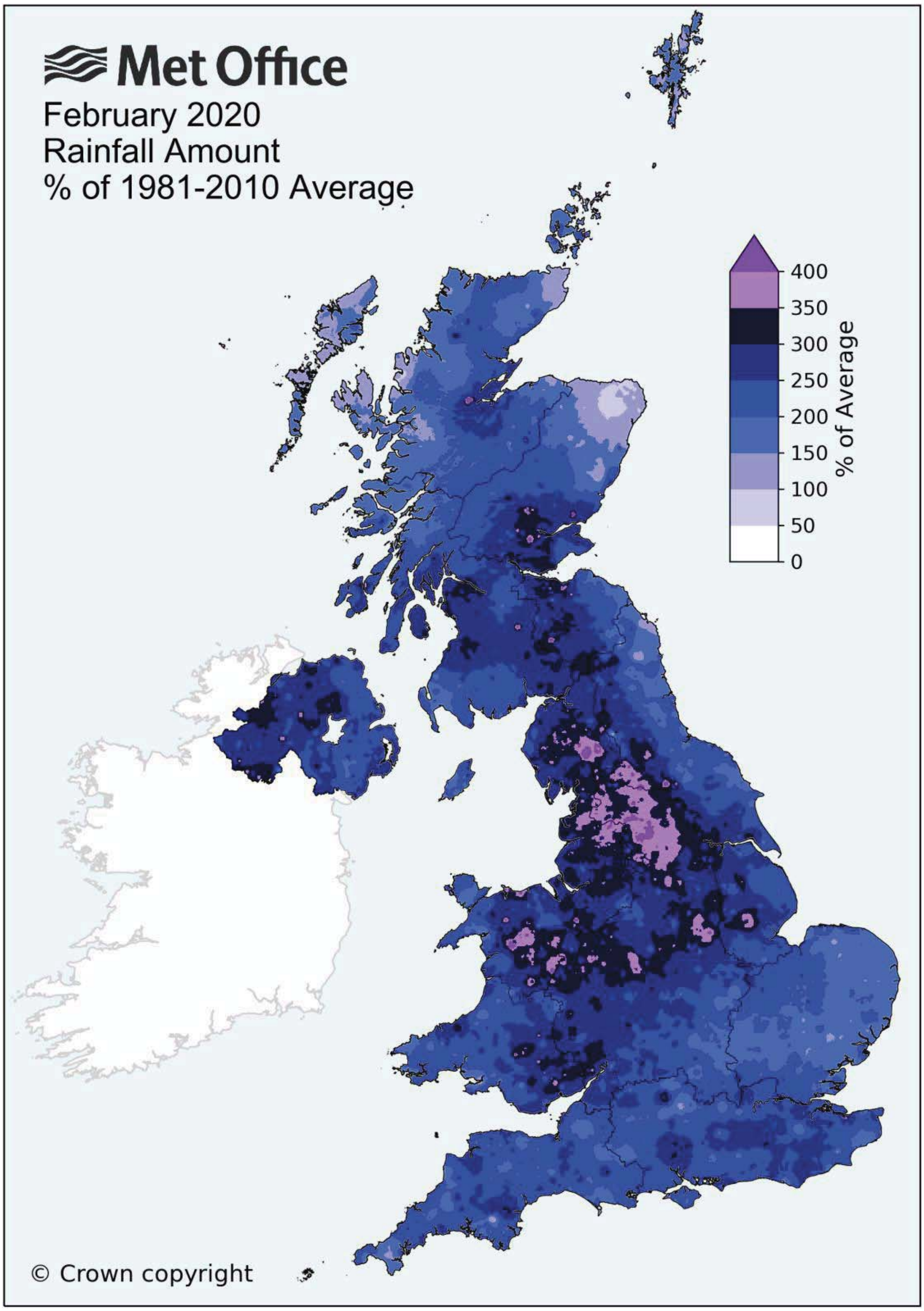
The panel of maps below shows daily rainfall totals through February 2020, with particularly wet days from Ciara (8th), Dennis (15th) and Jorge (28th).



The chart below shows UK area-average rainfall totals for each day of winter 2020 (December 2019 to February 2020 inclusive), illustrating the persistently wet nature of the weather from early February onwards, with the three peaks associated with these three named storms.



The provisional UK rainfall total was 209.1mm, 237% of the 1981-2010 average. This was the UK's wettest February and the fifth-wettest calendar month on record in a series from 1862. It was also the wettest February in the long-running England and Wales precipitation series from 1766.The map below shows UK rainfall totals for February 2020 as a percentage of the 1981-2010 February long-term average. Most of the UK received over twice the monthly average rainfall, with three times the average falling fairly widely and locally up to four times the average rainfall across parts of the south Pennines.



Author: Mike Kendon, Met Office National Climate Information Centre

Last updated 10/03/2020

Appendix B – Land Drainage and Surface Water Photos

Photo 19: The Sea Door where the Neddern Brook Outfalls into the River Severn taken June 2020

Photo 20: The Sea Door where the Neddern Brook Outfalls and Shows Silt Deposit in Front of Door taken June 2020

Photo 21: Shows the Screen on the Neddern Brook Culvert under the M4 Motorway taken June 2020

Photo 22: Showing the Flood Levels in the Neddern Brook, taken on 1st March 2020 in the Country Park

Photo 23: Showing the Flood Levels in the Country Park, taken on 1st March 2020

Photo 24: Showing the flooding at Castle Lea looking North from Jolyons Court on Sunday 1st March 2020

Photo 25: Shows Flooding at Normans Way Looking West towards the Neddern Brook, Sunday 1st March courtesy of SD sealants

Appendix C - BGS Nedern Brook Wetland SSSI Phase 1 Hydrological Monitoring

British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL
Arolwg Daearegol Prydain
CYNGOR YMCHWILYR AMGYLCHEDD NATURIOL

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.

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Nedern Brook Wetland SSSI in flood P83234

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British Geological Survey, Cardiff 2016

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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.

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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)

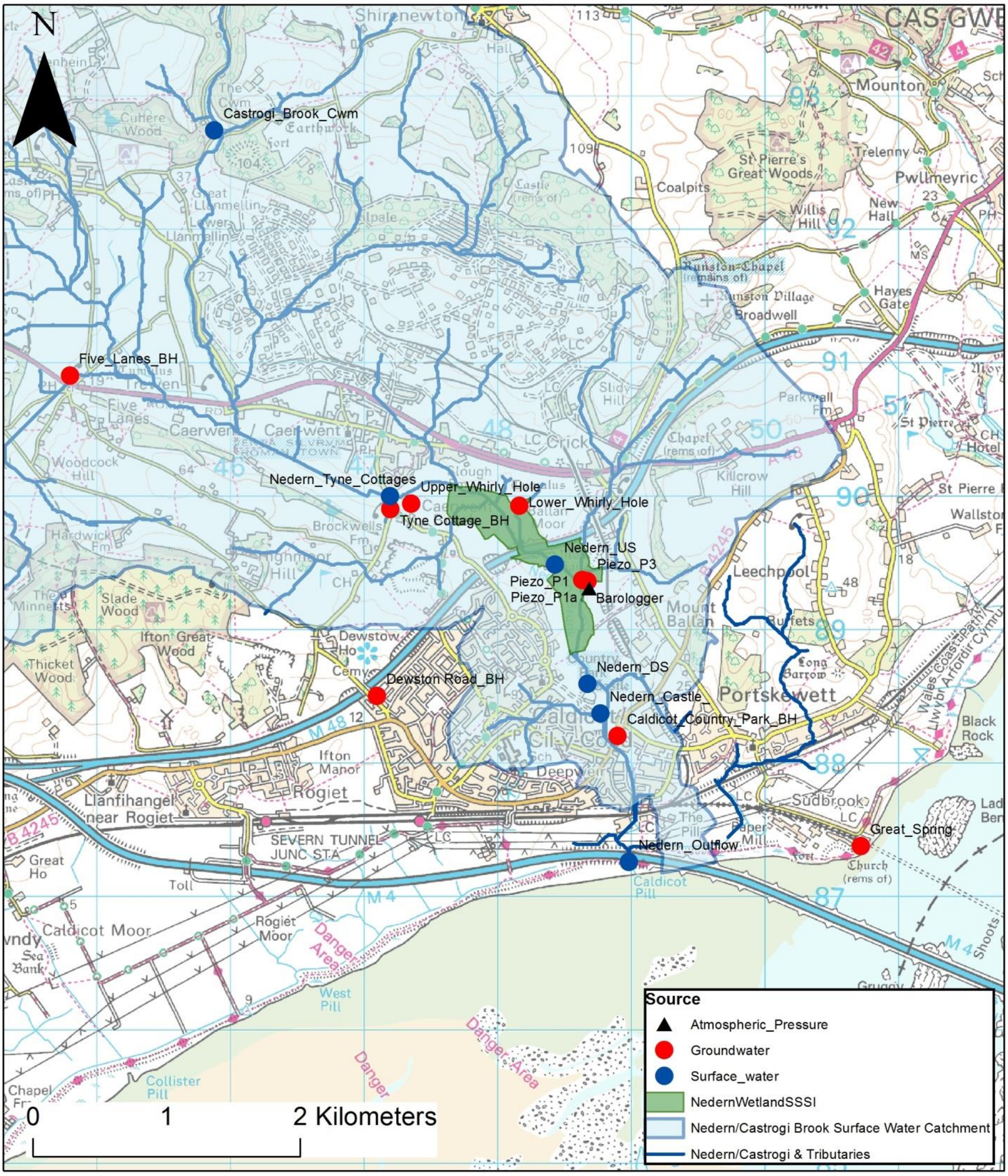

Figure 2 Hydrometric Monitoring Locations within the Nedern Brook catchment. Contains Ordnance Survey data © Crown Copyright and database rights 2015.

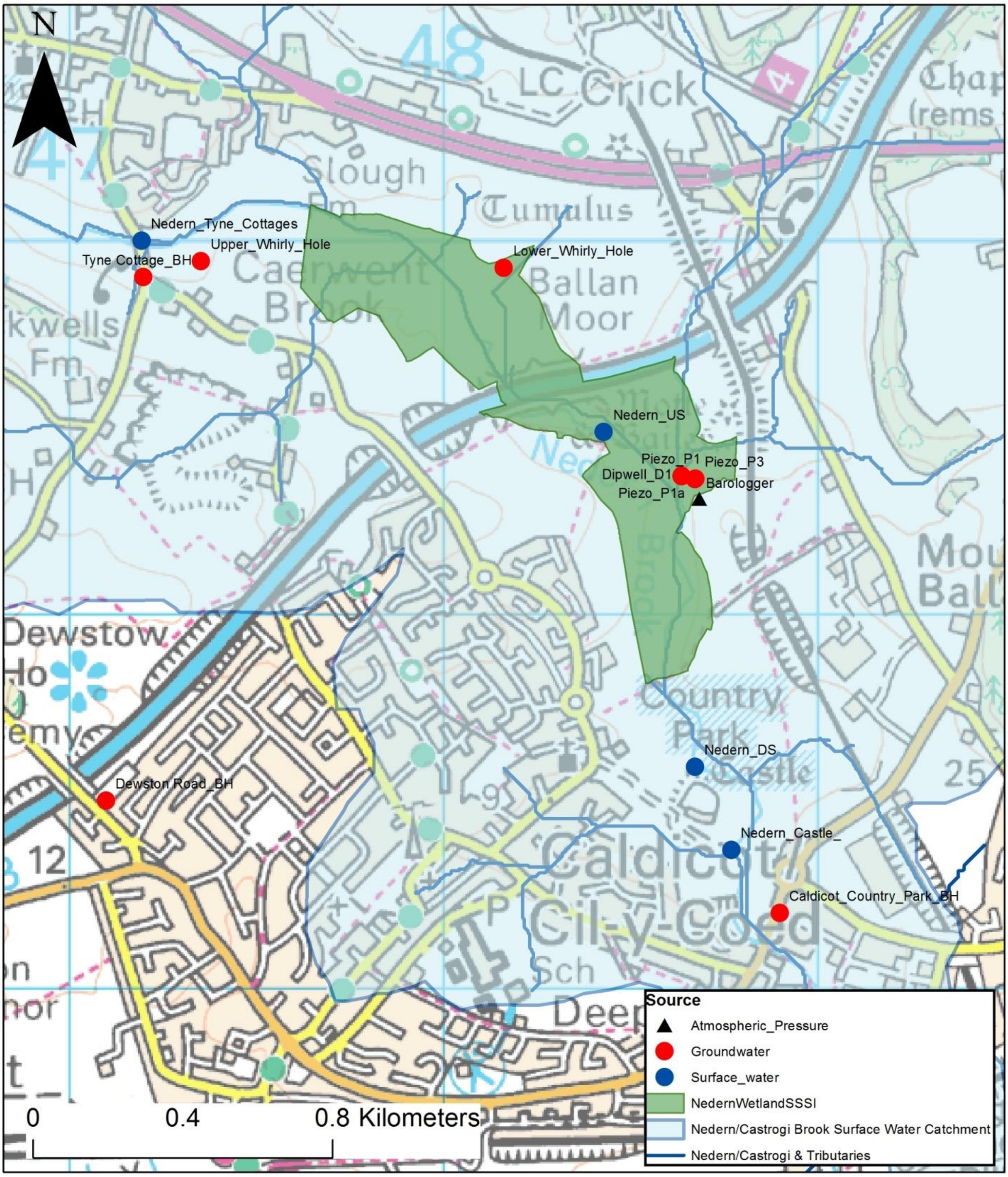

Figure 3 Hydrometric Monitoring Locations within the Nedern Brook Wetland SSSI catchment. Contains Ordnance Survey data © Crown Copyright and database rights 2015.

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.

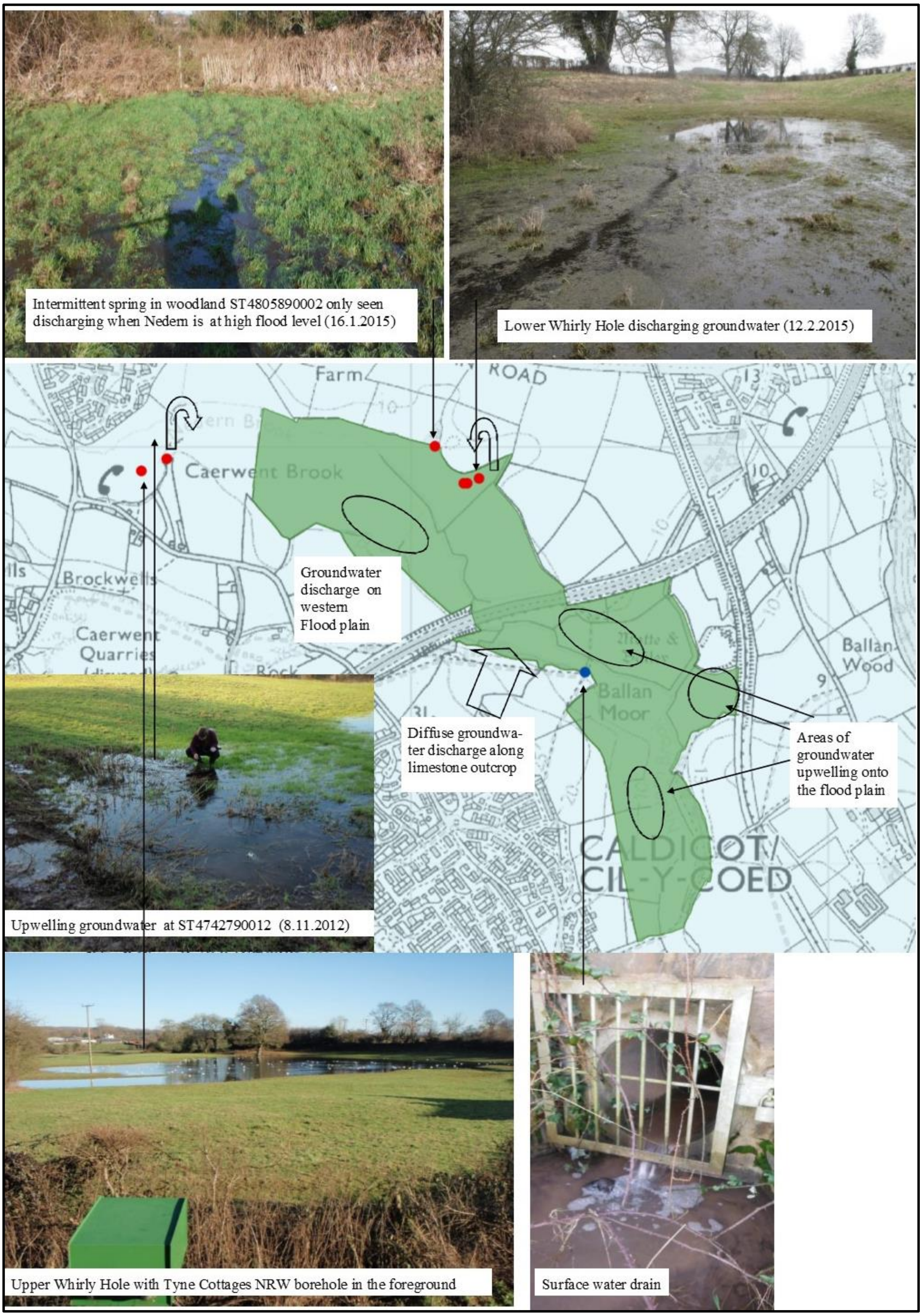

Figure 5 Key groundwater and surface water discharges in the Nedern SSSI (P502171, P915237, P915234, P915243). © BGS NERC.

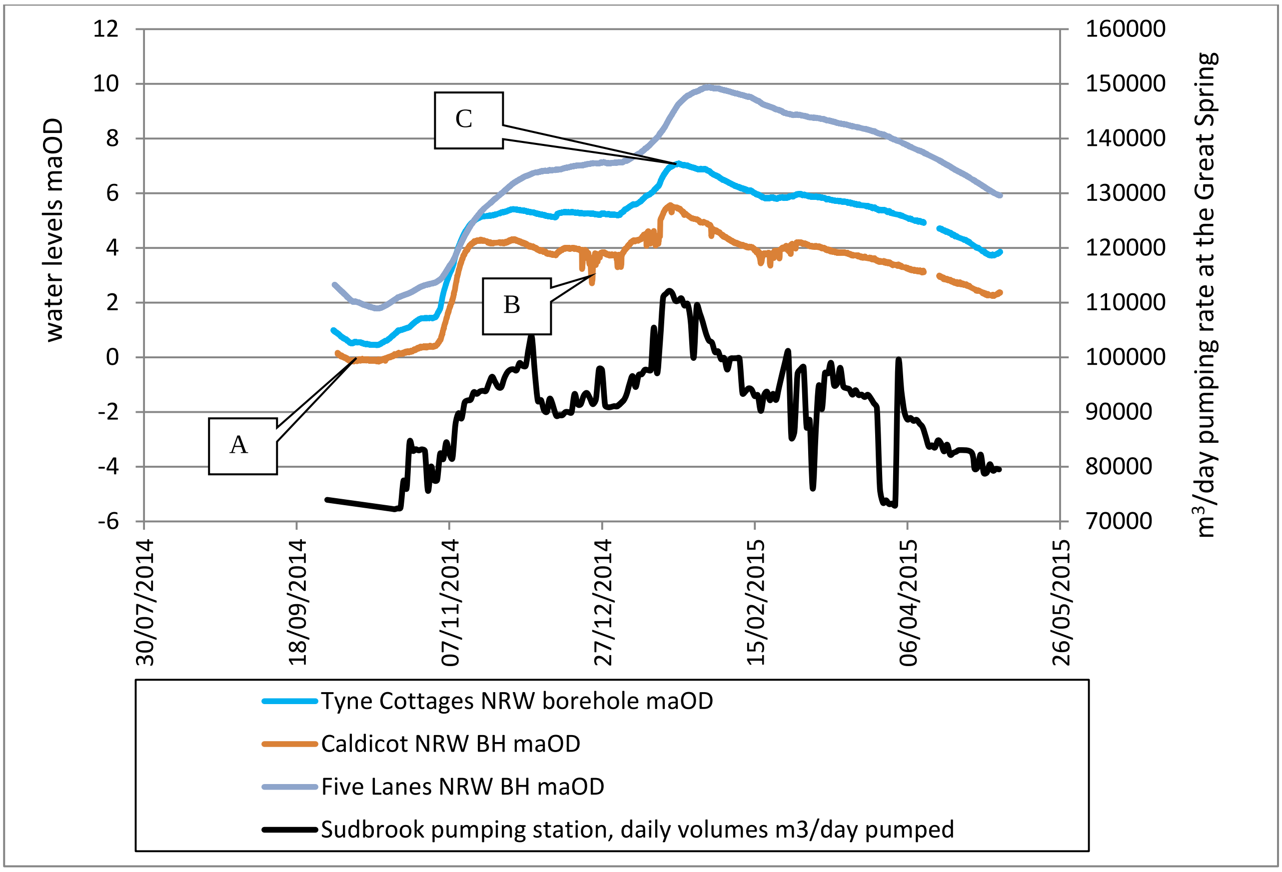

Figure 6 Groundwater levels in the Carboniferous Limestone aquifer compared to pumping rates at the Great Spring

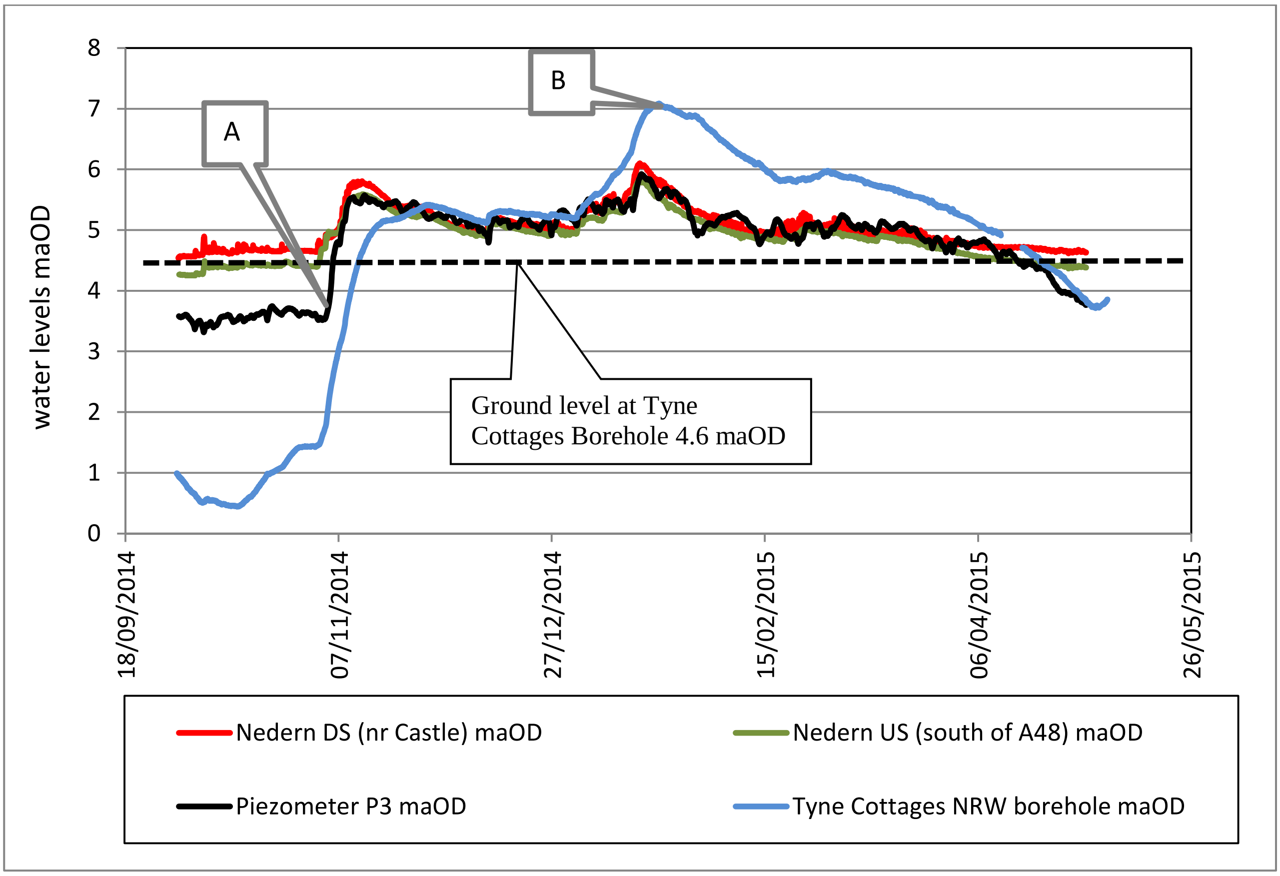

Figure 7 Groundwater and surface water levels in the wetland.

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.

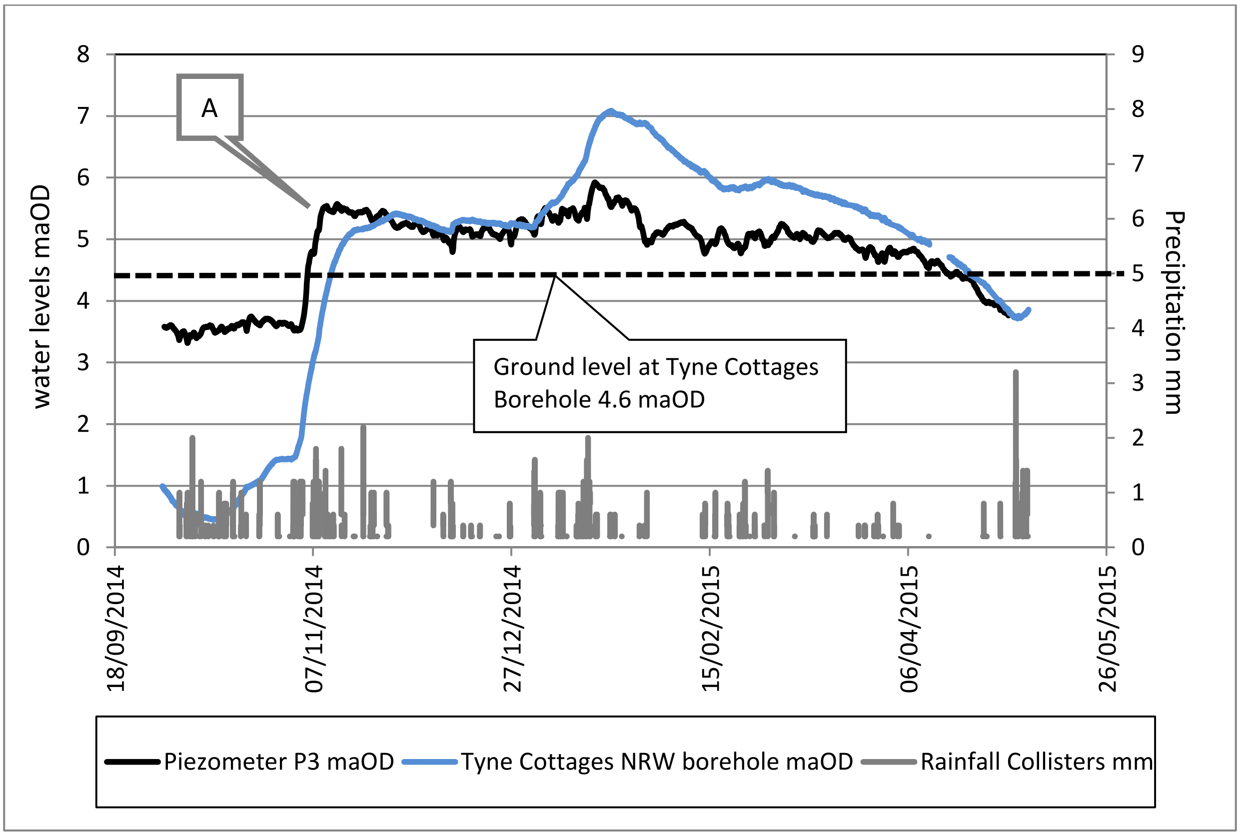

Figure 8 Rainfall compared to flood depth in the wetland (P3) and groundwater levels in the Carboniferous Limestone (Tyne Cottages).

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.

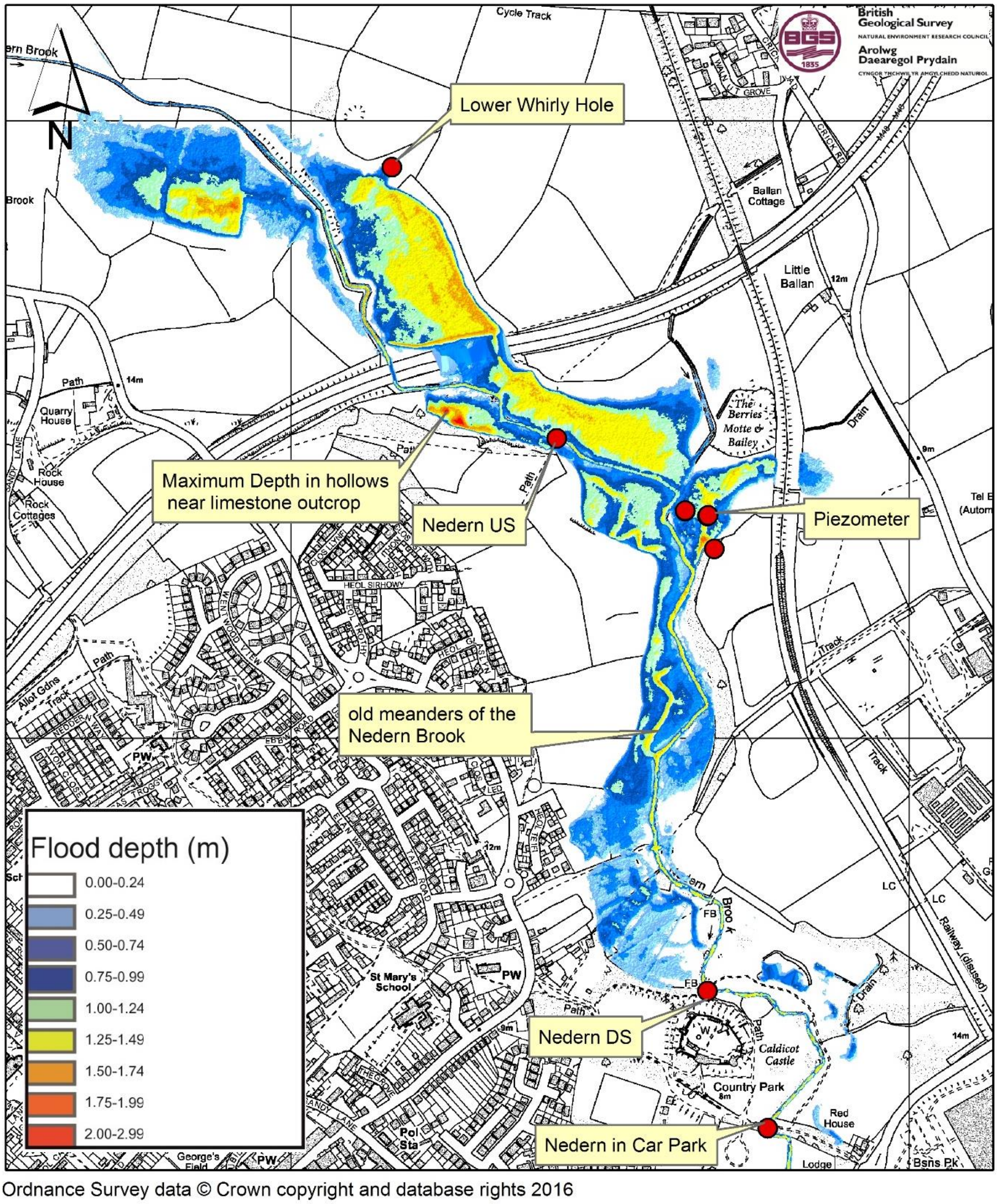

Figure 9 Maximum Flood levels based on 5.92maOD elevation of maximum flood depth between 30/09/2014 and 1/05/2015

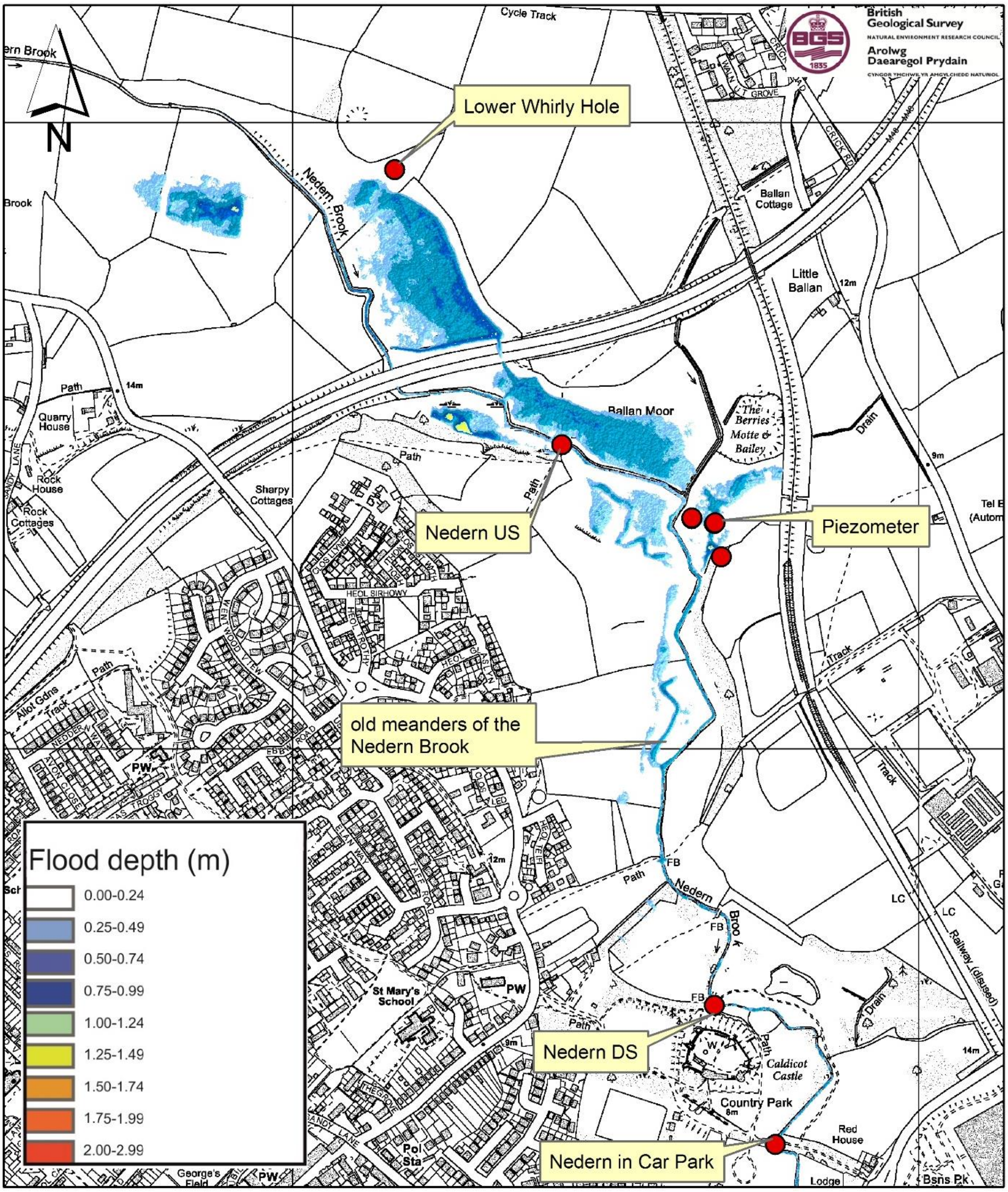

Figure 10 Mean flood depth, based on 5.15maOD elevation of average flood during between 30/09/2014 and 1/05/2015

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.

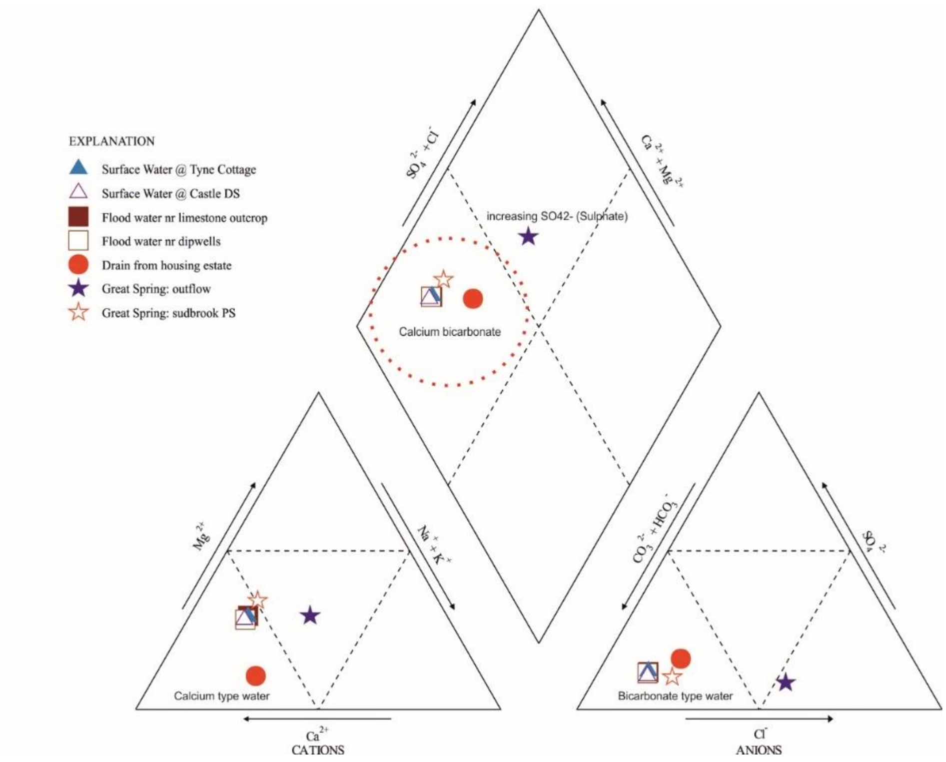

Figure 11 Major ions of water samples taken from Table 1, shown in a 'Piper Trilinear Diagram'. Most samples are of $CaHCO_3$ type as highlighted by the red dashed circle in the upper triangle.

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 depend 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

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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

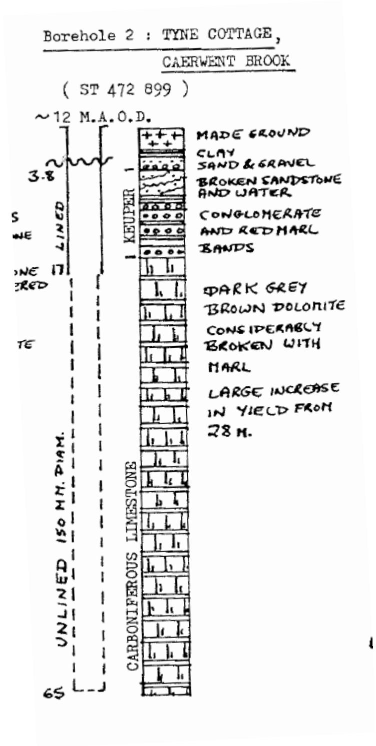
APPENDIX 3

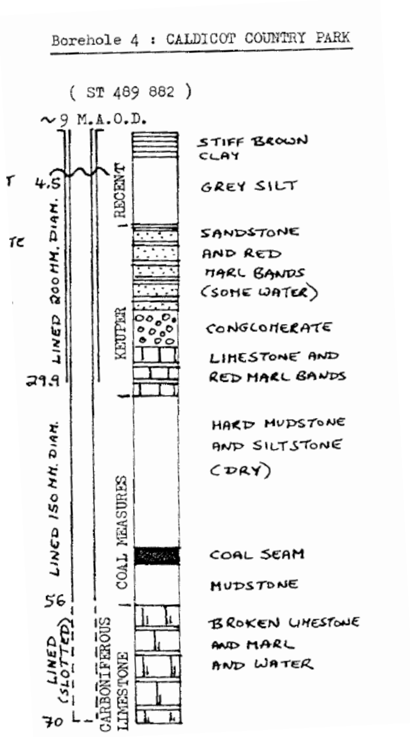
Field water chemistry

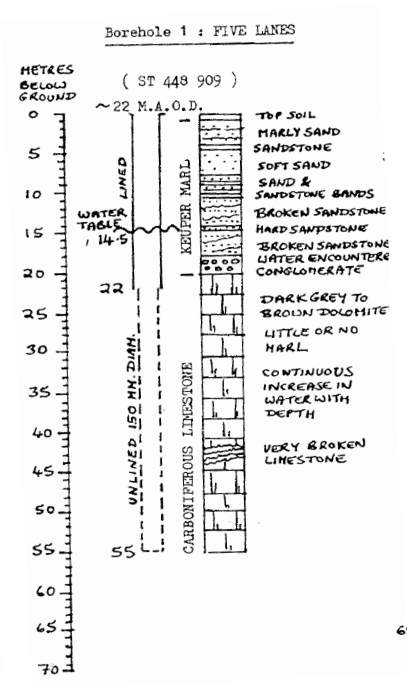
Survey	E	N	Comments	Type	Date	EC us/cm	Temp °C
51	348655	189272	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	Flood water	16.1.2015	290	5.8
37	348654	189275	Dipwell /Piezometer water level correction point (about 50m south of dipwells)	Flood water	18.12.2014	330	10
104	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

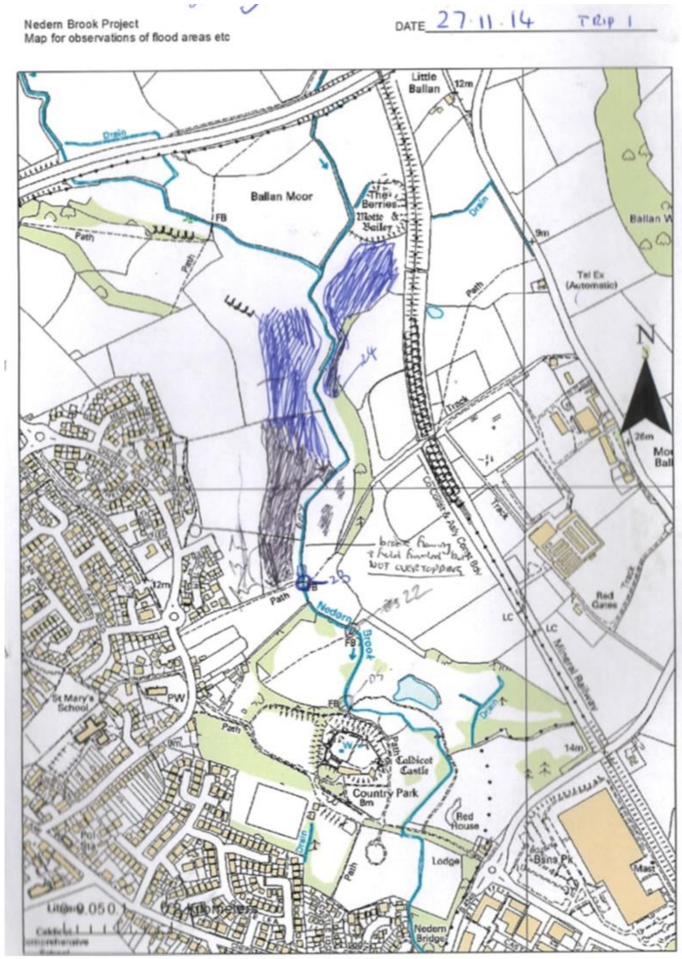
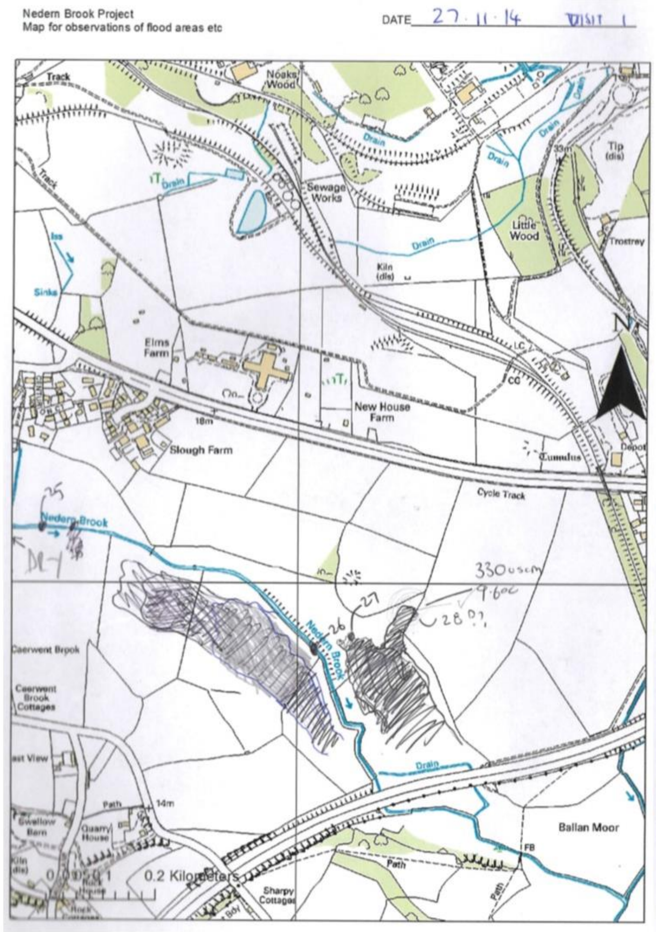
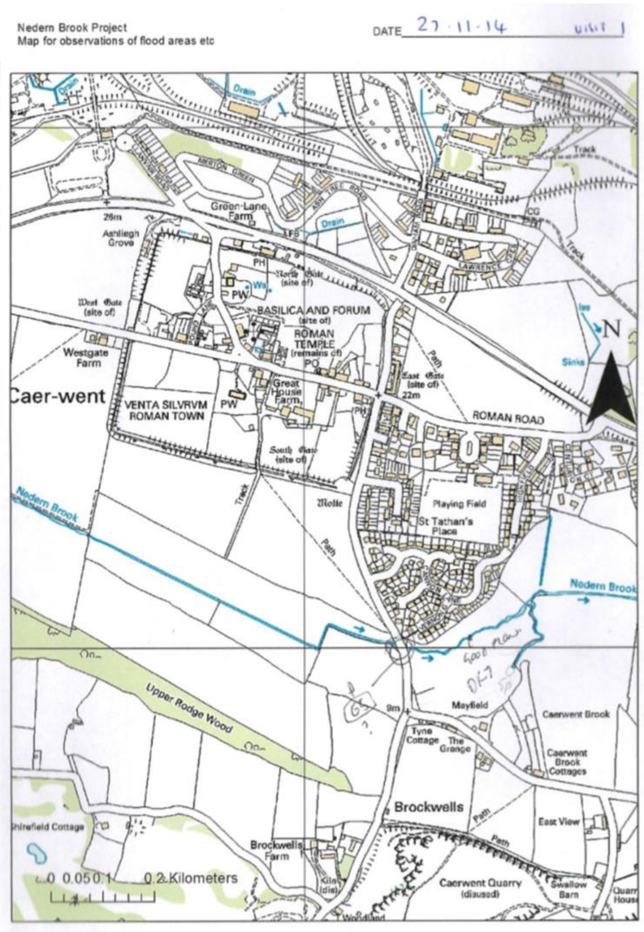

Borehole 2 : TYNE COTTAGE, CAERWENT BROOK
(ST 472 899)
~12 M.A.O.D.
3.8
17
65
LINED
UNLINED 150 MM. DIAM.
KEUPER
CARBONIFEROUS LIMESTONE
MADE GROUND
CLAY
SAND & GRAVEL
BROKEN SANDSTONE AND WATER
CONGLOMERATE AND RED MARL BANDS
DARK GREY BROWN DOLOMITE CONSIDERABLY BROKEN WITH MARL
LARGE INCREASE IN YIELD FROM 28 M.

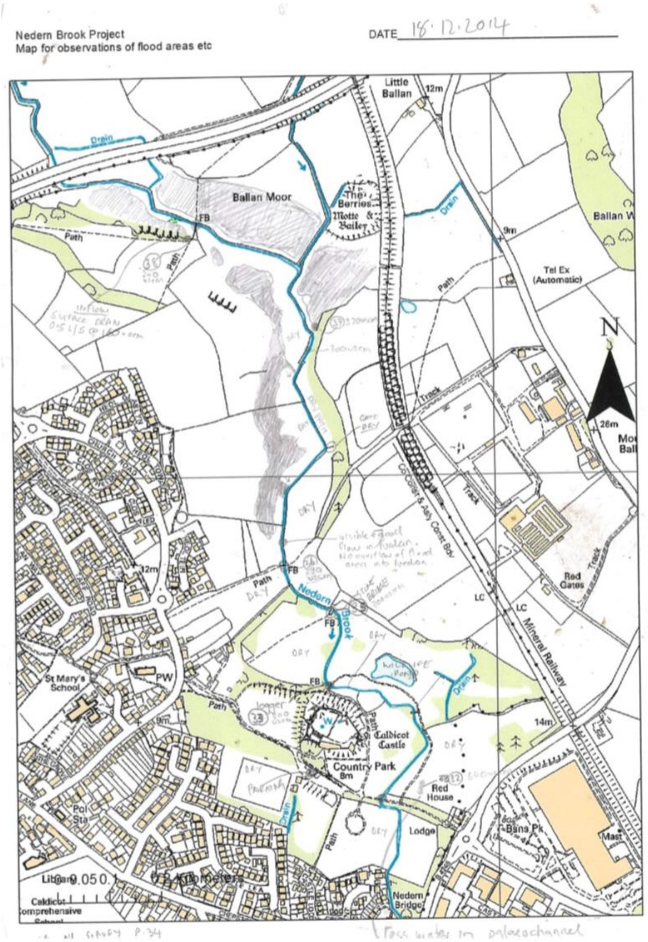

Borehole 4 : CALDICOT COUNTRY PARK
(ST 489 882)
~9 M.A.O.D.
4.5
29.9
56
70
LINED 200 MM. DIAM.
LINED 150 MM. DIAM.
LINED (SLOTTED)
RECENT
KEUPER
COAL MEASURES
CARBONIFEROUS LIMESTONE
STIFF BROWN CLAY
GREY SILT
SANDSTONE AND RED MARL BANDS (SOME WATER)
CONGLOMERATE
LIMESTONE AND RED MARL BANDS
HARD MUDSTONE AND SILTSTONE (DRY)
COAL SEAM
MUDSTONE
BROKEN LIMESTONE AND MARL AND WATER

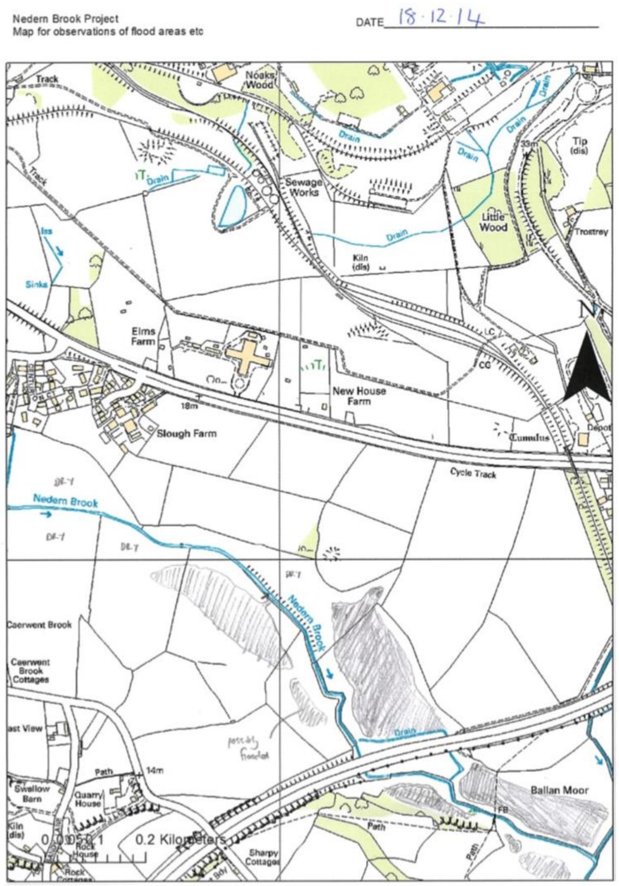

Borehole 1 : FIVE LANES
METRES BELOW GROUND
(ST 448 909)
~22 M.A.O.D.
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
WATER TABLE 14.5
22
55
LINED
UNLINED 150 MM. DIAM.
KEUPER MARL
CARBONIFEROUS LIMESTONE
TOP SOIL
MARLY SAND
SANDSTONE
SOFT SAND
SAND & SANDSTONE BANDS
BROKEN SANDSTONE
HARD SANDSTONE
BROKEN SANDSTONE WATER ENCOUNTERED
CONGLOMERATE
DARK GREY TO BROWN DOLOMITE
LITTLE OR NO MARL
CONTINUOUS INCREASE IN WATER WITH DEPTH
VERY BROKEN LIMESTONE

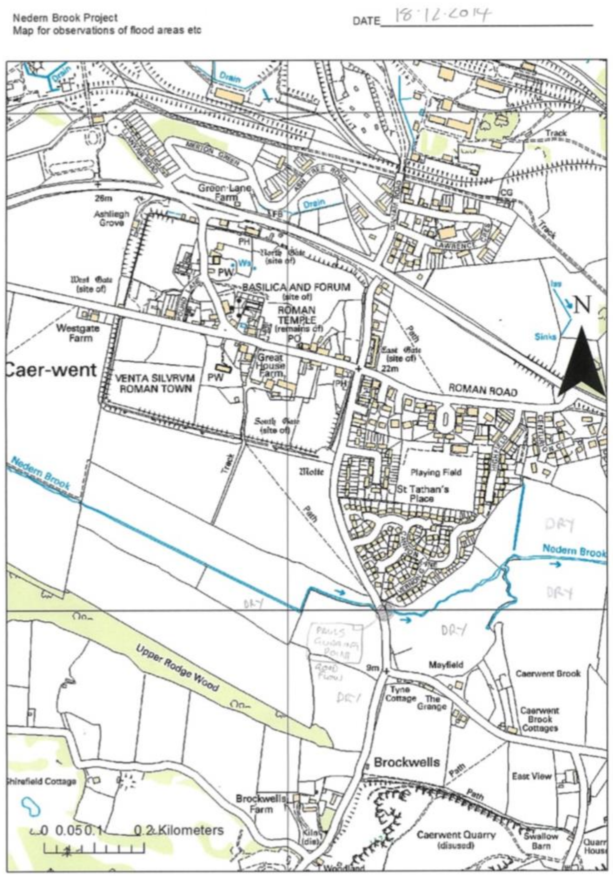
APPENDIX 5

Field maps with sketches of flood extent


Nedern Brook Project
Map for observations of flood areas etc
DATE 27.11.14 TRIP 1
Little Ballan
Ballan Moor
The Berries
Motte & Bailey
Tel Ex (Automatic)
Red Gates
St Mary's School
Caldicot Castle
Country Park
Red House
Lodge
Nedern Brook
Mineral Railway
Nedern Bridge
0.2 Kilometers

Nedern Brook Project
Map for observations of flood areas etc
DATE 27.11.14 VISIT 1
Noaks Wood
Sewage Works
Little Wood
Trostrey
Tip (dis)
Kiln (dis)
Elms Farm
New House Farm
Slough Farm
Cumulus
Cycle Track
Nedern Brook
Caerwent Brook
Caerwent Brook Cottages
Ballan Moor
Sharpy Cottage
0.2 Kilometers

Nedern Brook Project
Map for observations of flood areas etc
DATE 27.11.14 VISIT 1
Green Lane Farm
Ashleigh Grove
BASILICA AND FORUM (site of)
ROMAN TEMPLE (remains of)
Westgate Farm
Caer-went
VENTA SILVRVM ROMAN TOWN
Great House Farm
ROMAN ROAD
Playing Field
St Tathan's Place
Nedern Brook
Upper Rodge Wood
Tyne Cottage
The Grange
Mayfield
Caerwent Brook
Caerwent Brook Cottages
Brockwells
Brockwells Farm
East View
Caerwent Quarry (disused)
Swallow Barn
0.2 Kilometers







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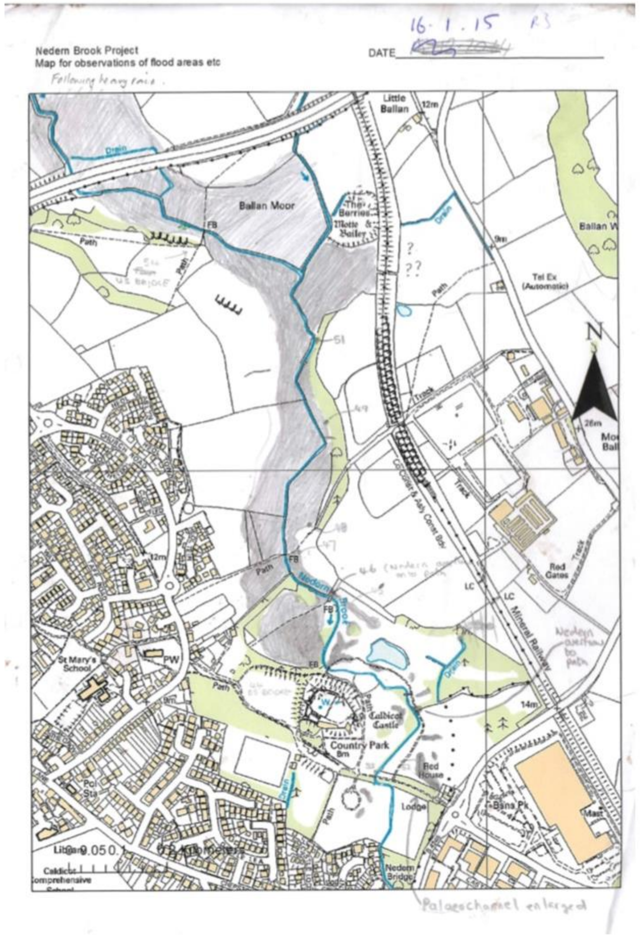

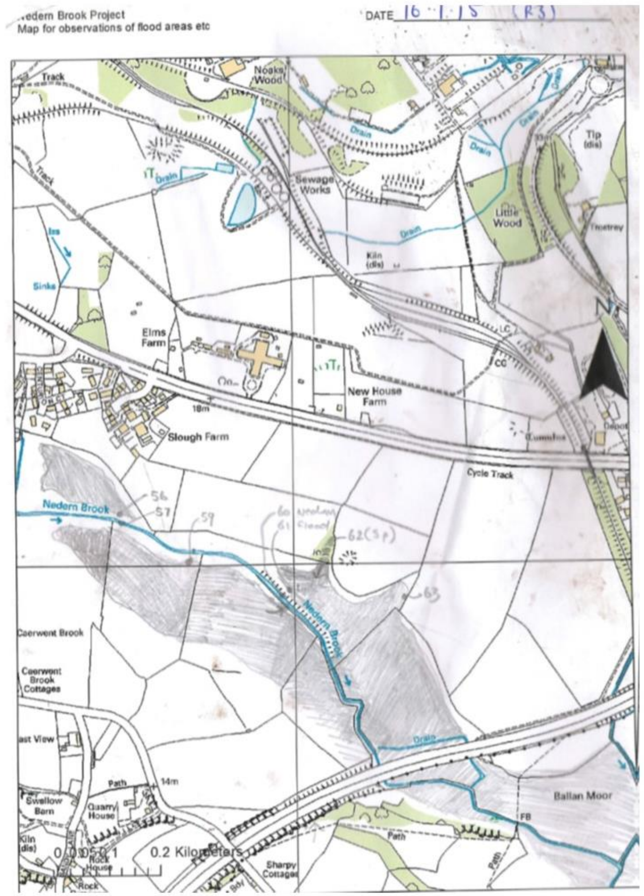

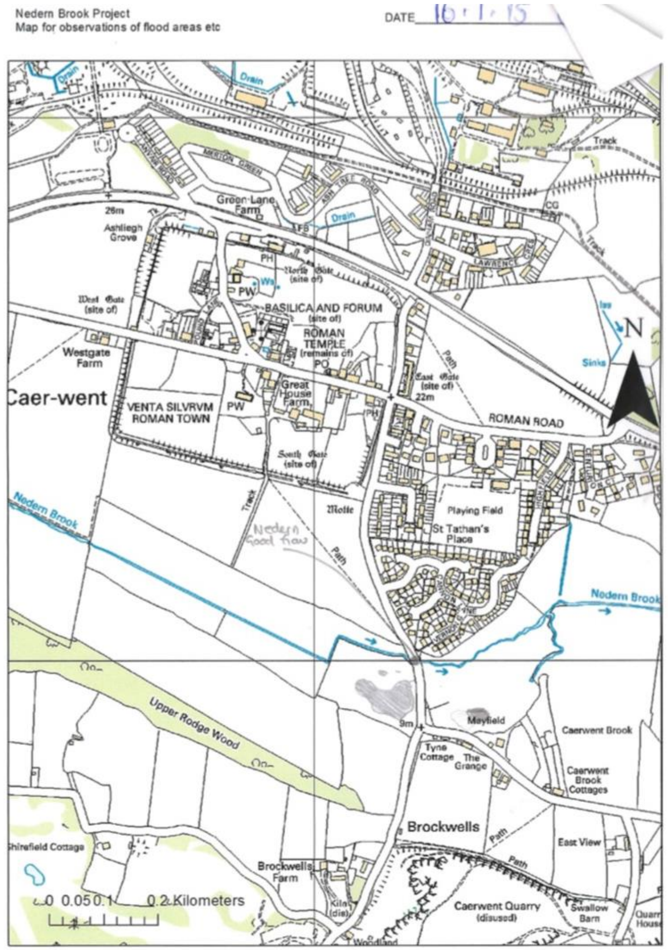

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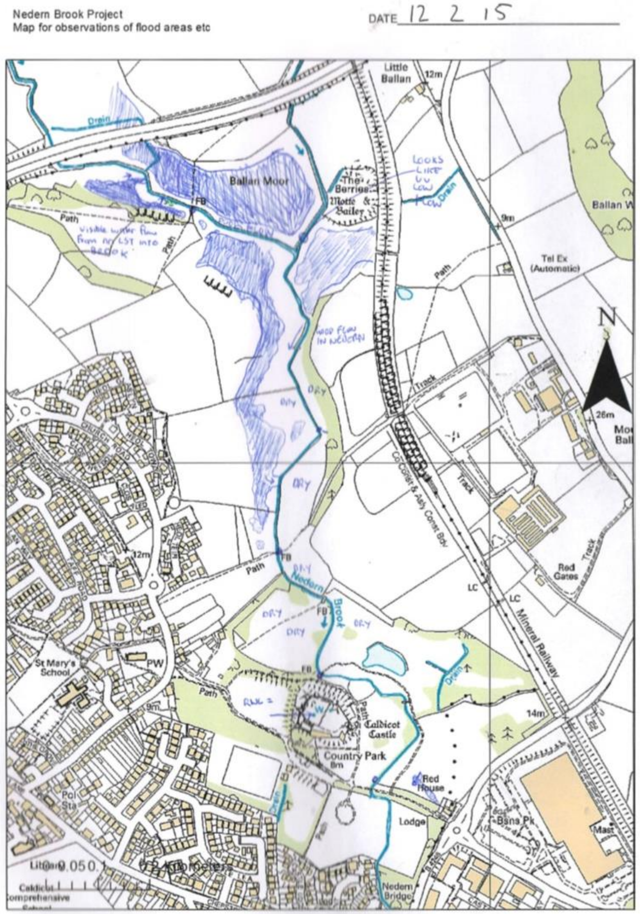

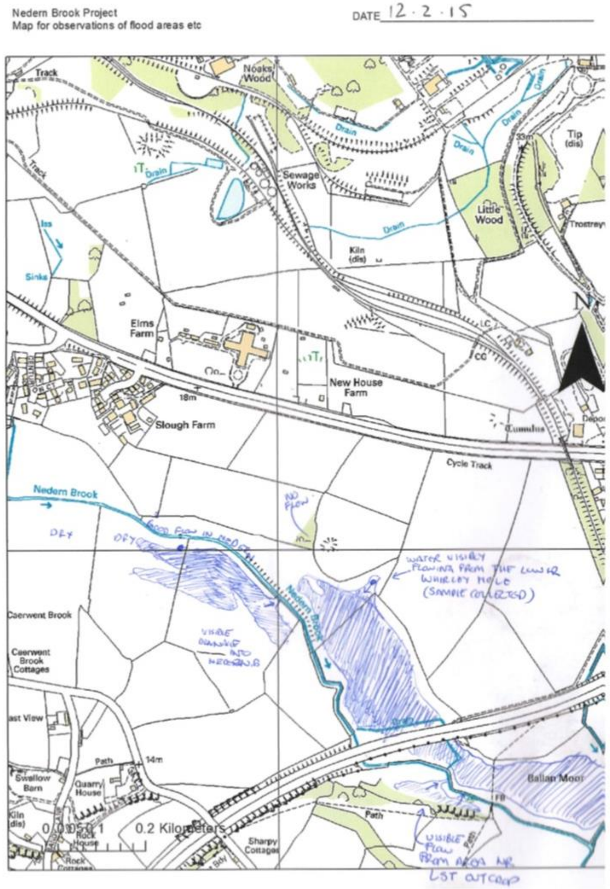

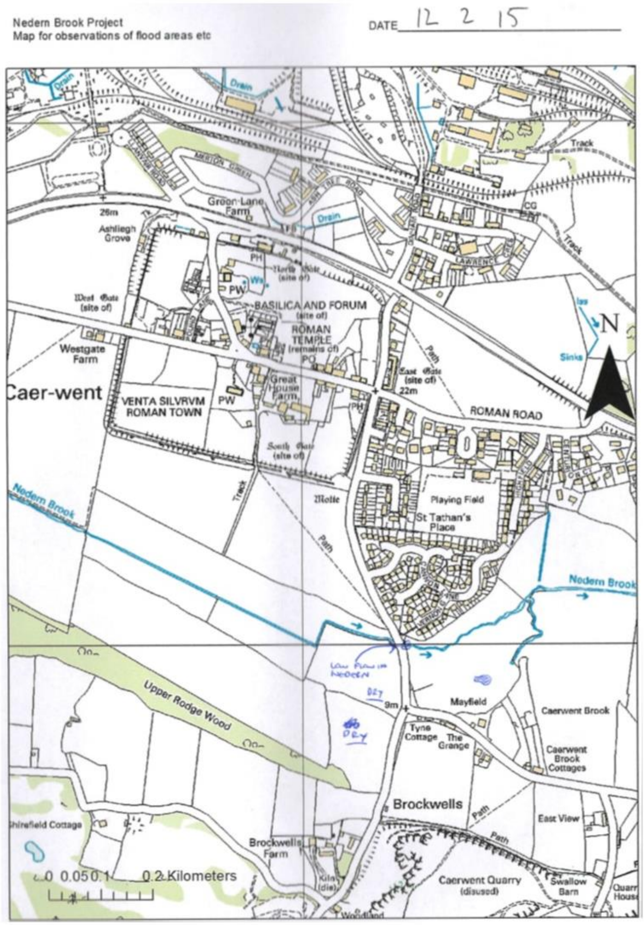

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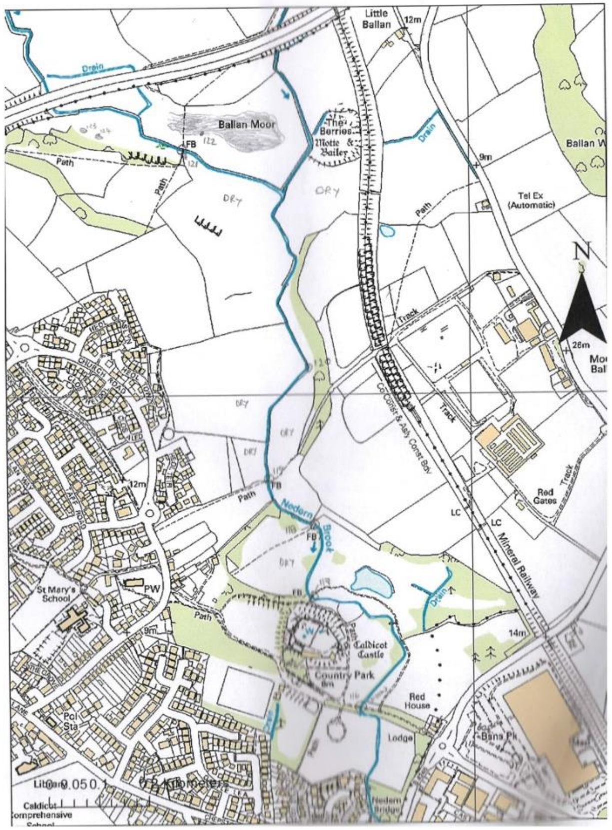
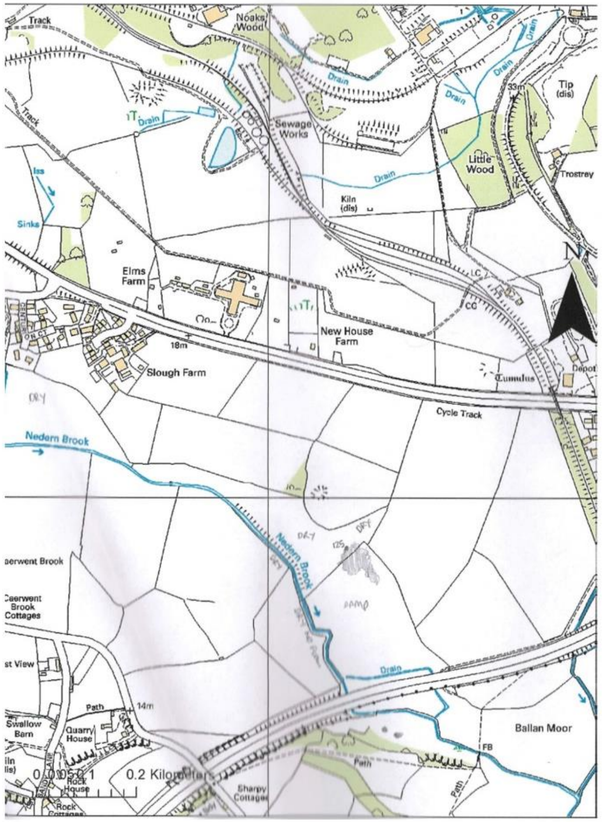
Nedern Brook Project
Map for observations of flood areas etc

DATE 1 MAY 2015



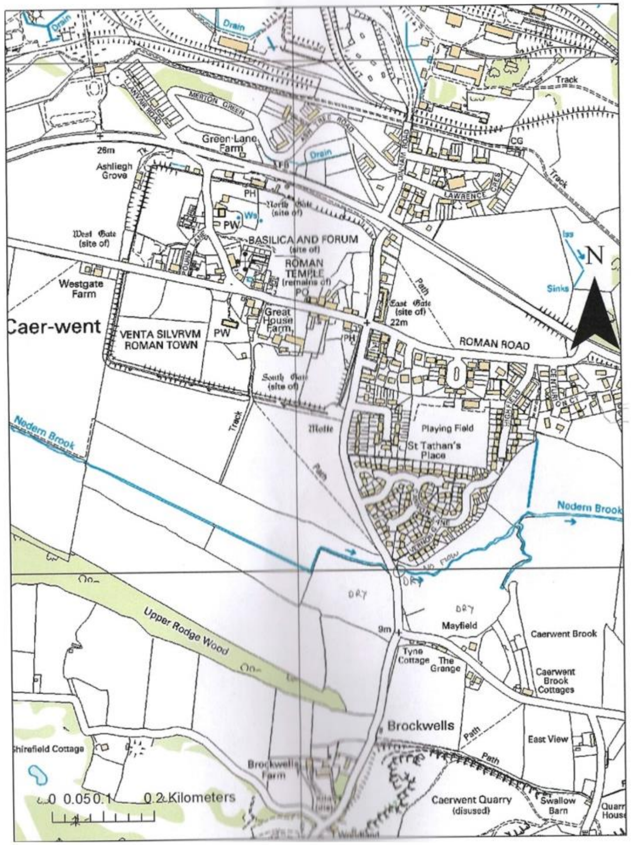
Nedern Brook Project
Map for observations of flood areas etc

DATE 1st May 2015



Nedern Brook Project
Map for observations of flood areas etc

DATE 1st MAY 2015



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