Cyfoeth Naturiol Cymru
Natural Resources Wales

Sands of LIFE: Hydrology Report

Alex Jones and Joseph Cherry
JBA Consulting Ltd

NRW Evidence Report No 570

September 2021

SoLIFE: LIFE 17 NAT/UK/000023
The Twyni Byw-Sands of LIFE project has received funding from the LIFE Programme of the European Union
Part funded by the Welsh Government

About Natural Resources Wales

Natural Resources Wales' purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales' well-being, and provide a better future for everyone.

Evidence at Natural Resources Wales

Natural Resources Wales is an evidence based organisation. We seek to ensure that our strategy, decisions, operations and advice to Welsh Government and others are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

This Evidence Report series serves as a record of work carried out or commissioned by Natural Resources Wales. It also helps us to share and promote use of our evidence by others and develop future collaborations. However, the views and recommendations presented in this report are not necessarily those of NRW and should, therefore, not be attributed to NRW.

Report series: NRW Evidence Reports
Report number: 570
Publication date: June 2021
Contract: SoLIFE Physical Monitoring
Contractor: JBA Consulting Ltd
Contract Manager: Kathryn Hewitt
Title: Sands of LIFE: Hydrology Report
Author(s): Joseph Cherry
Peer Reviewer Alex Jones
Restrictions: None

Distribution List (core)

NRW Library, Bangor 2
National Library of Wales 1
British Library 1
Welsh Government Library 1
Scottish Natural Heritage Library 1
Natural England Library (Electronic Only) 1

Distribution List (others)

None

Recommended citation for this volume:

Jones, A and Cherry, J, 2021. Sands of LIFE: Hydrology Report. NRW Evidence Report No: 570, 118pp, Natural Resources Wales, Bangor.

Contents

About Natural Resources Wales 1
Evidence at Natural Resources Wales 1
Distribution List (core) 2
Distribution List (others) 2
Recommended citation for this volume: 2
Contents 3
List of Figures 1
List of Tables 3
Crynodeb Gweithredol 4
Executive Summary 5
Introduction 6
Project background 6
Hydrological Controls and Generic Conceptual Model 6
Description of the Generic Conceptual Model from Davy et al. (2006) 7
Current guidance on vegetation types and associated water levels (Curreli et al., 2013) 11
National Vegetation (NVC) Classification 11
Designing Monitoring Requirements 12
Newborough 12
Baseline 12
Dune System Extent and Topography 12
Soils, Geology and Hydrogeology 14
Surface Water Features and Groundwater Boundaries 17
Site Data 18
Water Level Monitoring Networks 18
Groundwater Surfaces 20
NVC Surveys 25
Conceptual Model 25
Interventions and Monitoring 27
Newborough Interventions and Monitoring – Warren Slack 28
Target Habitat 28
Intervention Plan (to be implemented) 28
Current Water Level Ranges - Monitoring 28
Current Water Level Range – NVC 28
Implementation Advice 29
Monitoring Plan 29
Newborough Intervention and Monitoring – Pwll Treath Bach 30
Target Habitat 31
Initial plan – to be completed 31

Current water level ranges – monitoring 31
Current water level range – NVC 31
Implementation Advice 31
Monitoring Plan 31
Newborough Intervention and Monitoring – Gull Slack 31
Target Habitat 32
Intervention Plan – Implemented February 2021 32
Current Water Level Ranges – monitoring 32
Current water level range – NVC 32
Ecohydrological Implementation Considerations 32
Monitoring Plan 33
Newborough Intervention and Monitoring – Ffrydiau Pools 33
Target Habitat 34
Intervention Plan (to be implemented) 34
Current Water Level Ranges – Monitoring 34
Current Water Level Range – NVC 34
Implementation Advice 34
Monitoring Plan 34
Newborough Intervention and Monitoring - Pwll Pant Mawr 35
Target Habitat 35
Intervention Plan (implemented Winter 2020/2021) 35
Current Water Level Ranges – Monitoring 35
Current Water Level Range – NVC 35
Ecohydrology Implementation Considerations 35
Monitoring Plan 35
Morfa Harlech 37
Baseline 37
Dune System Extent and Topography 37
Soils, Geology and Hydrogeology 38
Surface Water Features and Groundwater Boundaries 41
Site Data 42
Water Level Monitoring Networks 42
Groundwater Surfaces 43
NVC Surveys 49
Conceptual Model 50
Interventions and Monitoring 52
Morfa Harlech Intervention and Monitoring – Morfa Harlech Scrape 53
Target Habitat 53
Intervention Plan (implemented March 2021) 53
Current Water Level Ranges - Monitoring 53
Current Water Level Range – NVC 54
Monitoring water levels and NVC levels summary 54

Ecohydrological Implementation Consideration 54
Monitoring Plan 54
Pembrey Burrows 55
Baseline 55
Dune System Extent and Topography 55
Geology 56
Surface Water Features and Groundwater Boundaries 60
Vegetation and Dune Slack Distribution 61
Site Data 62
Planned Intervention Locations 62
Conceptual Model 62
Interventions and Monitoring 63
Pembrey Burrows Intervention and Monitoring – West Slack 64
Target Habitat 64
Plan – Implemented January/February 2021 64
Current Water Level Ranges – Monitoring 64
Current Water Level Range – NVC 64
Ecohydrological Implementation Consideration 64
Monitoring Plan 65
Pembrey Burrows Intervention and Monitoring- 3 Small Slacks 65
Target Habitat 65
Plan – Implemented January/ February 2021 65
Current Water Level Ranges – Monitoring 66
Current Water Level Range – NVC 66
Ecohydrological Implementation Consideration 66
Monitoring Plan 66
Pembrey Burrows Intervention and Monitoring – North West Slack 67
Target Habitat 67
Plan – Implemented in January/February 2021 67
Current water level ranges – monitoring 67
Current water level range – NVC 67
Ecohydrological Implementation Consideration 67
Monitoring Plan 67
Kenfig 68
Baseline 68
Dune System Extent and Topography 68
Soils, Geology and Hydrogeology 69
Surface Water Features and Groundwater Boundaries 72
Site Data 73
Water Level Monitoring Networks 73
NVC Surveys 79
Conceptual Model 81

Interventions and Monitoring 82
Kenfig Interventions and Monitoring: Horseshoe Slacks (Slack 1 and 2) 82
Target Habitat 83
Plan – Implemented January/ February 2021 83
Current Water Level Ranges - Monitoring 83
Current Water Level Range – NVC 84
Monitoring water levels and NVC levels summary 85
Ecohydrological Implementation Consideration 86
Monitoring Plan 86
Monitoring and Interventions (Slack 3 – Birch Slack) 86
Target Habitat 87
Initial Plan (to be implemented) 87
Current Water Level Ranges – Monitoring 87
Current Water Level Range – NVC 88
Monitoring water levels and NVC levels summary 89
Implementation Advice 89
Monitoring Plan 89
Merthyr Mawr 90
Baseline 90
Dune System Extent and Topography 90
Soils, Geology and Hydrogeology 90
Surface Water Features and Groundwater Boundaries 94
Site Data 95
Water Level Monitoring Networks 95
NVC Surveys 101
Conceptual Model 102
Interventions and Monitoring 104
Monitoring and Interventions – Merthyr Mawr 104
Target Habitat 105
Plan – Implementation Plan 105
Current Water Level Ranges – Monitoring 105
Current Water Level Range – NVC 109
Monitoring water levels and NVC levels summary 109
Ecohydrological Implementation Considerations 109
Monitoring Plan 110
References 111
Data Archive Appendix 112

List of Figures

Figure 1: Model Gysyniadol Generig Twyni gan Davy et al., (2006) ... 4
Figure 2: Generic Dune Conceptual Model from Davy et al., (2006) ... 5
Figure 3: Generic Dune Conceptual Model from Davy et al., (2006) ... 8
Figure 4: Example of a Type B dune-slack at Winterton Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010). ... 8
Figure 5: Example of a Type D dune-slack at Horsey Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010). ... 9
Figure 6: Example of a Type E dune-slack at Winterton Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010). ... 9
Figure 7: WETMEC dune types: Water table conditions for defining humid dune slack habitat types from Davy et al. 2010. ... 10
Figure 8: Newborough Special Area of Conservation boundary and blown sands superficial deposits ... 13
Figure 9: Newborough Warren superficial geology ... 15
Figure 10: Newborough Warren bedrock geology ... 16
Figure 11: Newborough Warren bedrock geology ... 17
Figure 12: Monitoring Array with dipwell locations. ... 18
Figure 13: Example Hydrographs ... 19
Figure 14: Wet Winter Water table interpolated from dipwell monitoring data. top figure water level is in mAOD and bottom figure is in mbgl ... 21
Figure 15 : Dry Winter Water table. Top figure water level is in mAOD and bottom figure is in mbgl ... 22
Figure 16 :Wet Summer Groundwater level. Top figure water level is in mAOD and bottom figure is in mbgl. ... 23
Figure 17: Dry Summer Water Level top figure water level is in mAOD and bottom figure is in mbgl ... 24
Figure 18: NVC/WETMEC Slack Classification ... 25
Figure 19: Newborough Warren conceptual model cross section ... 27
Figure 20: Location of Newborough Warren slack ... 28
Figure 21: WETMEC classifications at Newborough Warren. ... 29
Figure 22: Location of the intervention area and dipwell. ... 30
Figure 23: Location of Pwll Treath Bach slack intervention ... 30
Figure 24: Location of Pwll Treath Bach slack intervention and dipwell ... 31
Figure 25: Location of Gull Slack intervention area. ... 32
Figure 26: Location of Gull Slack intervention and the dipwell. ... 33
Figure 27: Location of Ffrydiau Pools and Pand Mawr slacks ... 33
Figure 28: Location of Pwll Pant Mawr and Ffrydiau Pools intervention areas. ... 35
Figure 29: Location of the Pwll Pant Mawr slack intervention area and dipwell. ... 36
Figure 30: Morfa Harlech Special Area of Conservation boundary and blown sands superficial deposits. 38
Figure 31: Morfa Harlech superficial geology ... 40
Figure 32: Morfa Harlech bedrock geology ... 41
Figure 33: Dipwell monitoring network ... 42
Figure 34: Example Hydrographs ... 43
Figure 35: Wet Winter water table ... 44
Figure 36: Wet winter water table ... 45
Figure 37: Dry Winter Water table ... 46
Figure 38: Dry Winter Water table ... 46
Figure 39: Wet Summer Groundwater level ... 47
Figure 40: Wet Summer Groundwater level ... 47
Figure 41: Dry Summer Water Level ... 48
Figure 42: Dry Summer Water Level ... 48
Figure 43: NVC/WETMEC Slack Classification ... 49
Figure 44: NVC/WETMEC Slack Classification through the Groundwater Monitoring and Intervention Area. ... 50
Figure 45: Conceptual Model through Groundwater Monitoring Area. ... 51
Figure 46: Conceptual Model through Intervention Area ... 52
Figure 47: Map showing the location of the Morfa Harlech dune scrape ... 53
Figure 48: Wet winter water table at Morfa Harlech ... 54
Figure 49: Location of Morfa Harlech dune slack intervention and dipwell. ... 55
Figure 50: Pembrey Burrows Boundaries ... 56
Figure 51: Superficial geology ... 58
Figure 52: Bedrock Geology ... 59

Figure 53: 1879 OS Mapping and 2010 dune toe from Pye et al., 2014.. 60
Figure 54: Daily Water Level Ranges at the Afon Lliedi Tidal Mouth at Llanelli 61
Figure 55: NVC Survey and Dune Slack Communities.. 62
Figure 56: Conceptual Model 63
Figure 57: Location of the West Slack intervention at Pembrey Burrows. 64
Figure 58: West Slack and dipwell. 65
Figure 59: Pembrey Burrows 3 Small Slacks. 65
Figure 60:Planned dune slacks and dipwell.. 66
Figure 61: Location of Pembrey Burrows North West Slack 67
Figure 62: Kenfig SAC outline and blown sands superficial deposits. 69
Figure 63: Kenfig superficial geology 71
Figure 64: Kenfig bedrock geology.. 72
Figure 65: Current Water Level Monitoring Network 73
Figure 66: Water Level Monitoring Record.. 74
Figure 67: Water level monitoring record 75
Figure 68: 1980s Dipwell Network... 76
Figure 69: Dipwell network at Kenfig... 76
Figure 70: Winter Water table. 77
Figure 71: Winter Water table. 78
Figure 72: Summer Water table 78
Figure 73: Summer Water table 79
Figure 74: NVC Survey and WETMEC Classification. 80
Figure 75: Conceptual Model. 82
Figure 76: Location of the intervention area. 83
Figure 77: Summer water table depths 84
Figure 78: Winter water levels.. 84
Figure 79: NVC dune type.. 85
Figure 80: Location of East Slack borehole... 86
Figure 81: Location of Birch Slack... 86
Figure 82: Summer water table depths. 87
Figure 83: Winter water table depths. 88
Figure 84: NVC dune type at Slack 3. 88
Figure 85: Slack 3 and location of borehole 89
Figure 86: Merthyr Mawr SAC boundary and blown sands superficial deposits... 90
Figure 87: Merthyr Mawr superficial geology 92
Figure 88: Merthyr Mawr bedrock geology.. 94
Figure 89: Merthyr Mawr dipwell monitoring network.. 95
Figure 90: Merthyr Mawr hydrographs 96
Figure 91: Dry Winter Water table.. 97
Figure 92: Dry Winter Water table.. 97
Figure 93: Wet Winter Water table 98
Figure 94:.. 98
Figure 95: Dry Summer Water Level.. 99
Figure 96: Dry Summer Water Level.. 99
Figure 97: Wet Summer Groundwater level 100
Figure 98: Wet Summer Groundwater level 100
Figure 99: NVC/WETMEC Slack Classification... 101
Figure 100: NVC slacks with topography 102
Figure 101: Conceptual model cross section 104
Figure 102: Location of Merthyr Mawr slack interventions... 105
Figure 103: Slack 5 hydrograph. 106
Figure 104: Wet Summer Water Table... 107
Figure 105: Dry Summer Water Table 107
Figure 106: Dry winter water table 108
Figure 107: Wet Summer water table at West Slack 108
Figure 108: Dry summer water table at West Slack... 108
Figure 109: Slack 3 borehole 110
Figure 110: West Slack borehole 110

List of Tables

Table 1: Range of water levels for different dune types and associated vegetation types (Curreli et al., 2013)...... 11
Table 2: NVC Dune Slack and WETMEC Wetland Classification...... 11
Table 3: Table of Sands of LIFE Monitoring Requirements...... 12
Table 4: Summary of geological stratigraphy...... 14
Table 5: Example periods comprising particularly wet, or dry, summers, and winters...... 20
Table 6: Summary of geological stratigraphy...... 39
Table 7: Example Periods comprising particularly wet, or dry, summers, and winters...... 44
Table 8: Geological Units...... 57
Table 9: Summary of geological stratigraphy...... 70
Table 11: Example periods comprising particularly wet, or dry, summers and winters...... 77
Table 12: Monitoring water levels and NVC levels summary...... 85
Table 13: Monitoring eater levels and NVC levels summary....... 89
Table 14: Summary of geological stratigraphy...... 91
Table 15: Example Periods comprising particularly wet, or dry, summers and winters...... 96
Table 16: Water level at Merthyr Mawr Slacks...... 106
Table 17: Summary of water and NVC levels at Merthyr Mawr slacks...... 109

Crynodeb Gweithredol

Comisiynwyd JBA Consulting gan brosiect Twyni Byw Cyfoeth Naturiol Cymru i gynhyrchu modelau gysyniadol ecohydrolegol o bum system dwyni, sef:

- Niwbwrch
- Morfa Harlech
- Twyni Tywod Pen-bre
- Cynffig
- Merthyr Mawr

Mae'r twyni yn destun rhaglen o adferion ecolegol o dan y prosiect Twyni Byw. Ar y safleoedd, mi fydd twyni heneiddiol yn cael eu hadfer i creu cyfnod olynol cynnar ac amodau gwlypach, trwy gwaredi â tyweirch a'r haenau pridd uchaf, sy'n organig-gyfoethog, a trwy gostwng lefelau'r arwyneb.

Mae trefn hydrolegol llac-twyn yn hanfodol ar gyfer gweithrediad da ecosystem y llac twyn. Mae'r ffigur isod yn rhoi model cyffredinol gysyniadol sy'n dangos safle llac twyn o fewn rhanbarth arfordirol sy'n gysylltiedig i ardal mewndirol gyda dyfrhaen ranbarthol tanddaearol.

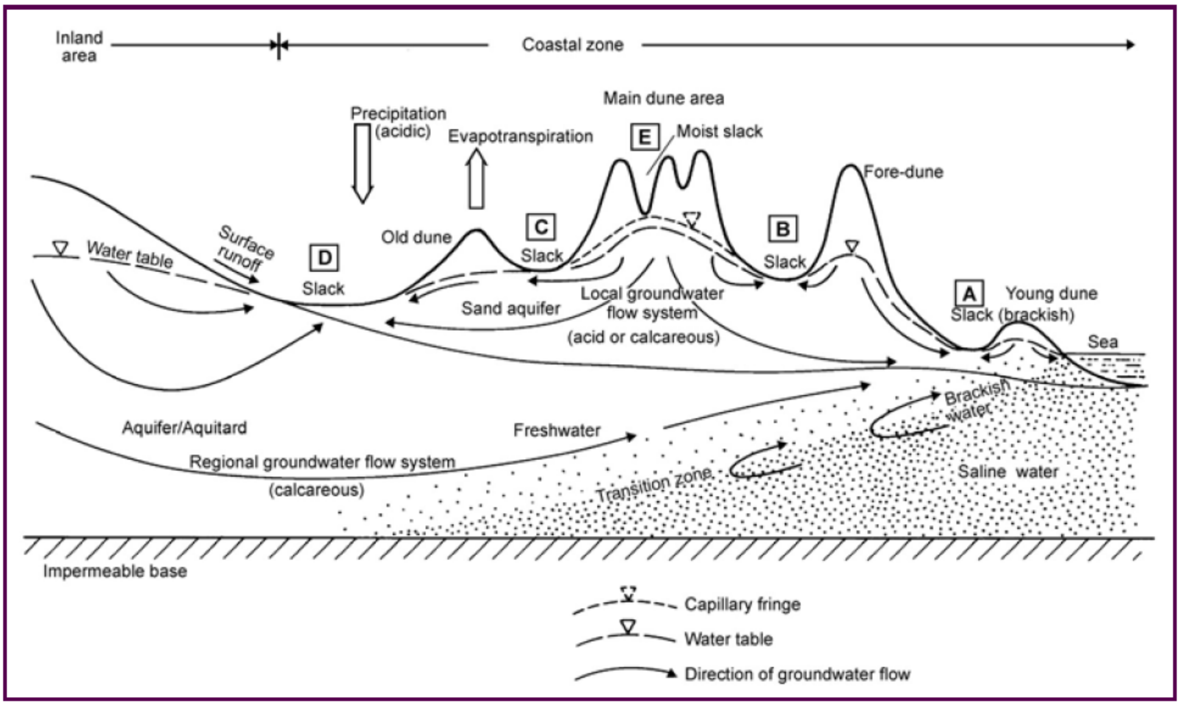


Figure 1: Model Gysyniadol Generig Twyni gan Davy et al., (2006)

Executive Summary

JBA Consulting were commissioned by Natural Resources Wales' Sands of LIFE project to produce ecohydrological conceptual models of five dune systems, namely:

- Newborough
- Morfa Harlech
- Pembrey Burrows
- Kenfig
- Merthyr Mawr

These dunes are subject to a programme of ecological restoration under the Sands of LIFE project. Senescent dune slacks at the named project sites will be restored to create wetter conditions and an early successional stage, by removing turf and organic-rich upper soil layers and lowering the surface levels.

The hydrological regime of a dune-slack is essential for good functioning of the dune-slack ecosystem. The figure below provides a general conceptual model showing the position of dune-slacks in a coastal zone connected to an inland area with an underlying regional aquifer or aquitard.

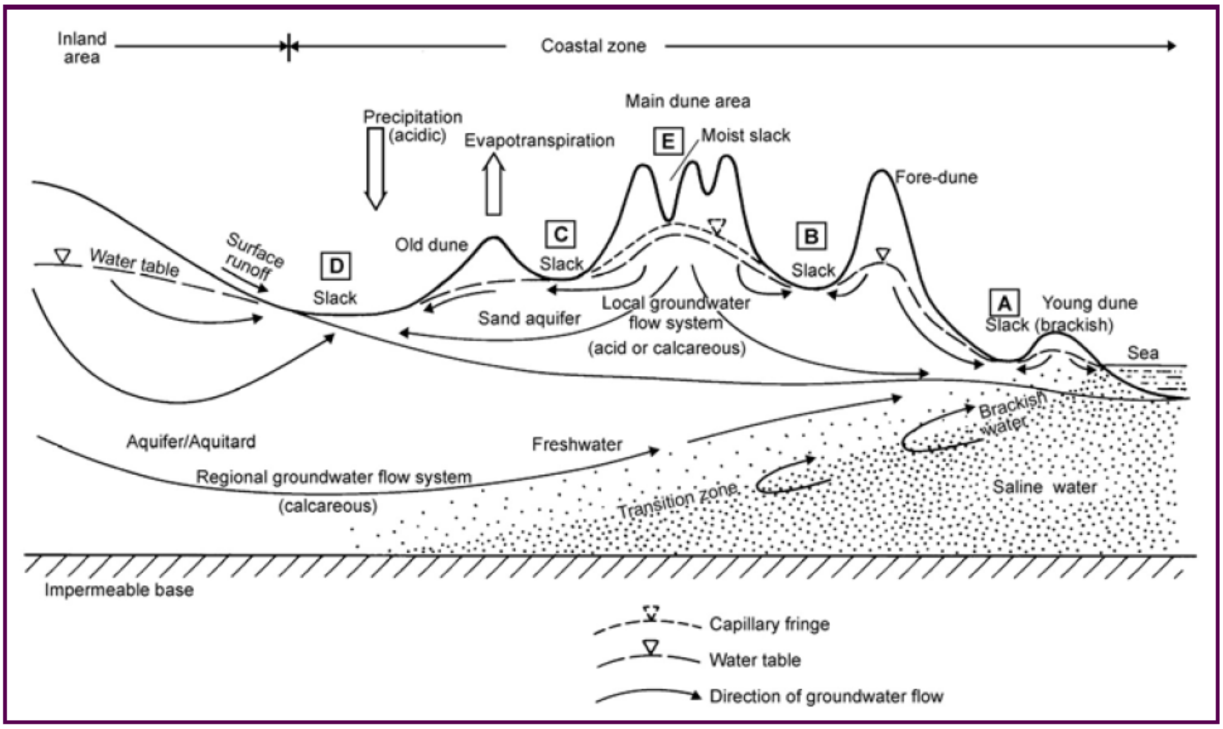


Figure 2: Generic Dune Conceptual Model from Davy et al., (2006)

This report outlines the process of going from a generic conceptual understanding of dune systems to understanding the controls at the particular intervention areas, and uses this to assess the proposed inventions works and design a water level monitoring array to assess their effectiveness.

Introduction

Project background

JBA Consulting have been commissioned by Natural Resources Wales' Sands of LIFE project to produce ecohydrological conceptual models of five dune systems, namely:

- Newborough
- Morfa Harlech
- Pembrey Burrows
- Kenfig
- Merthyr Mawr

These dunes are subject to a programme of ecological restoration under the Sands of LIFE project. Senescent dune slacks at the named project sites will be restored to create wetter conditions and an early successional stage, by removing turf and organic-rich upper soil layers and lowering the surface levels.

This report has the following aims:

- Outline the base ecohydrological concepts that support the development of ecohydrological conceptual models of dunes;
- Review the available hydrological, vegetation, and topography data available for each site;
- Present a baseline for each site;
- Present an outline conceptual model for each site;
- Review the implementation design parameters;
- Identify information gaps and requirements for water level monitoring of proposed interventions.

Hydrological Controls and Generic Conceptual Model

A number of the sites have been well studied with respect to ecohydrology in the past. Three of the five sites requiring conceptualisation under this project informed the development of a generic conceptual model of dune systems developed in:

- Davy et al., (2006). Development of eco-hydrological guidelines for dune habitats – Phase 1.
- Davy et al., (2010). Eco-hydrological Guidelines for Wet Dune Habitats Phase 2.
- Curreli et al., (2013). Eco-hydrological requirements of dune slack vegetation and the implications of climate change.

The generic conceptual model identified five dune slack types. A description of the model is given below.

Description of the Generic Conceptual Model from Davy et al. (2006)

Hydrological and hydrochemical controls on humid dune-slacks are dependent on several factors including climatic setting, coastal geomorphology, hydrogeological conditions and substrate mineralogy. The hydrological regime of a dune-slack is essential for a good functioning of the dune-slack ecosystem. To demonstrate the interconnection of these controls, Figure 3 provides a general conceptual model showing the position of dune slacks in a coastal zone connected to an inland area with an underlying regional aquifer or aquitard. Five types of dune-slack are shown, A, B, C, D and E. Not all types will be present at a location, for example Type D is not expected in island situations. Two groundwater flow systems are shown: a local circulation of fresh groundwater in the dune system and recharged directly by precipitation; and a regional groundwater flow system originating in the inland area and discharging in the coastal zone. The degree of influence of the regional flow system will depend on the extent and nature of the underlying geological unit as to whether it forms an aquifer of good hydraulic conductivity or an aquitard of poor hydraulic conductivity. Local groundwater flow circulation in the dune system will occur at depth if the sand is free draining with a shingle base but flow may be restricted vertically by the presence of clay lenses or peat layers.

The topographic elevation of the dune system and inland areas determines the shape of the water table. The inland area and the dune system are unconfined with groundwater discharge directed towards topographic hollows. Hollows in the dunes may be formed by blow outs or as a result of successive dune formation landwards. Dune of Types B and C are fed solely by precipitation infiltrating the dune sands. In Type B, groundwater flow is directed towards the slack and water is lost by evapotranspiration. In Type C, groundwater flows into the upgradient edge of the slack, flows through the slack and then exits the slack at the downgradient edge before continuing to flow in the direction of the hydraulic gradient (Stuyfzand 1993). In a dune area with several dune-slacks lying close together, slight differences in water level between the slacks may initiate groundwater flow from one slack to another (Kennoyer and Anderson 1989; Grootjans and others 1996).

Type D is at the boundary between the dune system and inland area and is fed by both the regional and local groundwater flow systems and, as shown, may receive some surface water runoff. Type E represents a moist dune-slack situated at a high elevation in the main dune area. Moisture in the capillary fringe above the water table keeps the base of the dune-slack moist with only occasional flooding when the water table is high in wet years. The dune-slacks inland of the large fore-dune (Types B, C, D and E) are above the brackish water body in the subsurface although the seaward Type A dune-slack is in reach of the transition zone between the circulation of fresh and saline groundwaters and so may be subject to brackish conditions. Dune-slack A is in the most dynamic part of the coastal environment and is considered only temporary as the developing dune system moves inland.

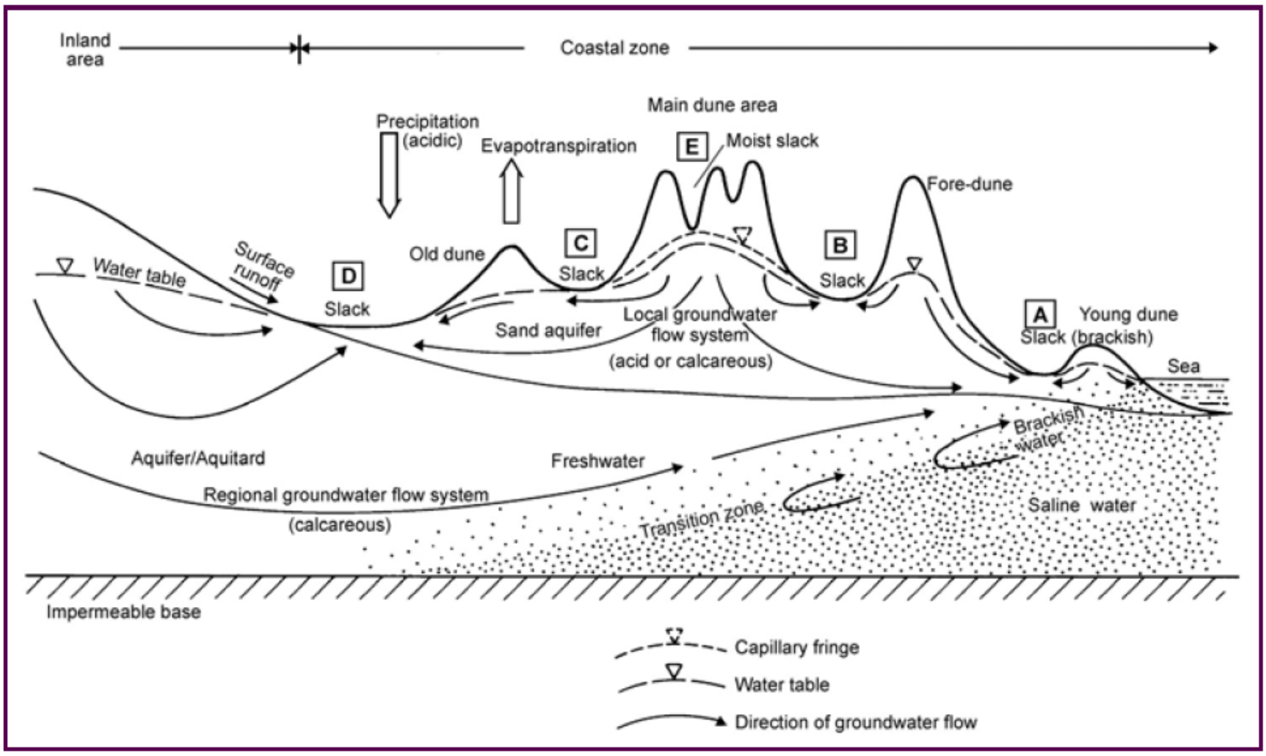


Figure 3: Generic Dune Conceptual Model from Davy et al., (2006)

Figure 4: Example of a Type B dune-slack at Winterton Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010).

Figure 5: Example of a Type D dune-slack at Horsey Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010).

Figure 6: Example of a Type E dune-slack at Winterton Dunes, Norfolk, in November 2005. Adapted from Davy et al., (2010).

In Phase 2 of the Davy Guidelines, the conceptual model was further developed and slack dune types were transformed into WETMEC dune types. The WETland

MEChanism types identified are reproduced below. It provides a description of the slack, National Vegetation Classification (NVC) communities generally associated with them, and water levels conditions including winter maximums, summer maximums and ranges. These are by their very nature, broad simplifications of the eco-hydrological controls on dune slacks, and they also present a continuum rather than discrete groups.

WETMEC dune type[1]	Dune slack	Dune habitat British Plant Community (NVC) type	Water Table Condition[2]	Comments
A	Young dune slack (brackish)	SD13 & 14	Winter[3] maximum: 2 to 10 cm Summer[4] maximum: -50 to -100 cm Water table fluctuation: 50 to 100 cm	Young stages of habitat development found at coastal fringe. SD14 tolerant of brackish conditions.
B	Rain-fed dune slack	SD14, 15 & 16	Winter[3] maximum: 2 to 20 cm Summer[4] maximum: -50 to -200 cm Water table fluctuation: 50 to 150 cm	Common hydrological condition for dune slacks with appearance of SD14, 15 & 16.
C	Rain-fed flow-through dune slack	SD14, 15 & 16	Winter[3] maximum: 2 to 20 cm Summer[4] maximum: -50 to -200 cm Water table fluctuation: 50 to 150 cm	SD15 dominant since tolerant of flow-through system water chemistry.
D	Boundary slack (semi-aquatic)	SD15 & 17	Winter[3] maximum: 5 to 50 cm Summer[4] maximum: -50 to -100 cm Water table fluctuation: 50 to 150 cm	SD15 tolerant of prolonged flooding and near-neutral pH. SD17 found in mature, low-lying areas, for example, shelly machair.
E	Moist dune slack	SD16	Winter[3] maximum: 0 to 5 cm Summer[4] maximum: -100 to 200 cm Water table fluctuation: 100 to 200 cm	Tolerant of dry conditions and preference for aerobic conditions.

1 WETMEC (Wetland Water Supply Mechanism) dune types after Davy *et al.* (2006).

2 Water level elevations given with respect to depth in centimetres below ground level (cm bgl). A positive number indicates a water level above ground surface, a negative number a level below ground surface.

3 Winter maximum water levels are normally recorded during the period of water level recovery between November and April.

4 Summer maximum water levels are normally recorded during the baseflow recession period between May and October.

Figure 7: WETMEC dune types: Water table conditions for defining humid dune slack habitat types from Davy et al. 2010.

Current guidance on vegetation types and associated water levels (Curreli et al., 2013)

Following the guideline established in Davy et al., (2010), Curreli et al., (2013) presented a study investigating the dune slack vegetation and implications of climate change. The study undertook additional analysis to better constrain the water level ranges for each dune slack type and the NVC communities. The results for dune types and associated vegetation types are shown in Table 2.

Table 1: Range of water levels for different dune types and associated vegetation types (Curreli et al., 2013).

Dune Type (Davy et al., 2006)	National Vegetation Classification communities	Min water level (mbgl)	Max water level (mbgl)	Range (m)
A	SD15b	0.61	-0.21	0.81
A	SD14b	0.62	-0.17	0.8
B	SD14c	0.70	0.00	0.69
B	SD14d	0.75	-0.02	0.77
C	SD16	0.98	0.25	0.72
D	SD8	-	-	-

Note: data for the SD8 vegetation type was not presented.
Mbgl = meters below ground level

National Vegetation (NVC) Classification

The Sands of LIFE project has commissioned NVC surveys of the dune systems. These have been reclassified based on the ecohydrological classification. This system has been adapted to provide further information.

Table 2: NVC Dune Slack and WETMEC Wetland Classification

Classification	Description
A	Young dune slack (brackish)
B	Rain-fed dune slack
C	Rain-fed flow-through dune slack
D	Boundary slack (semi-aquatic)
E	Moist dune slack
Aw, Bw, Cw, Dw, Ew	Dune slack communities with scrub woodland
A*	Artificial young brackish dune slack Habitat that is the result of human disturbance – e.g. excavation
F	Fen vegetation (e.g. M27, M28) Similar to D but with more established soils
G	Saltmarsh/dune slack interface
H	Artificial water bodies
Swamp	Swamp

Designing Monitoring Requirements

The conceptualisation produced in this phase aims to aid with the design and review of dune slack intervention work. This will and has involved reprofiling of certain dunes to create new ecohydrological conditions suitable for dune slack communities. The table below outlines the number of interventions the project had planned, their location and the groundwater monitoring that will be required. The dip wells will be installed after the invention works have occurred to monitor whether the desired conditions have been created.
At the end of each site conceptualisation, individual tables have been produced for each intervention site which summarise the current ecohydrological conditions, target habitats, reprofiling requirements and proposed monitoring design.

Table 3: Table of Sands of LIFE Monitoring Requirements

SoLIFE project sites	No. slacks	Area (ha)	Dipwell requirements
Newborough	5	7.25	5
Morfa Harlech	1	1.84	1
Pembrey Burrows	2	0.56	2
Kenfig	2	2.00	2
Merthyr Mawr	1	0.06	1

Newborough

Newborough Warren and Forest is a large dune system in the south of Anglesey. It can be divided in two in two main ways. The west of the site was converted to forestry between the late 1940s and 1965, while the east remained open. Secondly, a bedrock ridge passes through the middle of the site, this acts as a groundwater divide creating two groundwater systems.

Baseline

Dune System Extent and Topography

Newborough is bounded by the Irish Sea to the south, the Afon Cefni estuary to the north-west and the Menai Strait to the south-east. The area is surrounded by intertidal habitats and a circa 700m wide tidal flat extends seawards from the edge of the dunes. A spit extends into the Menai Strait in the south-east of the site, which encloses a saltmarsh on the north-east side with a relatively narrow mudflat section and creek at the centre. The extent of dune slack communities within the system is limited.

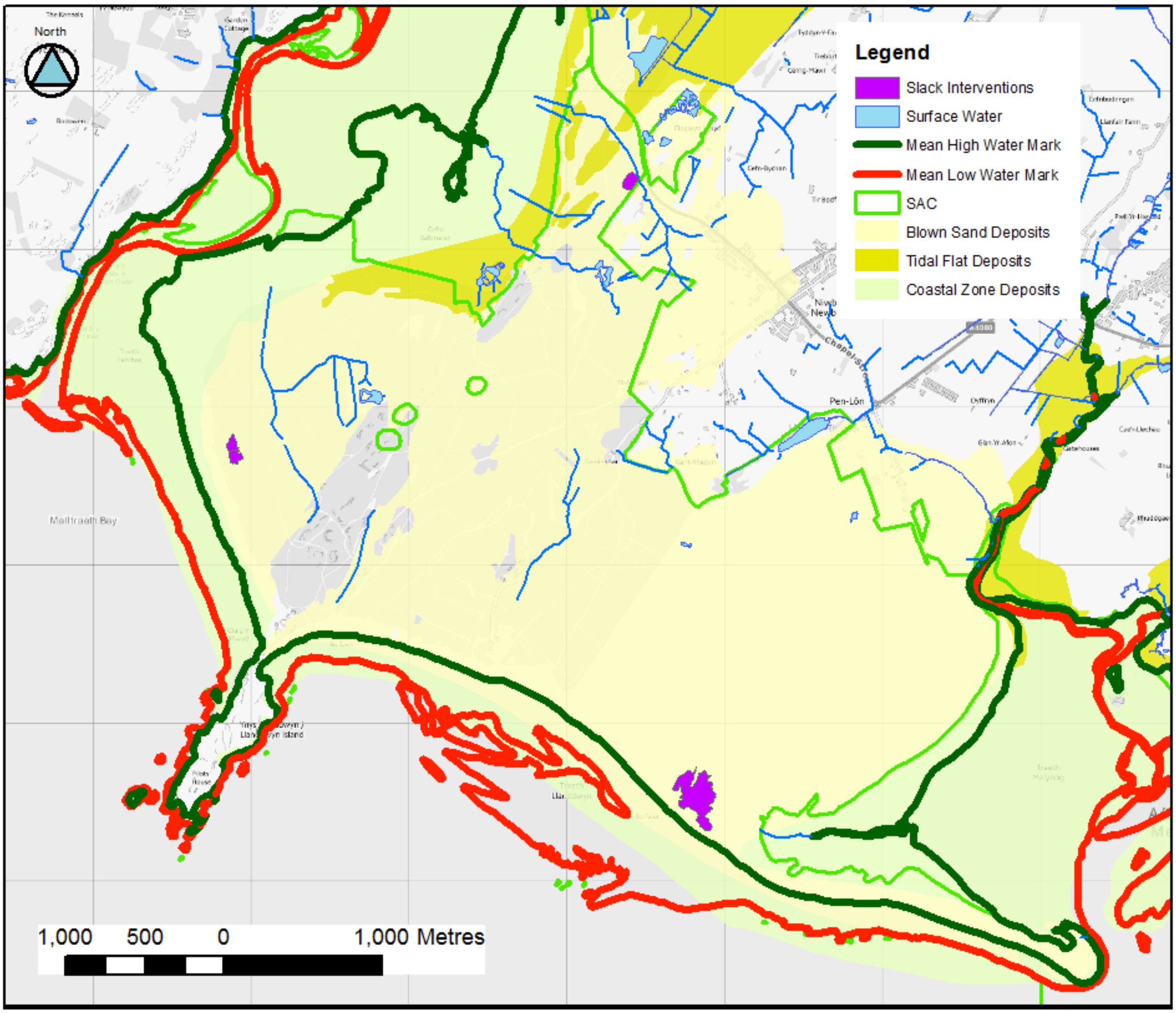


Figure 8: Newborough Special Area of Conservation boundary and blown sands superficial deposits

Soils, Geology and Hydrogeology

Information on the soils and geology of the site and surrounding area has been derived from the Soil Survey of England and Wales (1983), 1:50,000 BGS geology mapping (Sheet 105, Anglesey) and the BGS online borehole archive. The geology beneath the site is summarised in **Error! Reference source not found.** and maps of superficial and bedrock geology are shown in Figure 9 and Figure 10, respectively.

Table 4: Summary of geological stratigraphy

Age	Formation / Member /Group	Description	Thickness	Location	Hydrogeological Properties
Quaternary	Blown Sand	Fine Sands	Over 4m	Dune system	Moderate permeability
Unknown	Igneous Intrusion	Gabbro, Microgabbro and Diorite	Thin	Small section of east shore	Low Permeability
Carboniferous	Plas Brereton Formation	Interbedded sandstone and mudstone	Unknown	South-east end of the spit in the eastern part of Newborough Warren	Moderate permeability
Carboniferous	Millstone Grit Group	Fine- to very coarse-grained feldspathic sandstones, interbedded with grey siltstones and mudstones, with subordinate marine shaly mudstone, claystone, coals and seatearths*	150-1225m	Approximately 500m north of Newborough Warren across the estuary	Moderate permeability
Carboniferous	Clwyd Limestone	Diverse range of limestone facies with subordinate sandstone and mudstone units, and exhibiting local dolomitisation	Max 900m	Exposed to the south of the site area, extending north-east across the Anglesey coastline	Moderate permeability
Carboniferous	Un-differentiated Carboniferous Rocks	Mudstone, siltstone and sandstone	Unknown	Underlying north-west part of Newborough Warren forest	Moderate permeability
Precambrian to Lower Cambrian	Central Anglesey Shear Zone and Berw Shear Zone (BGS) Eastern Schist Belt	Hornblend/Mica Schists	Unknown	Underlying site area and exposure extending north-east	Low permeability
Precambrian to Lower Cambrian	Gwna Group – Mona complex	Grit, phyllite, quartzite, limestone, jasper, graphitic phyllite, spilitic pillow lavas and tuffs	Likely several hundred meters	Exposed to the north of the site on Ynys Llanddwyn peninsula and extends north-east through Newborough Forest	Low permeability

Sources – http://www.largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001841

Figure 9: Newborough Warren superficial geology

Contains Ordnance Survey data © Crown copyright and database right 2021. Derived from 1:50000 scale BGS digital data, British Geological Survey © NERC 2021.

Figure 10: Newborough Warren bedrock geology

Surface Water Features and Groundwater Boundaries

There is a rock ridge running from south west to north east through the dunes, with a significantly lower hydraulic conductivity than the sands. It forms a groundwater divide which splits the hydraulics of the dunes into two distinct parts. The potentiometric surface is draped over the rock ridge rather in the manner of a tent ridge pole, with groundwater flowing off its flanks into the sand. There is a small lake, Llyn Rhos-ddu, on the northern edge of the open warren, which receives drainage both from the warren and the higher ground inland. A groundwater divide lying to the south of Llyn Rhos-ddu migrates northwards towards the lake during drier (summer) conditions. The lake, therefore, feeds the groundwater system in summer but gains from groundwater in the winter because the lake acts as a near fixed head whereas the dune water table elevation fluctuates above and below this level.

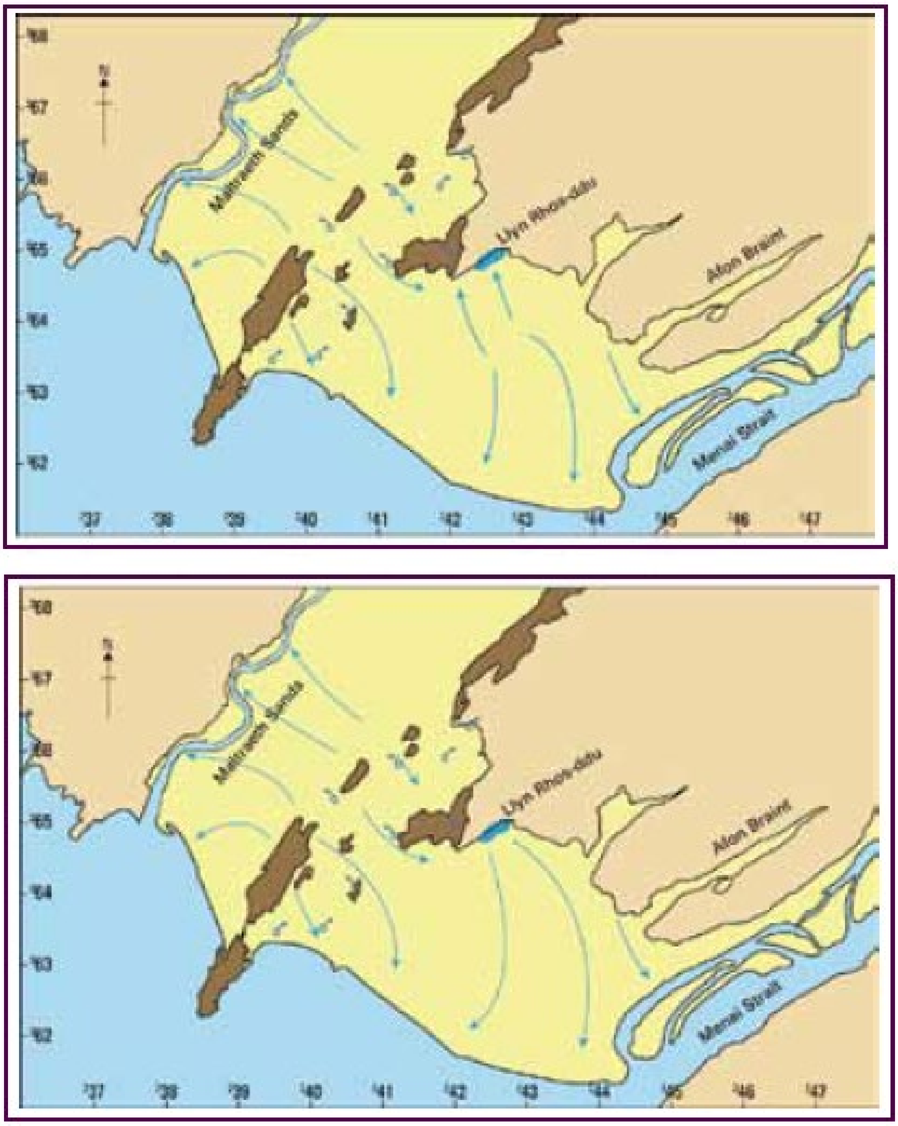


Figure 11: Newborough Warren bedrock geology

(Adapted from Figure G1 (Davy et al., 2010)). Sand cover is shown in yellow, the rock ridge in brown, and the sea below low water mark in blue, the foreshore being an important part of the groundwater system. Winter (top); summer (bottom).

Site Data

The section below reviews the available site information. This can be used to review the scrape intervention design and monitoring.

Water Level Monitoring Networks

The Centre for Ecology and Hydrology (CEH) provided water level monitoring records from 2005 to 2019 from the site. This incorporate dip reading from a number of different networks installed across the site in different periods. The array monitored is shown in Figure 12.

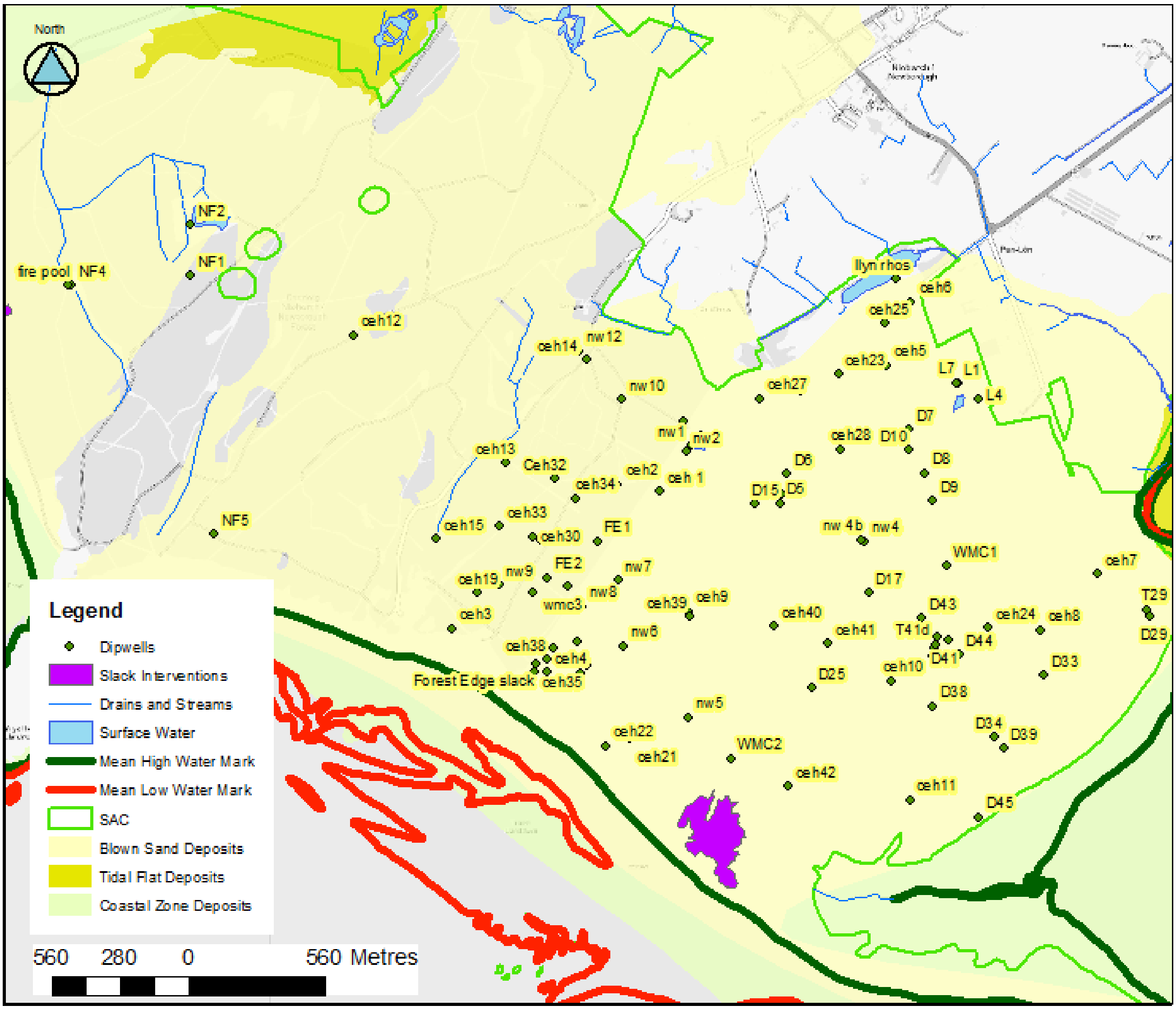


Figure 12: Monitoring Array with dipwell locations.

Figure 13 presents some example hydrographs from the site. These represent three broad hydrograph types represented in the record:

- Type 1 – in the winter water often pools on the ground surface for extensive periods of time and in summer drops to a maximum of circa 1m below ground level.
- Type 2 – like Type 1 but in winter water reaches the surface but does not pool. In most cases, this will be because the topography allows for the emergent groundwater to be shed.
- Type 3 – the water table is significantly below the ground surface but the amplitude of the pattern is similar to Type 1.

Interpreting these patterns needs knowledge of the specific topography of each dipwell location. Without context, the Type 3 dipwell could equally lie in the base of a dry slack or on the elevated side of a slack that experiences extensive flooding. The Type 2 hydrograph may lie on the edge of an ephemeral pool, or on a long shallow slope that sheds groundwater run-off via a long flow pathway. The next section provides groundwater surfaces to allow groundwater patterns to be interpreted spatially and relative to the local topography.

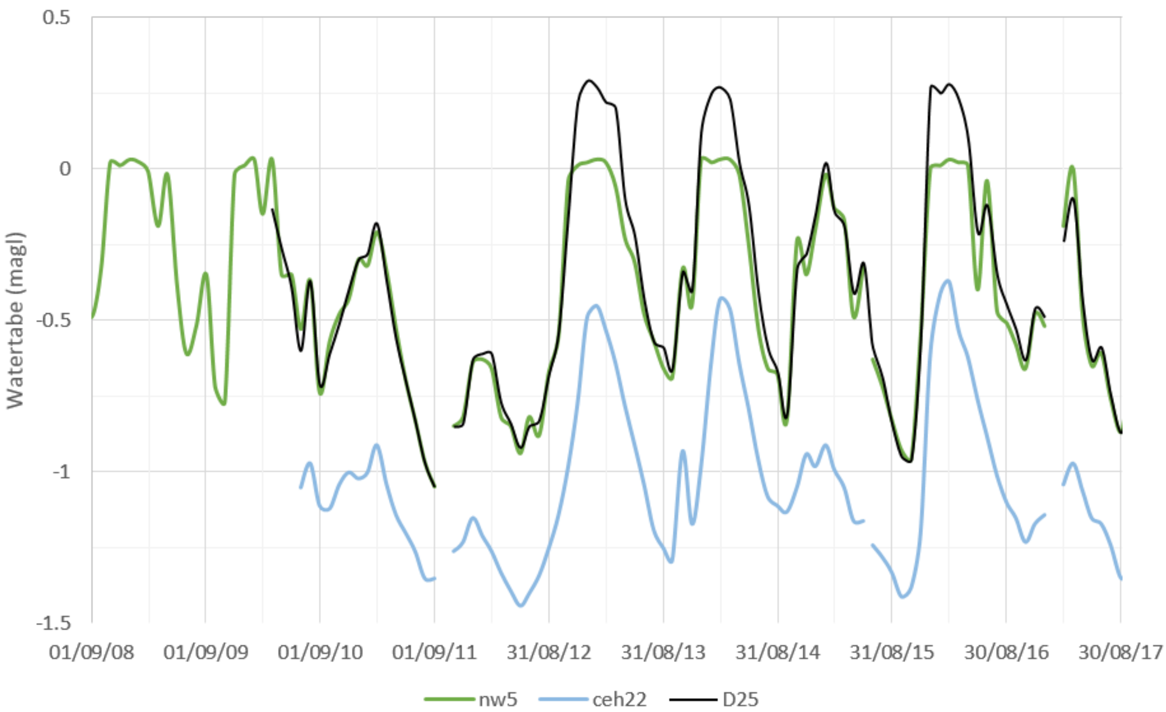


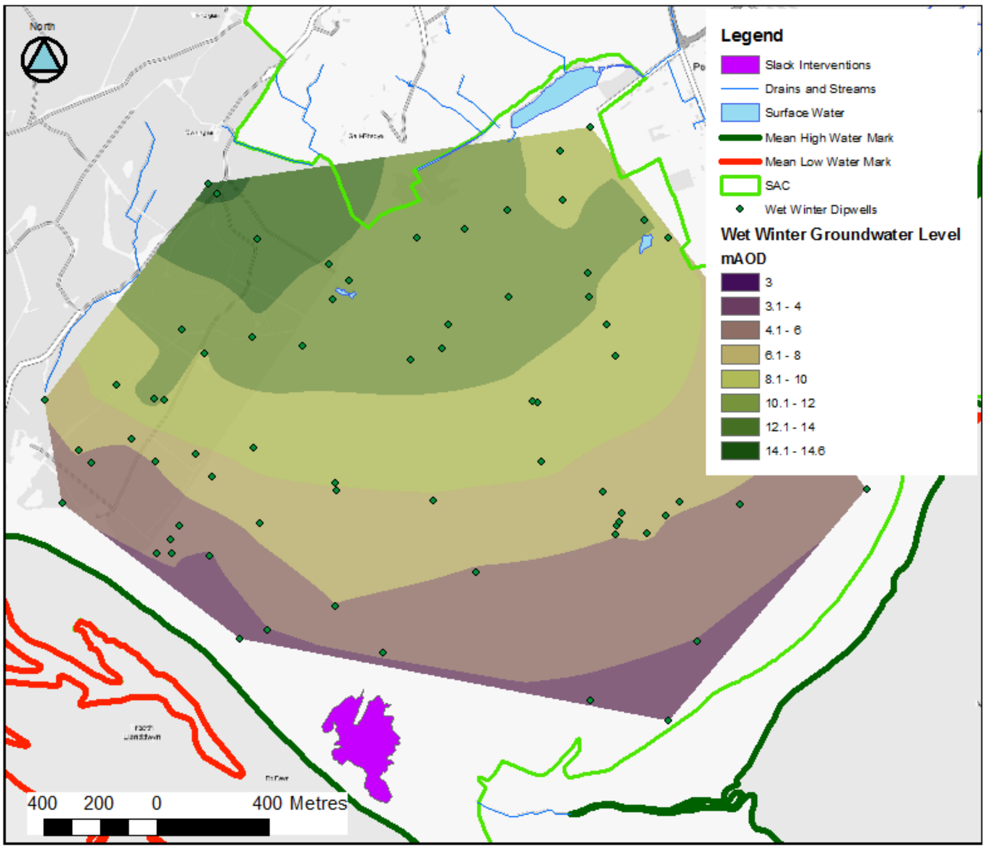
Figure 13: Example Hydrographs
Magl = Meters above ground level

Groundwater Surfaces

The hydrograph data record has been reviewed to produce a series of groundwater surfaces. The hydrographs have been reviewed to identify examples of historic summers and winters which were particularly wet and those which were drier than average. These are shown in **Error! Reference source not found.**. The water levels have been interpolated to produce groundwater surfaces in metres above ordnance datum (mAOD) and metres below ground level (mbgl). The extent of the surface produced is limited to where there is sufficient density of dipwells. These groundwater surfaces have been subtracted from the LIDAR topography surfaces to produce a depth to groundwater grid.

Table 5: Example periods comprising particularly wet, or dry, summers, and winters

Type	Date
Wet Winter	Feb 2014
Dry Winter	Feb 2012
Wet Summer	June 2016
Dry Summer	June 2012



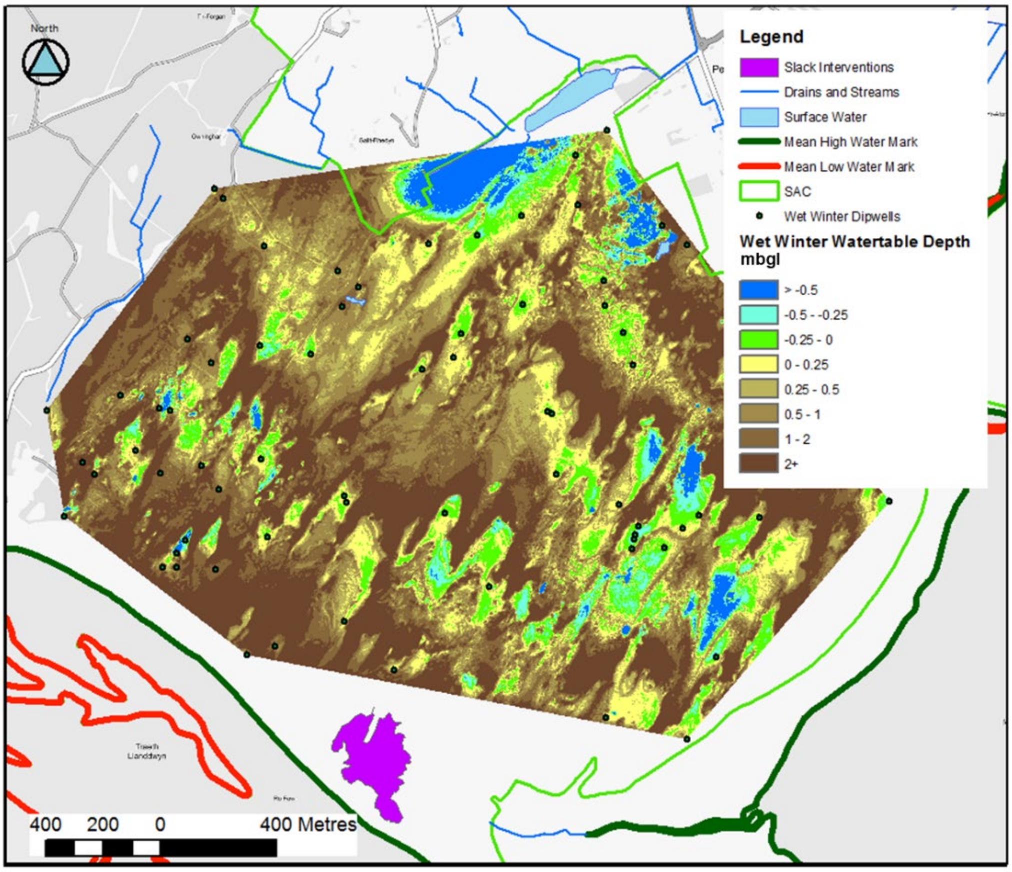
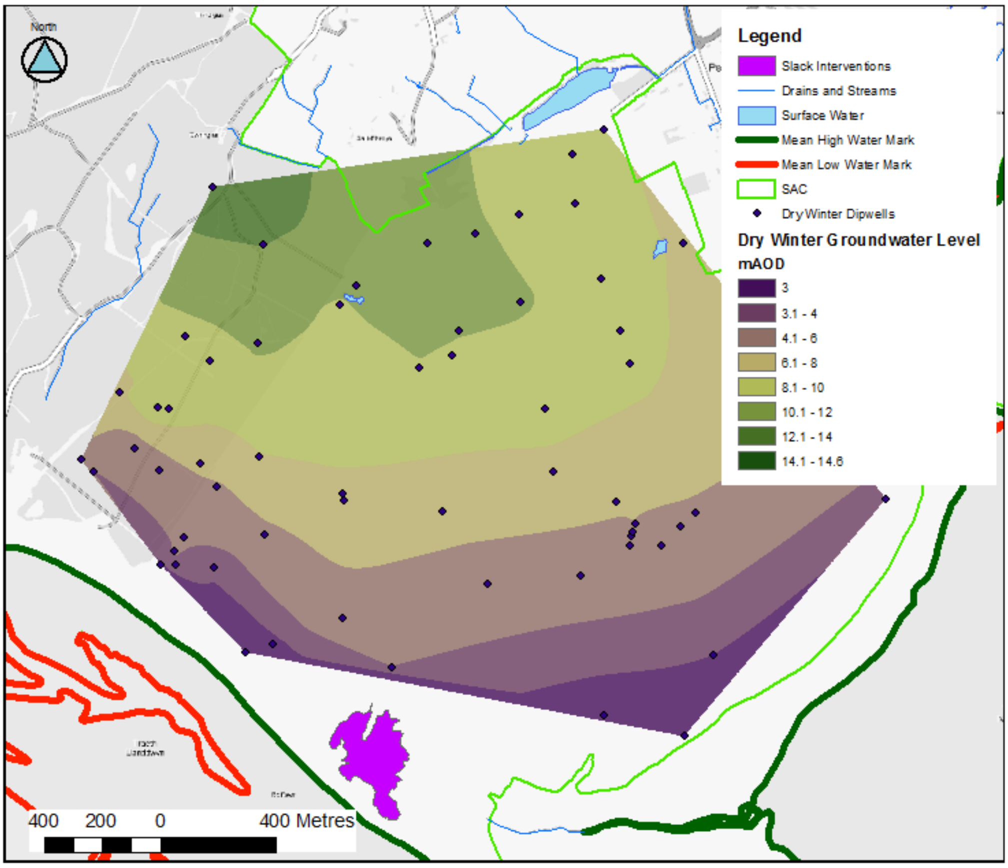


Figure 14: Wet Winter Water table interpolated from dipwell monitoring data. top figure water level is in mAOD and bottom figure is in mbgl



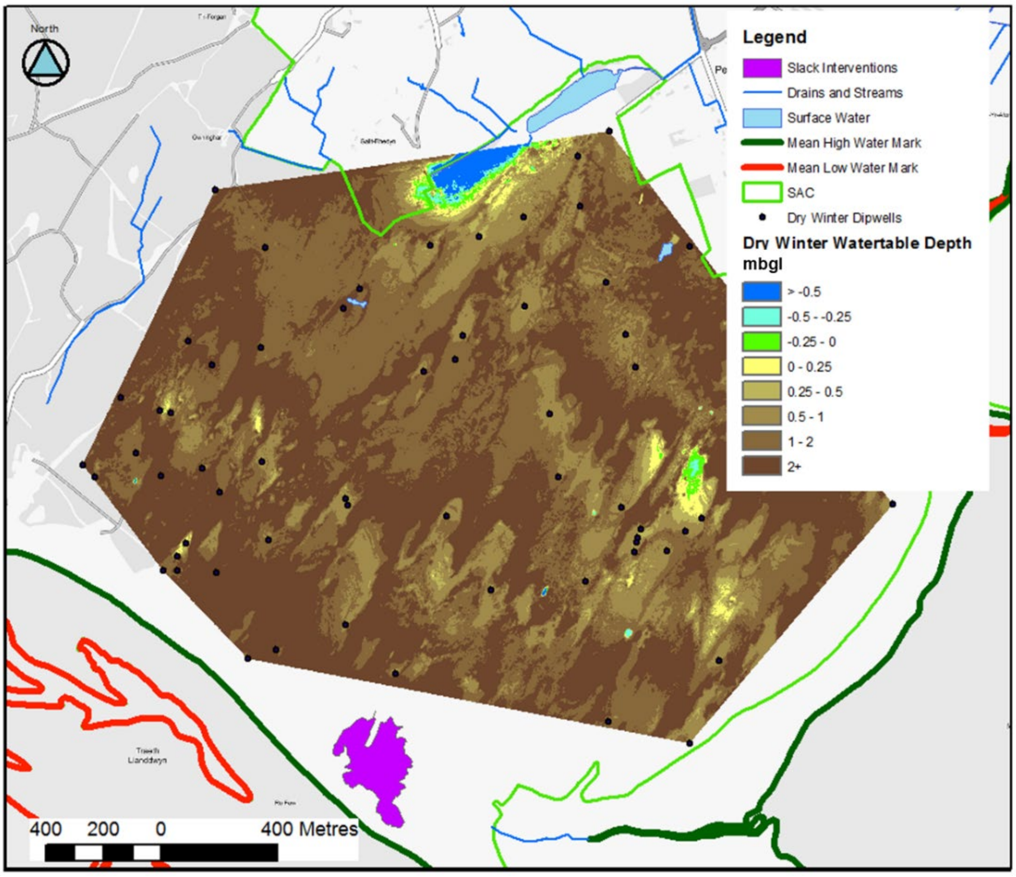


Figure 15 : Dry Winter Water table. Top figure water level is in mAOD and bottom figure is in mbgl

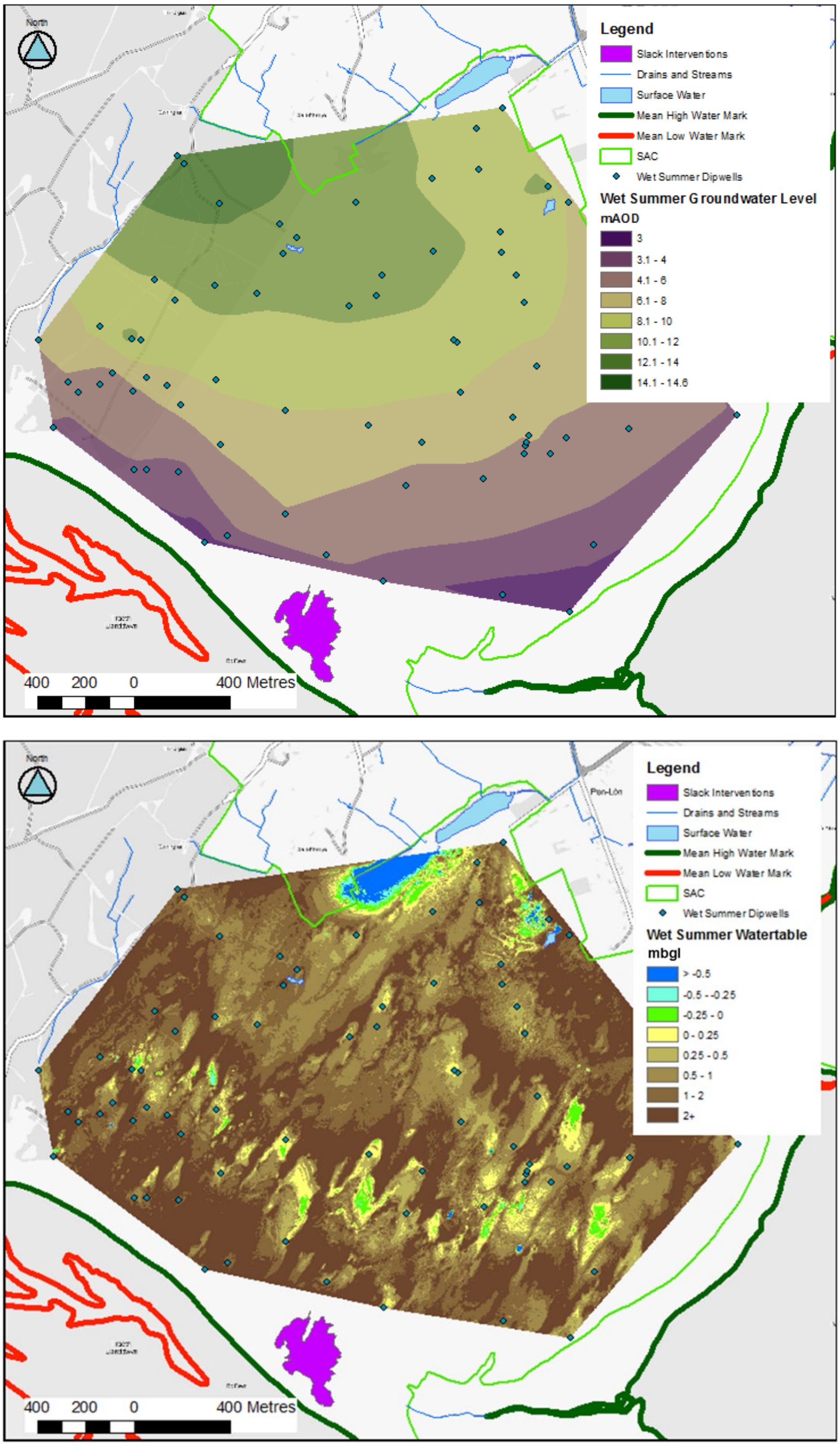
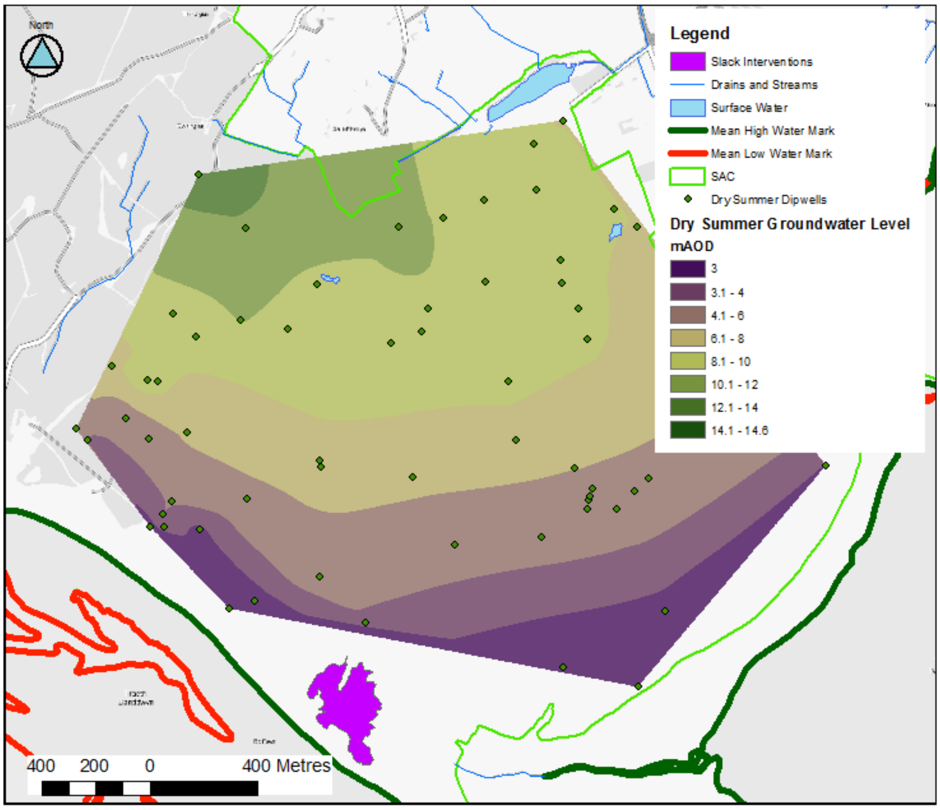


Figure 16 :Wet Summer Groundwater level. Top figure water level is in mAOD and bottom figure is in mbgl.



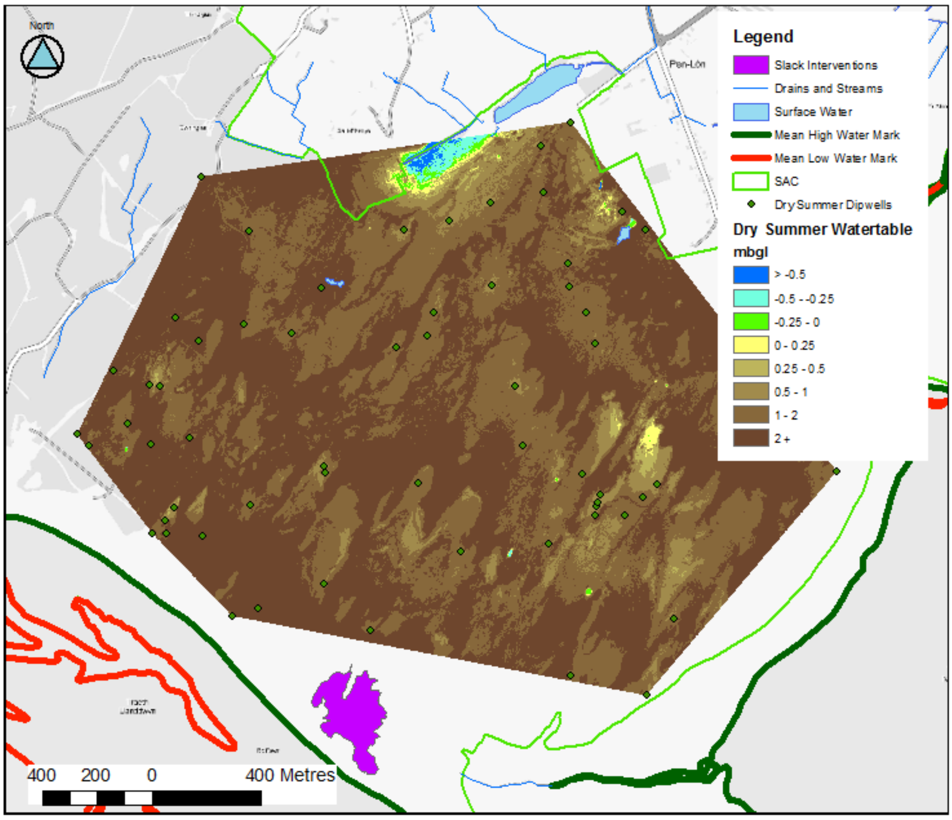


Figure 17: Dry Summer Water Level top figure water level is in mAOD and bottom figure is in mbgl

NVC Surveys

Figure 18 provides a classification of the slacks based on the methodology outlined in above. Of note in the distribution of the slacks is the limited extent of Type A slacks. This reflects the morphology of the foredune with steeply rising ground at the edge of the beach and the eroding coastline at Newborough Warren. In addition, the lack of new Primary (Type A) slacks illustrates the eroding coastline, which is likely to retreat in response to sea level changes. Consequently, groundwater lenses will reduce in size (Clark and Ayutthaya, 2010).

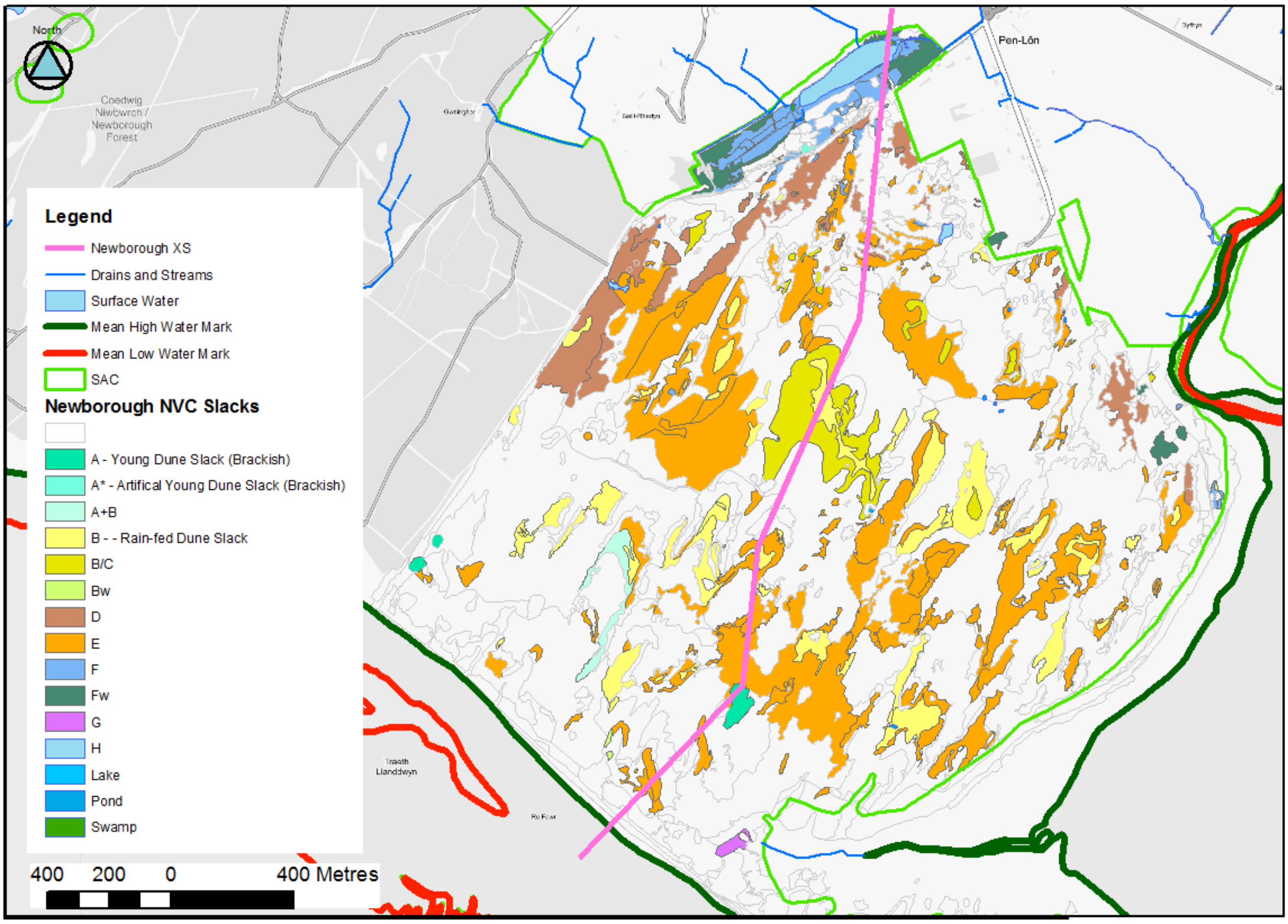


Figure 18: NVC/WETMEC Slack Classification

Note- Newborough XS = Line of Cross Section in Figure 18

Conceptual Model

A hydrogeological conceptual model is "a description of how a hydrogeological system is believed to behave" (Environment Agency, 2002). It describes "how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system" (Rushton, 2003).

The hydrogeological conceptual model for the site is shown in Figure 19, with line of cross section shown in Figure 18 which bisects one of the intervention areas. NVC codes for specific dune habitats are displayed, in additional the locations of dipwells.

The main features include:

- Topography
  - Dune system divided into a forestry section in the west and an open area in the east, separated by an exposed bedrock ridge running through the centre.
- Geology and hydrogeology:
  - Blown sands superficial deposits, with medium permeability, outcrop at the ground surface forming the extensive dune system. Limestone, of moderate permeability underlies the sands in the south-west, with metamorphic schists (low permeability) under the majority of the open part of the dune system. The forested area to the north is underlain by interbedded limestone, mudstone, siltstone and sandstone, of moderate permeability. The schists in the south form an aquitard, however the limestone in the south-east and carboniferous strata in the north are both likely to have a groundwater connection with the overlying blown sands above.
- Infiltration and recharge:
  - Main input to the blown sands dune aquifer is from direct rainfall recharge throughout the site area. Due to the presence of low permeability till to the east, it is unlikely that there is any significant groundwater contributions from neighbouring superficial deposits. However, the aquifer is likely to receive some groundwater from the Clwyd limestone and Carboniferous bedrock units.
- Groundwater surface interactions
  - Groundwater typically has a 1.5m range of levels across the site. The degree to which groundwater pools at the surface is controlled by the surface topography. In some areas emergent groundwater can pool, and in others it is removed via surface water flow paths. Different dune slack types and associated vegetation types depend on the nature of the water table and dune condition at each specific location.
- Figure 19
  - The model displays a south-west to north-east cross sectional view through the open part of the dune system. The water level range shows the degree to which ponded water in the slacks varies seasonally. Habitat classifications related to each dune sack are also represented in the model.

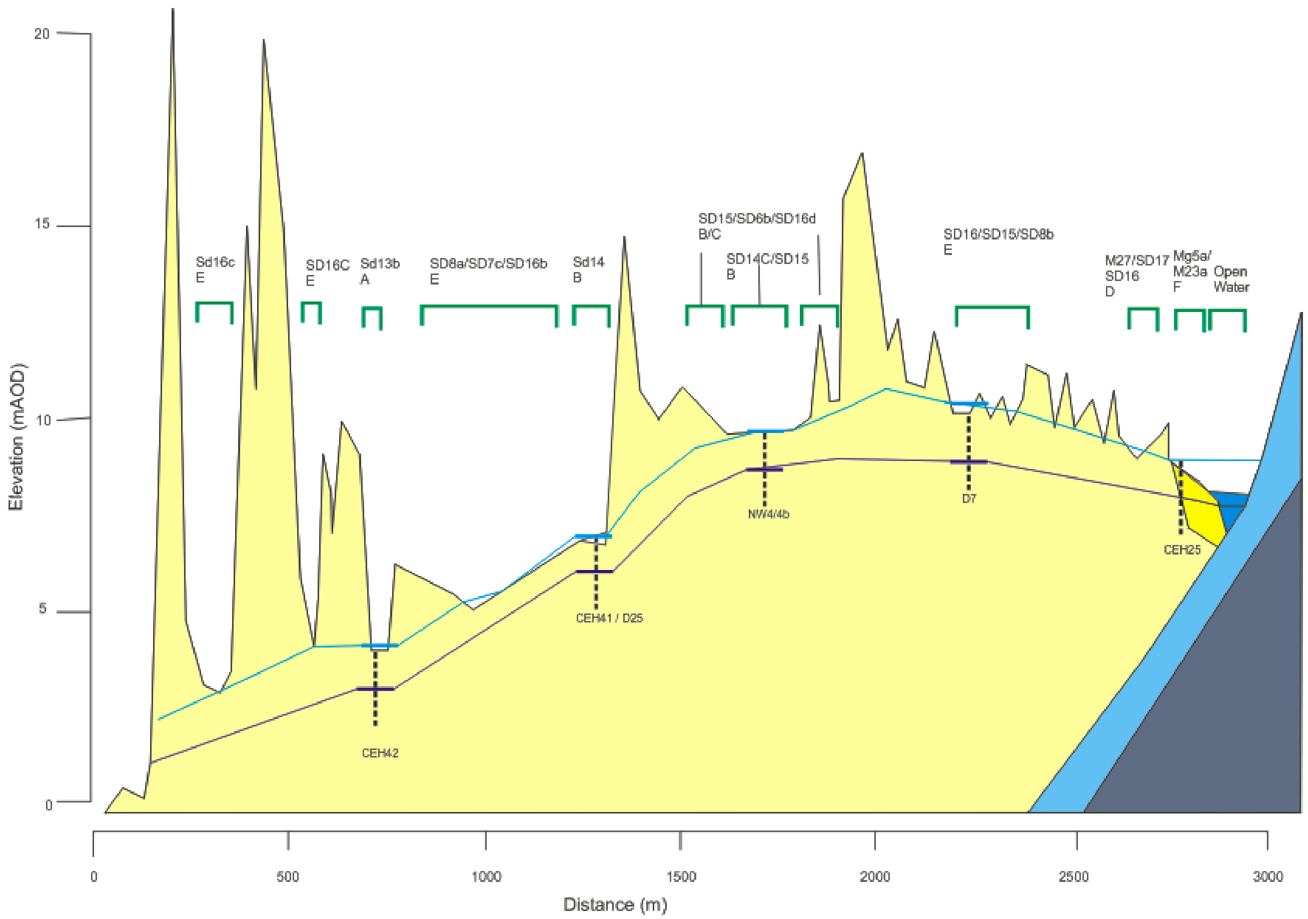


Figure 19: Newborough Warren conceptual model cross section.

Interventions and Monitoring

The Sands of LIFE project has identified several Slack Intervention Areas across Newborough Warren, where reprofiling works will and have been designed to improve the habitats. The tables below provides a summary of the Slack Intervention Areas, the current vegetation, available water levels and consideration of the monitoring requirements.

Newborough Interventions and Monitoring – Warren Slack

Figure 20: Location of Newborough Warren slack

Target Habitat

Annex I Humid Dune Slack H2190 and/or Dunes with Salix arenaria H2170
Four types are associated with the habitat type H2190: SD13, SD14, SD15 and SD17. (Houston, 2008)

Intervention Plan (to be implemented)

Create early successional stages. Scrape to reach water table to allow flooding in winter, damp in summer.
Remove all vegetation to bare sand. Scrape to depth of approx 0.5 metres to reach water table. Graded to sides.

Current Water Level Ranges - Monitoring

Slack is outside of the dipwell monitoring network

Current Water Level Range – NVC

Based on ranges given above. Predominantly WETMEC dune type E with NVC habitat SD16b/c. Small area classed as Bw.

Based on Currelli et al. 2013, the range for SD16 has a lowest water level of 0.98mbgl (metres below ground level) and highest of 0.25mbgl.

Figure 21: WETMEC classifications at Newborough Warren.

Implementation Advice

Presence of E habitats shows water level reaches with 0.25m of the surface and drop to 0.98 of the surface. To create conditions suitable for SD13, SD14, SD15 and SD17, water levels need to reach circa 0.2m above the surface in wet period and drop to circa 0.6m below the surface in dry periods. To create these conditions the area would need to be lowered by circa 0.4m.

Monitoring Plan

To capture the full range of levels, one monitoring borehole should be installed to 1.5 mbgl (1.57 mAOD) (0.5m below the minimum water level).

[redacted]

Figure 22: Location of the intervention area and dipwell.

Pre-scrape ground surface: 3.07
Post-scrape ground surface 2.57
Anticipated groundwater level range : 0.25mbgl to 0,98mbgl (2.09 – 2.82 mAOD)

Note – all levels relate to the pre-implementation levels for which there was monitoring and NVC survey.

Newborough Intervention and Monitoring – Pwll Treath Bach

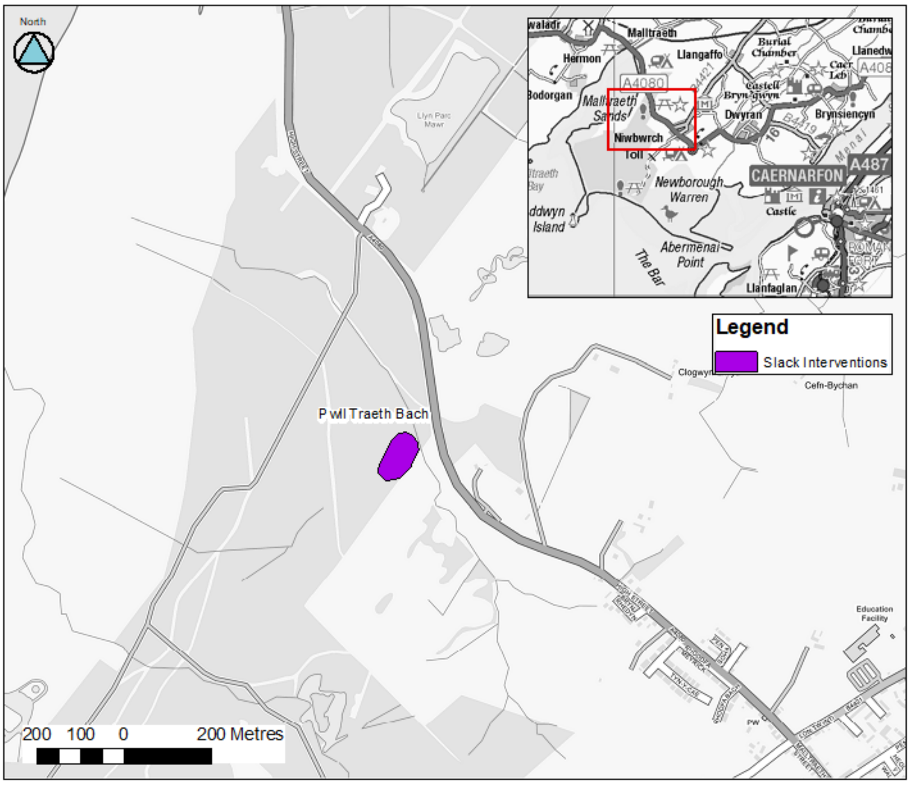


Figure 23: Location of Pwll Treath Bach slack intervention

Target Habitat
Remove all vegetation to bare sand around the ponds. Excavate pool sides to increase size.
Initial plan – to be completed
Increase size of pools and create early successional stages in habitat around the ponds. Improve Shore Dock and Great Crested Newt habitat. Maintain water levels as at present.
Remove all vegetation to bare sand around the ponds. Excavate pool sides to increase size.
Current water level ranges – monitoring
Slack is outside of the dipwell monitoring network.
Current water level range – NVC
No available data concerning current slack classification
Implementation Advice
Little information is known about the ecohydrological conditions at this site. The intervention design is based on extending existing levels on site to extend existing conditions.
Monitoring Plan
To capture the full range of levels, one monitoring borehole should be installed on the bank of the pond and extend down to a minimum of 0.5m below the level of the pond on the day of installation.

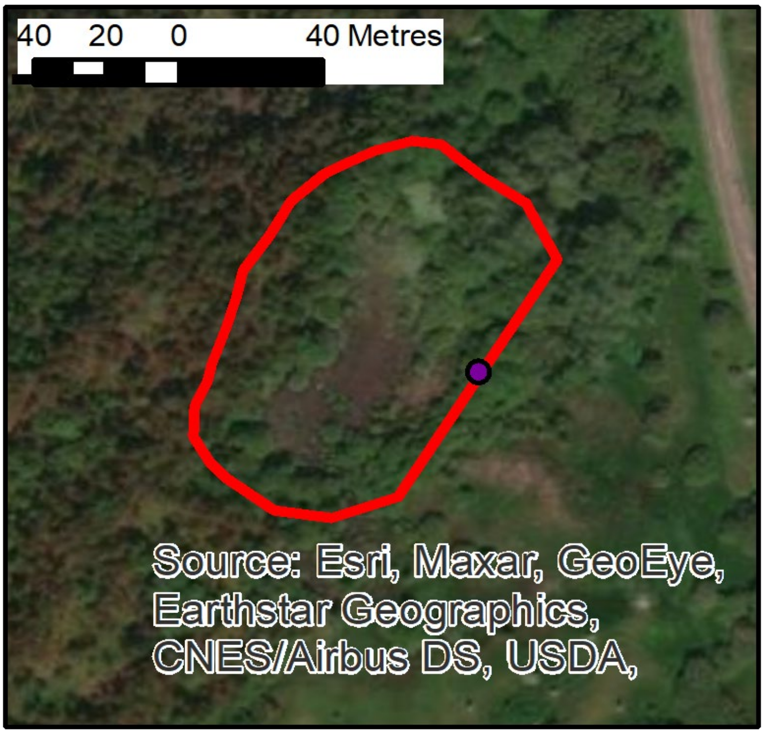


Figure 24: Location of Pwll Treath Bach slack intervention and dipwell

Newborough Intervention and Monitoring – Gull Slack

Figure 25: Location of Gull Slack intervention area.

Target Habitat

Annex I Humid Dune Slack H2190 and/or Dunes with Salix arenaria H2170
Four types are associated with the habitat type H2190: SD13, SD14, SD15 and SD17. (Houston, 2008)

Intervention Plan – Implemented February 2021

Create early successional stages. Scrape to reach water table to allow flooding in winter, damp in summer.
Remove all vegetation to bare sand. Scrape to depth of approximately 0.5 metres to reach water table. Graded to sides.

Current Water Level Ranges – monitoring

Slack is outside of the dipwell monitoring network

Current water level range – NVC

No available data concerning current slack classification.

Ecohydrological Implementation Considerations

There is no additional ecohydrological data available for this site to comment on the prediction that the water table lies 0.5m below existing ground level.
To create conditions suitable for SD13, SD14, SD15 and SD17, water levels need to reach circa 0.2m above the surface in wet period and drop to circa 0.6m below the surface in dry periods. If the water table is 0.5m below the surface, ground levels may have to be reduced by up to 0.7m (based on 0.5m being a high level in the water table range).

Monitoring Plan

To capture the full range of levels, one monitoring borehole should be installed to 1.5mbgl

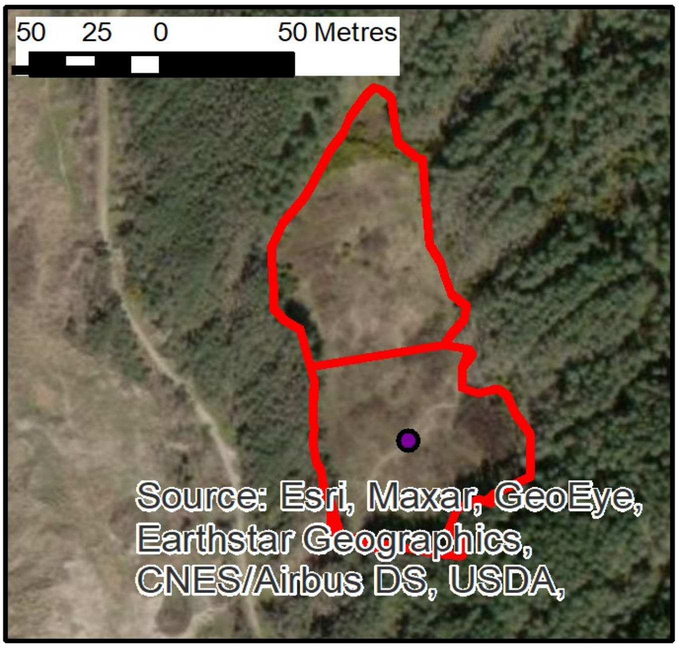


Figure 26: Location of Gull Slack intervention and the dipwell.

Newborough Intervention and Monitoring – Ffrydiau Pools

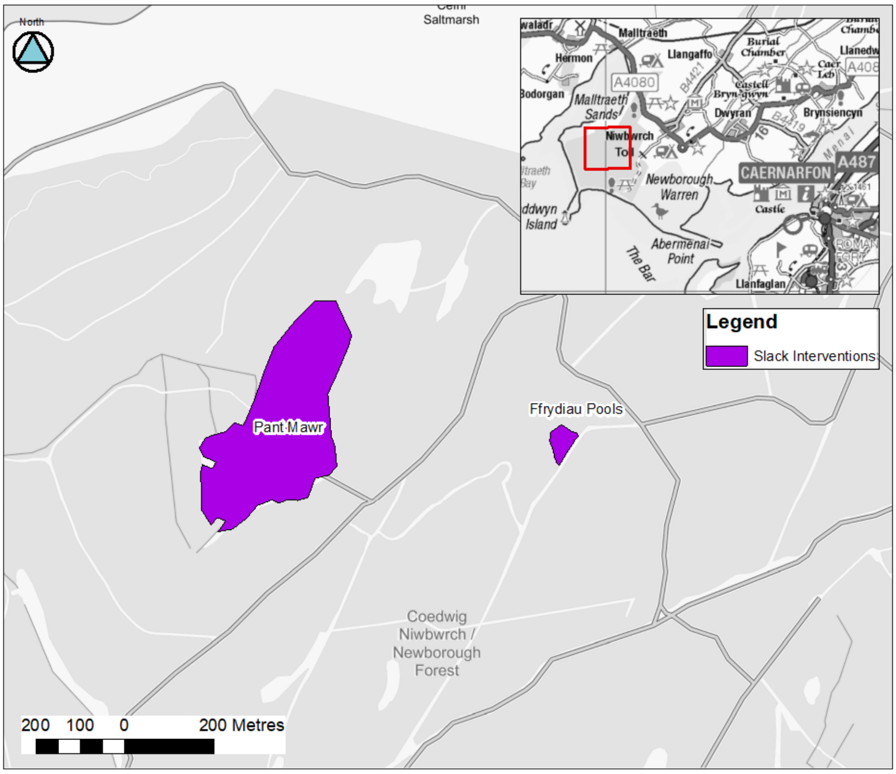


Figure 27: Location of Ffrydiau Pools and Pand Mawr slacks

Target Habitat
Annex I Humid Dune Slack H2190 and/or Dunes with Salix arenaria H2170
Four types are associated with the habitat type H2190: SD13, SD14, SD15 and SD17. (Houston, 2008)

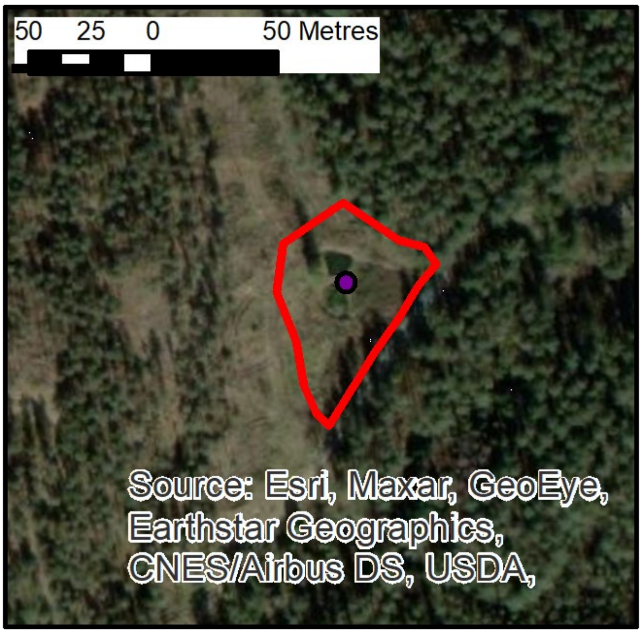
Intervention Plan (to be implemented)
Increase size of pools and create early successional stages in habitat around the ponds. Improve Shore Dock and Great Crested Newt habitat. Maintain water levels as at present.
Remove all vegetation to bare sand around the ponds. Excavate pool sides to increase size.

Current Water Level Ranges – Monitoring
Slack is outside of the dipwell monitoring network.

Current Water Level Range – NVC
No available data concerning current slack classification.

Implementation Advice
Little information is known about the existing ecohydrological conditions at this site. The intervention design is based on extending existing levels on site to extend existing conditions.

Monitoring Plan
To capture the full range of levels, one monitoring borehole should be installed on the bank of the pond and extend down to a minimum of 0.5m below the level of the pond on the day of installation.



Newborough Intervention and Monitoring - Pwll Pant Mawr

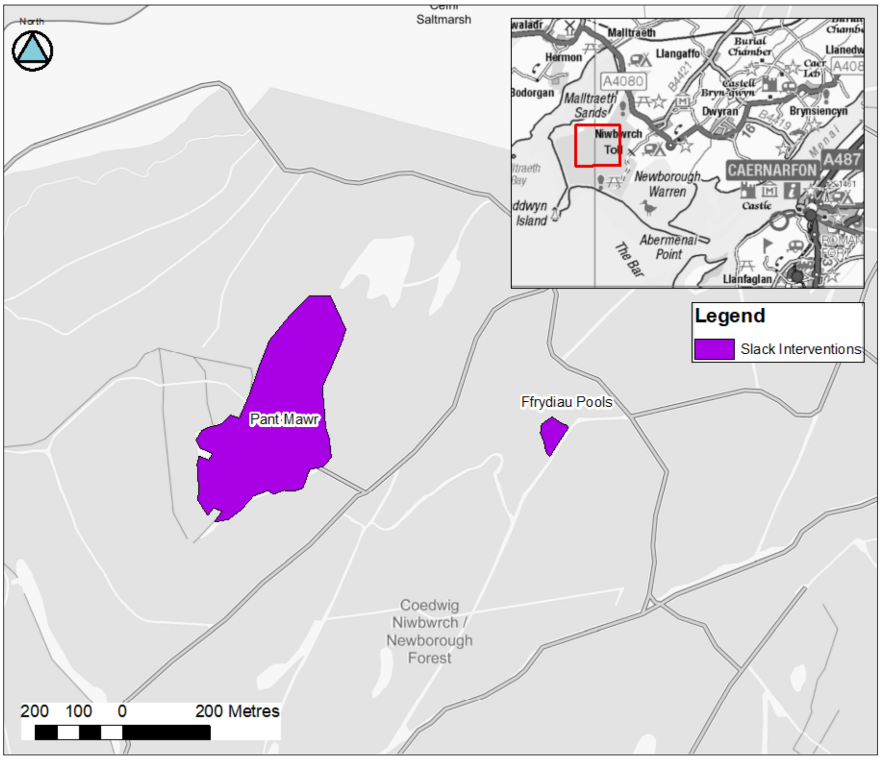


Figure 28: Location of Pwll Pant Mawr and Ffrydiau Pools intervention areas.

Target Habitat

Annex I Humid Dune Slack H2190 and/or Dunes with Salix arenaria H2170
Four types are associated with the habitat type H2190: SD13, SD14, SD15 and SD17. (Houston, 2008)

Intervention Plan (implemented Winter 2020/2021)

Increase size of pools and create early successional stages in habitat around the ponds. Improve Great Crested Newt habitat. Maintain water levels as at present. Remove all vegetation to bare sand around the ponds. Excavate pool sides to increase size.

Current Water Level Ranges – Monitoring

Dipwell data not included in study.

Current Water Level Range – NVC

No available data concerning current slack classification

Ecohydrology Implementation Considerations

Little information is known about the ecohydrological conditions at this site. The intervention design is based on extending existing levels on site to extend existing conditions.

Monitoring Plan

To capture the full range of levels, one monitoring borehole should be installed 0.5m below the minimum water level.

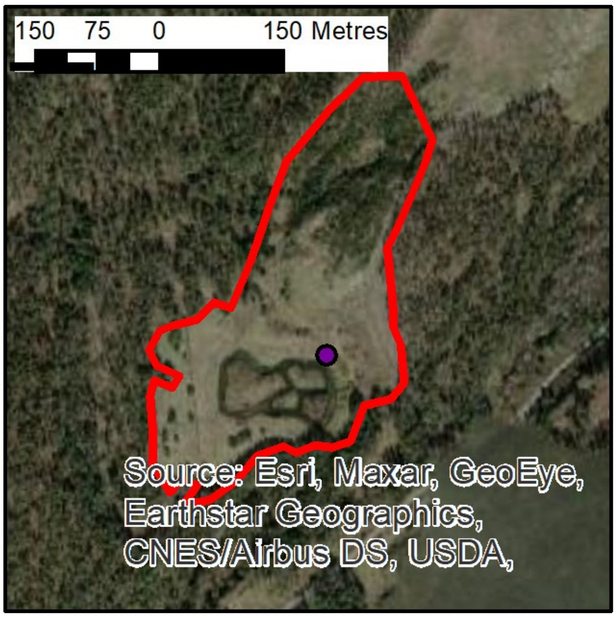


Figure 29: Location of the Pwll Pant Mawr slack intervention area and dipwell.

Morfa Harlech

Extending along the Meironydd coastline in north Wales, Morfa Harlech is a large, unstable and shifting dune system. The area was submerged under seawater as recently as the 13th century. Since then, the dune system has been actively growing due to longshore drift from the eroding coastline at Morfa Dyffryn to the south.

Baseline

Dune System Extent and Topography

Morfa Harlech dune system extends from the southern shore of the Dwyryd estuary and curves round the coastline to the south before reaching Harlech village. The system comprises a broad, low-lying landform with associated marshes and dunes, underlain by Tertiary and Jurassic sedimentary strata.

To the north, an extensive intertidal area occurs at the mouth of Dwyryd estuary, which narrows as it flows inland. The estuary also features distinctive 'islands' and ridges of higher ground on both sides. Morfa Harlech is also situated within Snowdonia National Park, where forested hills rise steeply and progress to an extensive area of mountainous terrain covering much of north-west Wales.

Associated habitats include intertidal mud, sand dunes and salt marshes. Also, wet pastures and coastal heath occur throughout the dune system

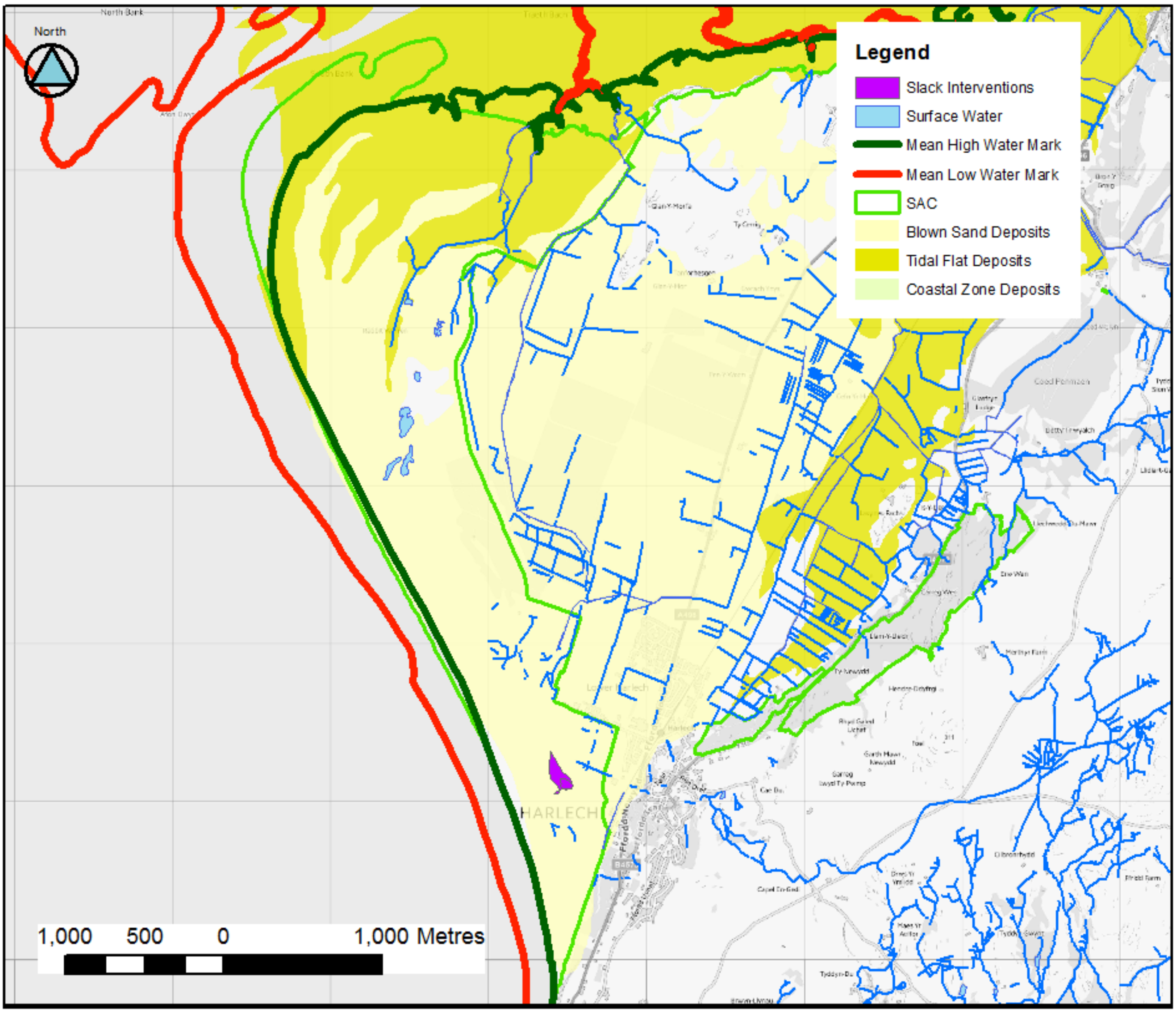


Figure 30: Morfa Harlech Special Area of Conservation boundary and blown sands superficial deposits.

Soils, Geology and Hydrogeology

Information on the soils and geology of the site and surrounding area has been derived from the Soil Survey of England and Wales (1983), 1:50,000 BGS geology mapping and the BGS online borehole archive. The geology beneath the site is summarised in Table 6 and a map of superficial and bedrock geology is shown in Figure 30 and Figure 31.

Table 6: Summary of geological stratigraphy

Age	Formation / Member/ Group	Description	Thickness	Location	Hydrogeological Properties
Quaternary	Blown sands	Fine sands	Over 4m	Beneath the site, extending throughout the low lying Morfa Harlech dune system	Moderate permeability
Quaternary	Tidal Flat deposits	Silty clays	Unknown	Beneath the blown sands, likely extending throughout the site	Low permeability
Quaternary	Marine beach deposits	Fine sands	Unknown	Exclusively located on the coastline	
Quaternary	Peat	Peat	Unknown	One main small patch within the dune system and several within the local areas	Low permeability
Quaternary	Till	Silty clays	Unknown	-	Low permeability
Tertiary	Paleogene and Neogene silts and clays	Interbedded silt and clay with sandy beds and thin lignites: conglomeratic in lower parts	600m	Beneath site and coastal area extending north to Traeth Bach estuary. Bounded by Moccras (normal) fault just east of site boundary, which has exposed older Cambrian units to the east of the fault.	Moderate permeability
Ordovician	Granodiorite Intrusion	Microgabbro	Unknown	Small intrusions into Cambrian units east of the main site area	Low permeability
Cambrian to Ordovician	Mawddach group	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Maentwrog Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Barmouth Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Clogau Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Harlech Grits Group	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Gamlan Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Haffoty Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Rhinog Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability
Cambrian	Llanbedr Fm	Mudstone, siltstone and sandstone	To depth	East of the north-south fault running through the centre of the dune system	Moderate permeability

Sources : BGS Online Geoindex Viewer – Online Lexicon

Figure 31: Morfa Harlech superficial geology

Figure 32: Morfa Harlech bedrock geology

Surface Water Features and Groundwater Boundaries

Within the dune system are areas of pools and dune slacks. The coast plain behind the dunes is occupied by forestry and pasture, it has an extensive drainage network. In the north of the site a drain has been cut connecting several dune slack areas and discharging into the salt marsh area to the north.

Watercourses in the vicinity of the dipwell monitoring network are displayed in Figure 33.

Site Data

The section below reviews the available site information. This can be used to inform the scrape intervention design and monitoring discussed below.

Water Level Monitoring Networks

The Centre of Ecology and Hydrology provided water level monitoring records from 1988 to 2016 from the site. This incorporated dip readings from a network of boreholes, which were installed at various times throughout the monitoring period. The array monitored is shown in Figure 33.

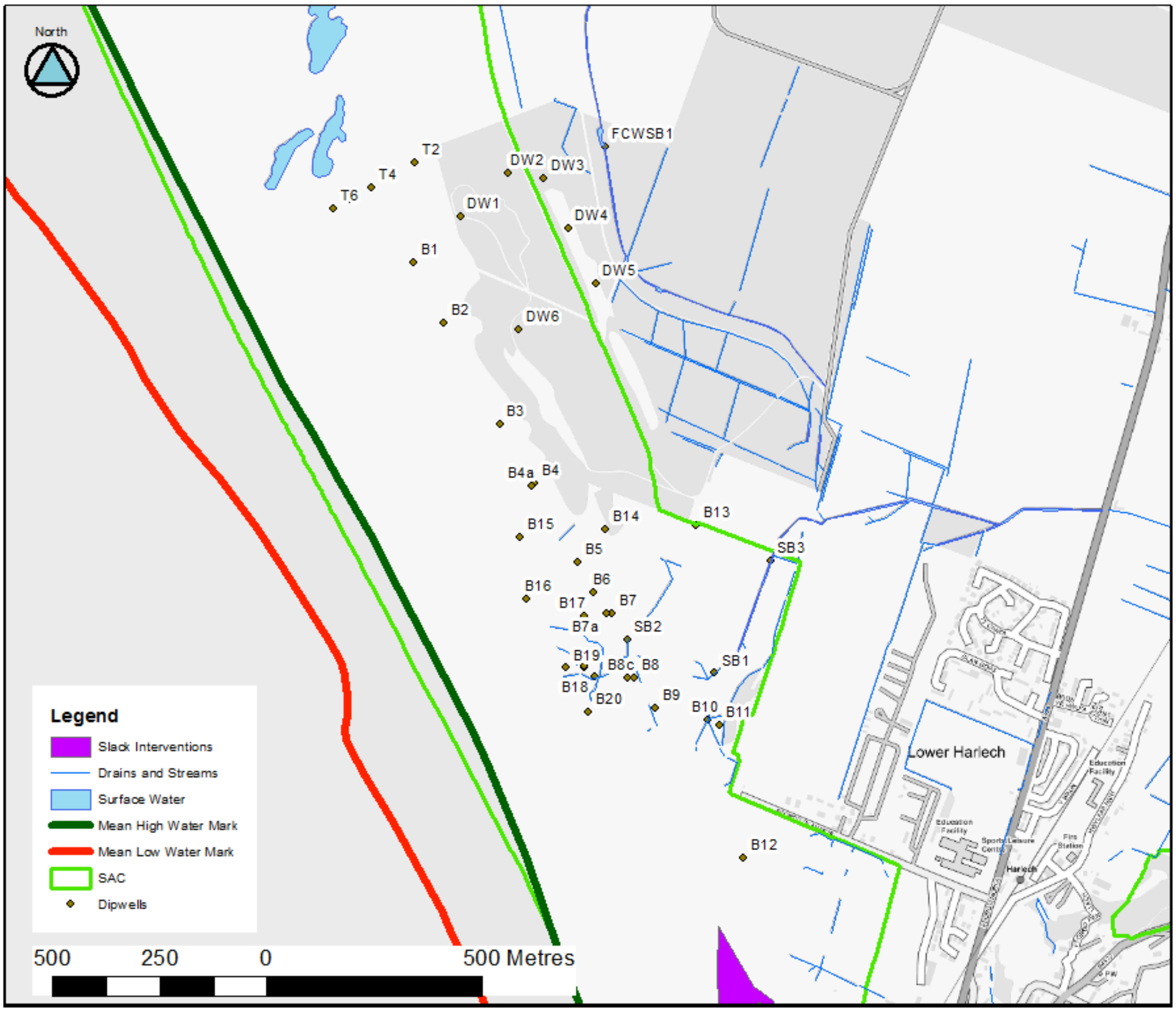


Figure 33: Dipwell monitoring network

Figure 34 presents some example hydrographs from the site. These represent three broad hydrograph types represented in the record:

- Type 1 – in the winter water often pools on the ground surface for extensive periods of time and in summer drops to a maximum of circa 1m below ground level.
- Type 2 – like Type 1 but in winter water reaches the surface but does not pool. In most cases this will be because the topography allows for the emergence groundwater to be shed.

- Type 3 – the water table is significantly below the ground surface, but the amplitude of the pattern is similar to Type 1.

Interpreting these patterns needs knowledge of the specific topography of each dipwell location. Without context, the Type 1 dipwell could equally lie in the base of a dry slack or on the elevated side of a slack which experiences extensive flooding. The Type 2 hydrograph may lie on the edge of an ephemeral pool, or on a long shallow slope which sheds groundwater run-off via a long flow pathway. The next section provides groundwater surfaces to allow groundwater patterns to interpreted spatially and relative to the local topography.

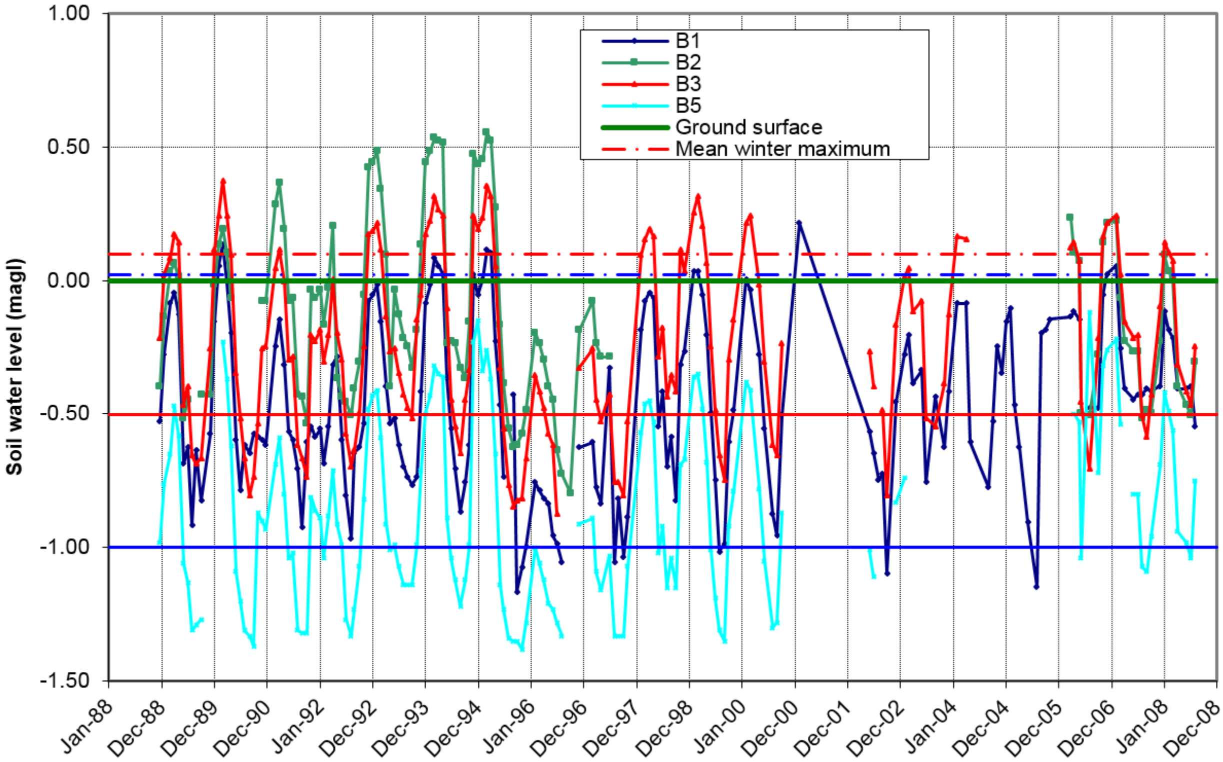


Figure 34: Example Hydrographs

Magl = meters above ground level

Groundwater Surfaces

The hydrograph data record has been reviewed to produce a series of groundwater surfaces. The hydrographs have been reviewed to identify examples of historic summers and winters which were particularly wet and those which were drier than average (Table 7). Contour plots were developed to show the range of water levels occurring during winter and summer periods from the available data record. The water levels have been interpolated to produce groundwater surfaces in metres above ordnance datum (mAOD) and metres below ground level (mbgl). The extent of the surface produced is limited to where there is sufficient density of dipwells. These groundwater surfaces have been subtracted from the LIDAR topography surfaces to produce a depth to groundwater grid (Figure 35 to Figure 37).

Table 7: Example Periods comprising particularly wet, or dry, summers, and winters

Type	Date
Wet Winter	January 2016
Dry Winter	December 2010
Wet Summer	July 2012
Dry Summer	August 2011

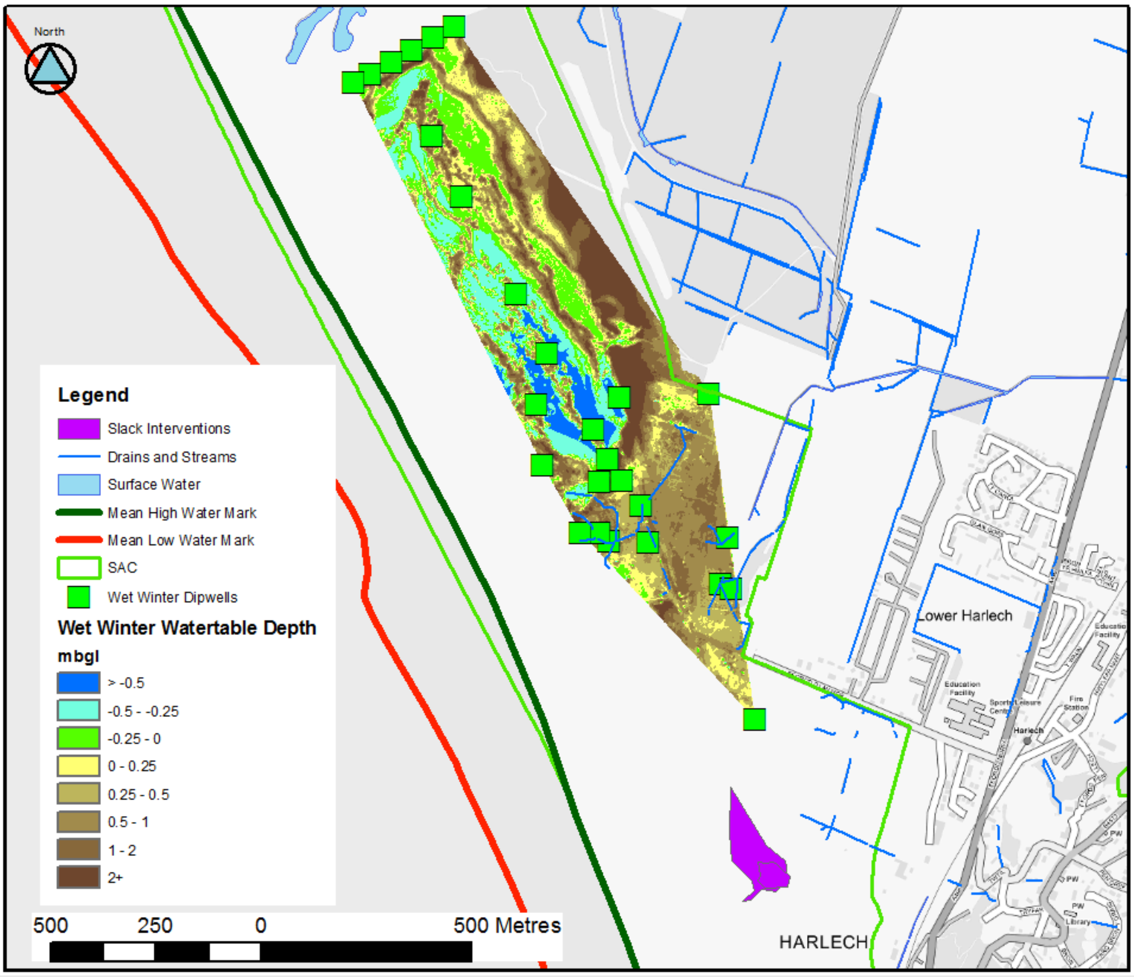


Figure 35: Wet Winter water table

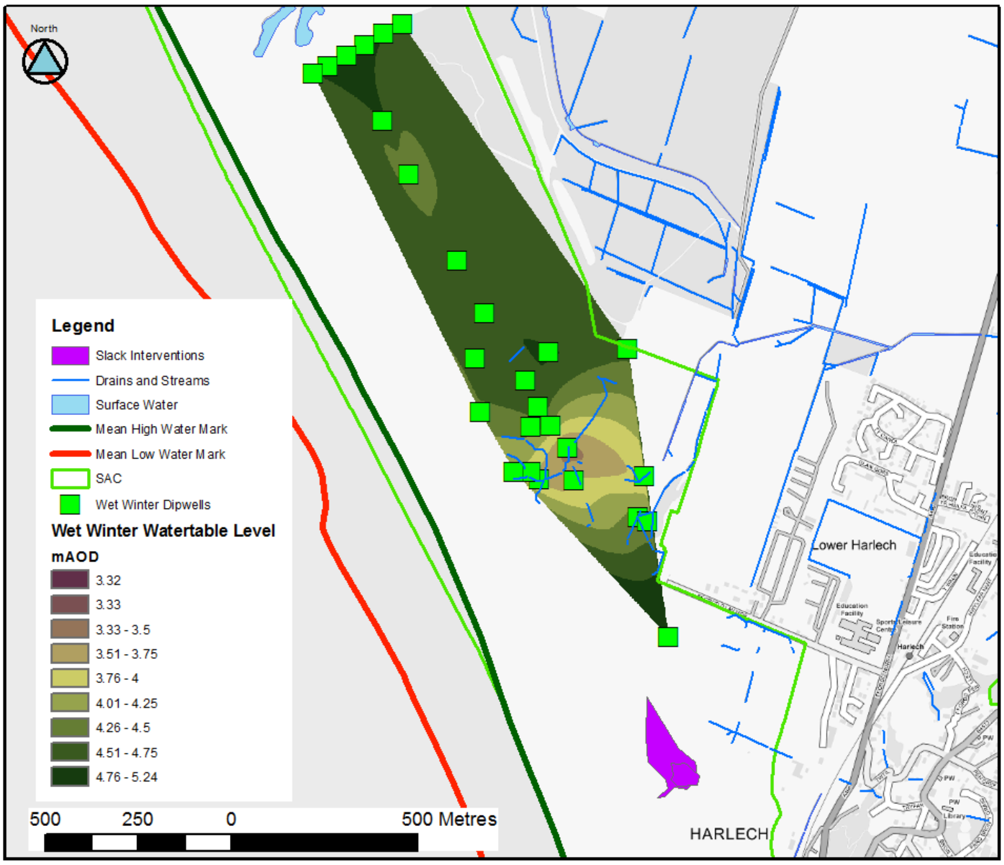


Figure 36: Wet winter water table

Note: Top figure water level is in mbgl and bottom figure is in mAOD.

Figure 37: Dry Winter Water table

Figure 38: Dry Winter Water table

Note: Top figure water level is in mbgl and bottom figure is in mAOD.

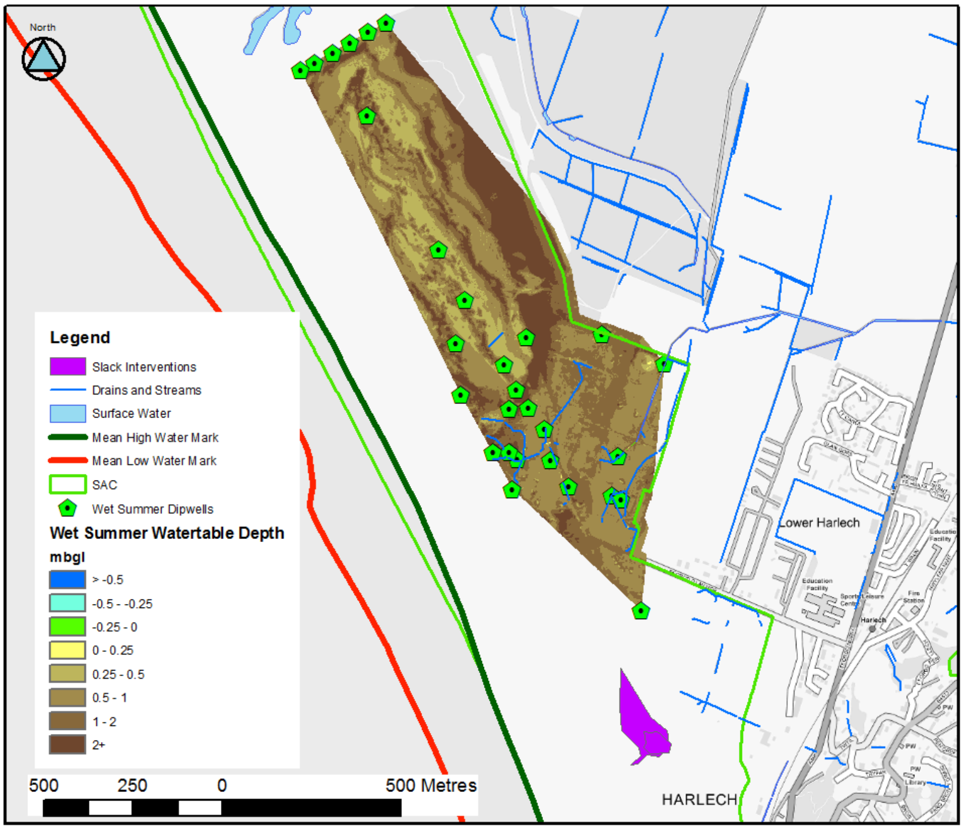


Figure 39: Wet Summer Groundwater level

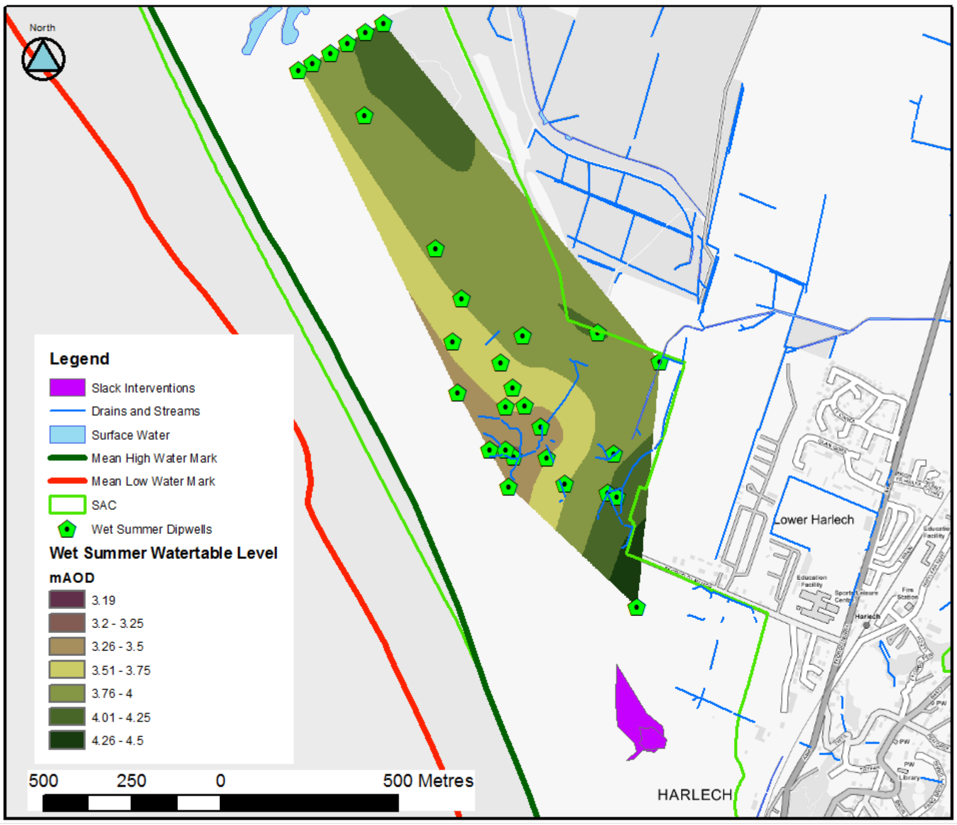


Figure 40: Wet Summer Groundwater level

Note: Top figure water level is in mbgl and bottom figure is in mAOD.

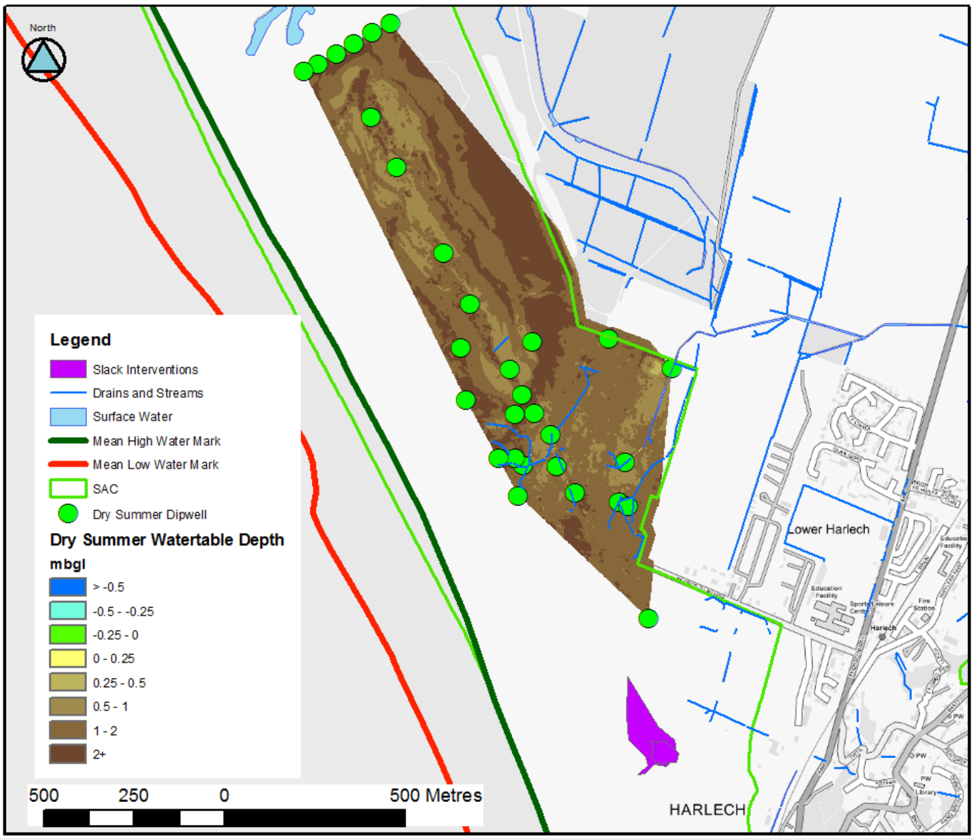


Figure 41: Dry Summer Water Level

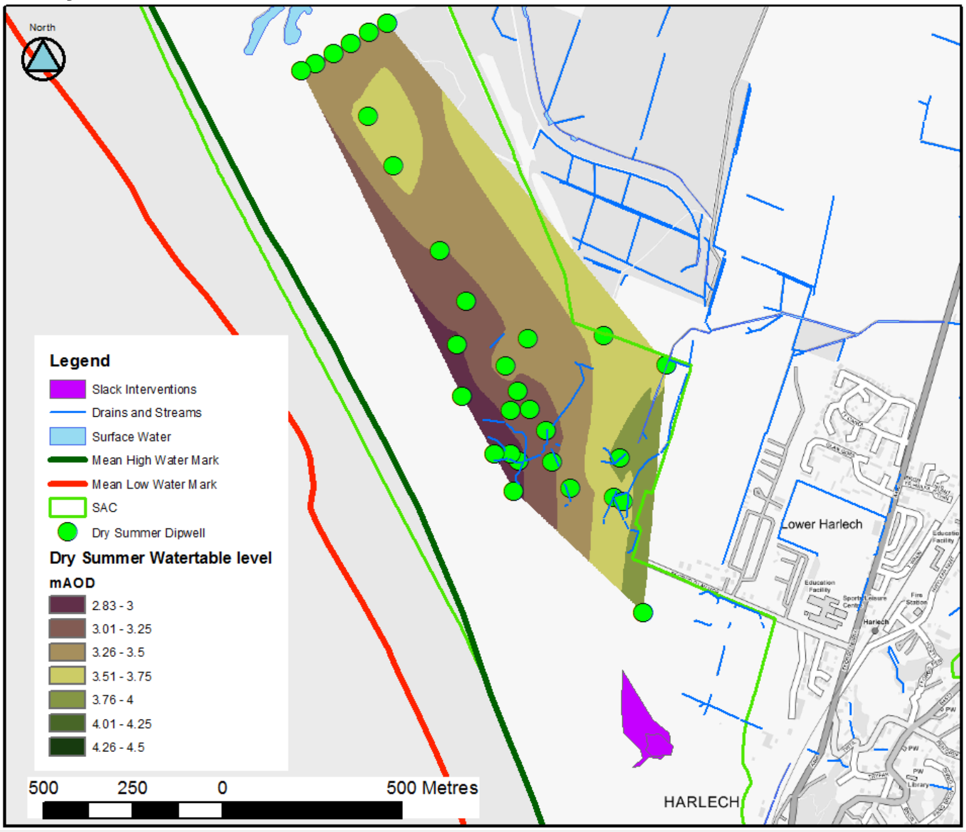


Figure 42: Dry Summer Water Level

Note: Top figure water level is in mbgl and bottom figure is in mAOD.

NVC Surveys

Figure 43 provides a classification of the slacks based on the methodology outlined above. Of note in the distribution of the slack is the limited extent of Type A slacks. This reflects the morphology of the foredune with steeply rising ground at the edge of the beach.

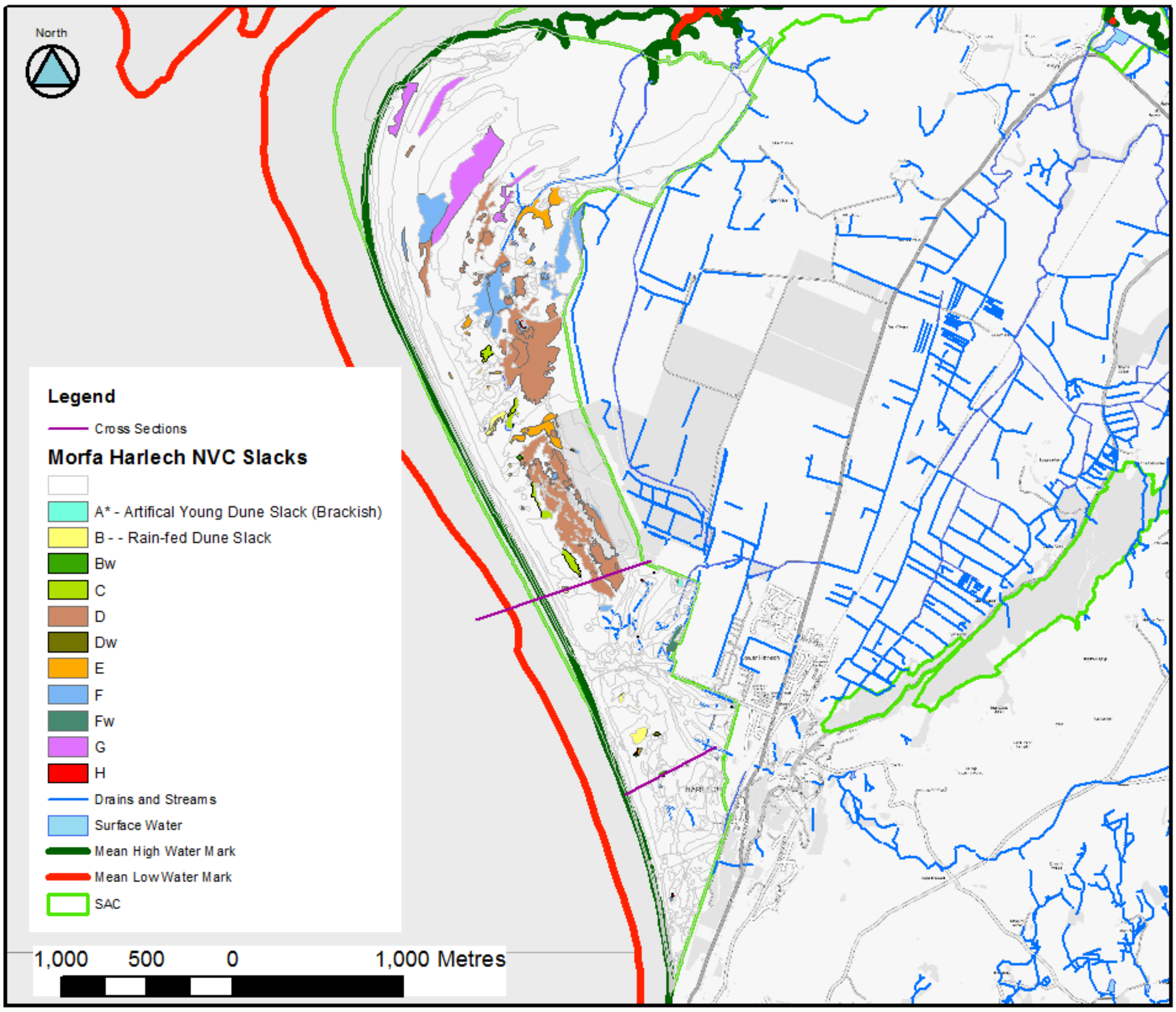


Figure 43: NVC/WETMEC Slack Classification.

Note - Morfa XS = Line of Cross Section in Figure 43 to Figure 44.

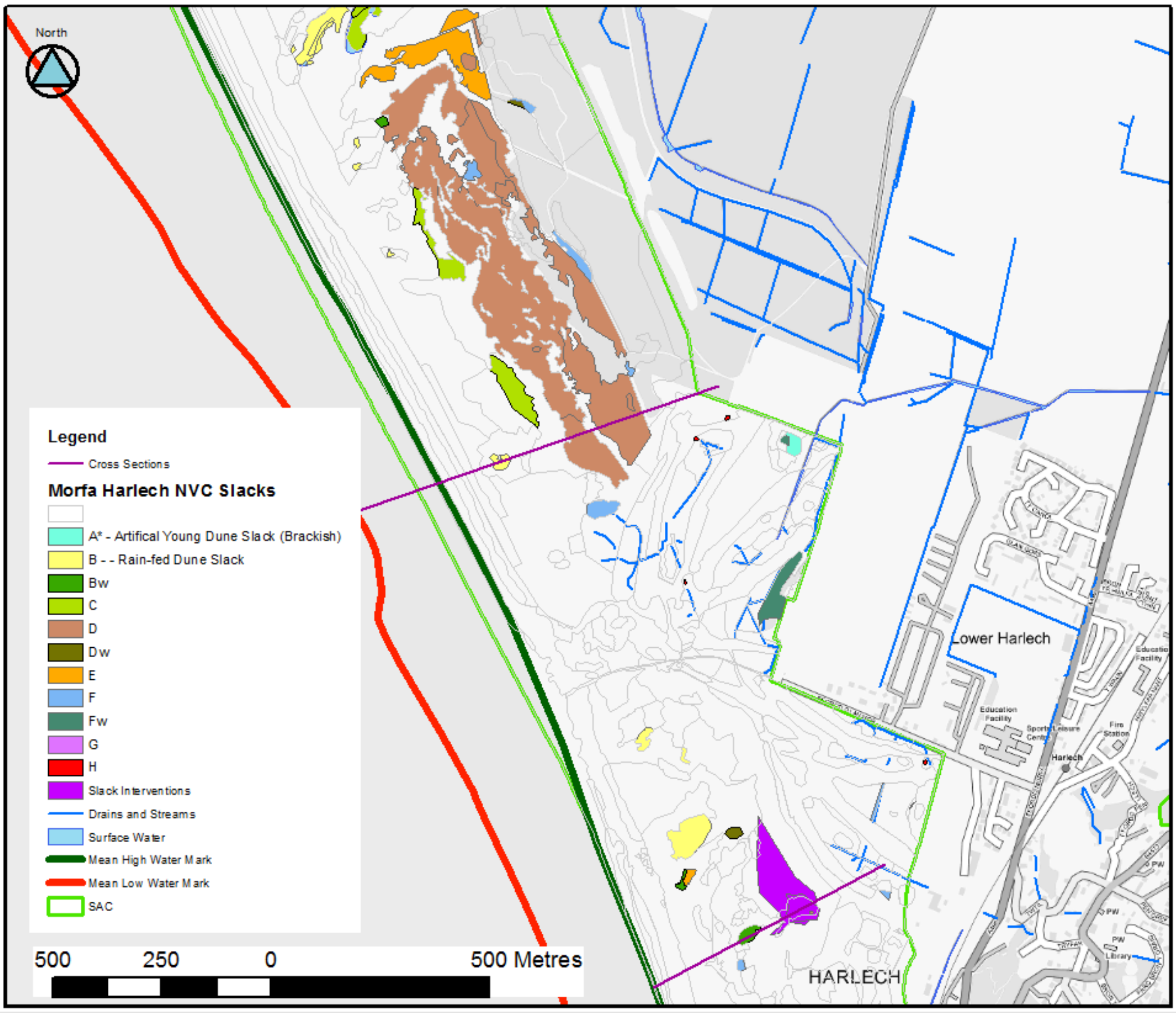


Figure 44: NVC/WETMEC Slack Classification through the Groundwater Monitoring and Intervention Area.

Conceptual Model

The hydrogeological conceptual model for the site is shown in Figure 45 and Figure 46 with lines of cross section shown in Figure 42 and Figure 43. The northern cross section (Figure 45) intersects the dipwell monitoring area where there is groundwater level data. The southern cross section (Figure 46) bisects one of the intervention areas, however it is outside the monitoring area. NVC codes for specific dune habitats are displayed, in additional the locations of dipwells.

The main features include:

- Topography
  - Undulating dune system featuring ridges (max of 22m AOD) and slacks. One prominent dune ridge positioned parallel to the coastline extends for 3.5km. In the southern part, near the intervention area, ridges begin to trend north-east to south-west and extend further inland. Behind the main ridge in the centre of Morfa Harlech, there is an extensive (1.1km) dune slack area, which is bounded by a second dune ridge to the east. Further north, the dune ridges curve round to the east, following the coastline as it progresses into the estuary.
- Geology and hydrogeology

- Blown sands superficial deposits, with moderate permeability, outcrop at the ground surface forming the extensive dune system. Lacustrine clays and stilt interbeds form an aquitard at the base of the blown sands, meaning there is minimal groundwater connection with the underlying glaciofluvial deposits.
- Infiltration and recharge
  - Main input to the blown sands dune aquifer is from direct rainfall recharge throughout the site area. It is likely water infiltrating into the golf course to the east contributes to the Morfa Harlech system (Figure 45).
- Groundwater surface interactions
  - Dune slacks comprises areas where the seasonally fluctuating water table within the dune system is exposed at the ground surface. Different dune slack types and associated vegetation types depend on the nature of the water table and dune condition at each specific location.
- Conceptual Model through monitoring area (Figure 45)
  - The model displays the aforementioned two main ridge lines, separated by a wide expanse of dune slack (Boundary Slack SD15/17). The water level range shows the degree to which ponded water in the slacks varies seasonally.
- Conceptual Model through intervention area (Figure 46)
  - Intervention area currently comprises W1 Slack with cut S19 Pond, where the minimum groundwater level is 1m below the ground surface, hence the slack area currently dries up during the summer months.

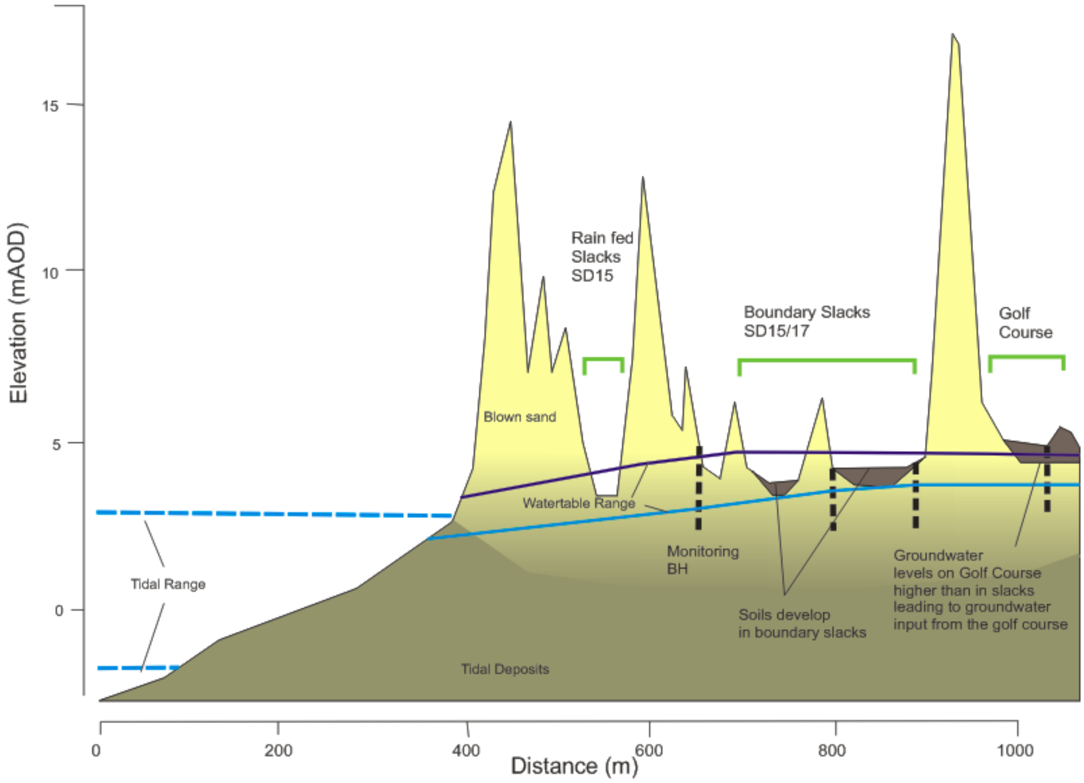


Figure 45: Conceptual Model through Groundwater Monitoring Area.

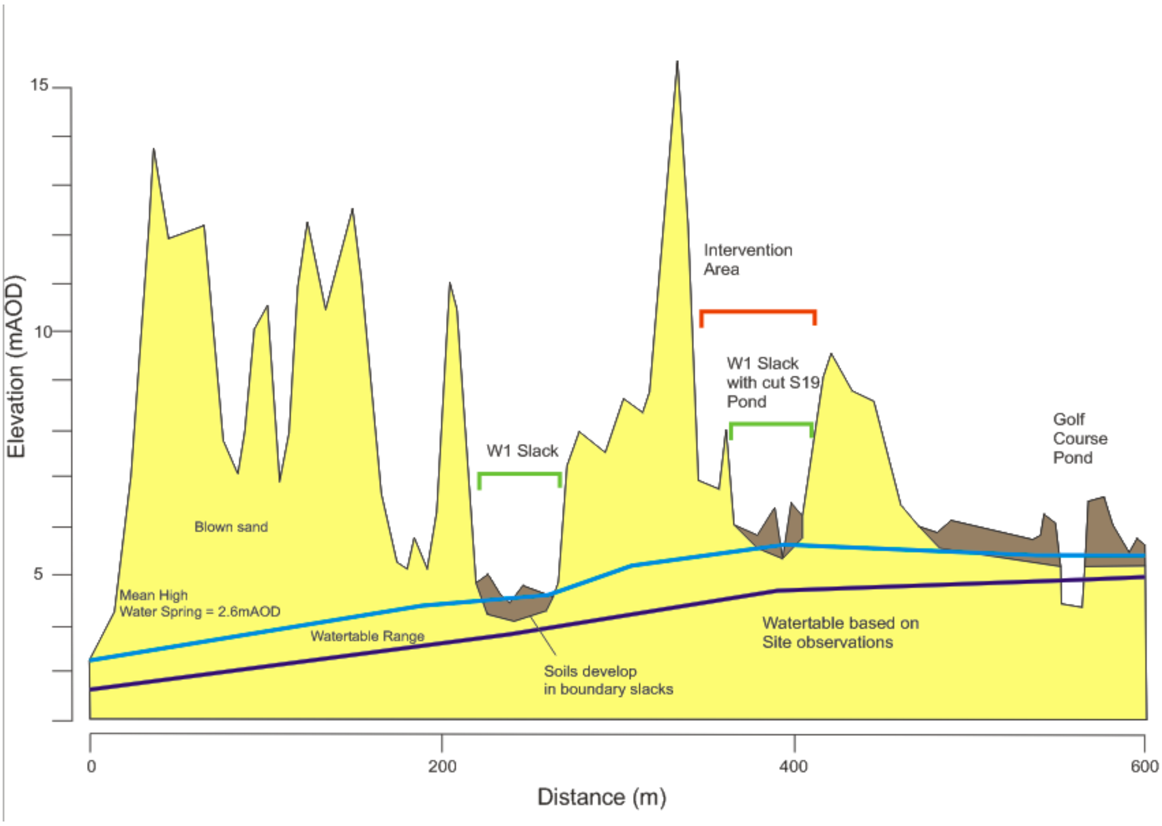


Figure 46: Conceptual Model through Intervention Area

Interventions and Monitoring

The Sands of LIFE project has identified several Slack Intervention Areas across Morfa Harlech where reprofiling works have been designed to improve the habitats. The Morfa Harlech Intervention and Monitoring section below provides a summary of the Slack Intervention Areas, the current vegetation, available water levels and consideration of the monitoring requirements.

Morfa Harlech Intervention and Monitoring – Morfa Harlech Scrape

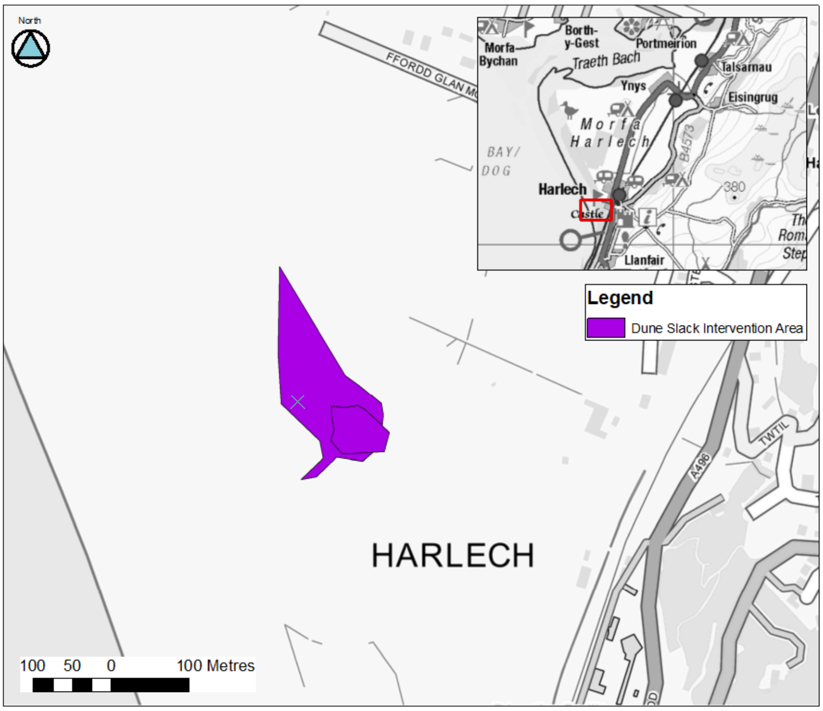


Figure 47: Map showing the location of the Morfa Harlech dune scrape

The dune slack is the smaller, roughly circular polygon within the Intervention Area. The remaining area is dry dune and slopes of dune ridges.

Target Habitat

Annex I Humid Dune Slack H2190.
Four types are associated with the habitat type H2190: SD13, SD14, SD15 and SD17. (Houston, 2008)

Intervention Plan (implemented March 2021)

Remove all vegetation to bare sand to create early successional stages. Increasing size of slack. Scrape to reach water table to allow flooding in winter, damp in summer.
Scrape sides of dune around slack.
Entire area scraped is circa 1.84ha. The slack area is circa 0.3ha.
Scrape to depth of approx. 0.5 metres to reach water table. Graded to sides.

Current Water Level Ranges - Monitoring

Ground water level monitoring does not cover the areas. However, based on the cross section in Figure 45, outside of the pond water level range is expected to between 4.5mAOD and 5.5mAOD

Figure 48: Wet winter water table at Morfa Harlech

Current Water Level Range – NVC

There is a small pond and an area of W2 wet woodland in the area in the lowest part of the intervention area. The pond is cut into the ground surface and is in contact with the water table.

Monitoring water levels and NVC levels summary

-	Monitoring	NVC	Comment
Slack intervention area	Water table expected to be between 4.5 mAOD and 5.5 mAOD	Pond cut into the water table	N/A

Ecohydrological Implementation Consideration

Figure 30 shows that pond within the scrape was an expression of the water table. Lowering the rest of the slack around 0.5m should allow for some limited pooling of water in winter.

Monitoring Plan

To capture the full range of levels, one monitoring borehole should be installed to 4.2mAOD or 1.5mbgl (whichever is lowest).

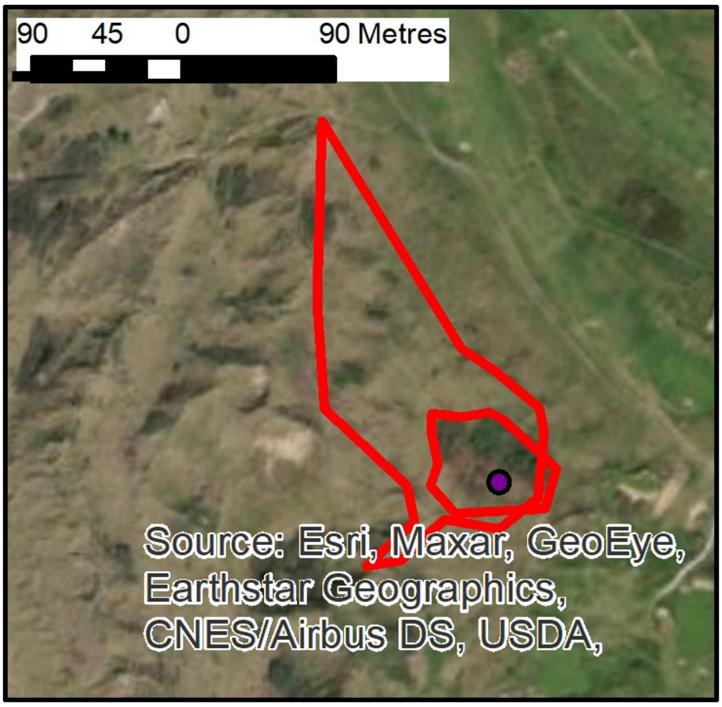


Figure 49: Location of Morfa Harlech dune slack intervention and dipwell.

Pembrey Burrows

The Pembrey Burrows Dune system is circa 600m wide and lies on a spit to the west of Porth Tywyn.

Baseline

Dune System Extent and Topography

Pembrey Burrow lies on a spit, surrounded by intertidal habitats on both sides. A circa 700m wide tidal flat extends seawards from the edge of the dunes. Around the base of the spit is a saltmarsh with a relatively narrow mudflat section and creek at the centre. The extent of dune slack communities within the system is limited.

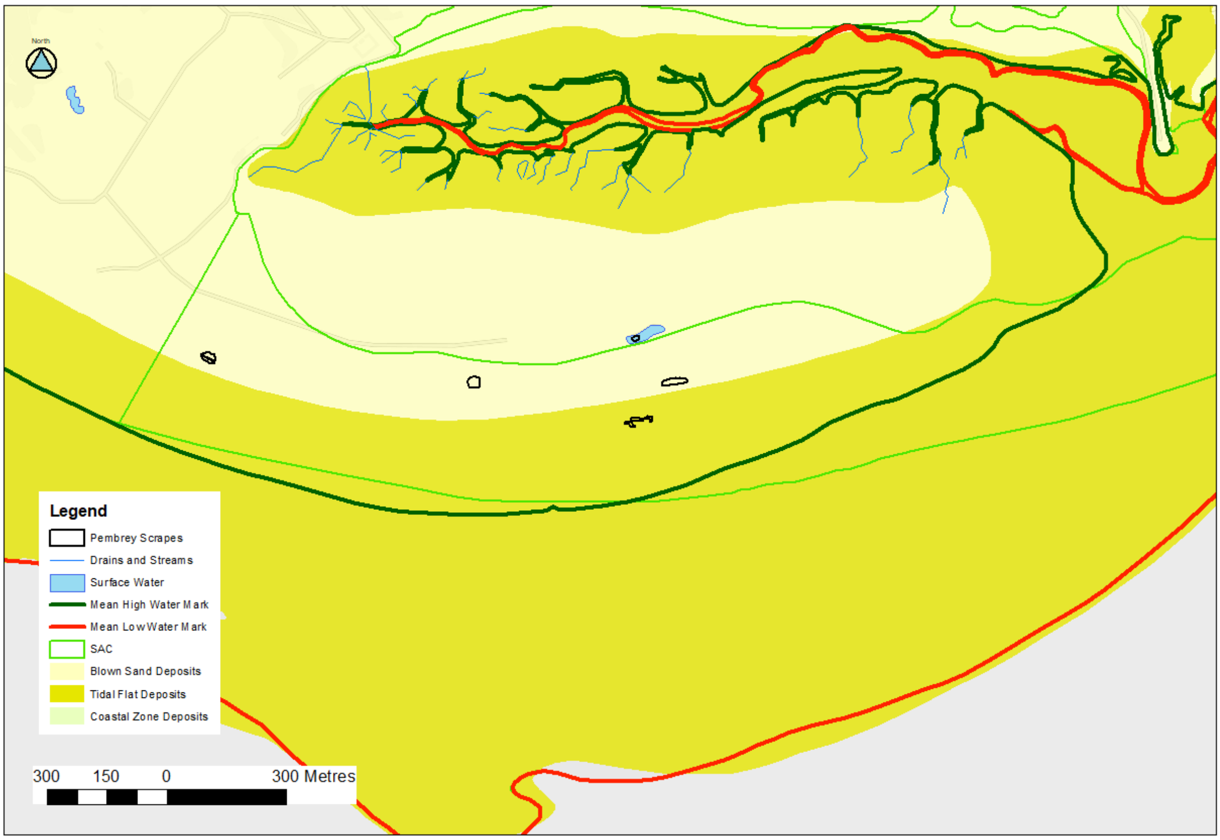


Figure 50: Pembrey Burrows Boundaries

Geology

The table below outlines the geological units of the area. Due to the isolated nature of the spit, the units are dominated by tidal deposits and blown sands (i.e. the dunes). The thickness of these is uncertain. The underlying bedrock comprises a succession of Carboniferous mudstones, siltstones and sandstones. The Pennant Sandstone Formation is the main unit underlying the dune system and is covered by superficial tidal flats and blown sand deposits. The Rhondda Member to the north-east (coastal hills) is covered by a thin, patchy layer of till. The geology beneath the site is summarised in Table 8 and maps of superficial and bedrock geology are shown in Figure 51 and 52.

Table 8: Geological Units

Age	Formation / Member /Group	Description	Thickness	Location	Hydrogeological Properties
Quaternary	Blown Sand	Fine Sands	Over 4m Maximum height of dunes c. 10mAOD	Dune System	Moderate Permeability
Quaternary	Tidal Flat and Saltmarsh deposits	Silty Clay	Unknown	In front and behind the spit	Low Permeability
Quaternary	Till	Silty Clays	Skim	Surrounding hills and potentially under the valley floor	Low Permeability
Carbon-iferous	Brithdir Member	Green-grey sandstones with conglomerate lenses at the bases and mudstone/siltstone interbeds*	Up to 200m*	-	Moderate Permeability
Carbon-iferous	Rhondda Member	Green-grey sandstones with mudstone/siltstone interbeds and thin coals.*	Up to 320m*	-	Moderate Permeability
Carbon-iferous	Pennant Sandstone Member	Green-grey and blue-grey, feldspathic, sandstones with thin mudstone /siltstone interbeds and mainly thin coals*	Up to 1350m	Beneath the majority of the main dune system	Moderate Permeability
Carbon-iferous	Llynfi Member	Green-grey and blue-grey, feldspathic, sandstones with thin mudstone/siltstone interbeds and mainly thin coals*	Up to 420m*	Limited exposure covering a portion of Pembrey forest north of the dune system	Moderate Permeability
Carbon-iferous	South Wales Lower and Middle Coal Measures	Mudstone, siltstone and sandstone*	Unknown	Thick strip of exposure from the coast at Pembrey Forest extending towards the north-east.	Moderate Permeability

Figure 51: Superficial geology

Figure 52: Bedrock Geology

Contains Ordnance Survey data © Crown copyright and database right 2021. Derived from 1:50000 scale BGS digital data, British Geological Survey © NERC 2021.

Pye et al., (2014) provides a detailed review of the geomorphology of the dune system. In the area of interest, the series of parallel ridges at the front of the system formed between 1945 and the present, with the parallel ridges at the back forming after the late 1800s (see Figure 53).

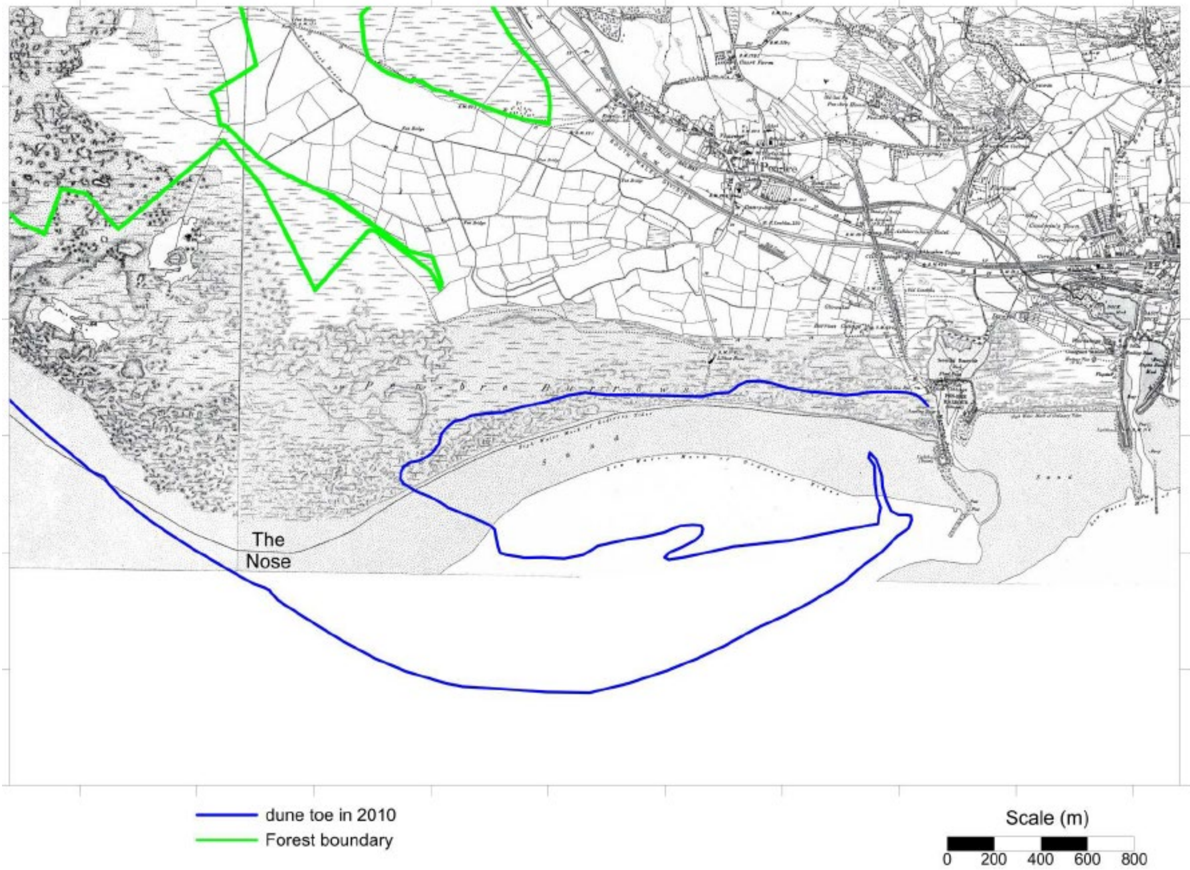


Figure 53: 1879 OS Mapping and 2010 dune toe from Pye et al., 2014

Surface Water Features and Groundwater Boundaries

Lying on a spit, the groundwater boundaries of the dune system are formed by sea levels on three sides. This means that the regional groundwater system is unlikely to form a significant role in supporting groundwater levels in the dune system.
The distribution of mudflats, saltmarsh and dune habitats provide an indication of the tidal ranges of the area. The general rule of thumb is as following

- Mudflats exist between Mean Low Water Spring (MLWS) and Mean High Water Neap (MHWN) tide levels
- Saltmarsh colonize between MHWN and the Highest Astronomical Tide (HAT).

The figure below provides the daily maximum, minimum and average water levels at Afon Lliedi Tidal Mouth at Llanelli 7km across the bay. It is likely to have a fairly similar pattern to the waters around Pembrey Burrows. Daily maximums range from circa 1.5mAOD to 5mAOD and average water levels lie around 1.5mAOD.

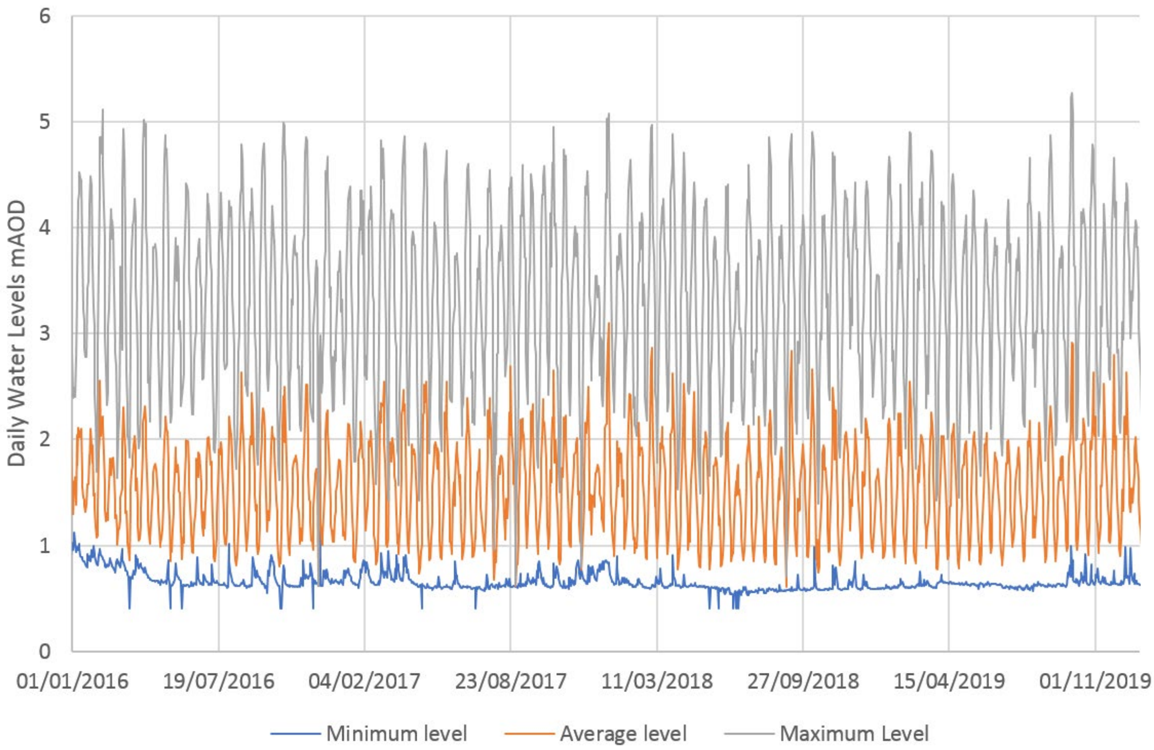


Figure 54: Daily Water Level Ranges at the Afon Lliedi Tidal Mouth at Llanelli

Vegetation and Dune Slack Distribution

The distribution of dune slack habitats is shown in the figure below. These are not wide-spread and are limited to the deeper slacks. The presents of SD16 suggests that even these slacks would be classified as Type E: Moist dune slacks, the driest class in the generic conceptual model typology, with maximum water levels at or near the surface in winter.

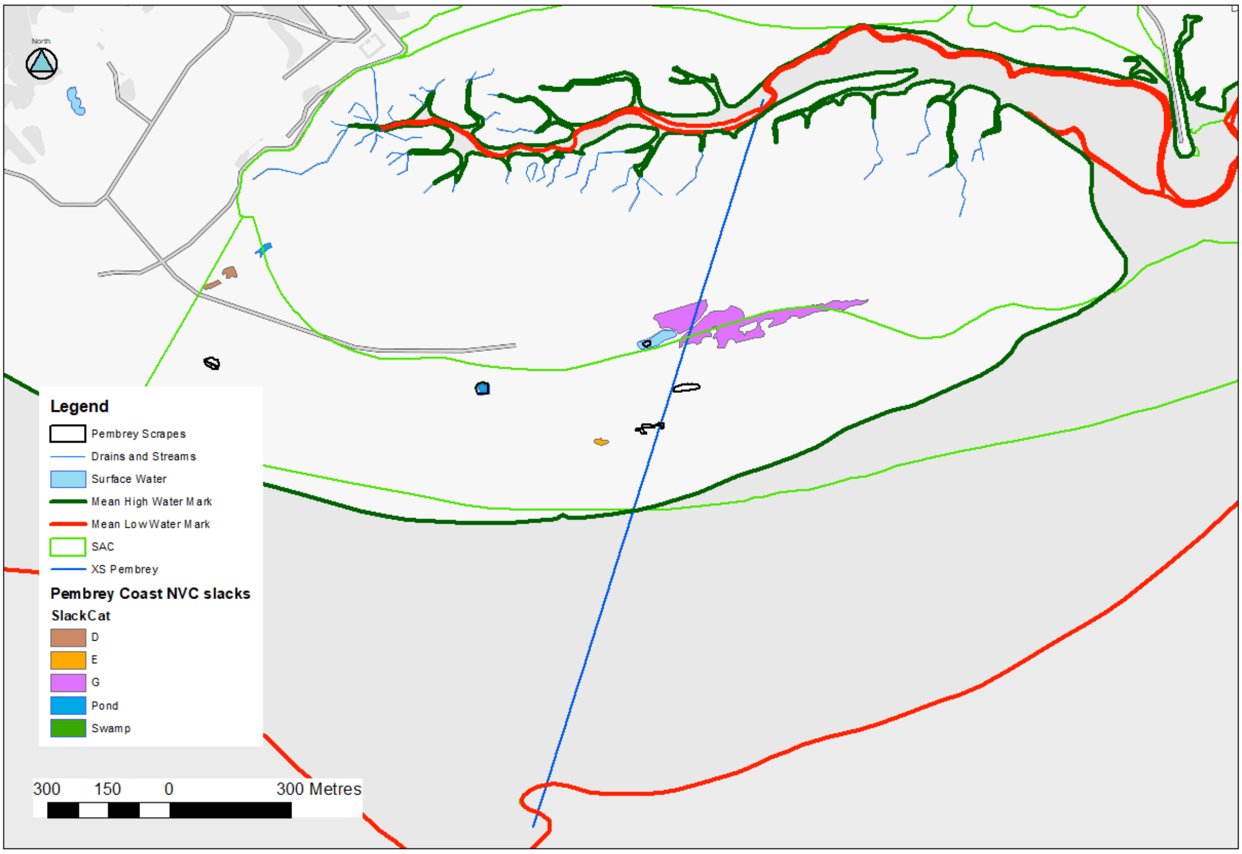


Figure 55: NVC Survey and Dune Slack Communities

Site Data

No water level records are available for the site. This may reflect the limited distribution of slack habitats onsite.

Planned Intervention Locations

Figure 51 the boundaries of the slack interventions at Pembrey. They are limited to 5 scrape areas including a group of three small scrapes. In addition, work is occurring in two ponds.

Conceptual Model

A hydrogeological conceptual model is "a description of how a hydrogeological system is believed to behave" (Environment Agency, 2002). It describes "how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system" (Rushton, 2003).

The hydrogeological conceptual model for the site is shown in Figure 56, with line of cross section shown in Figure 55 which bisects one of the intervention areas. NVC codes for specific dune habitats are displayed, in additional the locations of dipwells.

The conceptual model has the following features:

- The dunes have formed since the late 1800s, with the majority forming after 1945.
- The dunes lie on a spit and so the groundwater boundary is formed on all sides by the tidal range.
- The blown sands has moderate permeability while the surrounding tidal deposits have varying permeability. This is due to the large grain size distribution, which is a result of variation in the energy of the deposition environment. Mud dominates the upper salt marsh.
- Vegetation surveys indicate a limited proportion of dune slacks. Where these are present they can be classed as Moist Slack type. This means that the maximum groundwater level in winter is at or near the surface.

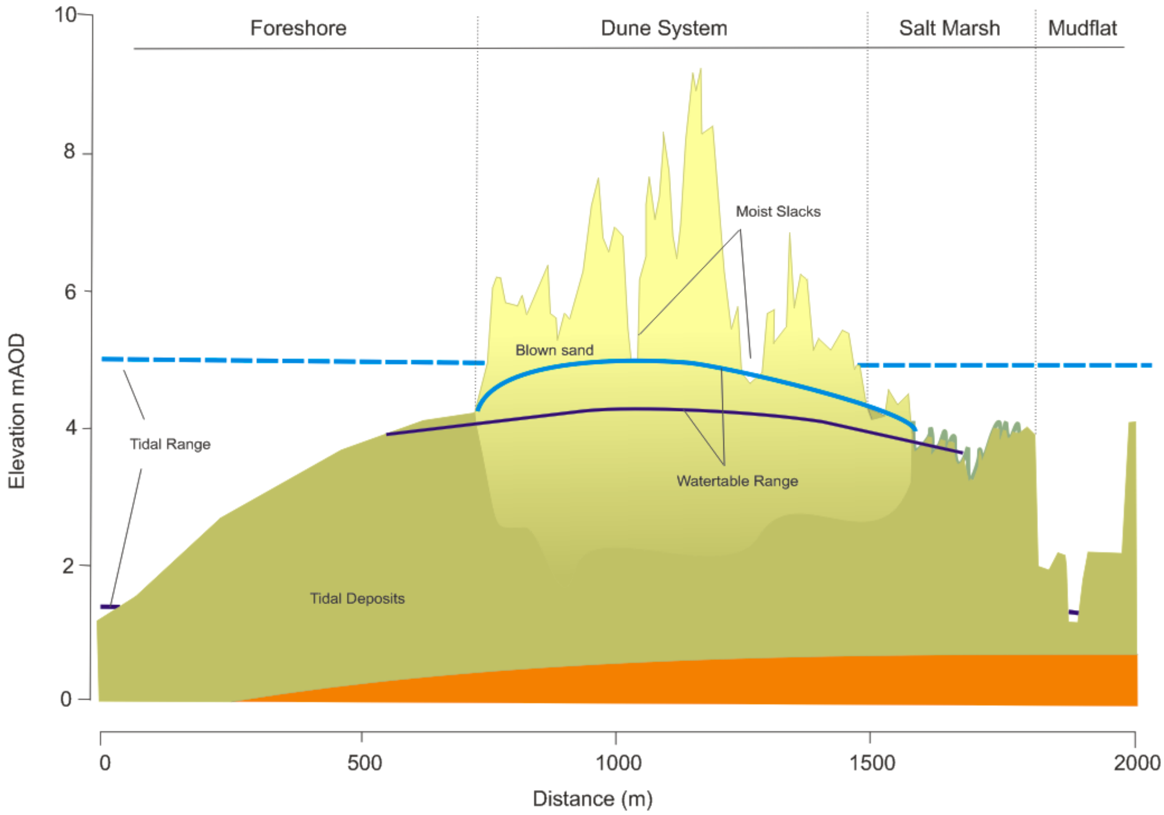


Figure 56: Conceptual Model

Interventions and Monitoring

The Sands of LIFE project has identified several Slack Intervention Areas across Pembrey Burrow, where reprofiling works have been designed to improve the habitats. The table below provides a summary of the Slack Intervention Areas, the current vegetation, available water levels and consideration of the monitoring requirements.

Pembrey Burrows Intervention and Monitoring – West Slack

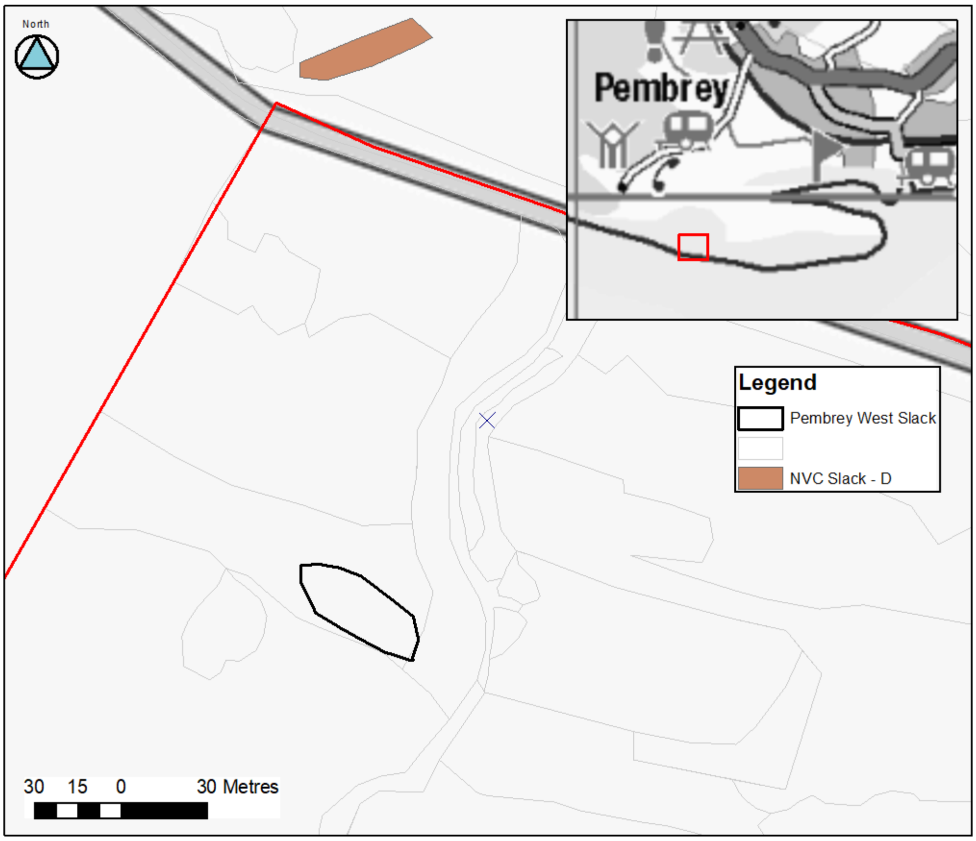


Figure 57: Location of the West Slack intervention at Pembrey Burrows.

Target Habitat
Annex I Humid Dune Slack H2190.

Plan – Implemented January/February 2021
Remove all vegetation to bare sand to create early successional stages. Scrape to reach water table to allow flooding in winter, damp in summer. Scrape to depth of approximately 0.8 meters to reach water table. Graded to sides

Current Water Level Ranges – Monitoring
No information is available. Pre-intervention ground levels were approximately 5.79 mAOD.

Current Water Level Range – NVC
No information, nearest moist dune slack is 180m to the north with an elevation of 5.96mAOD in the base.

Ecohydrological Implementation Consideration
Based on the conceptual model cross section, the water table never reached the ground surface. Excavating 0.8m will put the base beneath the height of the nearest moist slack and therefore there is likely to be a moderate amount of standing water in the base of the slack in winter.

Monitoring Plan

Given the uncertainties about the position of the water table, the monitoring borehole will be set relatively deep circa 1.5-1.8 mbgl (4,29 – 3.99 mAOD) if possible.

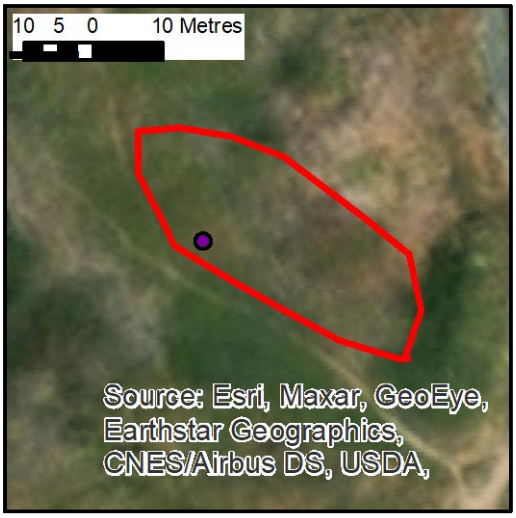


Figure 58: West Slack and dipwell.

Pembrey Burrows Intervention and Monitoring- 3 Small Slacks

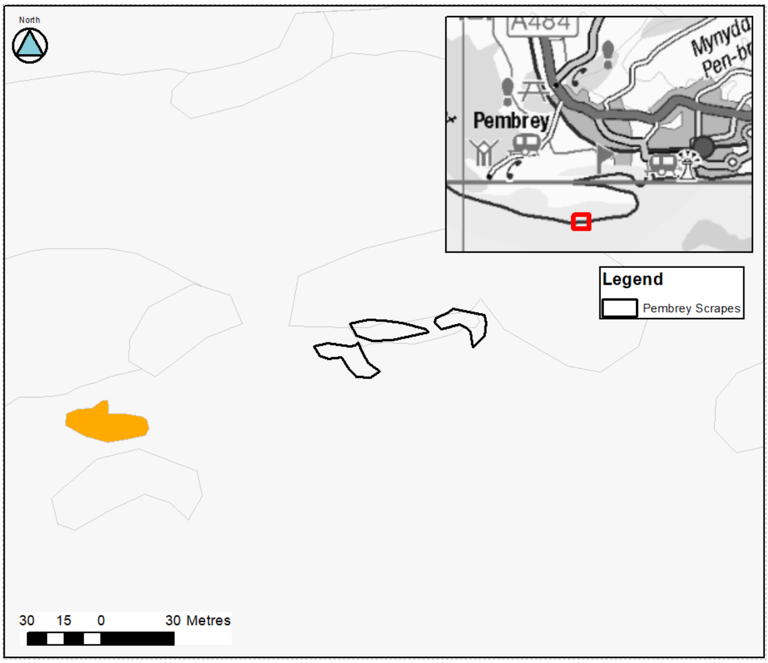


Figure 59: Pembrey Burrows 3 Small Slacks.

Target Habitat

Annex I Humid Dune Slack H2190.

Plan – Implemented January/ February 2021

Remove all vegetation to bare sand to create early successional stages. Scrape to reach water table to allow flooding in winter, damp in summer.
Scrape to depth of approximately 0.8 meters to reach water table. Graded to sides.

Current Water Level Ranges – Monitoring
No information is available. Nearest moist dune slack is 80 meters to the west with an elevation of 6.2mAOD in the base.

Current Water Level Range – NVC
No information. Nearest moist dune slack is 80 meters to the west with an elevation of 6.2mAOD in the base.

Ecohydrological Implementation Consideration
The area is lower than the moist slack, 80m to the west. Given the local topography it is not clear why this area did not also contain moist dune slack communities pre-intervention. Given the vegetation suggests slacks are currently dry and the aim is to create limited standing water, a 0.8m deepening appears appropriate. There is, however, the potential that the pre-implementation vegetation did not reflect the water levels in the area.

Monitoring Plan
Given the uncertainties about the position of the water table, the monitoring borehole will be set relatively deep circa 1.5-1.8mbgl if possible.

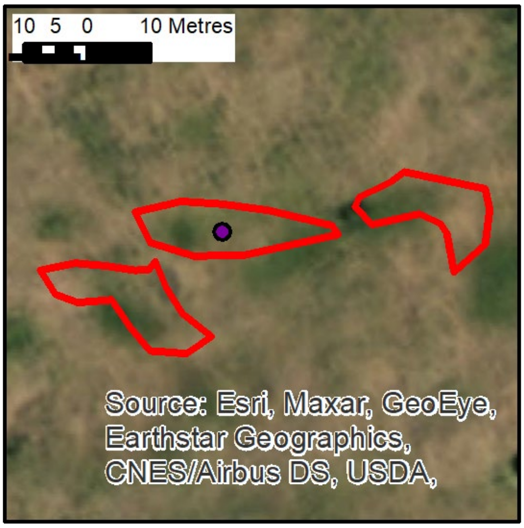


Figure 60:Planned dune slacks and dipwell

Pembrey Burrows Intervention and Monitoring – North West Slack

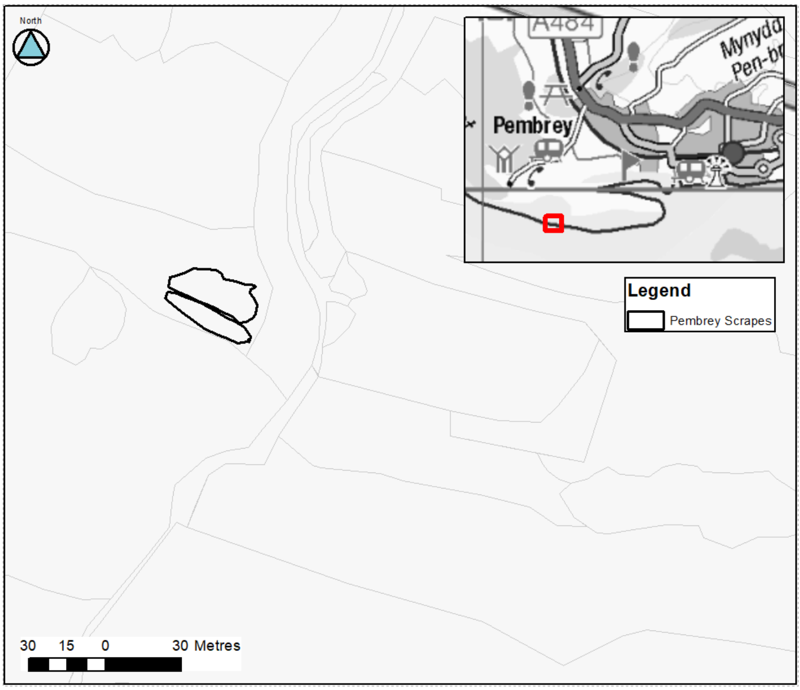


Figure 61: Location of Pembrey Burrows North West Slack

Target Habitat

Annex I Humid Dune Slack H2190

Plan – Implemented in January/February 2021

Remove all vegetation to bare sand to create early successional stages. Scrape to reach water table to allow flooding in winter, damp in summer.
Scrape to depth of approximately 0.8 meter to reach water table. Graded to sides.

Current water level ranges – monitoring

No information is available. Pre-intervention ground levels between 6 – 6.3 mAOD

Current water level range – NVC

No information. There is no dune slack communities close to the intervention.

Ecohydrological Implementation Consideration

Given the vegetation suggests slacks are currently dry and the aim is to create limited standing water, a 0.8m deepening appears appropriate. There is, however, no clear information on water levels in the area.

Monitoring Plan

The intervention was an additional work element and therefore there are no monitoring plans.

Kenfig

The Kenfig dune system is situated on the Bristol Channel coastline in South Wales. Designated a National Nature Reserve, Kenfig dunes have a large variety of flowering plants, lichens and bryophytes due to the shallow groundwater table (Jones, 1993a). Kenfig dunes are described in Jones (2017) as a hindshore dune system, which comprises an intricate series of overlapping dune ridges and secondary slacks.

Site specific data sources include:

- Jones, P.S. 1993. Ecological and hydrological studies of dune slack vegetation at Kenfig National Nature Reserve, Mid Glamorgan. Ph.D Thesis No Dx201209. University College of Wales.
- Jones, P.S., Farr, G., Low, R. and Etherington, J.R., 2017. Ecohydrological studies of dune slack vegetation at Kenfig dunes, South Wales, UK. Journal of Coastal Conservation, 21(5), pp.623-630.
- Cottrell, A. 2010. Construction of a groundwater model for Kenfig Pool and Dunes. MSc Environmental Hydrogeology. Cardiff University.

Baseline

Dune System Extent and Topography

With an area of 7.2km^2 located between Porthcawl and Port Talbot, Kenfig is one of the largest dunes systems in the UK. The system features up to 3km long dune ridges with crest heights of approximately 15m (Cottrell, 2010). The site is considered to have two distinct topographical areas: dune sand blown up to 3km inland and overlying glacial till and Mercia Mudstone; and a 4.3km^2 area of low-lying dunes overlying a sequence of estuarine clay, silt and peat.

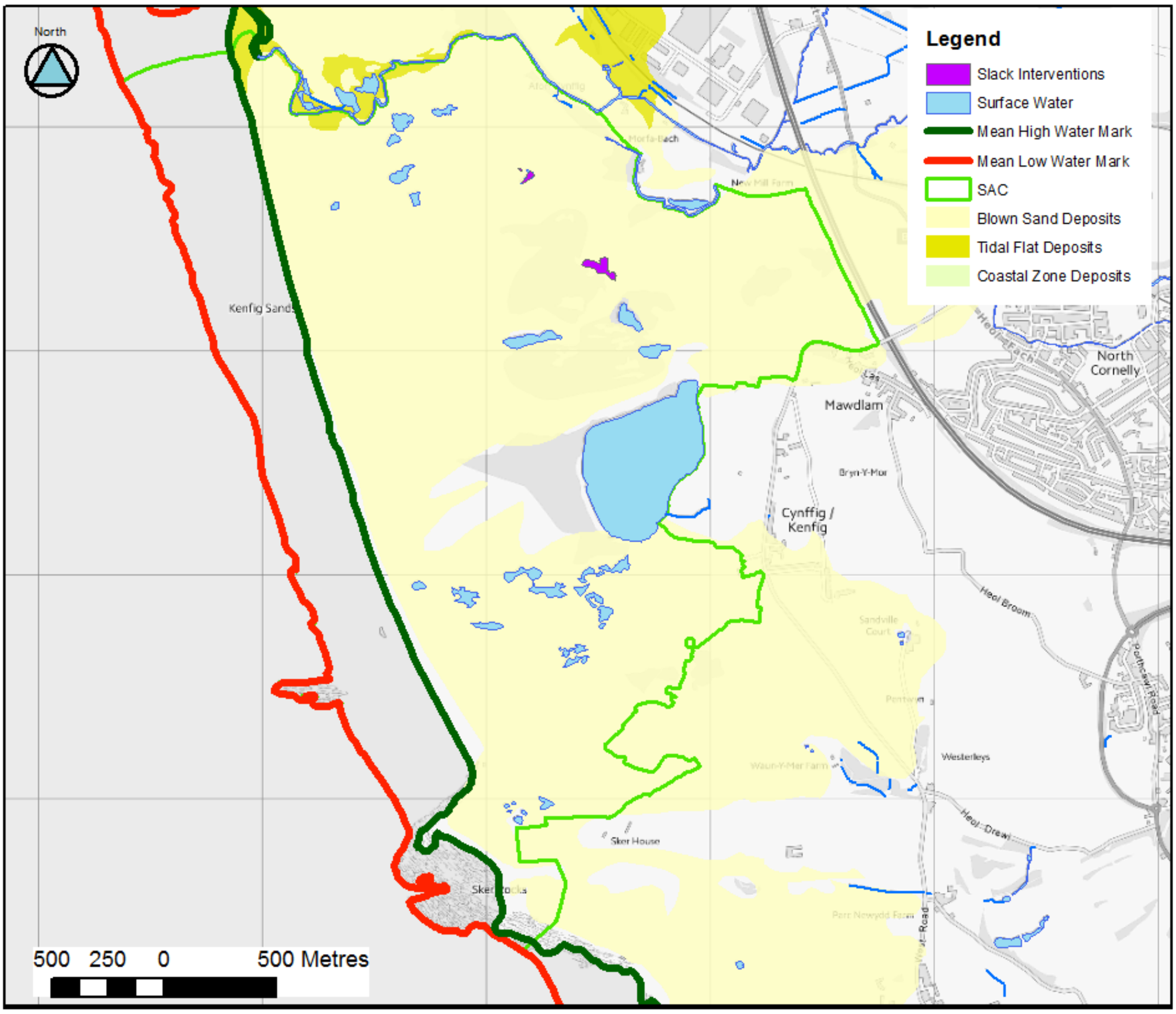


Figure 62: Kenfig SAC outline and blown sands superficial deposits.

Soils, Geology and Hydrogeology

Information on the soils and geology of the site and surrounding area has been derived from the Soil Survey of England and Wales (1983), 1:50,000 BGS geology mapping (Sheet 135, Harlech), and the BGS online borehole archive. The geology beneath the site is summarised in Table 9 and maps of superficial and bedrock geology are shown in Figure 63 and Figure 65.

Table 9: Summary of geological stratigraphy

Age	Formation / Member /Group	Description	Thickness	Location	Hydrogeological Properties
Quaternary	Blown Sand	Fine sands	Over 4m Maximum height of dunes c. 10mAOD	Dune system	Moderate Permeability
Quaternary	Lacustrine Deposits	Includes fine-grained sediments (i.e. clay and silt), commonly laminated, and can contain thin layers of organic material or sand	Unknown	Occurs on west side of Kenfig Pool	Low Permeability
Quaternary	Alluvium	Clays silts, sands and gravels	Unknown	Underlies and extends further west - west side of Kenfig Pool	Moderate Permeability
Jurassic	Lower Lias Group	Predominantly grey, well bedded, marine calcareous mudstone and silty mudstone; thin tabular or nodular beds of argillaceous limestone	c. 1300m	Underlying Quaternary deposits at site location – exposed further east.	Low Permeability
Late Triassic	Penarth Group	Grey to black mudstones with subordinate limestones and sandstones; predominantly marine in origin.	8-20m	Underlying Lower Lias Group – exposed further east	Low Permeability
Triassic	Mercia Mudstone Group	Variable, typically consisting of conglomerate and/or breccia with clasts derived locally from rocks lying immediately below the unconformable base of these deposits. The matrix generally consists of finer-grained rock fragments or, less commonly, siltstone, sandstone or micritic limestone.	Variable 1-100m	Underlying Penarth Group – widespread occurrence	Moderate Permeability
Carboniferous	South Wales Middle and Lower Coal Measures Fm	Mudstone, siltstone and sandstone	200-300m	North of the main dune system, extending eastwards from the coasts at Margam Sands	Moderate permeability
Carboniferous	Oyster-mouth Fm	Interbedded limestone and mudstone	60 – 100m	Limited exposure, just east of Kenfig Pool	Moderate permeability
Carboniferous	Oxwich Head Limestone Fm	Limestone	Up to 200m	Exposed east of the dune system and south of North Cornelly	High permeability

Age	Formation / Member /Group	Description	Thickness	Location	Hydrogeological Properties
Carboniferous	Pant Mawr Sandstone	Sandstone	1.5 – 4m	Thin bands exposed within the Oxwich Head limestone	High permeability
Carboniferous	Stormy Limestone Fm	Limestone	55 - 65m	Exposed south-east of Oxwich Head limestone to the east of the main site area	High permeability

Sources – http://www.largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001754

Figure 63: Kenfig superficial geology

Figure 64: Kenfig bedrock geology

Surface Water Features and Groundwater Boundaries

Kenfig Pool, which lies in the centre of the site area, represents the height of the local water table, which is observed to fluctuate seasonally by around 0.3m. Several other smaller ponds are located throughout the reserve area. In addition, the only watercourse within the site area, Afon Cynffig, flows north-west through from Pyle and follows a meandering path through the centre of the dune system to where it meets the sea.

Approximately 500m north-west of Kenfig pool, a groundwater dome within the dune system was identified by the Environment Agency (EA wet dune habitats) from dipwell water levels. From this location, groundwater flows radially, from south-west and west towards the coastline to northwards within the dune system.

The dunes represent a largely independent groundwater system due to a layer estuarine clay, which acts as an aquitard between the dune aquifer and underlying glaciofluvial deposits (EA wet dunes), with the main water source being direct rainfall recharge.

However, to the east of the site, it is believed that the dunes are hydraulically connected to the glaciofluvial deposits and the underlying bedrock (EA, wet dunes). Therefore, it is likely there is a groundwater supply to Kenfig from the higher ground to the east.

Site Data

The section below reviews the available site information. This can be used to inform the scrape intervention design and monitoring discussed above.

Water Level Monitoring Networks

Information is available from two networks:

- A currently managed network cover a small part of the site (Figure 65)
- A more extensive network from the 1980s (see Figure 68).

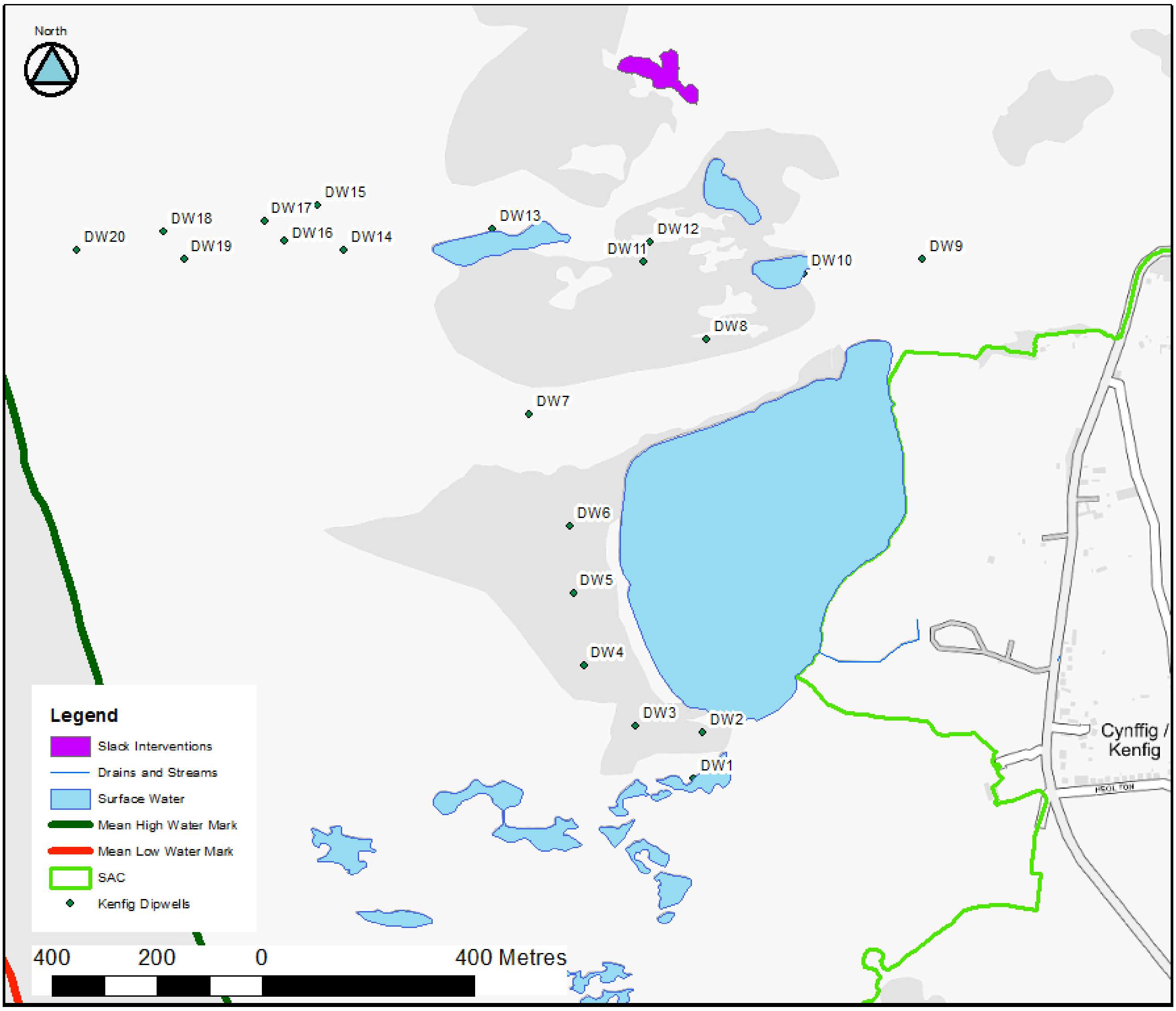


Figure 65: Current Water Level Monitoring Network

Figure 66 presents some example hydrographs from the site. These represent three broad hydrograph types represented in the record:

- Type 1 – in the winter water often pools on the ground surface for extensive periods of time and in summer drops to a maximum of circa 1m below ground level.
- Type 2 – like Type 1 but in winter water reaches the surface but does not pool. In most cases this will be because the topography allows for the emergence groundwater to be shed.
- Type 3 – the water table is significantly below the ground surface but the amplitude of the pattern is similar to Type 1.

Interpreting these patterns needs knowledge of the specific topography of each dipwell location. Within the types there are some general spatial trends. Water level ranges along the pond edges are more muted (e.g. DW6) compared to those in the central higher parts of the dune slacks (e.g. DW14), which shows how the open water body acts to mute groundwater level variations and tie in the water table.

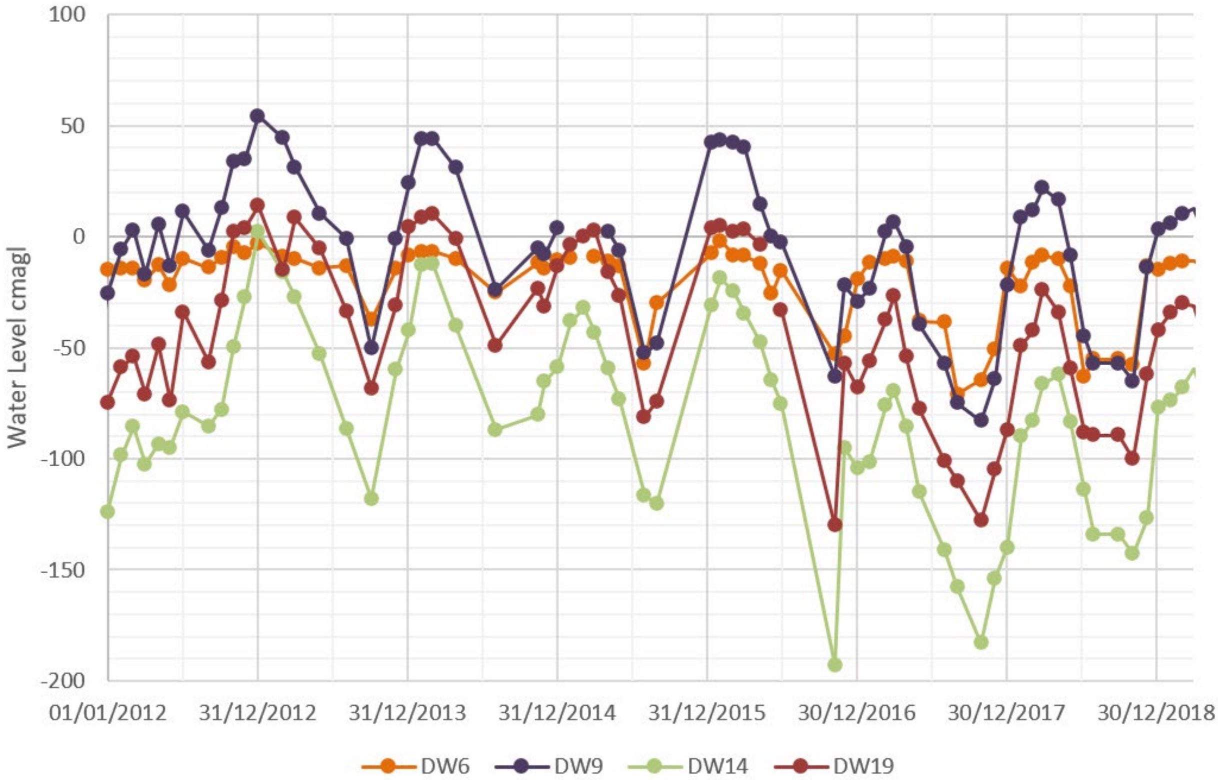


Figure 66: Water Level Monitoring Record

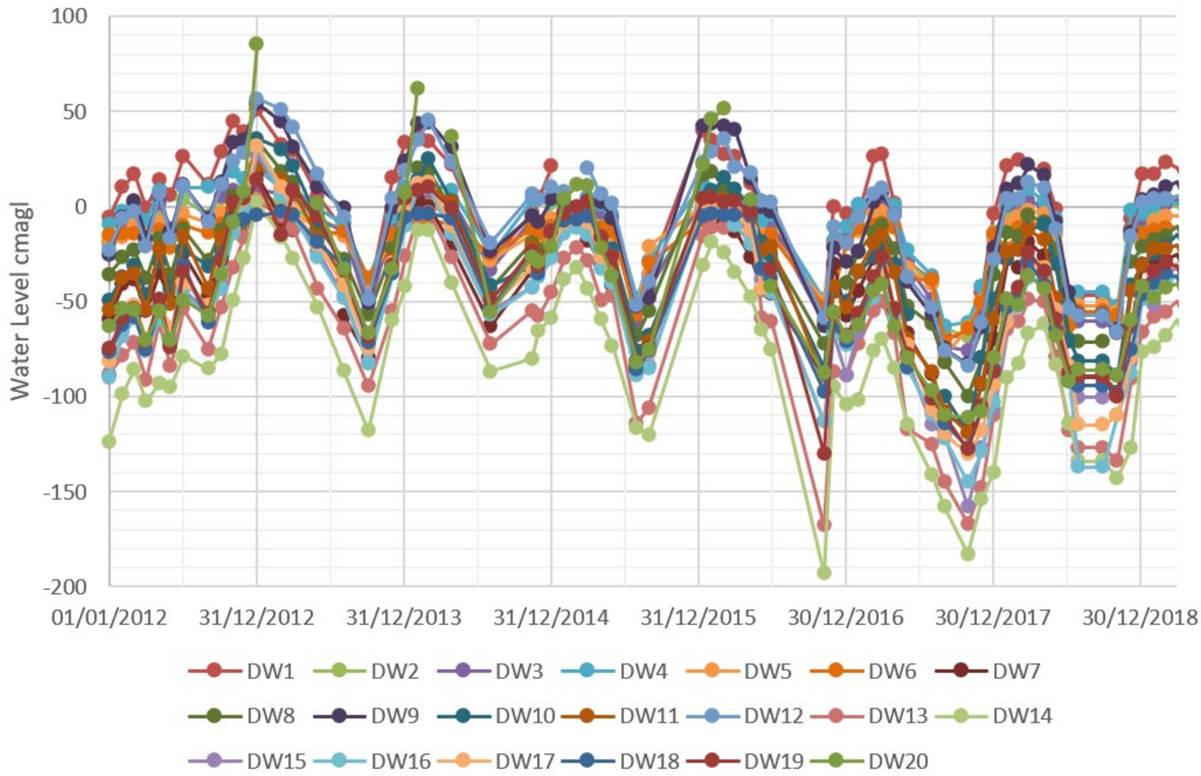


Figure 67: Water level monitoring record

Figure 68: 1980s Dipwell Network

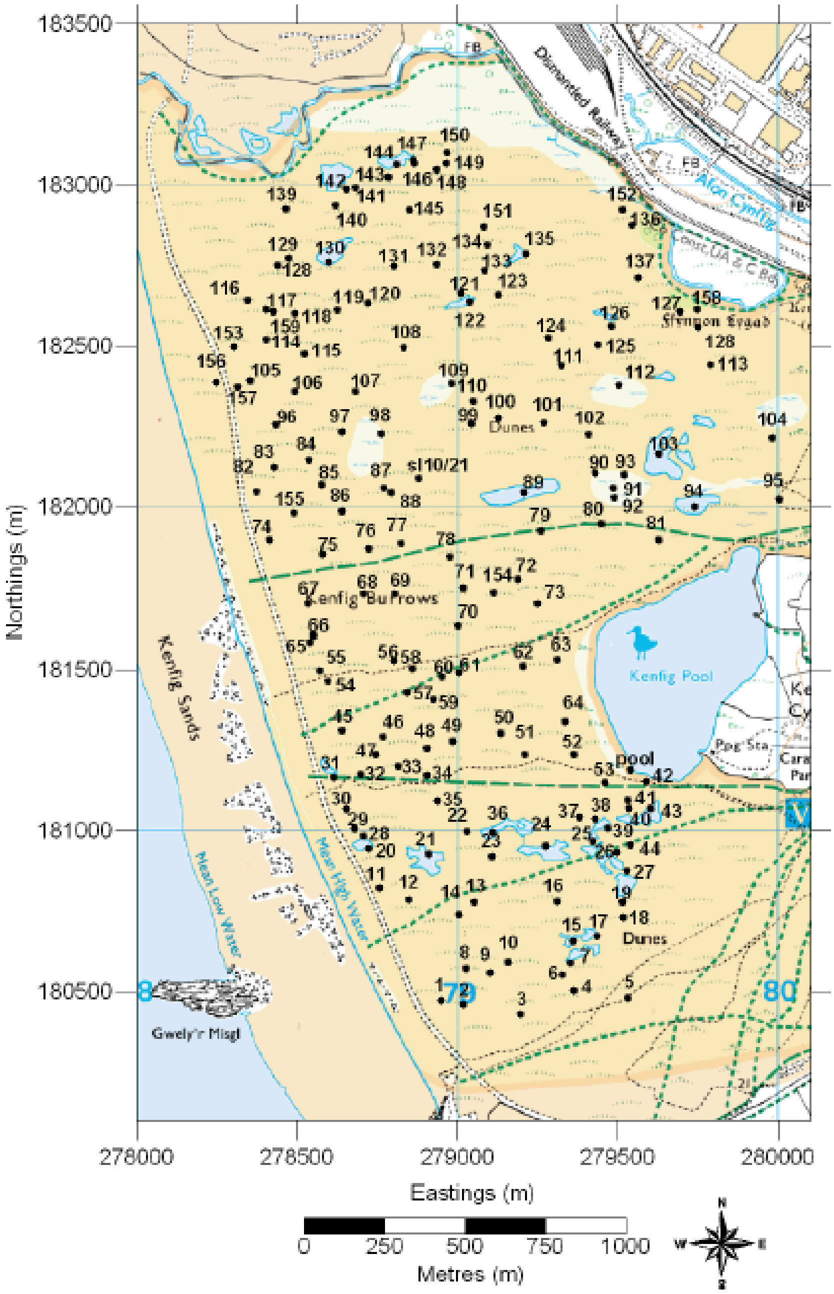


Figure 69: Dipwell network at Kenfig

Groundwater Surfaces

The hydrograph data record and contour data from Jones et al. (2017) has been reviewed, digitised and interpolated to produce a series of groundwater surfaces. The hydrographs have been reviewed to identify examples of historic summers and winters which were particularly wet and those which were drier than average (Table 11). Contour plots were developed to show the range of water levels occurring during winter and summer periods from the available data record (Figure 72 and 73). The water levels have been interpolated to produce groundwater surfaces in metres above ordnance datum (mAOD) and metres below ground level (mbgl) (Figure 70 and Figure 71). The extent of the surface produced is limited to where there is sufficient density of dipwells. These groundwater surfaces have been subtracted from the LIDAR topography surfaces to produce a depth to groundwater grid.

Table 10: Example periods comprising particularly wet, or dry, summers and winters

Type	Date
Wet Winter	December 2013
Dry Winter	November 2016
Wet Summer	Jun 2013
Dry Summer	July 2018

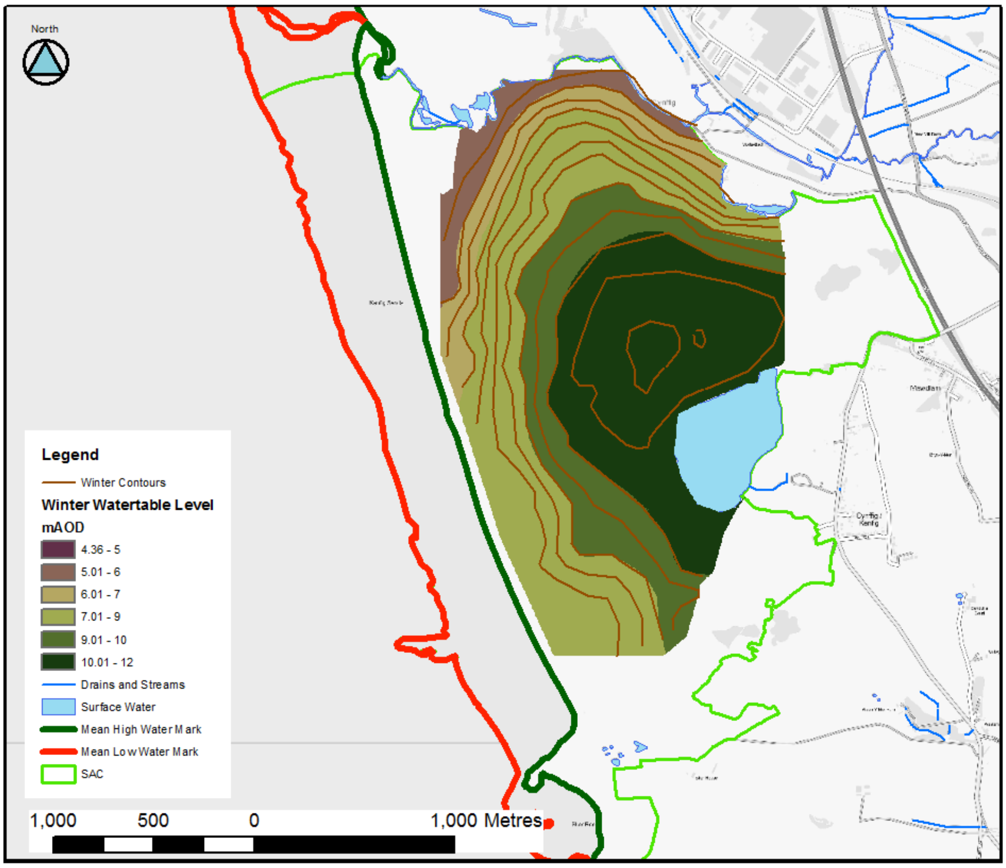


Figure 70: Winter Water table.

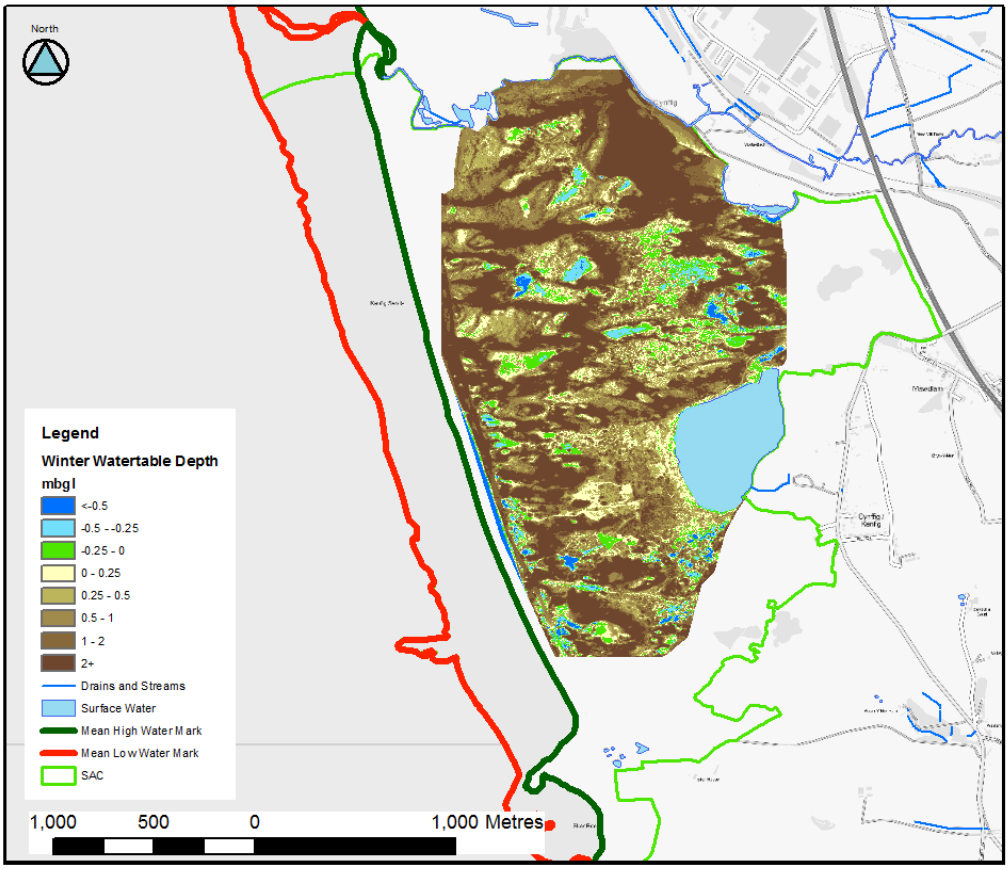


Figure 71: Winter Water table.

Note: Top figure water level is in mAOD and bottom figure is in mbgl

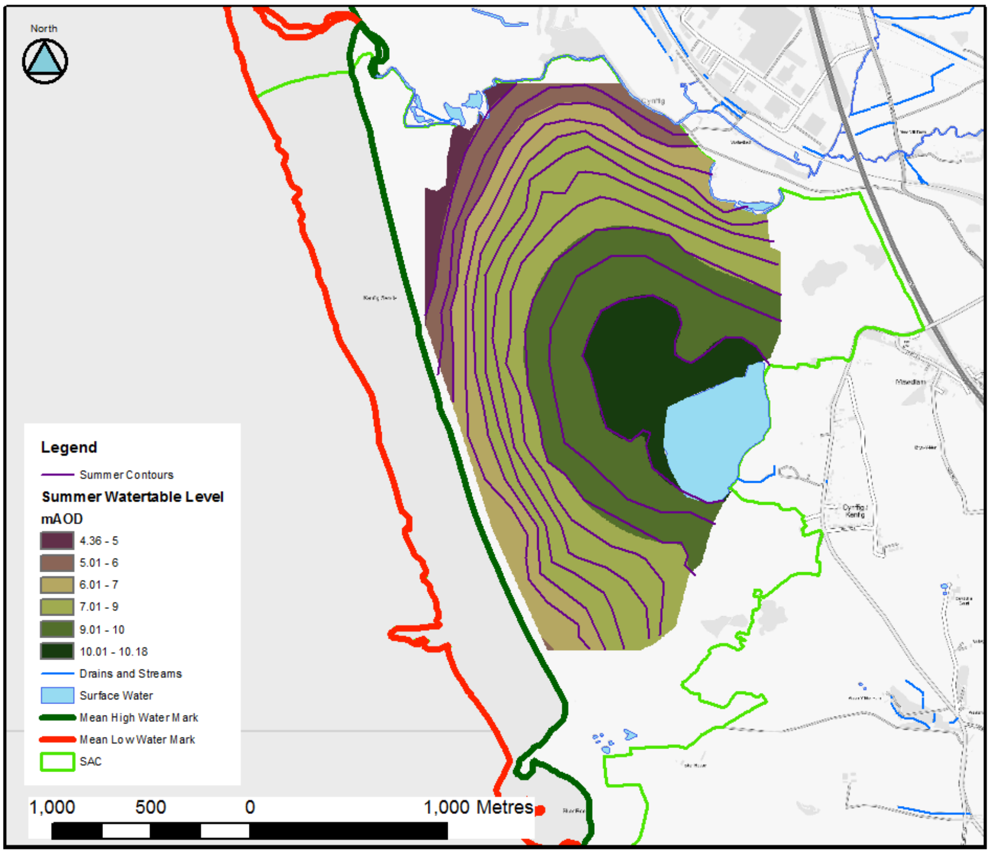


Figure 72: Summer Water table

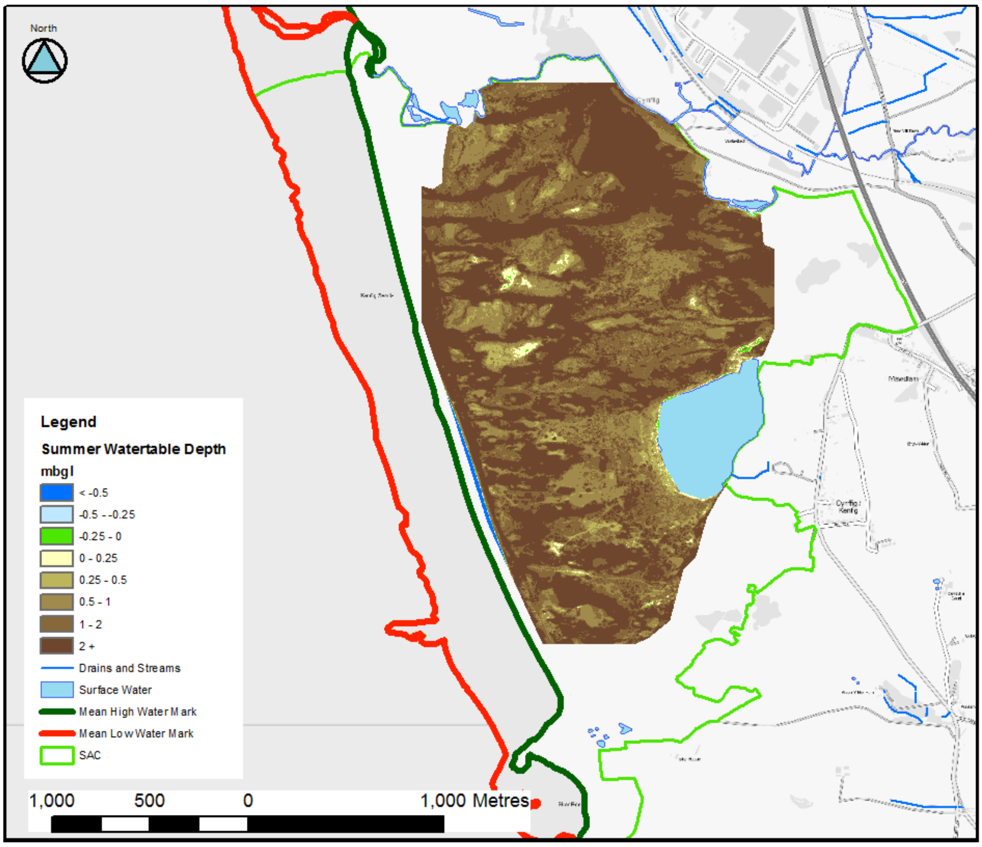


Figure 73: Summer Water table

Note: Top figure water level is in mAOD and bottom figure is in mbgl

NVC Surveys

The NVC survey for Kenfig dunes is displayed in Figure 74.

Figure 74: NVC Survey and WETMEC Classification.
Note - Kenfig XS = Line of Cross Section in Figure 74

Conceptual Model

The hydrogeological conceptual model for the site is shown in Figure 75 with line of cross section shown in Figure 74 which bisects one of the intervention areas. NVC codes for specific dune habitats are displayed, in additional the locations of dipwells. The main features include:

- Topography
  - Undulating dune system featuring up to 3km long ridges (max height of 15 mAOD) predominantly orientated west-east, and an array of dunes slacks separating the ridges.
- Geology and hydrogeology
  - Blown sands superficial deposits, with moderate permeability, outcrop at the ground surface forming the extensive dune system. Lacustrine clays form an aquitard at the base of the blown sands, meaning there is minimal groundwater connection with the underlying glaciofluvial deposits.
  - A groundwater dome features in the centre of the dune system, with radial flow from this location towards the coast to the rest, and rivers to the north and east.
- Infiltration and recharge
  - Main input to the blown sands due aquifer is from direct rainfall recharge throughout the site area. There is likely to be groundwater in from glaciofluvial deposits on higher topography to the north-east.
- Groundwater surface interactions
  - Dune slacks comprises areas where the seasonally fluctuating water table within the dune system is exposed at the ground surface. Different dune slack types and associated vegetation types depend on the nature of the water table and dune condition at each specific location.

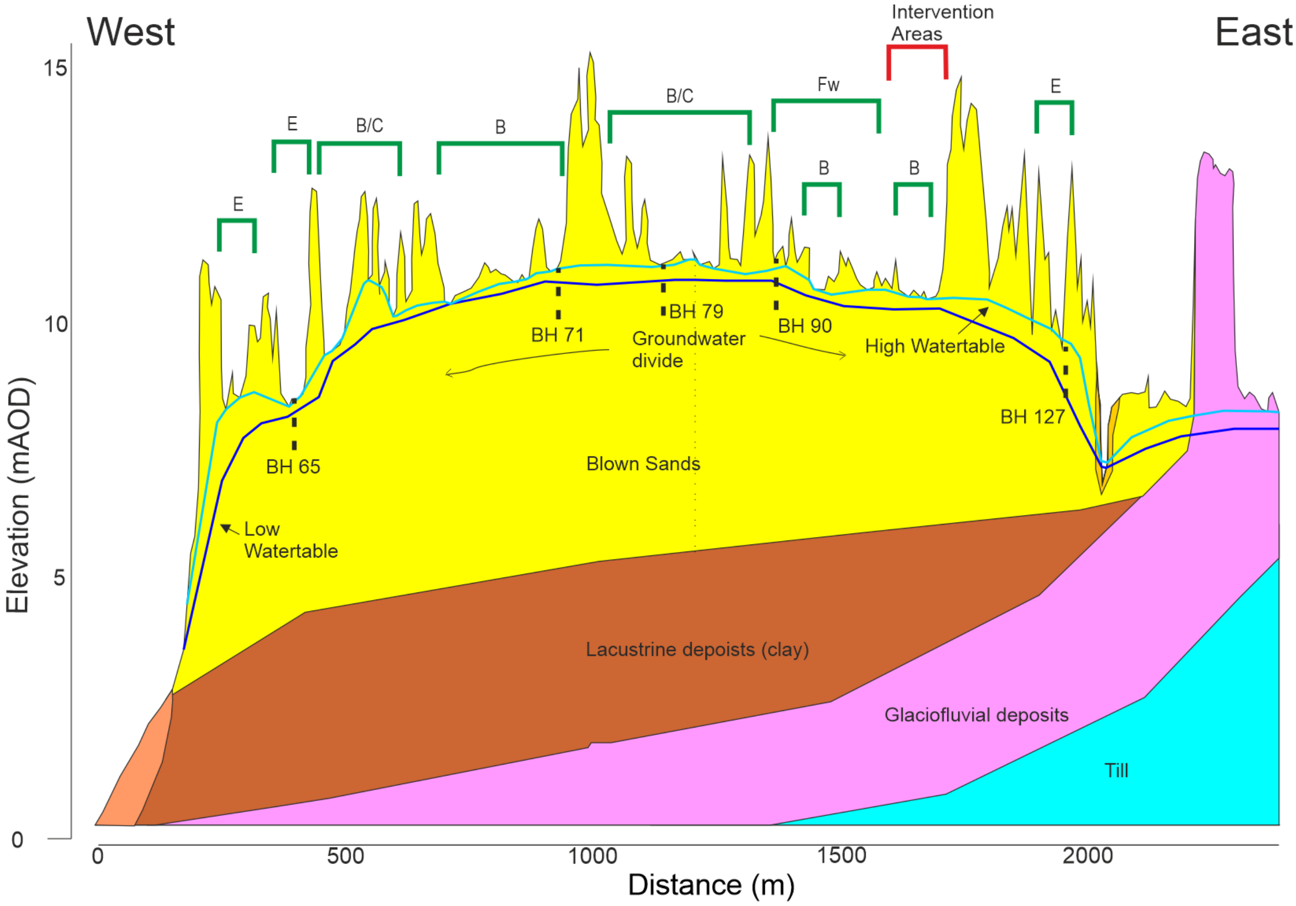


Figure 75: Conceptual Model.

Interventions and Monitoring

The Sands of LIFE project has identified several Slack Intervention Areas across Kenfig, where reprofiling works will and have been designed to improve the habitats. The table below provides a summary of the Slack Intervention Areas, the current vegetation, available water levels and consideration of the monitoring requirements.

Kenfig Interventions and Monitoring: Horseshoe Slacks (Slack 1 and 2)

[redacted]

Figure 76: Location of the intervention area.

Target Habitat
NVC category SD15. Annex I Humid Dune Slack H2190.

Plan – Implemented January/ February 2021
Remove all vegetation to bare sand to create early successional stages. Increasing size of slack to original horseshoe shape. Maintaining water levels as at present i.e. flooded in winter, damp in summer.
Shallow scraping no more than 30cm. Graded sides. No scraping of permanent pool area.

Current Water Level Ranges - Monitoring
Slack 1 and 2 (West and east slacks):

- Summer water level between 0.5 mbgl (meters below ground level) and 0.25 mbgl
- Winter water level between 0.25 mbgl and -0.5 mbgl.

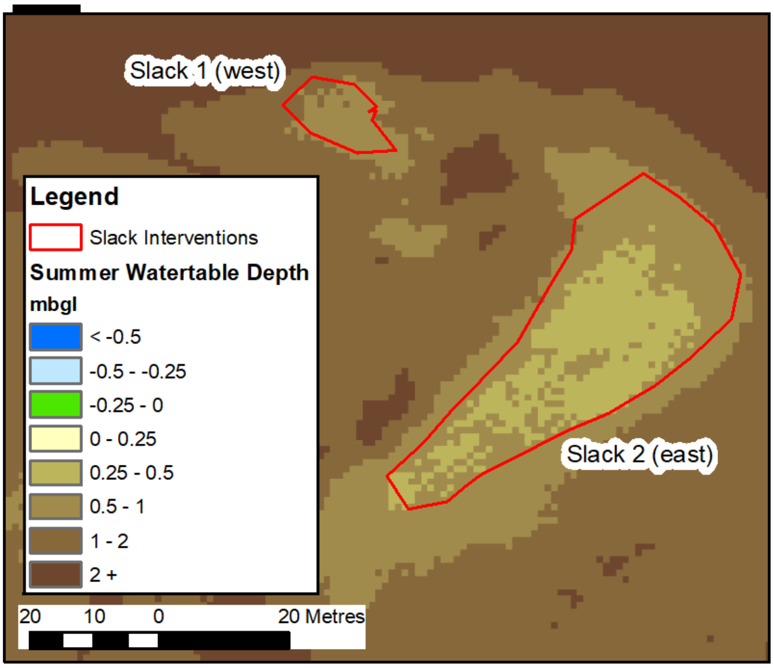


Figure 77: Summer water table depths

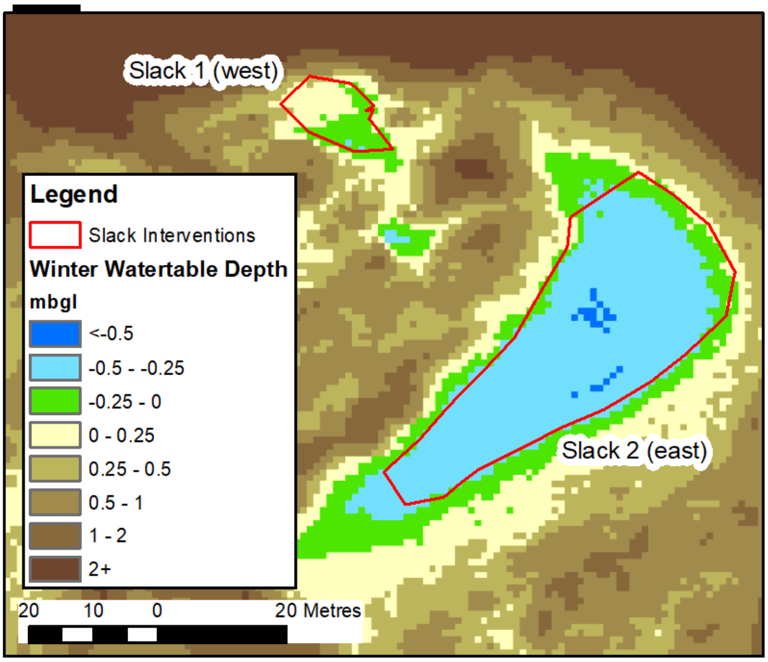


Figure 78: Winter water levels

Current Water Level Range – NVC

Based on ranges discussed above. Salck 1 (West Slack):

- Predominantly NVC dune type D with habitat SD15.
- Water level range is likely to be between a minimum of 0.61 mbgl (meters below ground level) and a maximum of -0.21 mbgl.

Slack 2 (East Slack):

- Predominantly NVC dune type D with habitat SD17d.
- No water level data is available for SD17d, therefore level information for SD15, the closest available habitat.
- Water levels between a minimum of -0.61 magl and 0.21 magl.

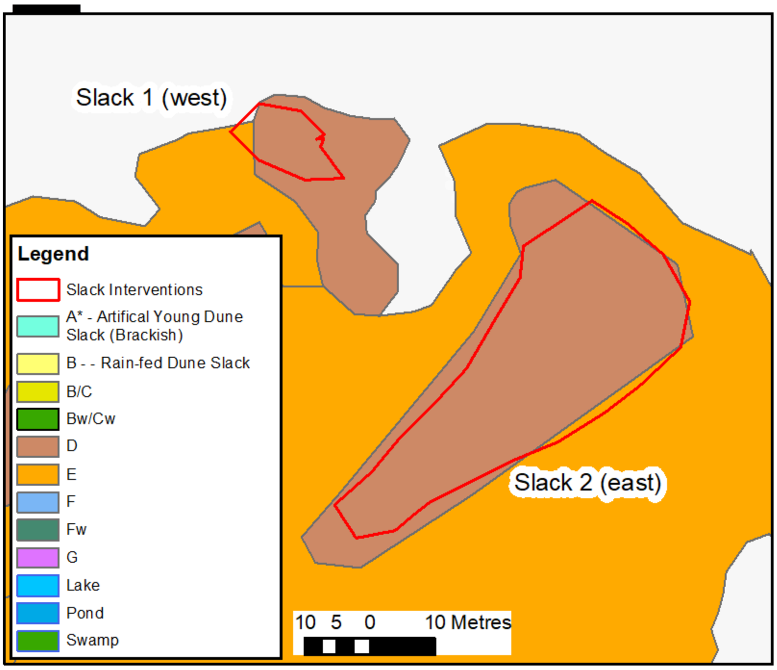


Figure 79: NVC dune type

Monitoring water levels and NVC levels summary

Table 11: Monitoring water levels and NVC levels summary

Slack	Monitoring	NVC	Comment
Slack 1(West Slack)	Min: 0.5 mbgl (9.0mAOD) Max: -0.5 mbgl (10.0 mAOD)	Min: 0.61 mbgl (8.89 mAOD) Max: -0.21 mbgl (9.71 mAOD)	From the information displayed, there appears to be an agreement between the monitored levels and the NVC dune classification levels, however the NVC levels indicate a slighter larger range.
Slack 2(East Slack)	Min: 0.5 mbgl (8.9 mAOD) Max: -0.5 mbgl (9.9 mAOD)	Min: 0.61 mgbl (8.89 mAOD) Max: -0.21 mgbl (9.71 mAOD)	From the information displayed, there appears to be an agreement between the monitored levels and the NVC dune classification levels, however the NVC levels indicate a slighter larger range.

Ecohydrological Implementation Consideration

The water levels were relatively good and therefore the implementation works only need to remove a minimal amount of vegetation.

Monitoring Plan

To capture the full range of levels, one borehole will be installed (with micro-sitting) at Slack 2, installed to 8.4 mAOD (0.5m below the minimum water table level).

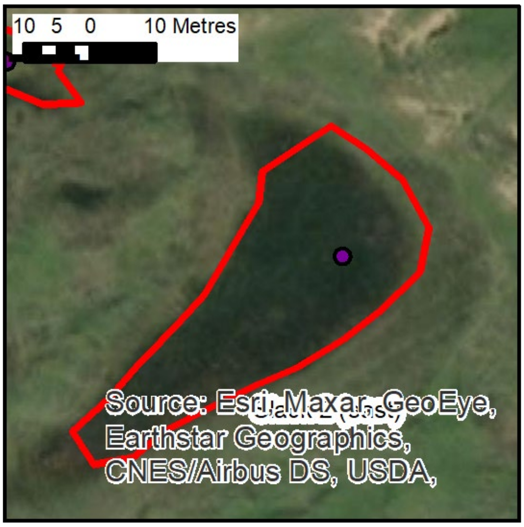


Figure 80: Location of East Slack borehole

Monitoring and Interventions (Slack 3 – Birch Slack)

Figure 81: Location of Birch Slack

Target Habitat

NVC category SD15. Annex I Humid Dune Slack H2190.

Initial Plan (to be implemented)

Remove minimum amount of material to remove vegetation and majority of roots, to a maximum depth of 20cm. Maintain water level as is.
Shallow scraping no more than 20cm. Graded to sides. No scraping around 5m buffer of *Drepanocladus sendtneri* locations.

Current Water Level Ranges – Monitoring

Slack 3 (south-east slack):

- Summer water levels from 1mbgl to 0.75mbgl (meters below ground level)
- Winter water level predominantly from 0.5 mbgl to 0 mbgl, with some small areas of standing water up to -0.5 mbgl.

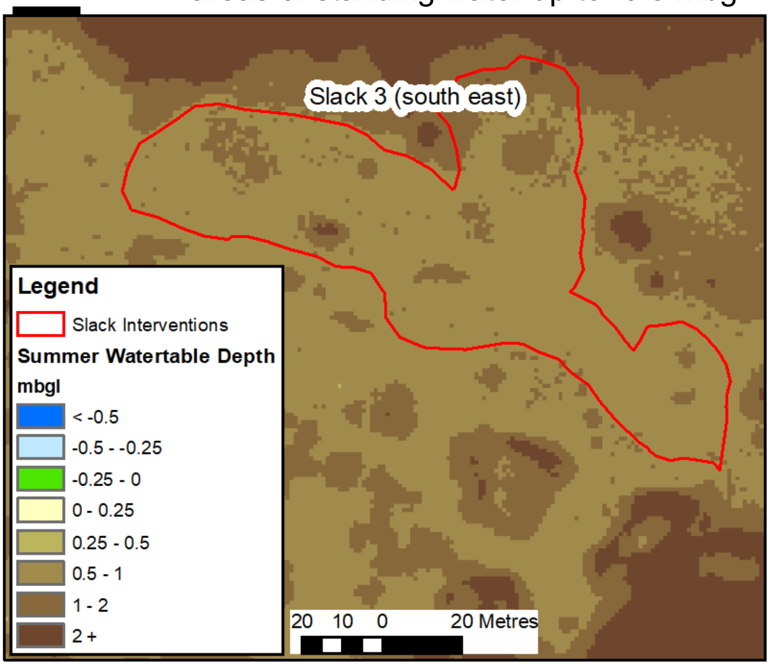


Figure 82: Summer water table depths.

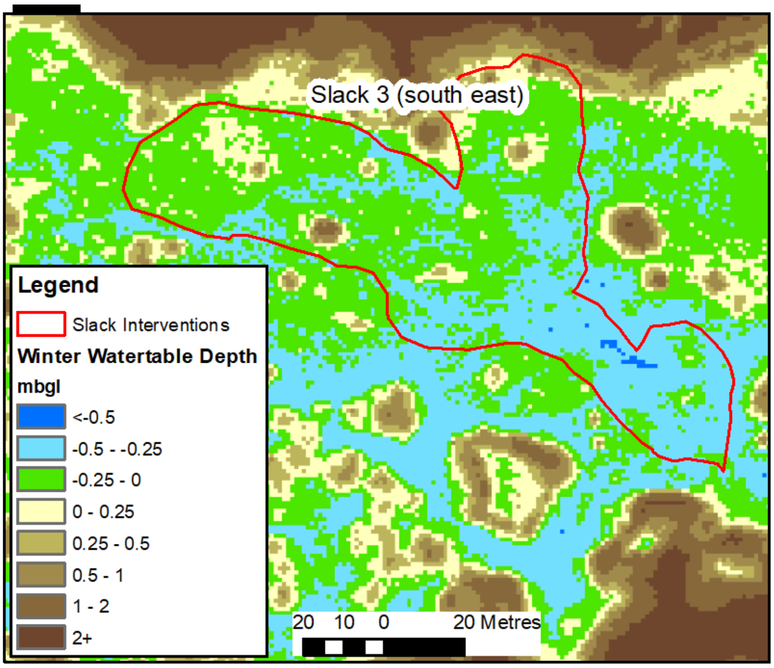


Figure 83: Winter water table depths.

Current Water Level Range – NVC

Slack 3 (South-east Slack):

- Mainly NVC dune type B/C (habitat SD15c) with small area of dune type F (habitat S24c in the north-west corner).
- Water range is likely to be between a minimum of 0.61 mbgl and maximum of 0.21 mbgl (meters below ground level).

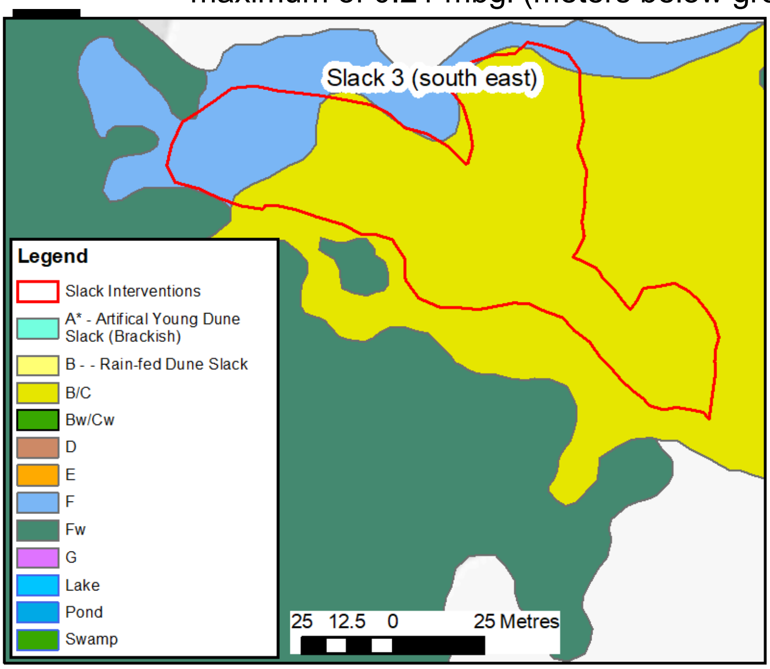


Figure 84: NVC dune type at Slack 3.

Monitoring water levels and NVC levels summary

Table 12: Monitoring eater levels and NVC levels summary.

Slack	Monitoring	NVC	Comment
Slack 3 (South-east Slack)	Min: 1 – 0.75 mbgl (10.1 mAOD) Max: -0.5 mbgl (11.6 mAOD)	Min: 0.61 mbgl (9.99 mAOD) Max: -0.21 mbgl (10.81 mAOD)	From the information displayed, there appears to be an agreement between the monitored levels and the NVC dune classification levels, however, the NVC levels indicate a slighter larger range.

Implementation Advice

Current water level as required – removal of sols should be kept to a minimum due to risk of over-deepening.

Monitoring Plan

To capture the full range of levels, a borehole will be installed (with micro-sitting):

- Installed to 9.28 mAOD (1.3 mbgl) (0.5m below minimum water table level)

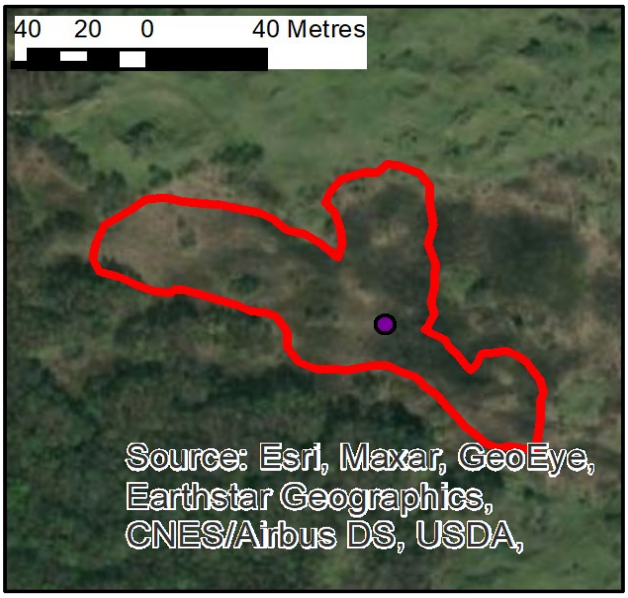


Figure 85: Slack 3 and location of borehole

Merthyr Mawr

Merthyr Mawr is a large humid dune system in South Wales, located approximately 5km south-west of Bridgend.

Baseline

Dune System Extent and Topography

The dune system is bounded by the Bristol Channel to the south, Porthcawl to the west and Afon Ogwr (River Ogmore) to the south-east, with a total area of 4.78km^2. Merthyr Mawr's topography is dominated by dune ridges and slacks, which are predominantly orientated west-east, extend up to 1km in length and reach heights of 25m. A variety of vegetation types overly the dunes, including unimproved grassland, bracken, woodland and scrubland. To the north, the topography rises steeply towards a limestone plateau, in which there are dry valleys which trend towards the dune system.

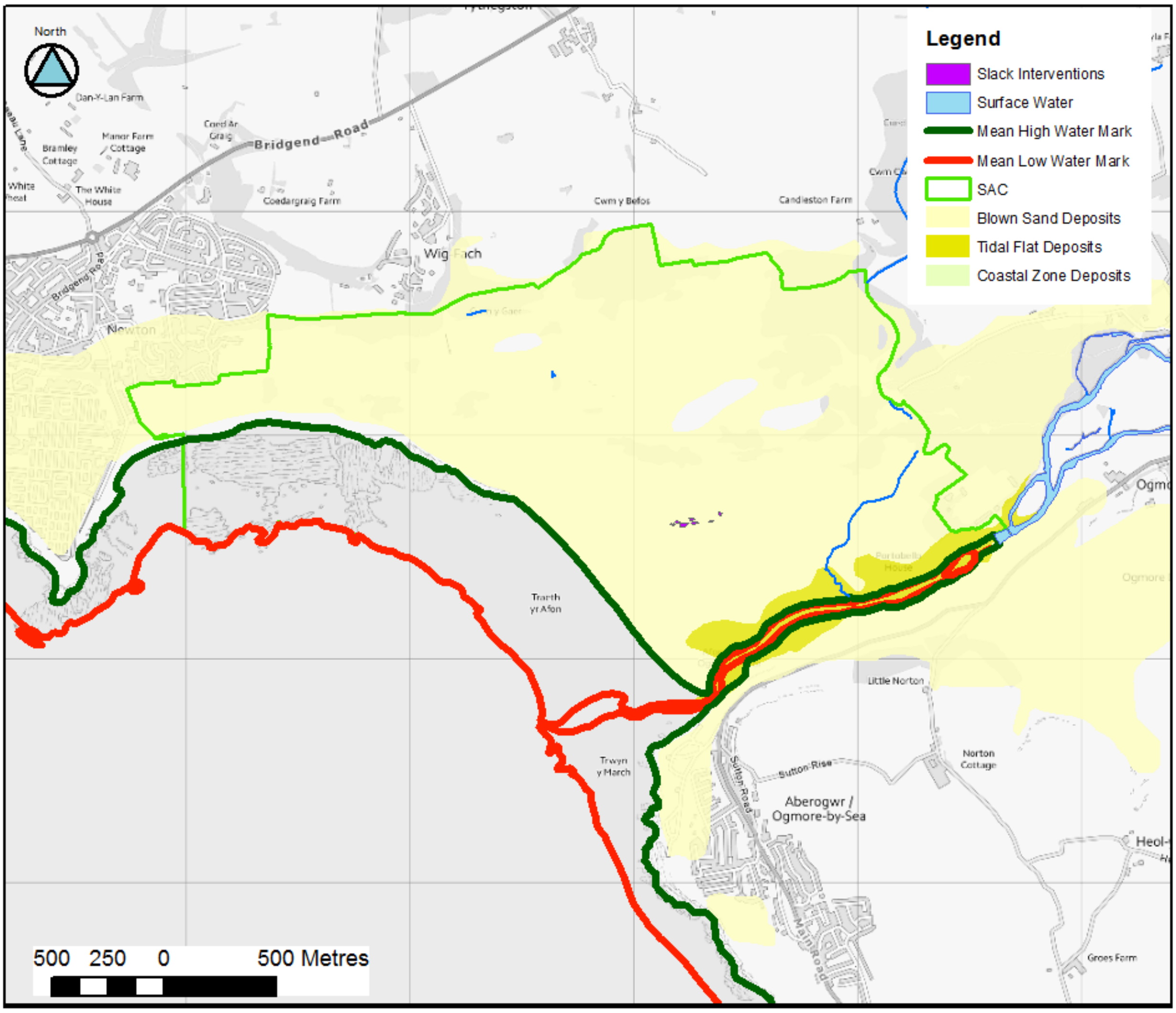


Figure 86: Merthyr Mawr SAC boundary and blown sands superficial deposits

Soils, Geology and Hydrogeology

Information on the soils and geology of the site and surrounding area has been derived from the Soil Survey of England and Wales (1983), 1:50,000 BGS geology mapping

(Sheet 5 Bridgend), and the BGS online borehole archive. The geology beneath the site and a map of superficial and bedrock geology are shown in Figure 87 and Figure 88

Table 13: Summary of geological stratigraphy

Age	Formation / Member / Group	Description	Thickness	Location	Hydrogeological Properties
Quaternary	Blown Sand	Fine Sands	Over 4. Maximum height of dunes c. 60mAOD	Dune System	Moderate Permeability
Quaternary	Marine Beach Deposits	Shingle, sand, silt and clay – in the form of dunes in association with the marine environment	Unknown	Coastline adjacent to site	Moderate Permeability
Jurassic	Blue Lias Formation	Limestone	Unknown	Exposure near the coastline, south of Ogmore River	High Permeability
Triassic	Mercia Mudstone Group	Variable, typically consisting of conglomerate and/or breccia with clasts derived locally from rocks lying immediately below the unconformable base of these deposits. The matrix generally consists of finer-grained rock fragments or, less commonly, siltstone, sandstone or micritic limestone.	Up to 100m	Exposed in the western part of the dune system	Low Permeability
Upper Devonian – Lower Carboniferous	Black Rock Limestone Group (Including Friars Point Limestone; Brofiscin Oolite Fm; and Barry Harbour Limestone Fm)	Thin to thick bedded, dark grey to black, fine – to coarse-grained packstones with subordinate thin beds of shaley argillaceous skeletal packstone and mudstone.	Up to 500m	Underlaying Quaternary deposits at site location	Moderate Permeability

Age	Formation / Member / Group	Description	Thickness	Location	Hydrogeological Properties
Lower Devonian	Lower Limestone Shale Group	Interbedded grey mudstones and thin to medium bedded skeletal packstones with gritstones. Thin units of calcite mudstone are locally present.	Up to 200m	Underlying Black Rock Limestone	Low Permeability
Lower Devonian	Old Red Sandstone	Grey-green fluvial sandstones and characteristic quartz pebble conglomerates	Up to 500m	Underlying Lower Limestone Shale Group	Moderate Permeability

Sources - http://www.largeimages.bgs.ac.uk/iip/mapsportal.html?id=1001754

Figure 87: Merthyr Mawr superficial geology

Figure 88: Merthyr Mawr bedrock geology
Contains Ordnance Survey data © Crown copyright and database right 2021. Derived from 1:50000 scale BGS digital data, British Geological Survey © NERC 2021.

Surface Water Features and Groundwater Boundaries

Afon Ogwr is the main watercourse in the area, which flows along the south-east boundary of the dune system where it meets the Bristol Channel. Dune slacks, which experience seasonally fluctuations in water levels, are the only other prominent surface water features within the site. Both the blown sand deposits and the underlying limestone bedrock are aquifers containing significant groundwater. Dune slacks derive their water from the blown sands aquifer, where direct rainfall is the main recharge mechanism. Whiteman et al., (2017) describes the occurrence of a thin clay layer under the blown sands, which acts as an aquitard between the two aquifer units. The largest dune slack 'Burrows Wells', in the centre of the site, formed due to a groundwater spring at the northern edge of the slack (Whiteman et al., 2017).

Site Data

The section below reviews the available site information. This can be used to inform the scrape intervention design and monitoring discussed above.

Water Level Monitoring Networks

Dipwell monitoring records are from 2010 to 2018 from the site and the data is displayed in Figure 90. This incorporates dip readings from a network of boreholes displayed in Figure 89.

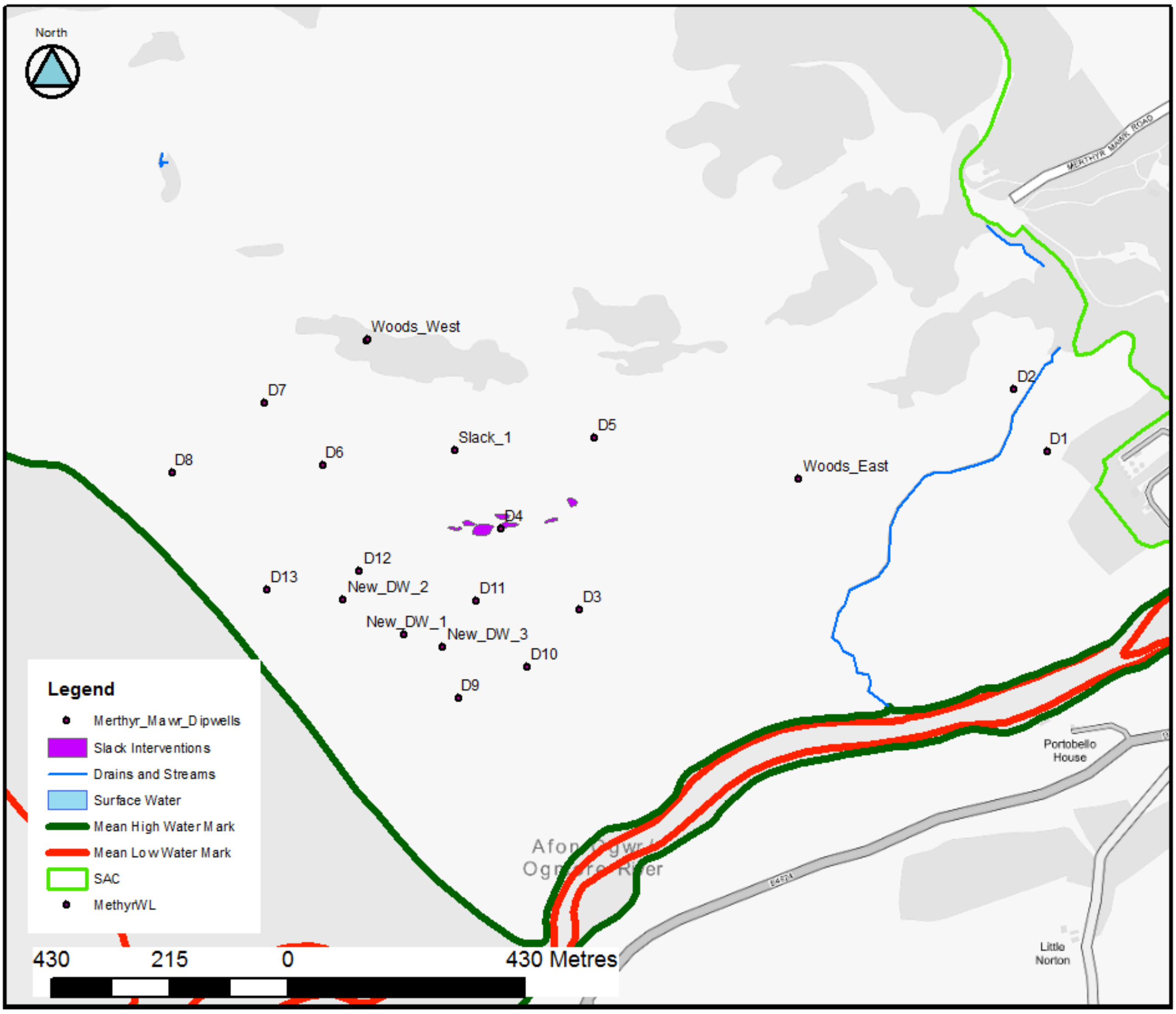


Figure 89: Merthyr Mawr dipwell monitoring network.

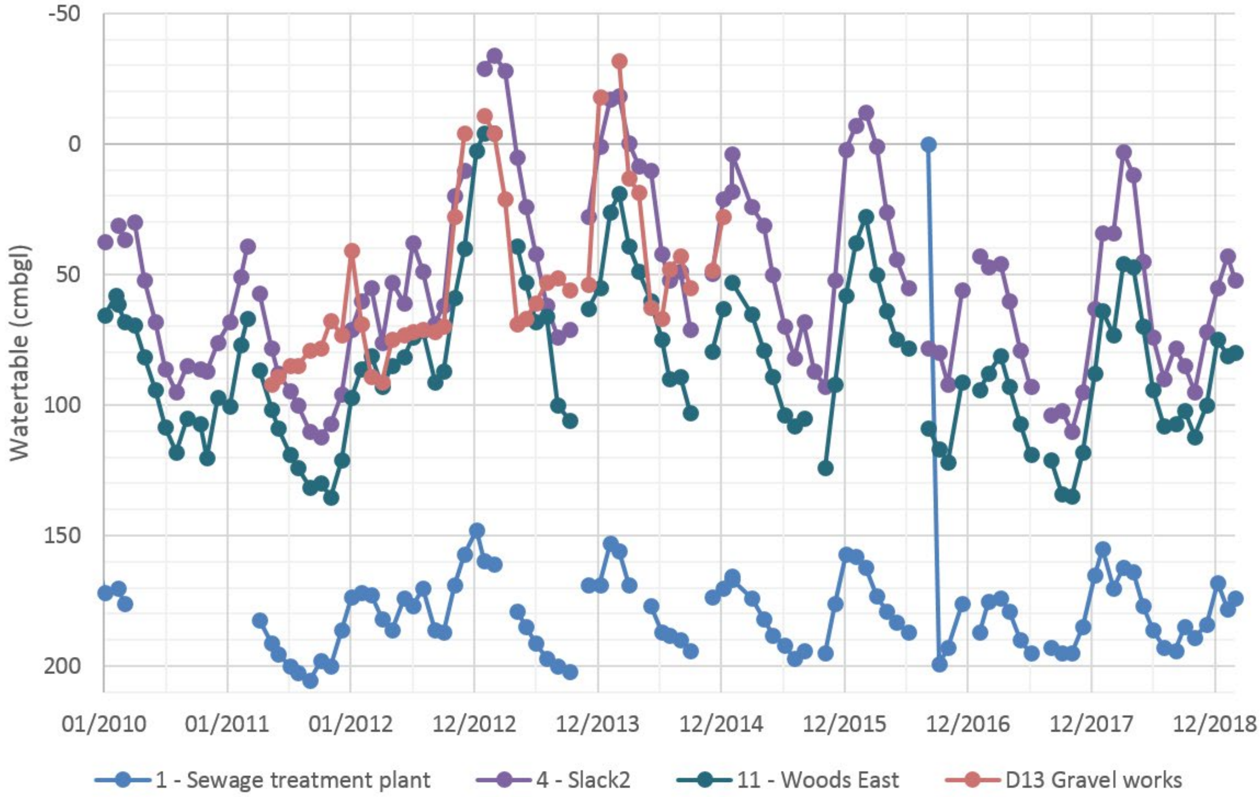


Figure 90: Merthyr Mawr hydrographs

Groundwater Surfaces

The hydrograph data record has been reviewed to produce a series of groundwater surfaces. The hydrographs have been reviewed to identify examples of historic summers and winters which were particularly wet and those which were drier than average. These are shown in Table 15. The water levels have been interpolated to produce groundwater surfaces in metres above ordnance datum (mAOD) and metres below ground level (mbgl). The extent of the surface produced is limited to where there is sufficient density of dipwells. These groundwater surfaces have been subtracted from the LIDAR topography surfaces to produce a depth to groundwater grid.

Table 14: Example Periods comprising particularly wet, or dry, summers and winters

Type	Date
Wet Winter	28/02/2013
Dry Winter	06/02/2019
Wet Summer	01/08/2013
Dry Summer	02/09/2011

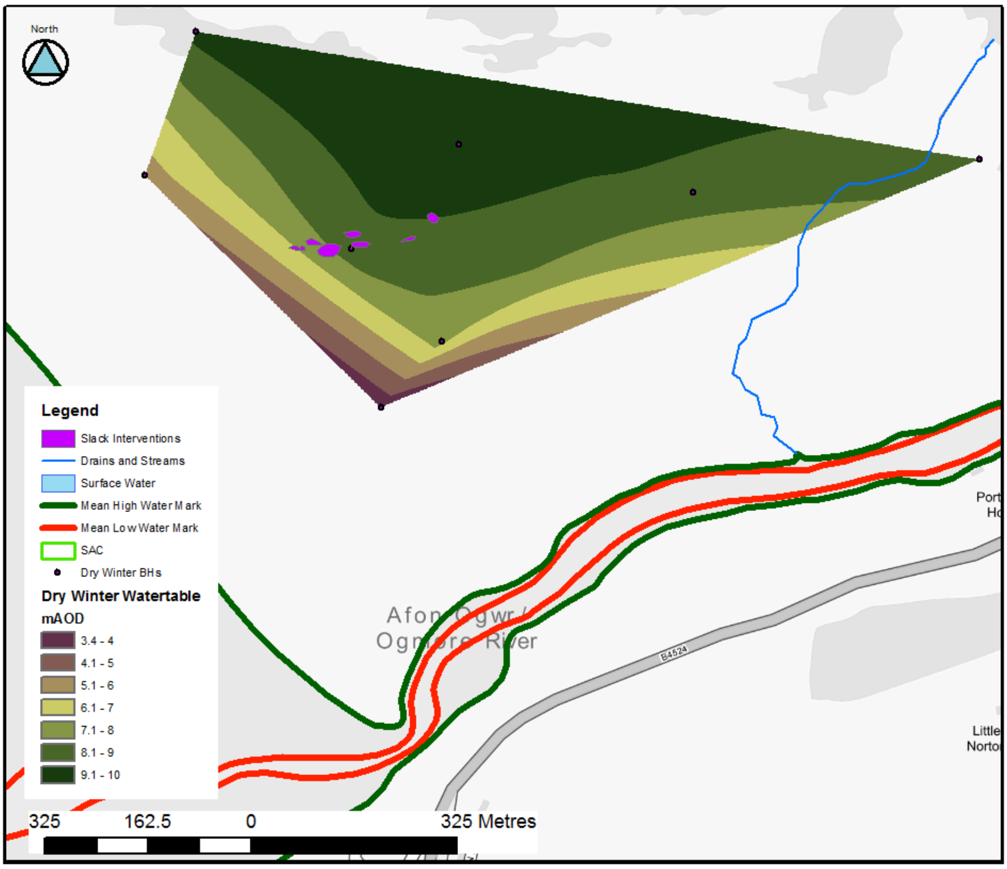


Figure 91: Dry Winter Water table

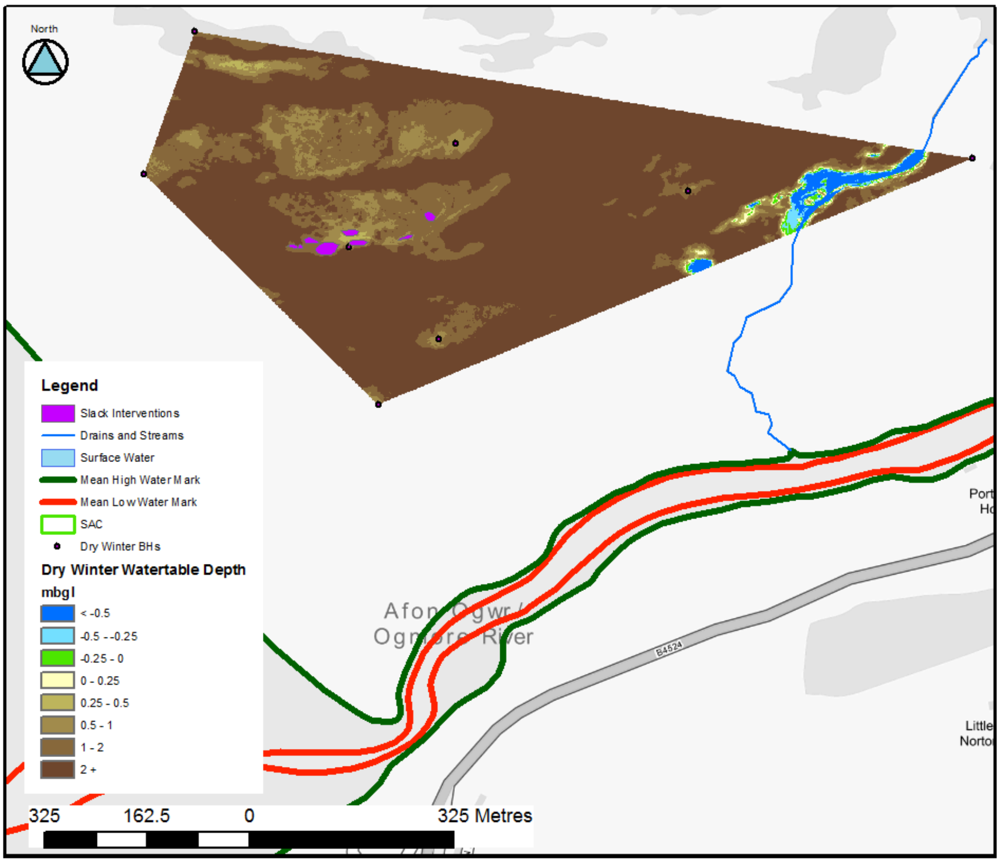


Figure 92: Dry Winter Water table

Note: Top figure water level is in mAOD and bottom figure is in mbgl

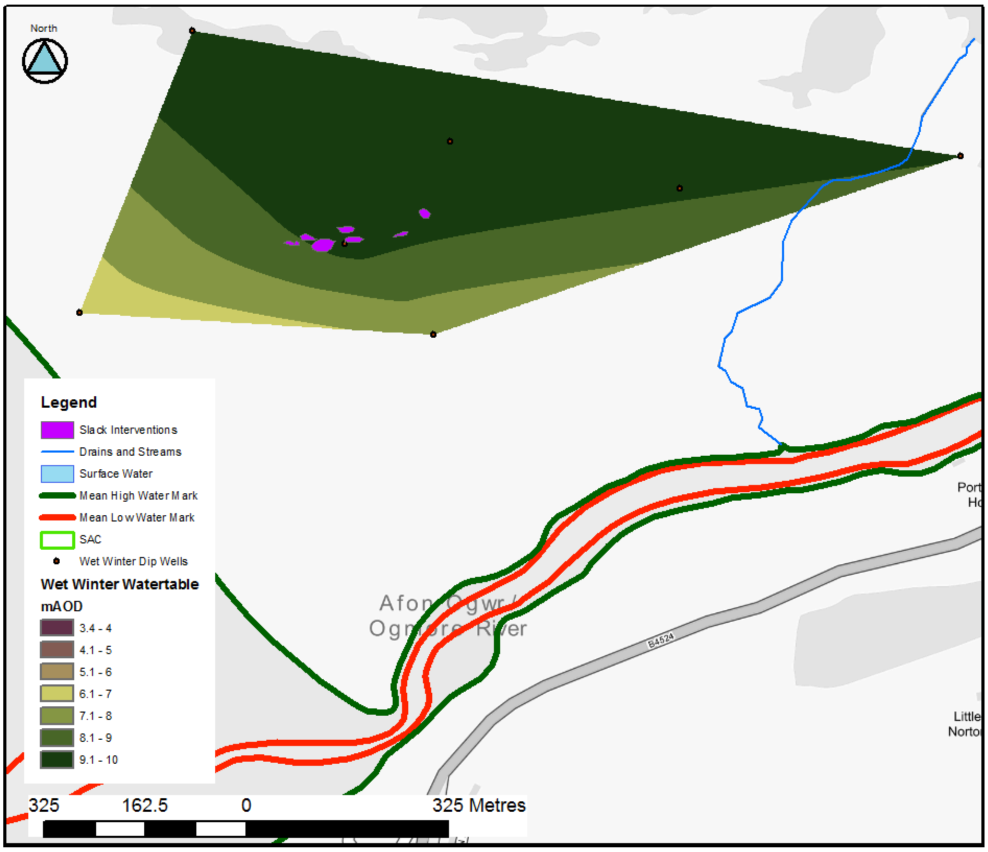


Figure 93: Wet Winter Water table

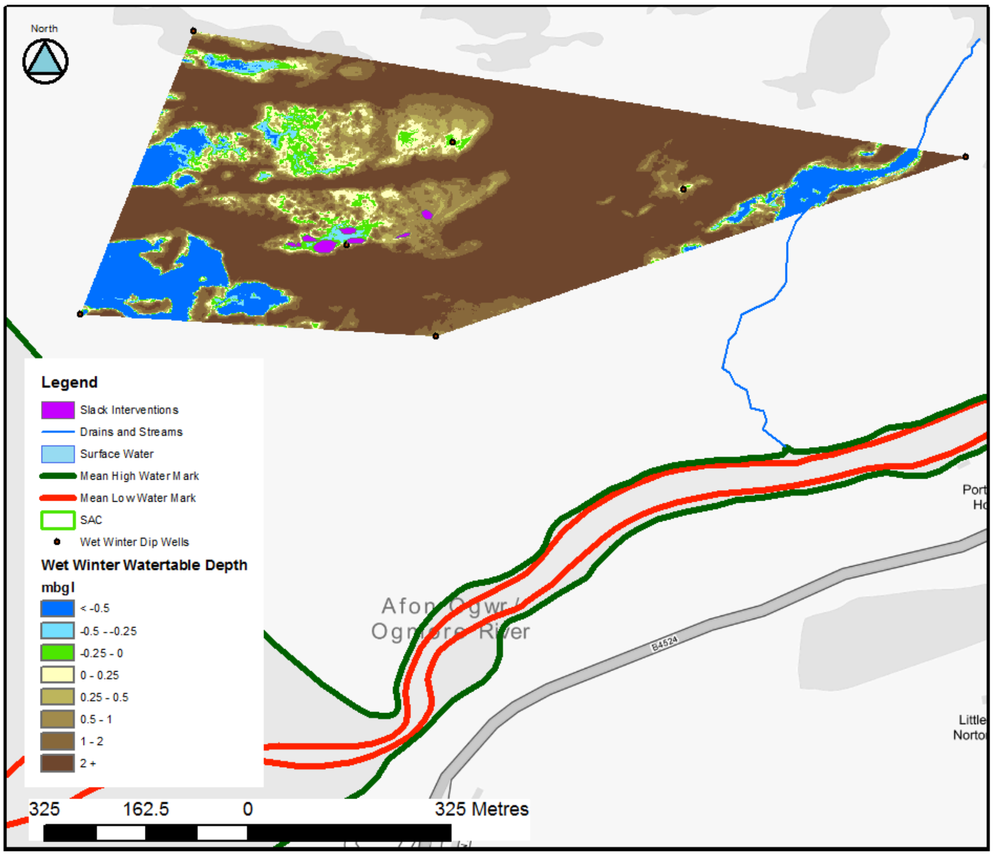


Figure 94:

Note: Top figure water level is in mAOD and bottom figure is in mbgl.

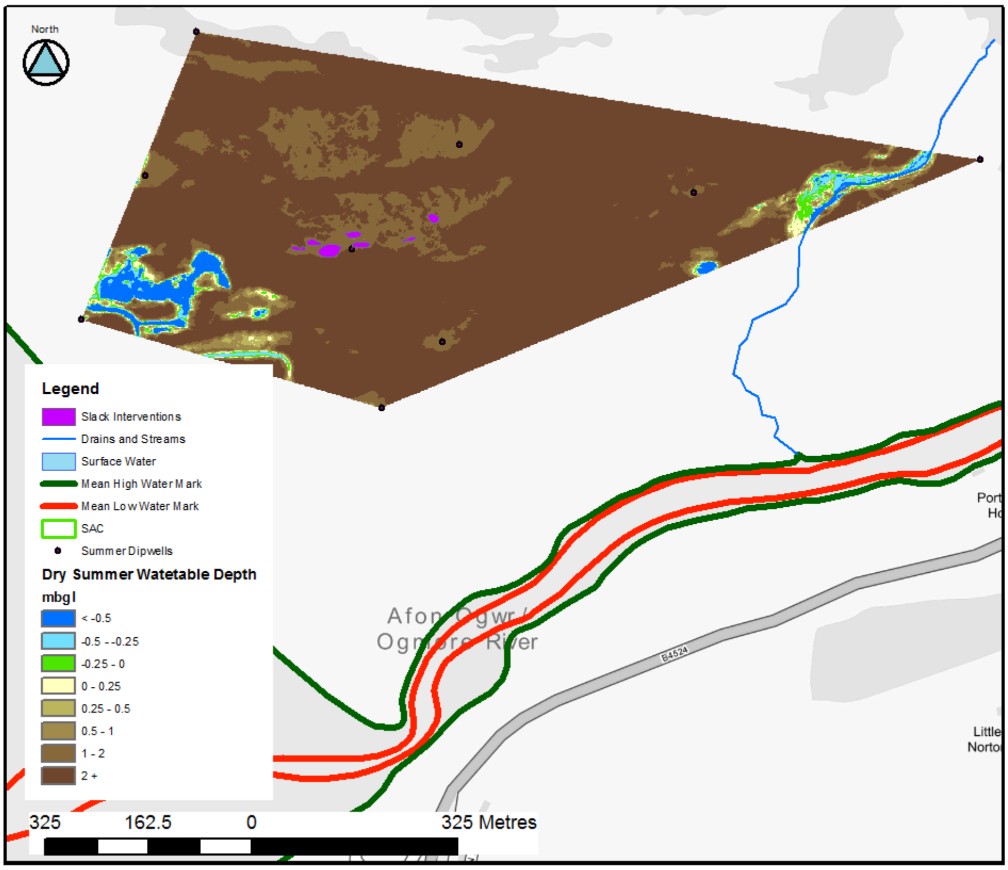


Figure 95: Dry Summer Water Level

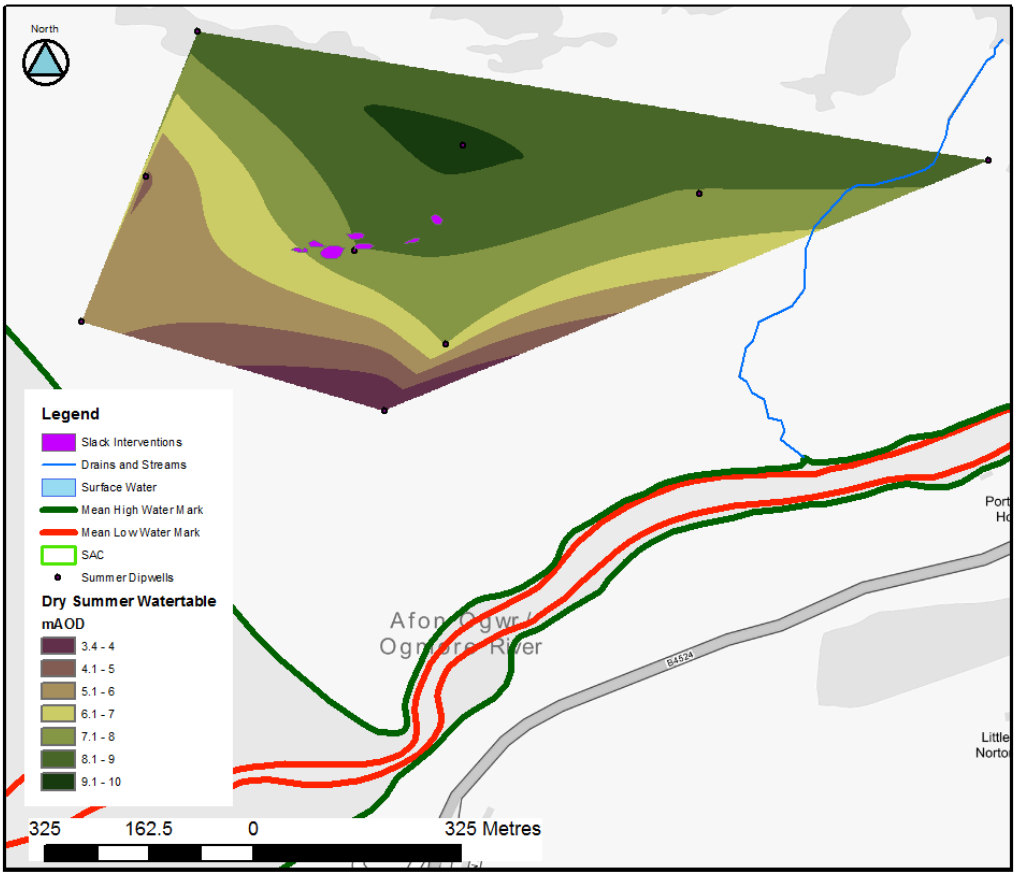


Figure 96: Dry Summer Water Level

Note: Top figure water level is in mAOD and bottom figure is in mbgl

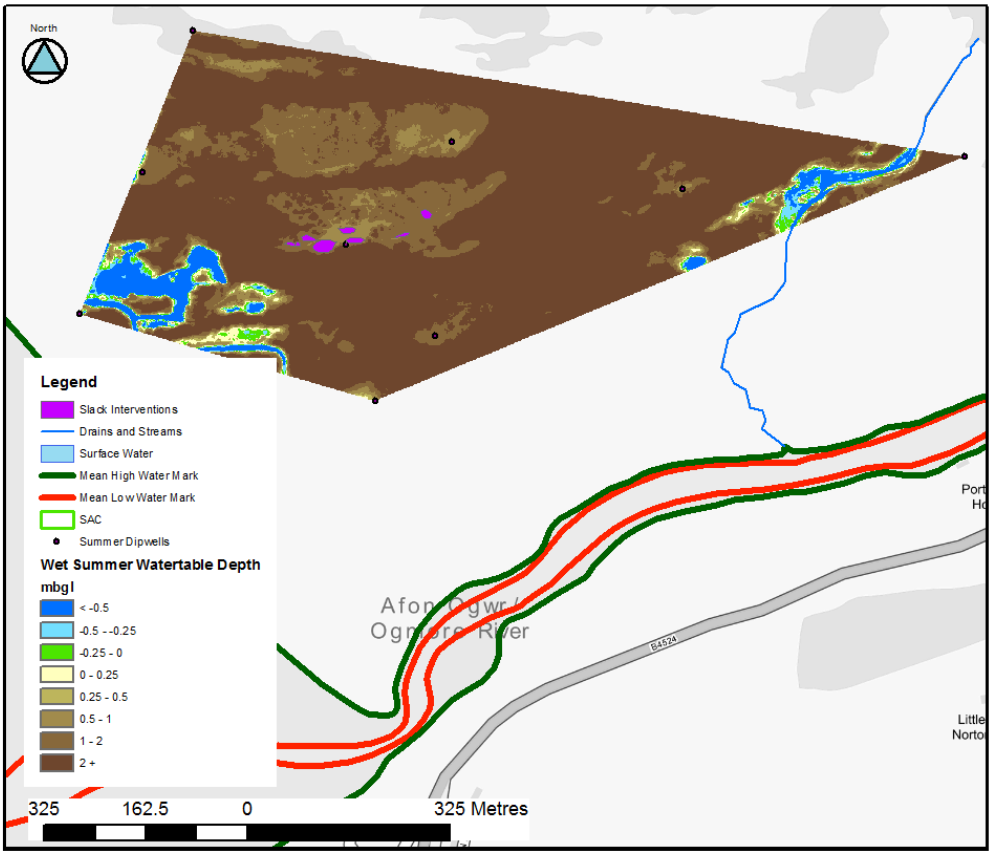


Figure 97: Wet Summer Groundwater level

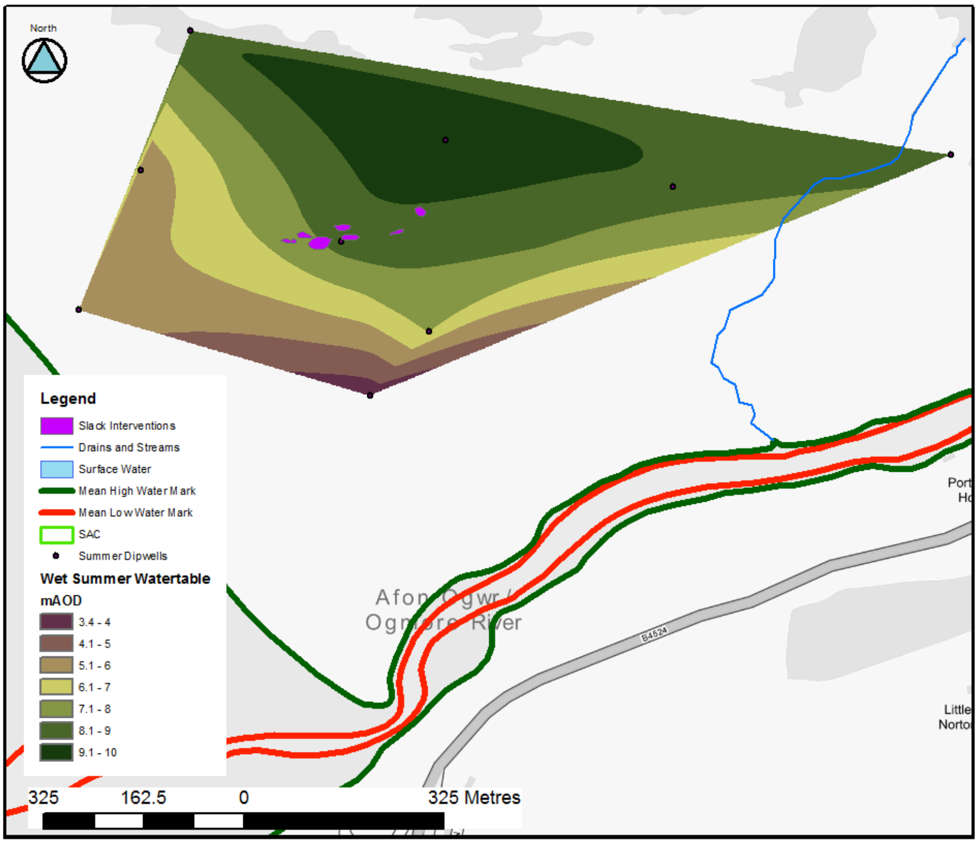


Figure 98: Wet Summer Groundwater level

Note: Top figure water level is in mAOD and bottom figure is in mbgl

NVC Surveys

Figure 18 provides a classification of the slacks. Of note in the distribution of the slacks is the limited extent of Type A slacks. This reflects the morphology of the foredune with steeply rising ground at the edge of the beach.

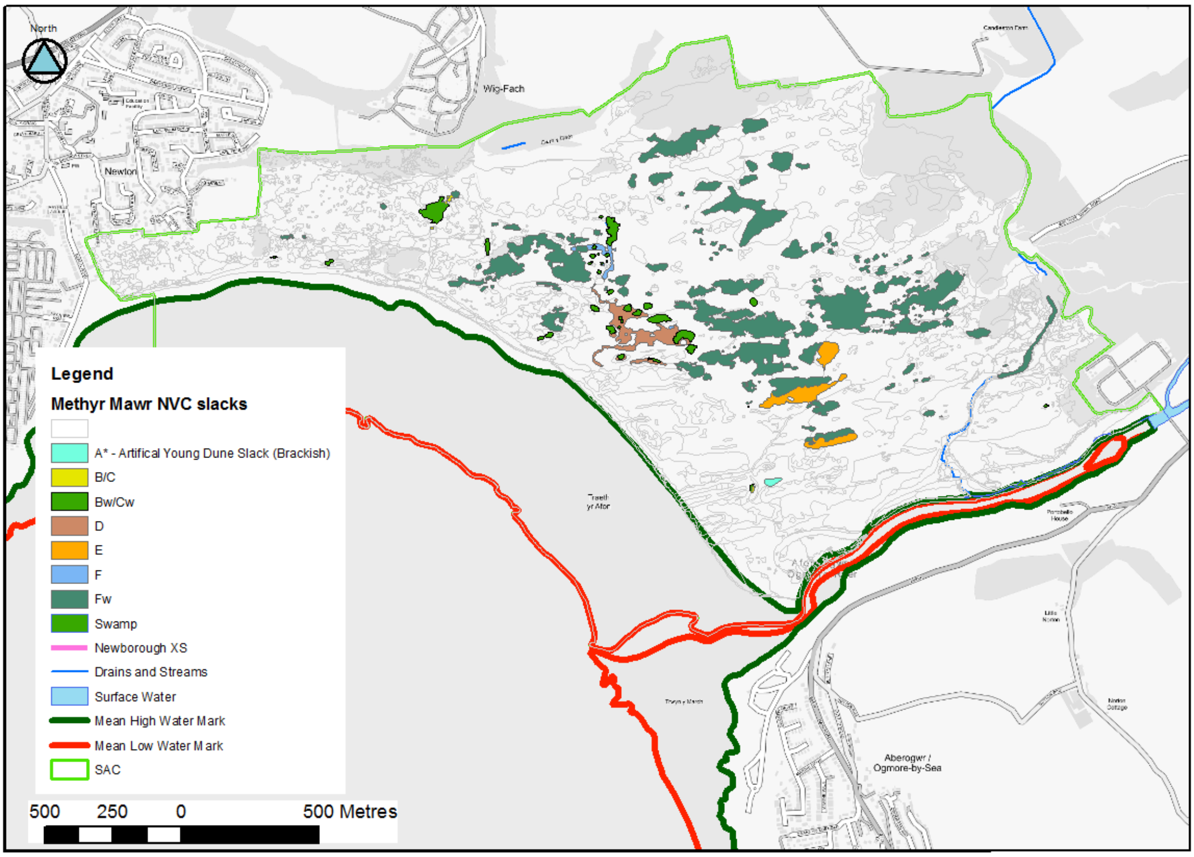


Figure 99: NVC/WETMEC Slack Classification

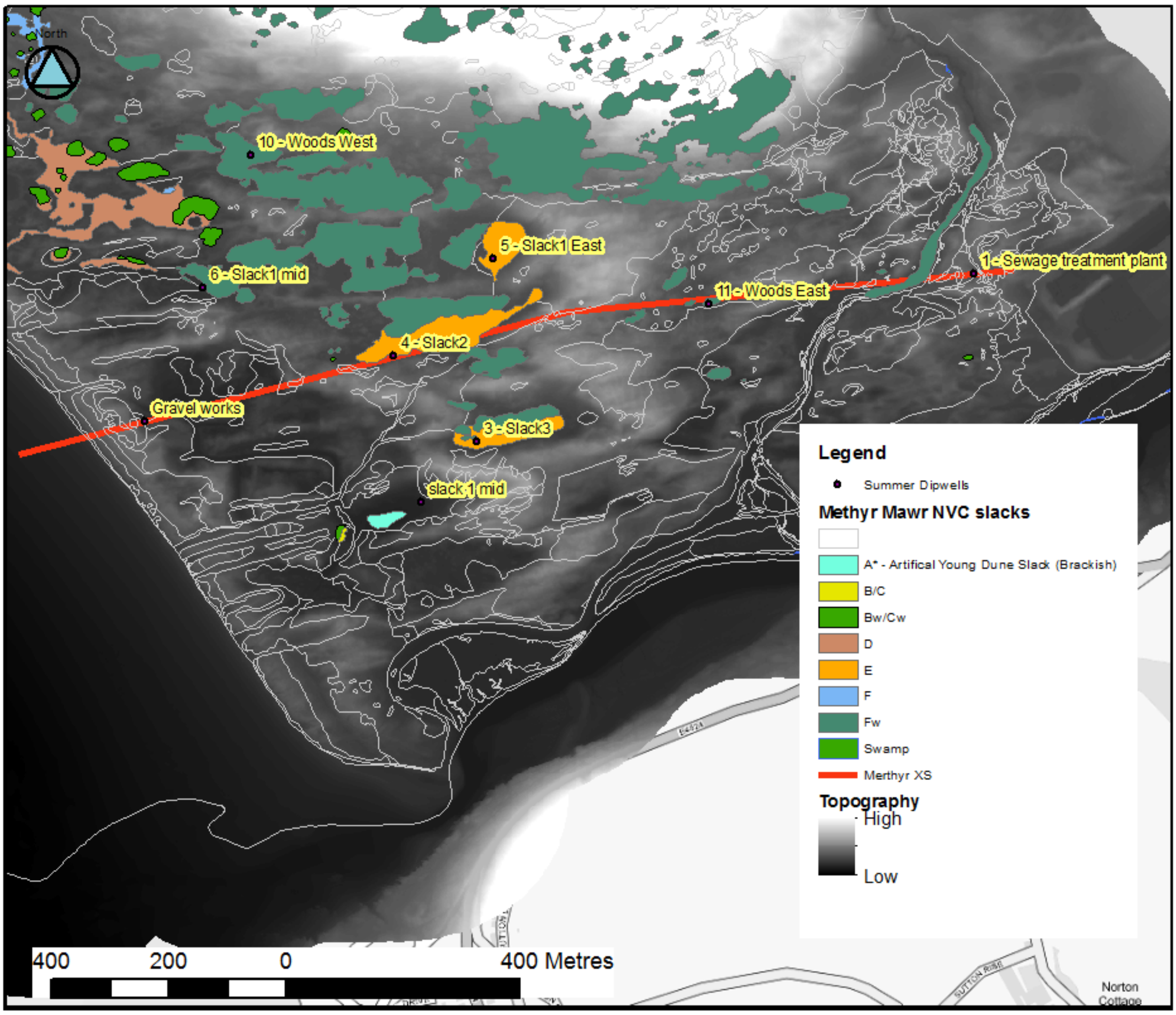


Figure 100: NVC slacks with topography

Note – Merthyr Mawr XS = Line of Cross Section in Figure 99

Conceptual Model

A hydrogeological conceptual model is "a description of how a hydrogeological system is believed to behave" (Environment Agency, 2002). It describes "how water enters an aquifer system, flows through the aquifer system and leaves the aquifer system" (Rushton, 2003).

The hydrogeological conceptual model for the site is shown in Figure 101.

Figure 101, with line of cross section shown in Figure 99, which bisects one of the intervention areas. NVC codes for specific dune habitats are displayed, in additional the locations of dipwells. The main features include:

- Topography:
  - Dune system comprising dune ridges and slacks, which extend up to 1km in length and predominantly trend west-east. Dune ridges reach a maximum height of 25mAOD. Inland to the north, the topography rises steeply towards a limestone plateau, in which there are dry valleys which trend towards the dune system.
- Geology and hydrogeology:

    - Blown sands superficial deposits, with medium permeability, outcrop at the ground surface forming the extensive dune system. Limestone (Black Rock Group), of moderate permeability underlies the sands in much of the dune system, while low permeability mudstone (Mercia Mudstone Group) is exposed in the north-east part of the site.
    - The underlying limestone is likely to have a groundwater connection with the blown sands superficial deposits and the corresponding dune slacks above.
- Infiltration and recharge:
    - Main input to the blown sands dune aquifer is from direct rainfall recharge throughout the site area. There is likely to be some groundwater input from alluvium and glaciofluvial deposits to the east, in addition to input from limestone bedrock to the east.
- Groundwater surface interactions:
    - Groundwater typically has a 1-1.5m range of levels across the site. The degree to which groundwater pools at the surface is controlled by the surface topography. In some areas emergent groundwater can pool, and in others it is removed via surface water flow paths. Different dune slack types and associated vegetation types depend on the nature of the water table and dune condition at each specific location.
- Conceptual Model through monitoring area (Figure 101)
    - The model displays a south-west to north-east cross-sectional view through the open part of the dune system. The water level range shows the degree to which ponded water in the slacks varies seasonally. Habitat classifications related to each dune sack are also represented in the model. The intervention area is currently classed as D4 slack with Sd16cE habitats.

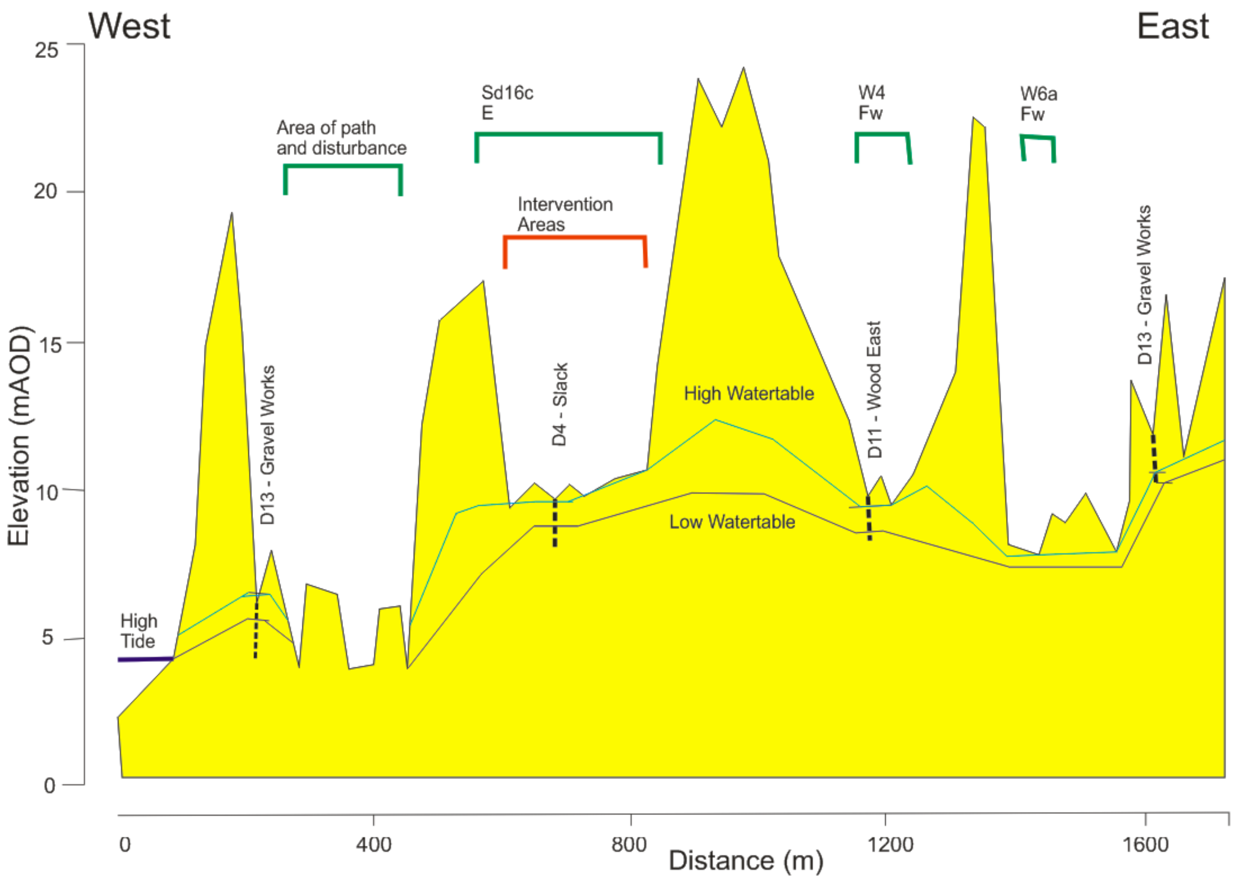


Figure 101: Conceptual model cross section

Interventions and Monitoring

The Sands of LIFE project has identified several Slack Intervention Areas across Merthyr Mawr, where reprofiling works will and have been designed to improve the habitats. The table below provides a summary of the Slack Intervention Areas, the current vegetation, available water levels and consideration of the monitoring requirements.

Monitoring and Interventions – Merthyr Mawr

Figure 102: Location of Merthyr Mawr slack interventions

Target Habitat

Annex I Humid Dune Slack H2190. Petalwort S139

Four NVC types are associated with the habitat type H2190: SD13. SD14, SD15 and SD17. (Houston, 2008)

Plan – Implementation Plan

Remove all vegetation to bare sand to create early successional stages in 7 areas in relatively close proximity.
Create flooding in Winter, damp conditions in Summer.
Shallow scraping no more than 30cm. Graded to sides

Current Water Level Ranges – Monitoring

Hydrograph on the south side of Slack 5 show a range between 0.3 magl and 1.1 mbgl. Slacks 4 and 5 have the shallowest water table with the depth deepening to the east and west.

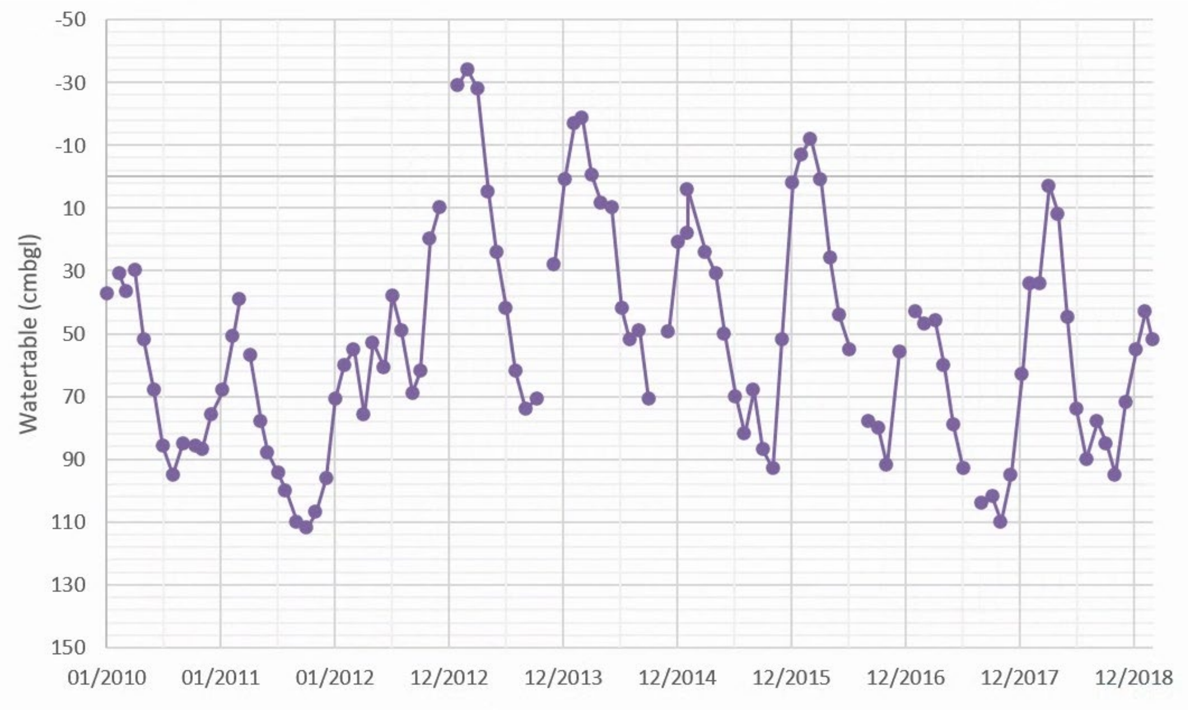


Figure 103: Slack 5 hydrograph.

Table 15: Water level at Merthyr Mawr Slacks

Slack	Summer water level	Winter water level
Slack 1	1.3 mbgl to 1.7 mbgl	- 0.25 mbgl (standing water) to 1.6 mbgl
Slack 2	1.3 mbgl to 1.7 mbgl	-0.25 mbgl (standing water) to 1.4 mbgl
Slack 3	0.9 mbgl to 1.4 mbgl	-0.25 mbgl (standing water) to 1.0 mbgl
Slack 4	0.75 mbgl to 1.1 mbgl	-0.3 mbgl (standing water) to 0.4 mbgl
Slack 5	0.7 mbgl to 1.1 mbgl	-0.5 mbgl (standing water) to 0.6 mbgl
Slack 6	1.3 mbgl to 1.6 mbgl	0.2 mbgl to 0.8 mbgl
Slack 7	1 mbgl to 1.8 mbgl	0.5 mbgl to 1.2 mbgl

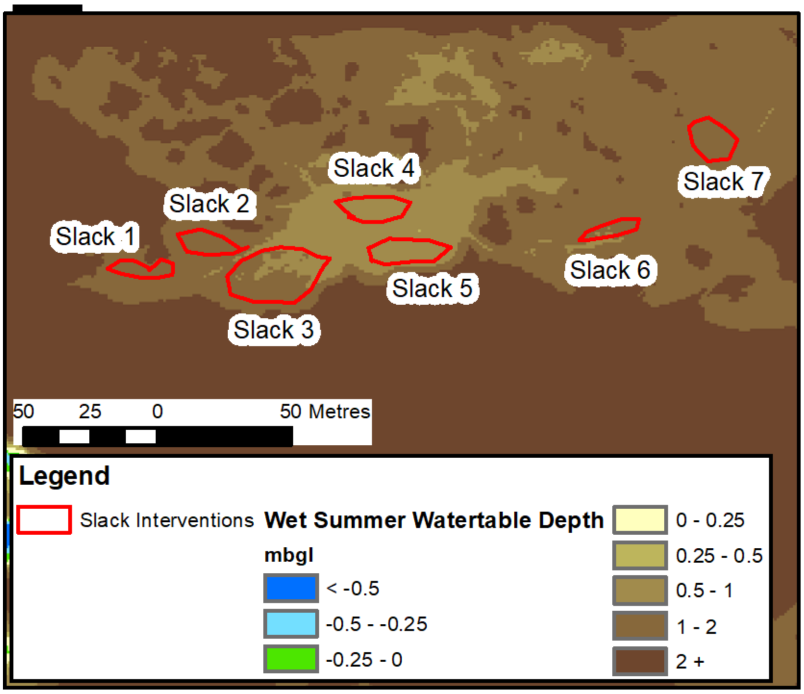


Figure 104: Wet Summer Water Table

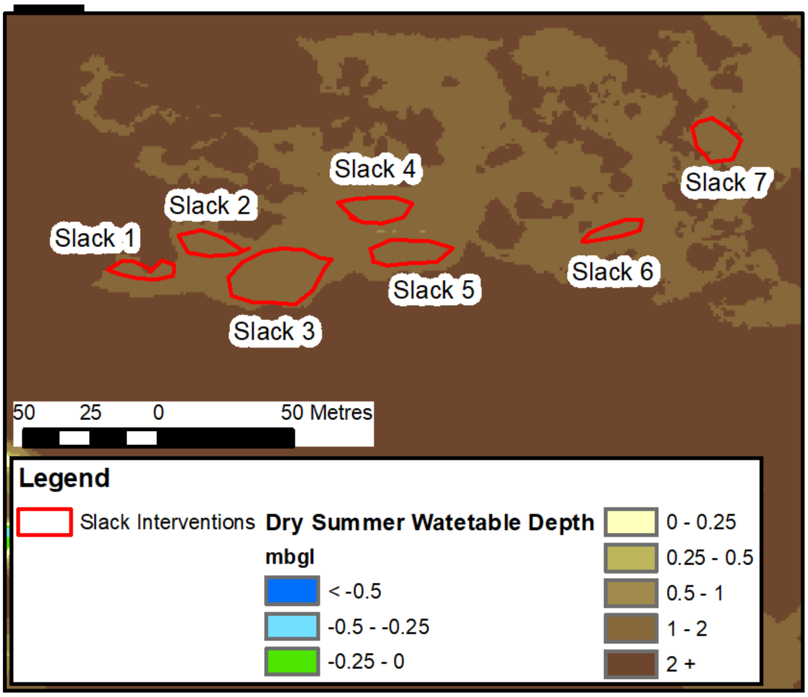


Figure 105: Dry Summer Water Table

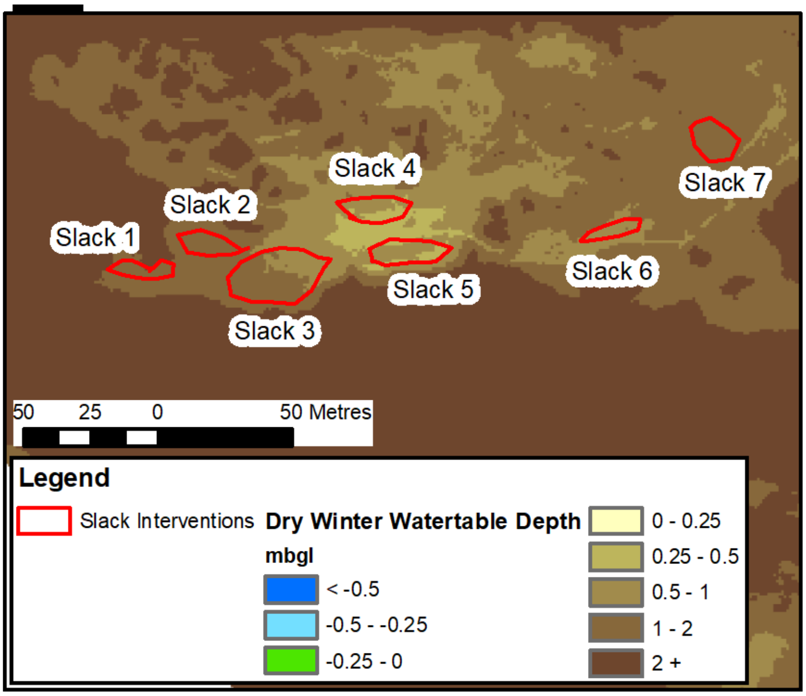


Figure 106: Dry winter water table

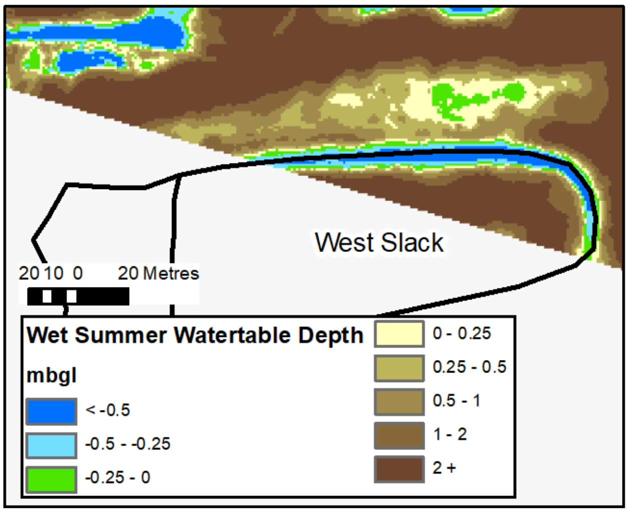


Figure 107: Wet Summer water table at West Slack

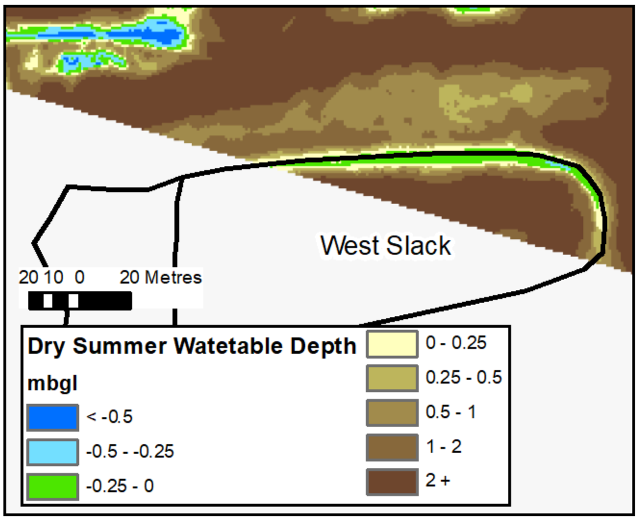


Figure 108: Dry summer water table at West Slack

Current Water Level Range – NVC

Slack 1 and 2: no dune slack habitats
Slack 3-7:

- Dune type E, NVC habitat SD16c
- Water level range is likely to be between 1mbgl and 0.25mbgl

Monitoring water levels and NVC levels summary

Table 16: Summary of water and NVC levels at Merthyr Mawr slacks

Slack	Monitoring	NVC
Slack 1	Min: 1.7 mbgl (6.7 mAOD) Max: 0.25 mbgl (8.95 mAOD)	Dry habitats – water table at depth
Slack 2	Min: 1.7 mbgl (7.0 mAOD) Max: 0.25 mbgl (9.25 mAOD)	Dry habitats – water table at depth
Slack 3	Min: 1.4 mbgl (7.0 mAOD) Max: 0.25 mbgl (9.25 mAOD)	Water level range is likely to be between 1mbgl and 0.25mbgl
Slack 4	Min: 1.1 mbgl (7.2 mAOD) Max: 0.3 mbgl (9.45 mAOD)	Water level range is likely to be between 1mbgl and 0.25mbgl
Slack 5	Min: 1.1mbgl (7.3 mAOD) Max: 0.5magl (7.8 mAOD)	Water level range is likely to be between 1mbgl and 0.25mbgl
Slack 6	Min: 1.6mbgl mbgl (7.7mAOD) Max: 0.2mbgl (9.7 mAOD)	Water level range is likely to be between 1mbgl and 0.25mbgl
Slack 7	Min: 1.8mbgl mbgl (8.3 mAOD) Max: 0.5mbgl (9.8 mAOD)	Water level range is likely to be between 1mbgl and 0.25mbgl
West Slack	Min: 1.5mbgl (2.66mAOD) Max: 0mbgl (gound surface at 4.16mAOD)	No recorded slack habitats

Ecohydrological Implementation Considerations

Wetter (lower) dune slacks may only need a limited scrape of the ground surface. Those to the East and West needed to be slightly deeper.

Monitoring Plan

Monitoring should be in slack 3 to monitor a formerly wet slack. To capture the full range of levels, the Slack 3 borehole should be installed to at least 1.6mbgl. If possible, the existing borehole in the slack should also be utilised.

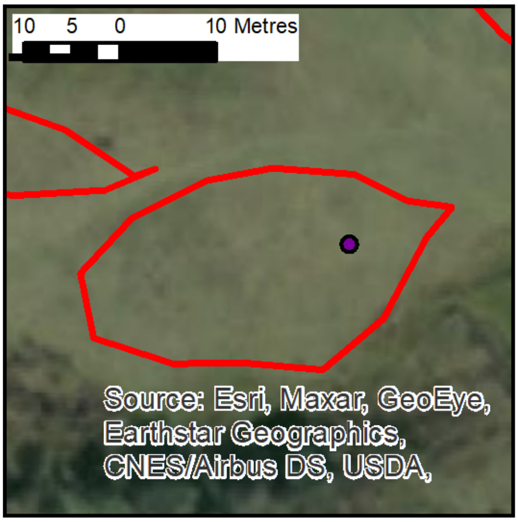


Figure 109: Slack 3 borehole

The West Slack borehole should be installed to at least 1.6mbgl to capture the full range of levels.

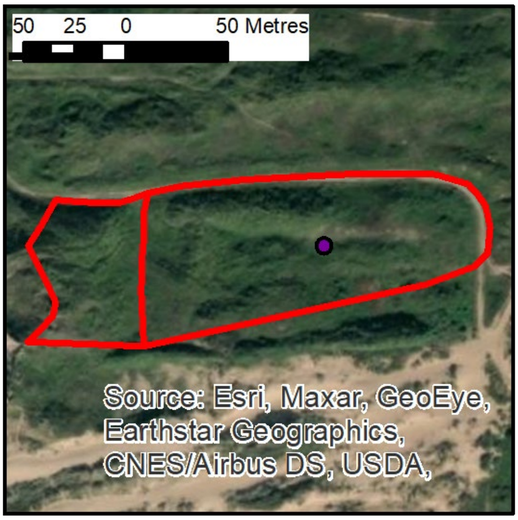


Figure 110: West Slack borehole

References

Clarke D, Sanitwong Na Ayutthaya S. (2010), Predicted effects of climate change, vegetation and tree cover on dune slack habitats at Ainsdale on the Sefton Coast, UK. J Coast Conservation p115–25

Cottrell, A. 2010. Construction of a groundwater model for Kenfig Pool and Dunes. MSc Environmental Hydrogeology. Cardiff University.

Davy et al., (2006). Development of eco-hydrological guidelines for dune habitats – Phase 1 available at http://publications.naturalengland.org.uk/publication/61018
Davy et al., (2010). Eco-hydrological Guidelines for Wet Dune Habitats Phase 2 (available at https://www.gov.uk/government/publications/eco-hydrological-guidelines-for-wet-dune-habitats

Curreli et al., (2013). Eco-hydrological requirements of dune slack vegetation and the implications of climate change, Science of the Total Environment 443, 910-919

Jones, P.S. 1993. Ecological and hydrological studies of dune slack vegetation at Kenfig National Nature Reserve, Mid Glamorgan. Ph.D Thesis No Dx201209. University College of Wales.

Jones, P.S., Farr, G., Low, R. and Etherington, J.R., 2017. Ecohydrological studies of dune slack vegetation at Kenfig dunes, South Wales, UK. Journal of Coastal Conservation, 21(5), pp.623-630.

Pye, K. and Blott, S.J. (2014) Pembrey Burrows - A Geomorphological Appraisal and Options for Dune Rejuvenation. KPAL Report to Natural Resources Wales. NRW Evidence Report 42, July 2014

Whiteman M.I., Farr G., Jones P.S., Schutten A., and Papaioannou A. (2017) Merthyr Mawr: a case study for the assessment of nitrate at humid dunes in England and Wales, Journal of Coast Conservation

Data Archive Appendix

Data outputs associated with this project are archived in Sands of LIFE (SoLIFE) DMS folders (D1 Physical Monitoring) on server–based storage at Natural Resources Wales.

The data archive contains:

[A] The final report in Microsoft Word and Adobe PDF formats.

[B] Collated dipwell data provided by NRW, SoLIFE and JBA in Excel format.

[C] A series of GIS layers on which the maps in the report are based with a series of word documents detailing the data processing and structure of the GIS layers.

Metadata for this project is publicly accessible through Natural Resources Wales' Library Catalogue https://libcat.naturalresources.wales (English Version) and https://catllyfr.cyfoethnaturiol.cymru (Welsh Version) by searching 'Dataset Titles'. The metadata is held as record no NRW_DS125446.

Cyfoeth Naturiol Cymru
Natural Resources Wales

Published by:
Natural Resources Wales
Maes-y-Ffynnon
Ffordd Penrhos
Bangor, Gwynedd
LL57 2DW

03000 653 000

Further copies of this report are available from:

Email: library@cyfoethnaturiolcymru.gov.uk