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ACKNOWLEDGEMENT

Brian Killingworth, the author of this report wishes to acknowledge the assistance provided by the Project Officer Dr Joan Daniels, NE, in the preparation of this report.

Cover Picture:

SAC boundary from Access Track to Land of Nod and Woodstyle looking south. Showing the flooding of land to be restored. Picture taken 29th March 2016 after 3 days rain (Storm Katie).

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Appendix 11 Drawings included in Appendices to illustrate FRA Text

Appendix 12 Construction Drawings included in Appendices

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REFERENCES

NE have provided the following reports and data sets for use in this Project.

- Hydrological Assessment of the Implications of NNR Management at Fenn's, Whixall and Bettisfield Mosses, Report to English Nature and Countryside Council for Wales – Kevin Gilman, MA, MCIWEM, November 2000

- Winter Flow Measurements on Fenn's, Whixall and Bettisfield Mosses, Report to English Nature – Kevin Gilman, MA, MCIWEM, March 2001

- Fenn's, Whixall, Bettisfield, Wem and Cadney Mosses Data Base – Martin Wright Associates – April 2014

Also referred to – sourced from the Internet

- Investigation of Flooding Problems at Whixall, Report No 1847/1. Report to Whixall P.C. August 2001 – Hydro Logic

1.0 EXECUTIVE SUMMARY

The Marches Mosses BogLIFE project (LIFE15 NAT/UK/000786) is a five year project running from 1 October 2016 to 31 December 2021. The project aims to restore Britain's 3rd largest lowland raised bog within the Fenn's, Whixall & Bettisfield Mosses and Wem Moss NNRs near Whitchurch, Shropshire and Wrexham in Wales. The LIFE project is led by Natural England working in partnership with Natural Resources Wales and the Shropshire Wildlife Trust. The project is financially supported by LIFE, a financial instrument of the European Commission and the Heritage Lottery Fund.

Natural England (NE) have commissioned Brian Killingworth (BK) to produce a Flood Risk Assessment (FRA) in support of an application for planning consent to carry out the restoration of an area of agricultural land at World's End, Whixall. The aim of the restoration is to provide appropriate conditions to support lagg habitat - a community comprising fen, swamp and wet woodland with areas of open water.

World's End is situated adjacent to Bettisfield Moss towards the southern perimeter of Fenn's, Whixall, Bettisfield, Wem and Cadney Mosses, which is the third largest raised bog Site of Special Scientific Interest (SSSI) in Britain. The Mosses are also a Special Area of Conservation (SAC) and form part of the Midlands Meres and Mosses Ramsar Site.

The present World's End drainage system is particularly complex as it contains a pumped field drainage scheme constructed some 42 years ago with the benefit of a grant from the Ministry of Agriculture Fisheries and Food (MAFF). The pumping station was probably provided to counter the poor drainage conditions within the area which are still prevalent today. The restoration of the land can only be achieved by the ability to control water levels within the area, but the changes to the drainage pattern to achieve this control, cannot impact adversely on the continued agricultural usage of neighbouring land, nor increase flood risk to properties or access to properties within the area.

In its present position, the fluctuating water levels within the World's End Drain, the principal open watercourse feeding the pumping station, are causing peat shrinkage within the SAC along the southern and eastern edges of Bettisfield Moss. The proposed changes to the drainage pattern include the re-alignment of this drain away from Bettisfield Moss together with a reduction in the area which presently drains to the pumping station.

The land to be restored is partly under-drained and in common with the entire World's End area is presently part of the catchment of the pumping station. While the area of field under-drainage has remained unchanged over the period when the pumping station has been operating, the surrounding ditch systems have progressively been linked to the pumped system resulting in an increase in run-off which can overwhelm the pumps during periods of high rainfall.

The proposed revisions to the present drainage system will reverse this trend by removing from the pumped catchment all areas which are still capable of gravity drainage. In future, drainage from these areas will by-pass the station and discharge directly to the Lord Hill's Drain downstream, via the re-aligned World's End Drain. To ensure that the present agricultural land usage is preserved, only the under-drainage serving the area of land to be restored will be blocked allowing pumped drainage to continue for the remainder. The reduction in the catchment area will reduce the energy presently consumed by the station in draining the entire area and the wear-and-tear on the pumps.

Once a direct connection to the Lord Hill's Drain via the re-alignment of the World's End Drain has been made, it will be necessary to provide floodbanks around three sides of the area of land to be restored, to ensure that access to properties and the properties themselves will be protected from possible flooding if high levels within the Lord Hill's Drain should occur as a result of wet weather. In case of an emergency affecting the integrity of the defences to be provided or excessively high levels within the Lord Hill's Drain, it will be possible to close the by-pass around the pumping station to enable the drainage of the entire area to revert back to the present pumping arrangements for the duration of the problem.

Conversely, if low water levels are experienced within the area to be restored, resulting from an extended period of dry weather, a penstock within the re-aligned World's End Drain can be adjusted to restrict flows from the area to maintain the appropriate conditions for the habitat restoration.

The proposals which are the subject of this FRA provide a means to control water levels and thereby enable the land to be restored. By diverting the present route of the World's End Drain, the integrity of the SAC is improved and a basis is provided for further restoration of adjacent agricultural land if it becomes available. The construction of the floodbanks adjacent to Moss Lane will provide additional flood protection to properties within World's End and pumped drainage can continue for those areas which are too low to drain by gravity.

It should be noted that the principal aim of these proposals is not to provide an improvement to either the drainage or the level of flood protection presently afforded to the World's End area but to restore an area of agricultural land to provide appropriate conditions to support lagg habitat. The present standard of drainage and flood protection experienced by land and properties which will remain within the catchment area of the pumping station will continue to be determined by the effectiveness of the pumped drainage system. However, as the catchment area to the pumping station will be reduced as a result of these proposals, this effectiveness is likely to increase.

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2.0 INTRODUCTION

The Marches Mosses BogLIFE project (LIFE15 NAT/UK/000786) is a five year project running from 1 October 2016 to 31 December 2021. The project aims to restore Britain's 3rd largest lowland raised bog within the Fenn's, Whixall & Bettisfield Mosses and Wem Moss NNRs near Whitchurch, Shropshire and Wrexham in Wales. The LIFE project is led by Natural England working in partnership with Natural Resources Wales and the Shropshire Wildlife Trust. The project is financially supported by LIFE, a financial instrument of the European Commission and the Heritage Lottery Fund.

2.1 Natural England (NE) has commissioned Brian Killingworth (BK) to carry out a Flood Risk Assessment (FRA) in support of an application for planning consent for the restoration of an area of agricultural land at World's End, Whixall. The land to be restored is adjacent to Bettisfield Moss NNR which forms part of Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses.

2.2 Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses is Britain's third largest raised bog Site of Special Scientific Interest (SSSI), a Special Area of Conservation (SAC) and part of the Midlands Meres and Mosses Ramsar site. Its lowland raised bog habitat requires a relatively wet hydrological regime to maintain the nature conservation interest. The centre of the site is designated as Fenn's, Whixall & Bettisfield Mosses National Nature Reserve (NNR), managed by Natural England (NE) and Natural Resources Wales (NRW). The land to be restored is owned by Shropshire Wildlife Trust (SWT) who also own the neighbouring Wem Moss. The scheme forms part of the restoration of the outer areas of the Mosses back to lagg habitat - a community comprising fen, swamp and wet woodland with areas of open water..

2.3 The land to be restored originally formed as shallow peat at the edge of the Moss and peat soils still remain. This marginal habitat has been eliminated from almost all British raised bogs, making the opportunity for restoration here of considerable importance. NE/SWT are planning to ensure that shallow surface water conditions can be consistently maintained across parts of the area during the spring and summer to provide suitable conditions to support semi-natural bog communities and improve the carbon storage. As a result of the scheme works, further small areas where restoration is appropriate may become available.

2.2 A plan showing the position of World's End in relation to the Mosses is provided as Appendix 1 to this report. A further plan (Drg No 028) showing the location of the land to be restored and other relevant features within World's End, is provided as Appendix 2.

2.3 In order to drain the peat bog for exploitation by forestry, peat cutting, transport systems and agriculture, a system of drains has been cut within the peat. Originally a lagg stream would have existed around the edge of the raised bog where the acidic water running off the rain-water fed (ombrotrophic) bog would have met the richer water running off the surrounding mineral slopes. To lower water levels on and around the edge of the bog at World's End, this lagg stream, fed from the Bettisfield Moss peat body and from the Hornspike mineral ridge to the south, has been canalised within the peat as the World's End Drain and the mineral ridge which contained the bog has been breached by a channel to connect the Drain to the Allman's Bridge (Slack's Bridge Drain) and Lord Hill Drain and Culvert. Together, these drains constitute the main drainage network and are tributaries of the River Roden.

2.4 Drainage at World's End is particularly complex due to the operation of a privately-owned pumping station and associated field drainage, which was installed in the 1970s to improve the drainage of the area for the benefit of agriculture. The pumped field drainage system is estimated to influence 50 ha of peatland in multiple ownerships. This has enabled the peatland

to be converted from bog to farmland and has destroyed much of the rare bog wildlife for which the SAC is notified.

2.6 Operation of the pumping station over the past 40 years has led to peat wastage through shrinkage and the creation of a low-lying "saucer" of land upstream of the pumping station. The land which SWT are seeking to restore by controlling water levels, is presently under-drained and makes up some 50% of the "saucer".

2.7 Ground levels within the "saucer" are now so low as a result of peat wastage, that natural drainage through the gravity by-pass provided within the pumping station can no longer be utilised and the ongoing effectiveness of the field drainage system is entirely reliant on the constant operation of the pumps. The effect of peat wastage has spread beyond the under-drained land into adjoining ownerships within the SAC, including the Bettisfield Moss NNR, where the peat is visibly eroding around its southern boundary.

2.8 The lack of natural drainage also results in part from the consistently high water levels within the Lord Hill's Drain downstream of the pumping station. Such high water levels are an indication of a lack of maintenance of this Drain, which poor condition appears to extend as far as its confluence with the River Roden.

2.9 The catchment area of the pumping station appears to have been progressively extended by adjacent landowners connecting their own drainage ditches into the pumped drainage system. The pumps are therefore working beyond their design capacity in an attempt to avoid flooding of the under-drained land and also maintain flood-free access to properties sited both in and around the "saucer".

2.10 As the area of land to be restored presently forms part of the pumped catchment, its present classification in terms of Flood Zone is uncertain. However, as the intention is to remove this land from the present pumped area, due to its present low ground levels, in future it could be classified as functional floodplain where only water-compatible uses and essential infrastructure works are permitted.

2.11 "Functional Floodplain" is defined as areas of land at risk of flooding in a 5% AEP (1 in 20 year return period) or greater design event. It forms part of land classified by the Environment Agency (EA) as Flood Zone 3. Flood Zones refer to the probability of river and sea flooding ignoring the presence of defences. They are shown on the Environment Agency's Flood Map for Planning (Rivers and Sea), as indicated in the table below.

Flood Zone	Definition
Zone 1 Low Probability	Land having a less than 1 in 1,000 annual probability of river or sea flooding. (Shown as 'clear' on the Flood Map – all land outside Zones 2 and 3)
Zone 2 Medium Probability	Land having between a 1 in 100 and 1 in 1,000 annual probability of river flooding; or land having between a 1 in 200 and 1 in 1,000 annual probability of sea flooding. (Land shown in light blue on the Flood Map)
Zone 3a High Probability	Land having a 1 in 100 or greater annual probability of river flooding; or Land having a 1 in 200 or greater annual probability of sea flooding. (Land shown in dark blue on the Flood Map)

Flood Zone	Definition
Zone 3b The Functional Floodplain	This zone comprises land where water has to flow or be stored in times of flood. Local planning authorities should identify in their Strategic Flood Risk Assessments (SFRA) areas of functional floodplain and its boundaries accordingly, in agreement with the EA. Note – Zone 3b is not separately distinguished from Zone 3a on the Flood Map.

A copy of the EA Flood Map containing the site is provided as Appendix 3 to this Assessment. As stated in the Table above, Zone 3b is not separated from Zone 3a on the Flood Map.

2.12 The proposals which are the subject of this FRA provide a means to control water levels and thereby enable the land to be restored. They include the following principal changes to the drainage of the World's End area:

- Re-alignment of the World's End Drain away from the edge of Bettisfield Moss to improve the integrity of the SAC site and provides a basis for further restoration of adjacent agricultural land (which also largely lies within the SAC), if further land becomes available. The re-aligned World's End Drain will convey gravity drainage from the area. This discharge could be controlled if necessary, to maintain water levels within the area to be restored during dry periods.
- Reduction in the catchment area draining to the pumping station. This reduction will reduce energy usage and wear and tear on the pump-sets.
- A gravity by-pass around the pumping station to provide a direct connection between World's End Drain and Lord Hill's Drain
- Construction of floodbanks to provide flood protection to properties and their accesses from possible high levels in the Lord Hill's Drain, once a direct link between World's End Drain and Lord Hill's Drain is established..

2.13 Land which cannot be drained by gravity will continue to drain via the pumping station. Adjacent agricultural land will therefore be unaffected by the proposals and indeed, the reduction in discharge to the pumping station, resulting from the smaller catchment, should provide a more efficient and effective means of drainage.

2.14 During exceptional wet weather periods when high levels might be experienced in the Lord Hill's Drain or if a failure of a defence were to occur, the gravity by-pass linking World's End Drain with the Lord Hill's drain would be closed and the drainage of the area would revert back to the pumping station for the duration of the problem During this type of event, it is expected that the pumps in the station would be supplemented by a further pump set as happens at present.

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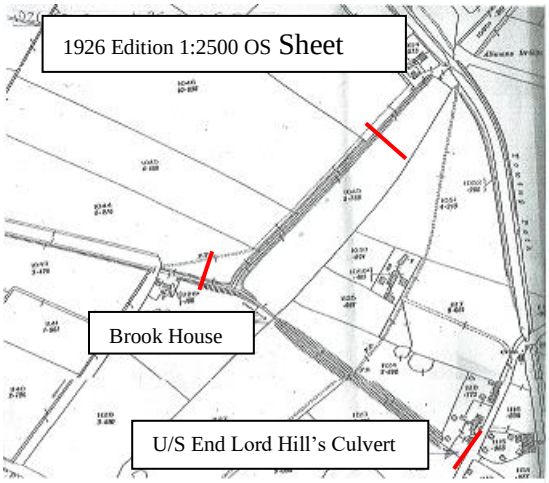
3.0 EXISTING DRAINAGE SYSTEM

3.1 The area known as World's End is situated towards the southern end of the Mosses. The area is bounded to the north and east respectively by the Llangollen Branch of the Shropshire Union Canal and the Prees Branch of the Ellesmere Canal and adjoins Bettisfield Moss to the west. Its southern boundary is formed by the Hornspike Ridge which historically contained the drainage from both Whixall Moss and the eastern end of Bettisfield Moss.

3.2 In order to drain the peat bog for exploitation by forestry, peat cutting, transport systems and agriculture, a system of drains was cut within the peat. Originally a lagg stream would have existed around the edge of the raised bog where the acidic water running off the rain-water fed (ombrotrophic) bog would have met the richer water running off the surrounding mineral slopes.

3.3 To lower water levels on and around the edge of the bog at World's End, this lagg stream, fed from the Bettisfield Moss peat body and from the Hornspike mineral ridge to the south, has been canalised within the peat as the World's End Drain and the mineral ridge which contained the bog has been breached at Brook House Farm, to provide a connection between World's End drainage and the drainage from Whixall Moss, which passes through a culvert at Allman's Bridge. These watercourses combine to form the Lord Hill's Drain flowing south through Lord Hill's culvert to eventually join the River Roden some 4.6km downstream at Wolverley. The "tadpole symbols " between the red lines as shown on the extract below from the 1926 edition 1:2500 OS Plans, depict a deep cutting which gives a good indication of the work required to cut through the clay ridge to make the connection between Whixall Moss and World's End drainage and the Lord Hill's Drain.



Extract from 1926 edition OS 1:2500 Sheet

3.4 Due to its position some 350m downstream of Brook House Farm, the Lord Hill culvert is key to the drainage of the World's End area It was constructed from brickwork in the early 1800s and is circular with a 1.2m diameter. However, at the upstream end of the culvert a 36in diameter concrete pipe has been inserted into the mouth of the culvert to provide a short extension. The purpose of this pipe is not clear but it provides a small restriction to flows which the culvert might pass. While the presence of the concrete pipe reduces the available area of flow, of far greater importance are the high water levels which are apparent throughout the watercourse both upstream and downstream of the culvert, even in "dry" conditions.

3.5 High water levels within this River Roden tributary have long been recognised as a problem. In 2001, the Whixall Parish Council commissioned a report "Investigation of Flooding Problems at Whixall" – Hydro-Logic Ltd Report 1847/1 – September 2001, which contained the following paragraph in relation to the Lord Hill culvert:

"Although the condition of the culvert at the outlet is in fair condition, the flow capacity of the culvert is clearly restricted by the condition of the channel downstream of the culvert. The evidence for this is provided by the standing water at the outlet; ideally, the culvert should be able to drain freely under all flow conditions, including the low flows observed at the time of the visit. It has not been possible to inspect the culvert under high flows, but it is highly likely that the condition of the channel would lead to high water levels at the outlet from the culvert. These in turn, would restrict outflow from the culvert."

3.6 In April 2014, NE commissioned a report to provide data on the water level control structures within Fenn's, Whixall, Bettisfield, Wem & Cadney Mosses SSSI/SAC. The data collected comprised the size, nature and level above Ordnance Datum (OD) of relevant structures. This exercise was also carried out during a "dry" period and produced similar results to those identified in the earlier report. Using the data collected in 2014, a long section of the Lord Hill tributary has been drawn between Brook House Farm and Ossage Bridge, a distance of some 1.5km, which ably demonstrates the consistent high water levels throughout the system. As stated in the 2001 report, as there is no obvious obstruction, this situation can only be caused by a lack of channel maintenance which effectively renders the channel too small for the flows it is attempting to pass. A copy of this long section and location plan, Drg Nos 015 and 016, are provided as Appendix 4 to this report. The importance of this receiving watercourse being able to effectively convey flows away from World's End cannot be stressed too highly. The flooding which is now occurring regularly in Morris's Bridge Fields upstream of the Allman's Bridge culvert, is almost certainly linked to high water levels in the Lord Hill Drain.

3.7 It is understood from Shropshire Council drainage engineers that a recent camera survey (2019) revealed no blockages within the structure. This is understandable since a protecting grid is present at the upstream end of the culvert. However, access to this grid for cleaning is not straightforward and while it is unlikely that a new culvert would ever be provided to improve the available capacity, a proportion of this capacity is unused due to debris lying against the screen. As a consequence, water levels upstream are raised to an unnecessary level and remain high for longer periods than necessary until the screen is cleaned. Now that the importance of this culvert has been highlighted, perhaps consideration could be given to improve access to the screen for cleaning purposes both easier and safer.

3.8 Appendix 5 to this report contains a drawing (Drg No 017) providing full details of the present drainage pattern within World's End. As can be seen from the drawing, the World's End Drain originates on the southern boundary of Bettisfield Moss East with flows predominantly from a catchwater drain along the toe of Hornspike Ridge. This catchwater flows in a north westerly direction between Hornspike and Coppice House at the western end of the catchment. From Bettisfield Moss, the World's End Drain flows in a south easterly direction along the southern side of the access track from Brook House Farm to the Land of Nod and Woodstyle.

3.9 Adjacent to Brook House Farm, within land belonging to Moss Lane Farm, is a pumping station which lifts flows from the World's End Drain into the Lord Hill's Drain downstream. This pumping station was constructed 42 years ago, with the assistance of a Ministry of Agriculture Fisheries and Food (MAFF) grant for agricultural benefit, by the then owners of Moss Lane and The Oaks Farms. Associated with the pumping station construction was the provision of field drainage within the land in their collective ownership. The position of the pumping station and the extent of the field drainage is also shown on Drg No 017. Details of

the as-constructed field drainage are shown on Drg No 019 which is also included within Appendix 5.

3.10 It is probable that the need for a pumping station was driven by the poor drainage conditions within the Lord Hill's Drain. There is anecdotal evidence that at least part of the Moss Lane Farm land was "*always just marsh with reeds and rushes until the pumping scheme was put in, and it always flooded out."* The provision of the pumped drainage scheme meant that drainage at World's End would always be possible regardless of the condition of the receiving watercourse.

3.11 Over the years the ownership of both Moss Lane Farm and The Oaks has changed while the extent of the land which has been under-drained has remained the same. Operation of the pumping station now rests with the owner of Brook House Farm but running costs and power costs are now shared by Moss Lane Farm and Brook House Farm. Brook House Farm now owns the land to the north of the access track to Land of Nod and Woodstyle, which was previously within the ownership of Moss Lane Farm.

3.12 While the catchment area draining to the pumping station may originally have been based upon the area of under-drained land, progressively, adjacent landowners have linked their own ditches into the pumped system. These actions have resulted in the pumping station receiving flows from both the under-drained land and the open ditch network which serves the remainder of the World's End area. A typical example of this is the anecdotal evidence which suggests that the Hornspike ridge toe-drain may originally have continued to flow westwards into the English/Welsh border drain down past Wem Moss, but was diverted by a previous owner of Coppice House Farm into the pumping scheme because of the lack of available fall in the drain passing Wem Moss. Such increases in area draining to the Station could in part explain an apparent short-fall in the design of the capacity of the pumps. The full catchment area is shown on Drg No 018 and is also included within Appendix 5 to this report.

3.13 The pumping station contains twin submersible electric pumps with 4in diameter pipework. The pumps were manufactured by Landia, a local company based in Whitchurch, which continues to maintain the pumps and switchgear. The pumps are fitted with P3-230 diameter impellors which are designed to achieve a high discharge at a low pumping head. A rating curve for the pumps has been obtained from Landia and is included as Appendix 6 to this report. From this rating curve, at a 5m pumping head, (which is higher than the World's End application), the pumps are rated at $160m^3$/hour or $0.04m^3$/s. Working together therefore, the maximum pumped discharge from the station will be $0.08m^3$/s.

3.14 Drg No 017 within Appendix 5 shows the present World's End drainage system including the field drainage and its infrastructure coloured fuschia. The field drainage information has been sourced from a plan prepared by the drainage contractor responsible for the work in 1974. The original plan is unfortunately incomplete but contains sufficient information to identify the principal drainage runs (generally 9" pipes) within the drained areas and the links into the system for the open ditch network. Drg No 019 is based upon this original plan and is also provided within Appendix 5 to this report.

3.14 Unfortunately, during the collection of additional survey information, water levels within the pumped system have always proved too high to see the various pipes discharging into Manholes 1 and 2 of the Field Drainage System shown on Drg 019 (Appendix 5) and it has not been possible to gain access to The Oaks where Manhole 3 and Weir 5 are situated. The following Table summarises the level data obtained on site as part of the Water Level Control Structures data project carried out in April 2014 and the present project.

Item	Invert Level	Floor Level	500mm By-Pass IL	Water Level within PS	Ground Level
Pumping Sta	82.51	87.01	85.88		86.71
	Invert Level	**Cover Level**		**Water Level within MH**	**Ground Level**
Manhole 1	82.99	85.95		85.16	85.71
Manhole 2	83.48	86.28		85.18	85.96
Manhole 3					
	Weir Crest	**Inlet Pipe**		**Water Level at Intake**	**Ground Level**
		Dia	**Invert Level**		
Weir 7	85.22	225 (9")	85.00	85.25	85.81
Weir 6	85.14	225	85.09	85.19	85.64
Weir 5					
Weir 4	85.68	300	85.63	85.70	87.32

3.15 Visible drainage infrastructure comprises concrete manholes (numbered 1, 2 and 3) which form a central "spine" and intake structures (numbered 4, 5, 6 and 7) around the perimeter. The input structures contain silt traps and weirs immediately upstream of the intake pipes. The Table below describes in detail the flow pattern reaching the pumping station as shown on Drg 017 (Appendix 5). The ditch intakes are at a high level in comparison with the field under drainage.

Item	Description
Pumping Station	Receives flow from MH 1 via twin 18" pipes which act as a reservoir and from Chapel House via ditch along Brook House Farm Access (Inv 84.37) plus under drainage from Moss Lane Farm (Area 6).
MH 1	Receives flow from MH 2 and Weir 7 and the principal drain and overflow pipe (250mm dia Inv 85.42) from the under-drained area now belonging to Brook House Farm (Area 5) and under drainage from Area 6.
MH 2	Receives flow from MH 3 and Weir 6
MH 3	Receives flow from Weir 4 (Ditch 1) and Weir 5 (Ditch 2.1)
Weir 4	Receives flow from Ditch 1 sub catchment
Weir 5	Receives flow from Ditch 2.1 sub catchment – part open ditch from Hornspike Ridge.
Weir 6	Receives flow from Ditch 2.2 sub catchment – part open ditch from Hornspike Ridge crossing Moss Lane and from under drained area of Moss Lane Farm (Area 6) and sub catchment Ditch 3. There is no visible connection for further drainage from properties to the west along the southern side of Moss Lane either easterly into Pear Tree House land or north across Moss Lane.
Weir 7	Receives sub catchment Ditch 4 (World's End Drain)

3.16 The action of the pumping station over the last 40 years has created shrinkage in the peat layer leading to a more difficult drainage condition and total reliance on the pumps to maintain low water levels. The amount of shrinkage can be clearly seen at Manholes 1 and 2 which were constructed at ground level but now have cover levels some 240mm and 320mm respectively above ground. Further evidence was obtained as part of the Water Level Control Structures data collection in 2014 when ground contours produced from LIDAR obtained in 2013 were compared with the results of a photogrammetric survey carried out in 1993. The comparison demonstrated that the 86.0m contour which defined the extent of the "saucer" created by peat shrinkage extended over an area of 6.6ha in 1993. By 2013, this area had grown to 12.5ha. The combined impact of high water levels in the Lord Hill's drain due to lack of maintenance and the peat shrinkage within the land upstream has meant that the gravity by-pass which

comprises a 500mm diameter pipe through the wall of the pumping station at an invert level of 85.88m, cannot be used for fear of backflow through the station. The highest observed level at Brook House at the head of the Lord Hill Drain is 86.68m, 1.46m higher than the crest of the intake weir at Weir 7, the intake for the World's End Drain into the pumped drainage system. The combination of all these factors has led to increased pumping at an increased cost. This situation can only worsen over time as the peat continues to shrink and there is no improvement in the condition of the Lord Hill's Drain.

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4.0 REVISIONS TO THE DRAINAGE SYSTEM

4.1 The previous section described the existing drainage system and predicted a worsening and more expensive situation if the present land usage was to be maintained. The restoration of part of the land within the pumped field drainage scheme by SWT could provide a catalyst for change and benefit the entire area, providing that it can be demonstrated to have no detrimental impact on remaining land and property.

4.2 To enable the land to revert to bog vegetation, SWT must be able to control water levels around its perimeter by removing it from the pumped system. This would prevent further shrinkage and wastage of the peat which is particularly apparent in the upper part of the World's End Drain along the southern boundary of Bettisfield Moss.

4.3 Clearly from the previous analysis, natural (gravity) drainage simply by removing the pumping station is not an option since those areas presently under-drained within the "saucer" would form a permanent lake and the access to properties or some properties themselves around the perimeter of the "saucer", would be flooded by water flowing back up the World's End Drain from the Lord Hill's Drain.

4.4 Any revision must therefore ensure that the pumped drainage scheme can continue to operate for the benefit of the remaining land and properties, once the SWT land is removed from the system, and access to properties and the properties themselves within World's End, must remain free from flooding caused by high levels in the Lord's Hill Drain

4.5 The diversion of the World's End Drain from its present position along the southern side of the access track from Brook House Farm to the Land of Nod and Woodstyle, south to follow the line of Moss Lane, enables the capture of the upper catchment of the drain from Hornspike Ridge. In this position, the diversion containing the captured water can be routed around the pumping station. In addition, the re-aligned World's End Drain is away from the edge of Bettisfield Moss and thereby enables the existing course of the drain to be filled or dammed for the ongoing protection of the SAC.

4.6 Comparison of the highest level witnessed in the Lord Hill's Drain with the levels of the access track to the Land of Nod and Woodstyle from Brook House Farm and within Moss Lane, between Moss Lane Farm and Coppice House Farm, demonstrates that if these accesses are to be kept flood-free, flood banks are required to constrain overland flows from the World's End diversion channel, once it has been linked to the Lord Hill's Drain.

4.7 A further advantage to the diversion of the World's End Drain along the north side of Moss Lane is that for the majority of its length it is within the ownership of either SWT or NE and hence able to facilitate the restoration of the SWT land. There is however some private involvement at the western end of Moss Lane where the co-operation of the owners of Coppice House Farm is required and similarly at the eastern end of Moss Lane, the co-operation of the owners of Moss Lane Farm and Brook House Farm is also required.

4.8 Consultation with the above landowners has indicated that this co-operation is forthcoming particularly as there are achievable benefits for both farms from the proposed drainage revisions. In the case of Coppice House, flows from the Hornspike Ridge toe-drain flood the farmyard after heavy rain. This problem will be relieved by the diversion of the World's End Drain by providing a means to capture flows from the Hornspike toe-drain upstream of the Farm. With regard to Moss Lane and Brook House Farms, at present these two farms bear the entire cost of the pumping operation despite the fact that land within their ownership is a relatively small proportion of the catchment draining to the pumping station. Both farms will

therefore welcome the construction of the diversion since any water which it captures will reduce the loading on the pumping station and thereby reduce operating costs.

4.9 In addition, at Brook House Farm the existing old brick structure which formed the original World's End Drain culvert beneath the access to Woodstyle and Land of Nod is exhibiting considerable distress with extensive cracking either side of the culvert barrel. The position of the proposed culvert forming the gravity by-pass as part of the diverted World's End Drain has to be constructed close to this original structure and there are real concerns that the old brick structure could fail in the course of this construction. To attempt to secure the structure is not an option since it would be more expensive than a simple replacement and the ongoing integrity of the bridge is important as it is the only vehicular access to the two properties, Land of Nod and Woodstyle. Presently, the old structure carries the discharge from the pumping station which outfalls to a remnant length of the World's End Drain upstream of the structure through 2 no 150mm dia pipes.

4.10 Accordingly, it has been decided to replace this old structure with a new culvert formed from a 500mm dia twin walled Weholite plastic pipe. The new culvert will be constructed along the same line as the barrel of the existing brick structure from a precast concrete manhole where the pumps will discharge in future, to an outfall adjacent to the proposed gravity by-pass culvert. Future maintenance of the new culvert will be the responsibility of NE with day-to-day maintenance and operation resting with the owners of Brook House Farm.

4.11 Full details of the proposed diversion of the World's End Drain between Coppice House Farm and Brook House Farm is shown on Drg No 021 within Appendix 7 of this FRA, with further details of key sites – Coppice House Farm, Moss Lane Farm and Brook House Farm in the form of Construction drawings (Drg Nos prefixed with a "C") detailing the special arrangements required to maintain the use of pumped drainage for those properties within the "saucer" created by previous pumping.

5.0 FEASIBILITY OF PROPOSED DRAINAGE ARRANGEMENTS

5.1 Black and Veatch Consulting Engineers (BV) have carried out a Feasibility Study of the proposed revisions to the drainage system. Broadly, these revisions comprise the construction of a diversion of the World's End Drain from its present course to a new position along the north side of Moss Lane. The diverted drain would capture by gravity drainage as much of the present pumped catchment as possible without compromising the future drainage of the land remaining within the pumped field drainage scheme, and in addition, the access routes and properties within World's End would be protected against flooding from water flowing back along the diversion from the Lord Hill's Drain, by the construction of Flood Defences.

5.2 The BV Study comprised two sections – **Hydrology and Hydraulic Modelling**

5.2.1 Hydrology

The pumping station presently drains a total area of 1.51 km^2. 44% of this area is contained within the area demarcated as raised peat bog. The rest of the catchment is located to the south of the peat bog and is underlain by clay soils.

The catchment has been divided into a series of sub-catchments, as shown separately as Drg No 020 and as Fig 2.1 within Appendix 8. This sub-division has been made based on the drainage system shown in Appendix 5, and how it will be utilised to control water levels to rewet the land to be restored.

To determine the flows from each sub-catchment, the Flood Estimation Handbook (FEH) rainfall-runoff method has been used. Although this is generally regarded as being superseded by the Revitalised Flood Hydrograph (ReFH) method, the FEH method is still viable on lowland pumped catchments. It also has the benefit of allowing Standard Percentage Runoff (SPR) to be directly adjusted to represent the variability of SPR amongst the sub-catchments. SPR values used outside of the peat bog area are taken from the FEH CD-ROM v3 and those within the peat bog are based on Gilman (2000)[1]. The values of SPR used are as follows:

- Outside peat bog boundary = 40%
- Peat Bog = 25%
- Re-wetted areas of peat cutting = 70%

Where sub-catchments contain a combination of these types, SPR has been calculated on a proportional basis. Other parameters calculated for use in the FEH rainfall-runoff method are DPLBAR (average drainage path length) and DPSBAR (average drainage path slope). DPLBAR has been calculated using catchment area[2] and DPSBAR has been estimated using LiDAR. The PROPWET parameter is assumed to be constant across the catchment and taken from the FEH CD-ROM v3 (PROPWET =0.34).

The critical storm duration has been calculated for the whole catchment as follows and has been applied to determine peak flows for each sub-catchment:

1 Hydrological assessment of the implications of NNR management at Fenn's, Whixall & Bettisfield Mosses, K.Gilman (Nov-2000)

2 DPLBAR = $AREA^{0.548}$

Tp (0) = 4.27 $DPSBAR^{-0.35}$ $PROPWET^{-0.80}$ $DPLBAR^{0.54}$ $(1+URBEXT)^{-5.77}$
Tp (0) = 5.10

where DPSBAR = 5.1 m/km; PROPWET = 0.34; DPLBAR = 0.80km; URBEXT = 0
D = (1+SAAR/1000) x Tp(0)
D = 8.7 hours

where Standard Annual Average Rainfall (SAAR) = 708mm

Table 2.1 below gives key parameters and peak flows for the 1 in 100 annual chance flow for each sub-catchment.

Table 2.1 – Subcatchment Peak Flows

Sub-catchment	Areas (km^2)				SPR	DPLBAR (km)	DPSBAR (m/km)	1 in 100yr Flow (m^3/s)
	Non-Peat	Peat	Peat Cutting	Total				
Ditch 1	0.390	0	0	0.390	40%	0.60	4.1	0.35
Ditch 2.1	0.120	0.006	0	0.126	39%	0.32	10.0	0.16
Ditch 2.2	0.057	0.014	0	0.071	37%	0.23	9.7	0.09
Ditch 2.3	0.042	0.014	0	0.056	36%	0.21	10.0	0.07
Ditch 3	0.095	0.003	0	0.098	40%	0.28	10.0	0.13
Ditch 4.1*	0.043	0.023	0	0.066	63%	0.53	2.5	0.41
Ditch 4.2*	0	0	0.246	0.246	0%	0.00	0.00	0.00
Area 5	0.015	0.221	0.035	0.271	32%	0.49	2.5	0.22
Area 6	0.034	0.108	0	0.142	29%	0.34	2.5	0.10
Total								**1.53**

*** The Project Officer Dr Joan Daniels (NE) has stated that no run-off occurs from Bettisfield Moss within the catchment area for Ditch 4 – hence the split between Ditch 4.1 and 4.2. This has been confirmed this year by Mrs Helen Evans of Brook House Farm. Therefore the combined figure shown above within Table 2.1 for Ditch 4 is high. However, the overall impact of a reduction in flow from this one area is not considered to be sufficient to enable the crest level of the floodbank to be reduced. The flow estimates are conservative and if they are proven to be high the result will be a greater freeboard allowance, i.e. a higher factor of safety against over-topping, which can only be beneficial..**

5.2.2 Modelling

Black & Veatch have also been tasked with carrying out hydraulic calculations to determine the channel and culvert sizes for the proposed diversion of the World's End Drain and the crest level of the required flood defences. A plan of the revised drainage incorporating the route of the diverted drain and the position of the flood defences is provided as Drg 021 within Appendix 7, with further details on the various Site Plans, Long Sections and Cross sections (Drg No C001 – C027) provided as part of the Contract Documents for the Construction phase of the project and included within this FRA as Appendix 12. A 1-dimension ISIS model has been built to simulate the hydraulics of the proposed revisions and is described below. The chainages/nodes referred to in the description relate to the Long Sections and Site Plans within Appendix 12. The model has been based on the following data:

Channel

The model starts at the western end of Moss Lane (chainage: 0943). From this point, an existing drain runs intermittently along the north side of Moss Lane which can be utilised as the route of the diverted World's End Drain. For the purpose of this study it is assumed that all channel sections (whether newly excavated or re-sectioned) will take a trapezoidal form with a 1m wide bed and banks with a 2:1 vertical:horizontal slope. The steepness of these bank sides is viable due to the peaty nature of the ground through which the ditch runs.

The diverted World's End Drain route runs for a length of 680m along the southern and eastern boundaries of the land to be restored before turning east into land belonging to Moss Lane Farm (chainage: 0260) and continue in open channel towards Brook House pumping station. Instead of reaching the pumping station, the flow is directed into a short culvert around the pumping station and Brook House Farm buildings (chainage: 0020) before discharging into the Lord Hill's Drain. The model extends for 300m towards Lord Hill's Culvert using the existing channel sections taken from the survey work carried out for NE in 2014.

Channel roughness within the Diversion has been set at a Manning's 'n' roughness of 0.030 and assumes the ditches will be lightly vegetated and well maintained.

Structures

There are two culvert structures in the model. The schematisation of these is described in Table 3.1 below.

Table 3.1 – Modelled Structures

Structure Name	Chainage/Node	Description	Modelling
Flood Bank Culvert	0263	6m long, 600mm dia. Culvert through proposed Flood Bank	Modelled as ORIFICE unit.
Brook House Culvert	0020 to 0000	20m long, 600mm dia. Culvert past Brook House	Modelled as a CIRCULAR conduit with INLET and OUTLET units

Floodplain

To contain out-of-bank flows from the diverted drain and thereby prevent flooding of nearby properties and their access, a flood defence will be necessary along three sides of the land to be restored. The left-bank of the diverted drain will be adjacent to the land to be restored and water will spill out of the drain onto this land during periods of higher flows. This area has been represented using a RESERVOIR unit (chainage : 0943S) with the area-elevation relationship determined from LiDAR. A series of SPILL units connect the left-bank of the Diversion Drain (chainage: 0943 to 0263) to the RESERVOIR unit.

Boundary Conditions

The model has been set up for a worst-case scenario. For ease of modelling a single inflow has been applied at the upstream end using the sum of Ditches 3 and 4 along with Area 6. Thus the total flow conveyed by the Diversion Drain will be 0.64 m^3/s in

a 1 in 100 annual chance flood. Ditch 1 has also been diverted out of the remaining pumped area to allow it to enter the diverted drain upstream of the culvert by-passing the pumping station at Brook House Farm. Including Ditch 1, the peak flow entering the Lord Hill's Drain from the Diversion Drain increases to 1.0 m^3/s. The hydrograph is generated using the FEH rainfall-runoff unit in ISIS based on the whole catchment and with a critical storm duration of 9 hours.

The downstream boundary uses a HTBDY. The highest recorded level within the Lord Hill's Drain at Brook House (86.68m OD pre 2019) has been used. In the past the position of the pumping station has meant that elevated water levels downstream have not been able to pass upstream into this area, but this will not be the case when a direct connection by-passing the pumping station is provided.

Results obtained from the model are given below:

Figure 4.1 below shows a hydrograph of water levels occurring in the diverted World's End Drain adjacent to the land to be restored and Figure 4.2 shows a long-section of the peak water levels. This shows that elevated water levels downstream of Brook House will eventually back-up along the Diversion Drain and cause flooding within the area to be restored. This event would take a number of days to occur, but does indicate that tailwater conditions within the Lord Hill's Drain are the most significant flood risk to the area.

To assess the required height of the flood embankments to contain the flooding, the inflow hydrograph has been delayed until the water level upstream and downstream of the flood embankment equalise at 86.68m OD – the highest observed water level at Brook House Farm in the Lord Hill's Drain. The 1 in 100 annual chance hydrograph, results in an increase of 0.12m in the water level to a level of 86.80m OD. Neither the residences nor their accesses in this area are currently afforded a 1 in 100 year standard of protection and therefore, this seems a more than adequate combination of conditions to determine the required crest level of the flood bank.

Figure 4.1 – Stage Hydrograph for area contained by Flood Embankments

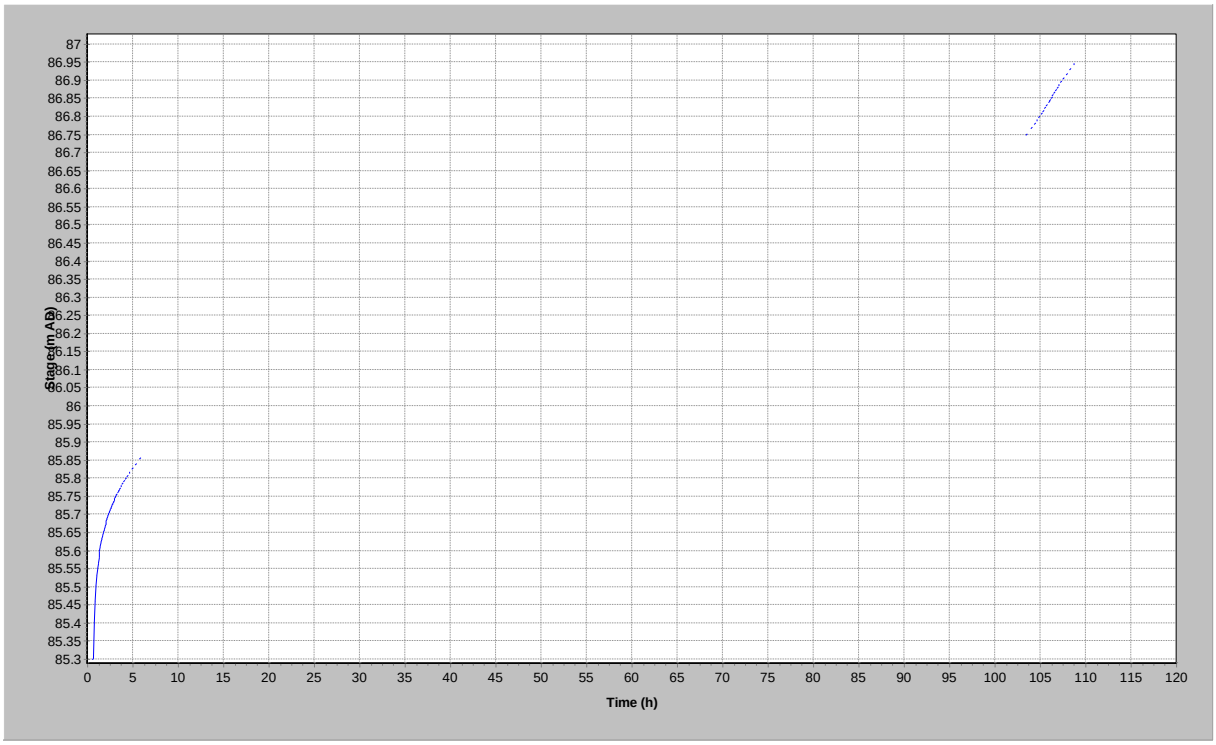
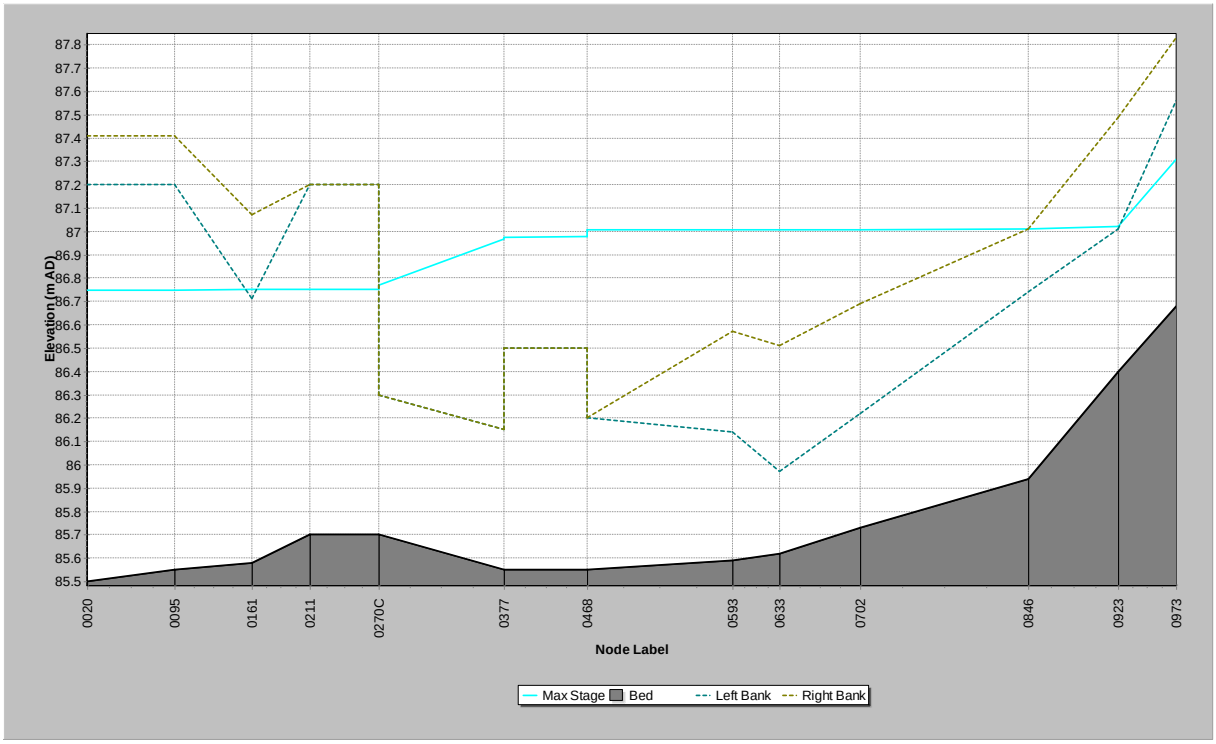


Figure 4.2 – Long-Section of Peak Water Level along Diversion Drain



5.3 The Feasibility Study carried out by Black and Veatch has confirmed the following:

- the present drainage system at World's End can be revised to enable water levels to be controlled and thereby facilitate the re-wetting of the land to be restored and prevent further damage to the SAC through peat shrinkage, wastage and erosion.

- at least 67% of the present pumping station catchment can be diverted around the pumping station.

- the access to all properties in Moss Lane, together with the access to Land of Nod and Woodstyle can be protected from flooding caused by high water levels in the Lord Hill's Drain by the construction of floodbanks around three sides of the land to be restored. The properties accessed from Moss Lane are not at risk from flooding due to their height above the predicted 1 in 100 year flood level, however, it should be noted that Woodstyle and Land of Nod are sited within the "saucer" and are therefore reliant on the pumping station for ongoing drainage and protection from flooding.

- the remaining areas of under-drainage can continue to be drained via the pumping station. The sub-catchments forming the revised pumped catchment are

  Ditch 2.1/2.2 a revised connection via a sealed pipeline through the land to be restored is required into the pumped system.

  Area 5 to continue to receive flows from the Land of Nod ditches into the pumped system, the length of World's End Drain between the outfall from the Land of Nod and Woodstyle ditch outfall and Weir 7 will need to remain open when the remainder of the upstream length of ditch is backfilled/dammed. Further details of this arrangement are provided in subsequent Appendices. The field drainage and overflow from Area 5 will continue through the direct connection to Manhole 1

- while the catchment area to the pumping station has been considerably reduced, the capacity of the pumping station ($0.08m^3/s$) is tiny in comparison with the flows from even the reduced catchment. Even with the large Ditch 1 catchment removed, the pumping station output is less than a 1 in 2 year storm flow. A common Indicative Standard used for agricultural schemes to satisfy MAFF criteria in the 1970s was a 1 in 10 years return period storm.

	Return Period Flows – m^3/s				
	Area km^2	**2 years**	**10 years**	**30 years**	**100 years**
Ditch 2	0.126	0.050	0.080	0.110	0.160
Area 5	0.271	0.070	0.109	0.152	0.215
Totals	**0.397**	**0.120**	**0.189**	**0.262**	**0.375**

5.4 Further details of the BV Feasibility Study are provided as Appendix 8 to this report.

6.0 DESIGN OF REVISED DRAINAGE ELEMENTS

6.1 General Works to be carried out along Diversion Route

The BV modelling has confirmed the following general items:

6.1.1 Channel Geometry – bed width 1.0m minimum; side slopes 2 (vertical):1 (horizontal). Banks to be seeded with seed mix specified by SWT/NE. It should be noted that much of the existing channel within the diversion route is below the modelled gradient of 1:1,000. Only limited excavation is therefore necessary leading to a potential shortfall in spoil from which to construct the floodbanks. However, further material can be excavated if necessary, from within the land to be restored. Examples of channel sections are provided within the Construction drawings within Appendix 12 (Drg Nos C006 – C008)

6.1.2 Flood Bank Geometry – crest width 2.0m; side slopes 1 (vertical):1 (horizontal). Crest and side slopes to be seeded with seed mix specified by SWT/NE. Crest level 87.00m allowing 200mm of freeboard above the modelled figure of 86.80m. Peaty material is not a recommended soil type from which to construct floodbanks or indeed upon which to construct floodbanks. The advice of a Geo-technical Engineer is presently being sought regarding the use of a Geotextile in the detail design of these structures. However, the basic floodbank design will be trapezoidal with a clay core and a key trench excavated through the peat to connect with the underlying clay as shown on Drg No C016 within Appendix 12. Mounds of clay excavated locally by the previous owners of Moss Lane are already located around the site. This quantity can be supplemented from further excavations within the land to be restored if required.

6.1.3 Culverts – with the exception of the culvert forming the diversion around the pumping station at Brook House Farm, all culverts within the diversion will be constructed from 600mm dia Weholite 2kN/m^2 plastic, twin-walled pipe. The pipe for the diversion at Brook House Farm is to be 750mm dia Weholite with a 4kN/m^2 stiffness. As stated previously, the most significant flood risk associated with the drainage revisions is from the high levels within the Lord Hill's Drain which need to be contained. The culvert size is therefore of little consequence providing head losses are minimised in conveying flows along the diversion. A 600mm diameter pipe satisfies this criteria and is large enough to pass the typical floating debris which might be expected at this rural location. A typical design for the culverts is also shown on Drg No C026 within Appendix 12.

6.2 Further details of key sites – Coppice House Farm, Moss Lane Farm and Brook House Farm together with the special arrangements required to maintain the use of pumped drainage for those properties within the "saucer".

6.2.1 Moss Lane Farm and Brook House Farm

Details of the Diversion culvert at Brook House Farm are provided as Drg Nos C010-C012 within Appendix 12. The downstream end of the 750mm dia culvert at Brook House Farm will be fitted with a penstock to close the diversion and prevent back-flows from the Lord Hill's Drain. Operation of this penstock will depend on the Operating Rules governing the revised drainage arrangements for the World's End area. A copy of these Rules is provided in Appendix 9. Broadly, the penstock which is normally fully open will be closed if excessively high levels in the Lord Hill's Drain are experienced or problems such as a failure of a flood defence occurs. Closure of this penstock severs the diversion and prevents flows from Lord Hill's Drain entering the World's End area. In tandem with the closure of this penstock, a penstock fitted to the upstream end of a culvert through the northern embankment bounding

the land to be restored has to be opened. This culvert outfalls into the remaining open section of the original course of the World's End Drain and thereby enables the diversion water to enter the pumped system via Weir 7. The length of the World's End Drain between the Land of Nod ditch outfall and Weir 7 will have to remain open to permit drainage from Land of Nod to continue to enter the pumped system even though the remaining upstream length of the Drain will be backfilled/dammed to provide protection against the continued shrinkage of Bettisfield Moss.

Conversely, during periods of dry weather, to prevent the land to be restored from drying out, discharge from the diverted drain can be controlled by the use of a further penstock sited at the upstream end of a culvert through the floodbank along the eastern boundary of the land to be restored which protects Moss Lane Farm. This penstock is normally fully open but can be adjusted to suit the prevailing weather conditions.

Further details of these arrangements are provided as Drg Nos C014 and C015 within Appendix 12.

As described previously in paras 4.9 and 4.10, due to its poor, structural condition, it has been decided to replace the old brick culvert, formerly the crossing of the World's End Drain, with a new 500mm dia plastic pipe. Further details of these arrangements are provided as Drg No C013 within Appendix 10.

6.2.2 Diversion of Ditch 1

The diversion of Ditch 1 from the pumped catchment can be readily achieved by the re-sectioning and regrading of the ditch along the south side of Moss Lane between Weir 4 and the ditch along the west side of the access track to Brook House Farm. The 500mm dia culvert beneath Moss Lane, which presumably marks the former route prior to the construction of the pumping station, is already in place to link these two lengths of ditch. Details of these channel works are shown on Drg Nos C017 and C018 in Appendix 12. In addition, as shown on Drg Nos C019 and C020, Weir 4 will be fitted with a penstock to prevent flows entering the pumped drainage system. If required for whatever reason, flows from Ditch 1 can return to the pumping station by opening this penstock.

6.2.3 Continued discharge of Ditch 2.

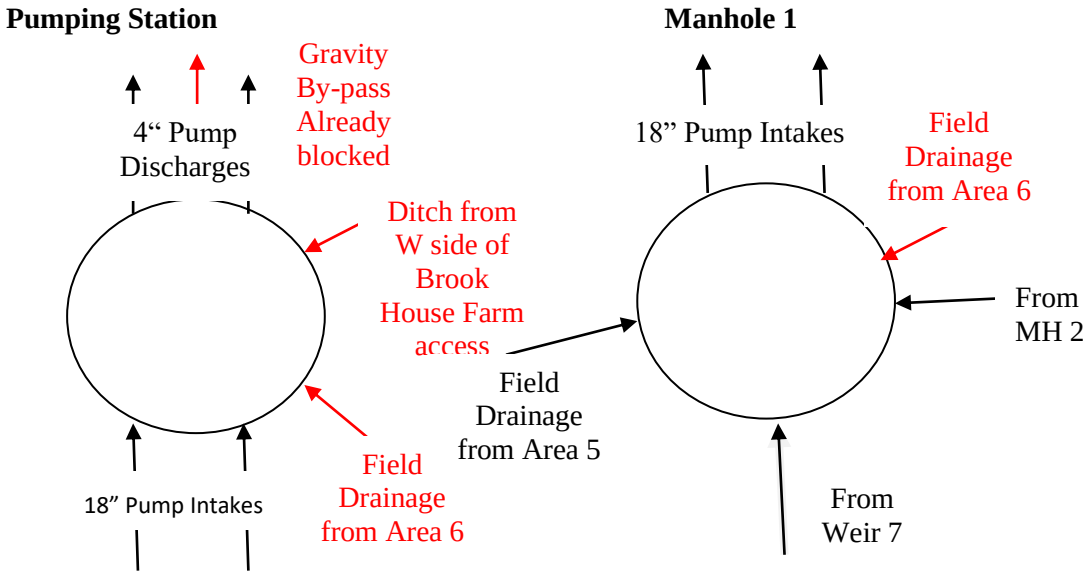
Lengths of Ditch 2, the catchwater drain from Hornspike Ridge, are at present connected to the pumped drainage system via 2 no pipes crossing Moss Lane. The precise location of these crossings (225mm and 250mm dia pipes) is shown on Drg No 017 within Appendix 5 with further details provided on Drg Nos C002 and C004 within Appendix 12. The present ditch system to the north of Moss Lane within the land to be restored, receives flows from the two crossings which are then conveyed via open ditch to Weir 6. The bed levels of the diversion drain provided as part of the drainage revisions will be too high to accept flows from the two crossings and therefore to ensure continuation of this arrangement, the two crossings will need to be combined and piped beneath the diversion drain. This new pipe will then need to be extended to Manhole 2 across the land to be restored. Since the land to be restored will be subject to flooding and contain flood banking around its perimeter at this point, this entire arrangement will need to be carried out within sealed pipework to avoid gravity drainage entering the pumped system. Details of these works are shown on Drg Nos C021 to C023 within Appendix 12.

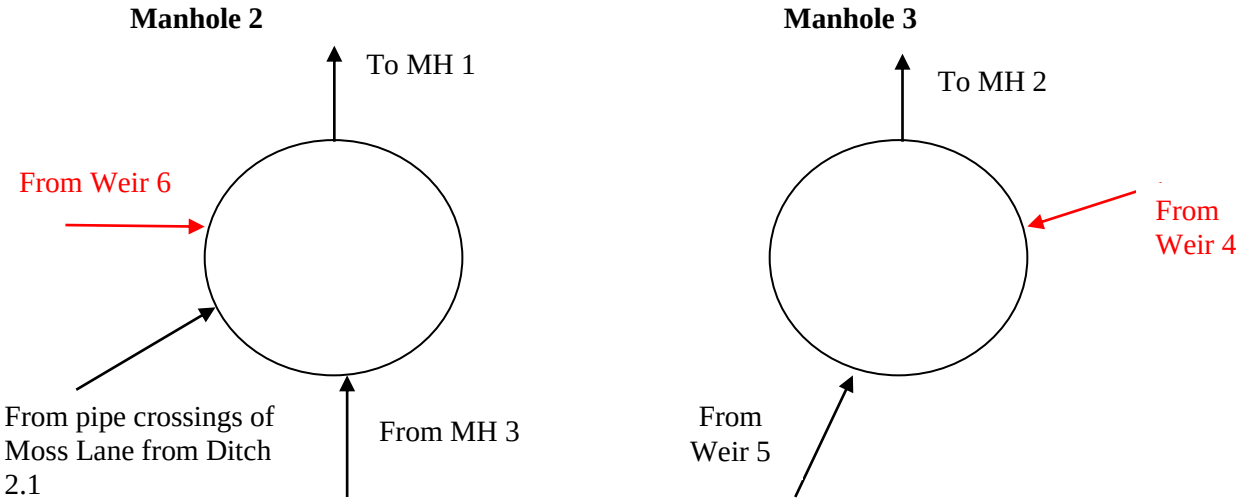
6.2.4 Coppice House Farm

At present, there is no known connection south to north for the Ditch 3 sub-catchment beneath Moss Lane. The majority of the water arising from Hornspike Ridge flows north to the end of the catchment creating flooding problems within the Farmyard at Coppice House Farm before entering the World's End Drain (Ditch 4) sub-catchment. As part of the revised drainage arrangements, it is proposed to intercept the flows along the toe of Hornspike Ridge and divert them north to the access road to Coppice House Farm, where a connecting culvert beneath the access road will discharge to the diversion drain. The ditch conveying the Hornspike Ridge toe-drain to the Coppice House Farm access road will be excavated by the owner of Coppice House Farm who will be responsible for its ongoing maintenance. The culvert beneath the access road will form part of the scheme works and be maintained by NE. Details of these arrangements are shown on Drg Nos C024 and C025 within Appendix 12. In addition, also shown on Drg No C024 are works to the north of Moss Lane which form the start of the Diversion and enable the present course of the World's End Drain to be blocked to prevent further damage to Bettisfield Moss. Details of these works are shown on Drg Nos C002, C005, and C008 within Appendix 12.

6.2.5 Blockage of Field Drainage.

Those areas which contain field drainage which will no longer be required need to be isolated from the remainder of the pumped drainage system. The full extent of all pipes serving the present system cannot be identified due to high water levels, however, based on limited observation and the arrangements shown on the Contractors Plan (Appendix 5, Drg No 019), the following schematics demonstrate the number of pipes to be blocked.





Connections shown in red, on both this and the previous page, are to be blocked with the use of a bung within the manholes. The connection from Weir 6 to Manhole 2 has to remain open to facilitate the pipes crossing from the north side of Moss Lane. The two main drains discharging to this connecting pipe will need to be severed locally to prevent field drainage continuing in the land to be restored. Weir 4 is to be fitted with a penstock.

Manholes 1 and 2 are to be sealed by the provision of a 150mm thick concrete surround from invert level to ground level to prevent gravity drainage entering the pumped system during "normal" operation.

7.0 OPERATING RULES

7.1 The modelling work carried out by Black and Veatch to assess the feasibility of the proposed changes to the drainage pattern of World's End to enable the restoration work to proceed, has confirmed that the greatest flood risk from the new proposals is from high water levels in the Lord Hill's Drain downstream of its confluence with Slack's Bridge Drain at Brook House Farm. This length of drain, between Brook House Farm and Ossage Bridge formed part of the survey work carried out on behalf of NE in 2014 which highlighted the poor condition of the drain in terms of channel maintenance.

7.2 As previously described in Section 3 above, the Lord Hill's Drain controls the drainage from both World's End and Whixall Moss. Drainage from Whixall Moss (Slack's Bridge Drain) passing through Morris's Bridge Fields and Allman's Bridge culvert, converges with the pumped discharge from World's End, between Brook House and the upstream end of the Lord Hill's Culvert some 350m downstream.

7.3 High water levels upstream of the Lord Hill's Culvert control the discharge through the culvert at Allman's Bridge by raising water levels downstream of this structure. Survey work carried out on behalf of NE in 2014 found that the channel between the Allman's Bridge culvert and the confluence with Lord Hill's Drain had been over-deepened, presumably in an attempt to lower water levels, and relieve the flooding problem which regularly occurs upstream of Allman's Bridge. It is also likely that the construction of the pumping station at Brook House draining World's End was triggered by the poor drainage conditions downstream in the Lord Hill's Drain.

7.4 The Lord Hill's Culvert has in the past been considered to be responsible for these conditions but this is not the case. It is true that the circular area of flow provided by the culvert which is approximately 1.0m in diameter could be greater but without regular maintenance of the channel section, particularly downstream of the structure, a larger culvert would continue to be restricted by high water levels downstream. The following Table illustrates this particular point by providing flow figures for varying upstream water levels between 86.22 and 86.72m AOD with two different downstream water levels – 85.48m representing a well-maintained channel and 85.90m AOD representing either a poorly maintained channel or one which is simply too small. 85.90 was the water level recorded in 2014 after a particularly dry period.

Upstream Water Level (m AOD)	**Downstream Water Level (m AOD)**		
	85.90 Recorded figure 2014	**85.48 assumes 0.2m water depth**	**% increase in flow**
86.22	0.93 m^3/s	1.41 m^3/s	52
86.32	1.06	1.51	42
86.42	1.18	1.59	35
86.52	1.29	1.68	30
86.62	1.39	1.75	26
86.72	1.49	1.83	23

7.5 In terms of the Diversion Drain proposed for World's End, the performance of the Lord Hill's Culvert is a key factor in determining the crest level of the floodbanks to be constructed around three sides of the land to be restored. The feasibility of the proposal has been proved by modelling based on a highest observed level for the Lord Hill's Drain at Brook House of 86.68m AOD. From the model, a crest level for the floodbank was determined as 86.80m AOD, to which a freeboard allowance was added to give a design level of 87.00m AOD.

7.6 The above paragraph shows the degree of influence which the performance of the Lord Hill's Drain and Culvert have in determining the level of flood protection provided for the accesses to properties and the properties themselves within World's End. To maintain this degree of protection, clearly the drain downstream of the outfall of the Diversion at Brook House needs to be regularly maintained to a high standard, both upstream and downstream of the Lord Hill's Culvert.

7.7 To further illustrate this point, in June of this year (2019), 200mm of rainfall was recorded at Brook House Farm over a 13 day period which resulted in a peak level of 86.84m AOD at the confluence of Slack's Bridge Drain with Lord Hill's Drain. This level is the highest ever witnessed at Brook House Farm, some 160mm above the previously recorded peak. Over this period the River Roden at Roddington was observed to rise by 1.0m and the World's End Drain by 750mm. Subsequently, the River Roden level fell by 600mm over the next few days whereas the World's End Drain only dropped by 30mm. No obstructions were found in the Lord Hill's Drain, but at that time of year, the weed growth was prodigious. In addition, a camera survey carried out by Shropshire Council following the flood event revealed no obstructions within the culvert.

7.8 The above analyses have been included first to stress the need for ongoing maintenance of the Lord Hill's Drain; second, in response to the myth that the Lord Hill's culvert is to blame for the poor drainage of the area, and third, most importantly in this instance, to illustrate the need for Operating Rules both to control discharge to the Lord Hill's Drain and from the Lord Hill's Drain if high levels are experienced within the drain downstream of Brook House Farm.

7.9 At the confluence of Slack's Bridge Drain and the Lord Hill's Drain a gauge board has been erected which is read daily by the owners of Brook House Farm and is to be used as a trigger for appropriate action. The modelling carried out by Black and Veatch demonstrated that against a water level within the Drain of 86.68m AOD – the highest level witnessed prior to June this year - the 1 in 100 year flood level on the land to be restored upstream would be 86.80m AOD and hence the floodbank crest was set at 87.00m AOD, providing a freeboard of 200mm.

7.10 In view of the water levels witnessed in June this year, it is proposed to close the penstock on the downstream end of the 750mm dia gravity by-pass culvert at Brook House Farm, once a level of 86.68m AOD within the Lord Hill's Drain is witnessed on the gauge board. At this level, the 200mm freeboard against the floodbank crest will be maintained.

7.11 Once the penstock at the downstream end of the 750mm culvert is closed, the penstock within the line of the floodbank adjacent to the access track between Brook House Farm and the two properties Land of Nod and Woodstyle must be fully opened to enable the drainage of the area to revert back to pumped drainage discharging through the pumping station at Brook House Farm. It is likely, under these conditions, that a further pump set would be necessary to discharge the floodwater in addition to the two fixed pumps within the pumping station. The need for an additional pump under extreme conditions has already been demonstrated – in June this year a subsidiary pump was required for 2 weeks.

7.12 A suggested trigger for the re-opening of the penstock at the downstream end of the 750mm dia gravity by-pass would be a level of 86.65m AOD, although this level could be refined over time as experience is gained in operating the system.

7.13 Once the penstock at the end of the gravity by-pass is re-opened, then the penstock controlling flows from the land to be restored, which is sited within the floodbank adjacent to the access track between Brook House Farm and Land of Nod and Woodstyle, would need to be closed.

7.14 In times of drought, the size of the opening of a further penstock, which is located on the line of the diversion channel through the floodbank located on the boundary between the SWT land and the western boundary of Moss Lane Farm, can be adjusted to limit discharge from the land to be restored.

7.15 Drg No 014 and 026 within Appendix 9 and Drg Nos C014 and C015 within Appendix 12 provide further details of the penstocks and their positions. A copy of the Operating Rules is also provided within Appendix 9.

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8.0 PLANNING APPROVAL AND LAND DRAINAGE CONSENT

8.1 Planning Approval

Following a meeting between NE and Shropshire Council Planners a pre-application submission has been made to Shropshire Council for comment covering both this scheme and a similar one referred to as Morris's Bridge Fields at a neighbouring location. Both schemes have a similar aim to restore land around the edge of the internationally important Whixall, Fenns, Wem, Cadney and Bettisfield Mosses. The response to the pre-application inquiry from Shropshire Council was contained in a letter dated 9th May 2018, ref: PREAPP/19/00018. The letter contained the following comments with regard to Drainage.

"For this pre-application, the responses provided to our comments dated 27 March 2019 indicate that the intention is to maintain the status quo of flooding in the area, which is acceptable. My colleague, Richard Cheal, who has been involved with this application and that of flooding in the area, is currently working away from the office. As our initial concerns have been answered, we have no further comment to make for the preapplication. Further details/clarification may be requested for the full planning application and Ordinary Watercourse Consent."

Copies of the Shropshire Council letter which contains the above comment, plus the original drainage comments made by their consultants (WSP) and the response to those comments made by BK which are referred to in the letter are provided in Appendix 10.

8.2 Land Drainage Consent

Under the Land Drainage Act 1991 Consent will be required for Works Affecting Watercourses and/or Flood Defences. No lengths of main river are involved in the proposed changes to the drainage of World's End, therefore the advice of the Shropshire Council Flood and Water Management Team will be sought regarding which particular elements of the proposals require Ordinary Watercourse Consent.

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9.0 CONCLUSIONS

9.1 In order to restore the SWT land the present system of pumped drainage which serves the area must be revised. This work will include the diversion of some flows presently reaching the pumping station out of the pumped catchment. At present the pumping station receives flows from areas which could drain naturally by gravity. This is both costly and unsustainable over time as energy costs continue to rise, climate change creates wetter conditions and the drained peat within the pumped catchment continues to shrink creating more reliance on the pumping station for effective drainage. In addition, the present position of the World's End Drain, the principal feeder ditch into the pumping station along the southern boundary of Bettisfield Moss and the operation of the pumps, has led to peat shrinkage which is damaging this corner of the SAC site.

9.2 The re-wetting of the area to be restored will not compromise the drainage of neighbouring agricultural areas which will continue to enjoy the benefit of pumped drainage. In addition, flood-banks will be constructed around three sides of the acquired land. The crest level of these floodbanks has been assessed using the flood level from a 1 in 100 year return period storm over the World's End catchment once gravity discharge is in place alongside the pumped drainage. Additionally, the floodbanks will also provide protection from back flooding by flows from the Lord Hill's Drain. It is essential that the Lord Hill's Drain between Brook House, where the diverted flows will outfall, and the River Roden is maintained to as high a standard as possible to reduce and keep water levels within this watercourse to a minimum level, otherwise the level of protection provided by the floodbanks will be reduced. While there is little chance of the Lord Hill's culvert being replaced, to improve the access to the screen for cleaning purposes at the upstream end of the culvert, would help to ensure that the culvert was performing to its full capacity. A further reason for the reduction of water levels within Lord Hill's Drain is to provide the most favourable operating conditions for the Lord Hill's culvert which in turn will increase flows through Allman's Bridge culvert and reduce the flooding on land upstream.

9.3 The diversion of flow away from the pumped catchment will reduce the area draining to the pumping station by 42% with the potential for a further reduction to 67% if the area served by Ditch 1 is also removed. However, even with a 67% decrease in catchment and despite the fact that the pumps have been regularly maintained and serviced, the present capacity of the pumping station taken from the pump Rating Curve of $0.08m^3/s$, is insufficient to discharge estimated flows from a 1 in 2 year return period storm ($0.12m^3/s$) and flooding will therefore continue to occur within those areas remaining within the pumped catchment, following heavy or prolonged rainfall which exceeds this criteria. It is likely that flooding will tend to occur more often in these areas in future as the field drainage network is damaged by the ongoing peat shrinkage.

9.4 There is evidence to confirm that the operation of the pumping station over the past 42 years has caused peat shrinkage and created a "saucer" within the land upstream leading to increased reliance on the pumping station to provide effective drainage. Land within the area to be restored which is within the "saucer" will therefore be subject to shallow flooding once it is removed from the pumped catchment.

9.5 In the event of a problem occurring with for example the floodbanks, or high water levels within the Lord Hill's Drain due to excessive rainfall, there is provision within the proposed works to close the Diversion Drain by use of a penstock sited at the downstream end of the culvert at Brook House. Under these circumstances a second penstock can be opened within the north eastern corner of the land to be restored to discharge flows from the Diversion Drain into the pumped system via Weir 7 which is situated at the downstream end of the remains of the original course of the World's End Drain. This length of drain remains open to allow

access from Land of Nod ditches into the pumped system. In a falling flood situation, Penstock 2 can be partially closed to reduce flows to the pumped system and thereby utilising storage which is available within the floodbanked land to be restored upstream. However, this operation needs to be closely monitored and should not be used too early in a flooding situation as the storage taken may be required to cater for further events within the same period.

9.6 Control of summer water levels within the land to be restored with the Diversion Drain discharging directly to Lord Hill's drain around the Pumping Station will be achieved by the partial closing of a penstock provided at the upstream end of a culvert passing through a floodbank linking the two floodbanks across the "mouth" of the Diversion at the north eastern corner of the land adjacent to Weir 7.

9.7 The proposals for revising the present drainage contained within this report are designed solely to facilitate the re-wetting of the land to be acquired by SWT. They will not reduce the frequency of flooding which affects the area in general as these conditions are mainly the result of a lack of maintenance of the Lord Hill's Drain and the inadequate capacity of the pumping station. However, the construction of the floodbank will provide protection from back-flooding from the Lord Hill's Drain and flooding caused by a 1 in 100 year storm over the World's End Drain catchm/ent for the accesses and properties around or within the "saucer" i.e. Moss Lane properties and Land of Nod and Woodstyle. However, in the case of Land of Nod, there will be, as at present, a constant threat of flooding due to the inadequacy of the pumped system.

9.8 The functionality of the floodplain at World's End which contains the land to be restored will be unaffected by the proposals.

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