REPORT

Sirius Minerals North Yorkshire Polyhalite Project: Section 73

'Shadow' Habitats Regulations Assessment Report.

Client: Sirius Minerals PLC

Reference: 40-RHD-WS-83-WM-RP-0001 REV 3

Revision: 03/Final

Date: 03 November 2017

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Enhancing Society Together

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Document title:	Sirius Minerals North Yorkshire Polyhalite Project: Section 73
Document short title:	'SHADOW' HABITATS REGULATIONS ASSESSMENT REPORT
Reference:	40-RHD-WS-83-WM-RP-0001 REV 3
Revision:	03/Final
Date:	03 November 2017
Project number:	PB1110
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Date / initials:	02/11/2017 MH
Approved by:	Matthew Hunt
Date / initials:	02/11/2017 MH

Classification
Project related

MANAGEMENT SYSTEM CERTIFICATION
DNV·GL
ISO 9001 ISO 14001
OHSAS 18001

Royal HaskoningDHV

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1 Introduction

1.1.1 In 2015 Sirius Minerals plc (Sirius Minerals) was granted planning permission (NYM/2014/0676/MEIA) to develop a polyhalite mine and underground Mineral Transport System (MTS), subject to conditions.

1.1.2 A Habitats Regulations Assessment (HRA) for the project was prepared alongside the Environmental Statement (ES) that accompanied the planning application (Royal HaskoningDHV, 2014). It considered all elements of the North Yorkshire Polyhalite Project, i.e. Woodsmith Mine, MTS and intermediate sites, Material Handling Facility (MHF) and Harbour facility. It concluded the following:

- The Harbour facility and MHF would not affect the structure or function of the Teesmouth and Cleveland Coast Special Protection Area (SPA) and Ramsar site; and
- The Woodsmith Mine or MTS sites would not affect the structure or function of the North York Moors Special Area of Conservation (SAC) or SPA as mitigation measures (including groundwater control measures) to limit any potential effect would be implemented.

1.1.3 Under Regulation 61 of the Habitats Regulations[1], the North York Moors National Park Authority (NYMNPA) as the Competent Authority, commissioned Amec Foster Wheeler (June, 2015) to undertake an Appropriate Assessment of the scheme elements in June 2015. This is the adopted assessment for the consented scheme and it concluded the following:

- The effects of dewatering at the Woodsmith Mine site on the integrity of the SPA and SAC would be avoided through the implementation of appropriate mitigation measures;
- Adverse effects on the integrity of the SPA and SAC from nitrogen and dust emissions would be avoided through the implementation of appropriate mitigation measures, ensured by planning condition; and
- The Harbour facility and MHF would not give rise to adverse effects on the integrity of the Teesmouth and Cleveland Coast SPA and Ramsar site.

1.1.4 In December 2016, a non-material amendment to the approved scheme was granted by the NYMNPA under Section 96A of the Town and Country Planning Act 1990. The approved amendments were:

- Realignment of the main internal access road linking the approved welfare building complex and the mine site; and
- Minor amendments to the drill pad levels.

1.1.5 In addition to the above applications, information has been submitted to partially discharge conditions attached to the planning permission NYM/2014/0676/MEIA and enable the initial stages of construction. Works commenced at the site on 1 April 2017.

1.1.6 Further minor material amendments to the scheme, limited to Works at Woodsmith Mine (formerly Dove's Nest Farm), are currently being sought via an application submitted under Section 73 of the Town and Country Planning Act 1990 (the S73 application, see **Section 2**). That application was accompanied by a Supplementary Environmental Statement (SES) (Lichfields, 2017) which considers any potentially altered environmental effects.

1.1.7 Due to the nature of the S73 amendments, it has been agreed with the NYMNPA that an updated review of any effects on European Designated sites (e.g. SAC, SPA) or Ramsar sites should also support the S73 application.

1.1.8 This document presents the findings of a revised shadow HRA, incorporating a screening assessment for likely significant effect (LSE), and subsequent consideration of whether adverse effects on the integrity (structure or function) of the sites in question will be avoided. This document only focuses on those sites that are relevant to the Woodsmith Mine site. The conclusions presented in the 2014 report remain valid for the other elements of the project and have not been repeated.

1.1.9 Throughout this document, reference is made to documentation submitted by Sirius Minerals to the NYMNPA in partial satisfaction of the planning conditions, as they relate to a defined scope of works being carried out within a particular 'Phase' of development. The latest Phase to be approved by the NYMNPA was Phase 4. The S73 application covers works beyond Phase 4 through to the completion of the development. Prior to the commencement of future Phases of development all relevant planning condition discharge documentation will be updated, and submitted for approval, to ensure that the project's environmental management, monitoring and control measures remain appropriate.

2 Site Description and S73 Scheme Amendments

2.1.1 Woodsmith Mine is located approximately 4km south of the outskirts of Whitby and wholly within the boundary of the North York Moors National Park. It is fully described in the previous application documents, and that information is not repeated here.

2.1.2 The approved development site boundary is shown on approved drawing YP-P2-CX-550. The requested S73 amendments are shown on drawing 653-AP-0005.

2.1.3 In summary, the proposed S73 amendments to the approved scheme comprise:

- Woodsmith Mine site layout - Variations to the layout of buildings at the Woodsmith Mine site to include wider diameters for the Men & Materials and Minerals foreshafts. This variation replaces the need for the previously approved Drift mine access route, its associated on-site structures and the -45m level road network, as well as reducing the size requirement of the Intake Ventilation Equipment building;

- Construction methods and sub-surface structures - Amendments to the construction methods associated with the above including the removal of two of the three 45m high temporary winding towers and revised groundwater management;

- Shaft Diameters and Bunding – Adjustments to the shaft diameters and amendments to the non-screening bunding to the south of the main platform to accommodate the revised road layout and adjusted spoil quantities;

- Water Attenuation – the relocation of the water attenuation ponds into the northern field, along with the addition of a silt trap within the southern field;

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[1] *The Conservation of Habitats and Species Regulations 2010, as amended*

- Construction and Operational Platform Extension - an extension to the southern extent of the platform with a reduction in its width and the creation of access ramps; and
- Internal Access Road – amendments to the route of the access road linking the approved welfare building to the construction/operational platform location, and the associated relocation of the gatehouse.

3 Designated Site Screening Methodology

3.1.1 Previous reports (Royal HaskoningDHV, 2014; Amec Foster Wheeler, 2015) initially applied a 5km buffer to each element of the project to identify sites that have the potential to be affected.

3.1.2 This buffer remains appropriate to the S73 application, and has been applied around the Woodsmith Mine site boundary. The North York Moors SAC and SPA sites remain the only sites[2] identified. Information relating to the sites' designations (features and objectives) are summarised in Table 1.

[2] *Note the two designations apply to the same area.*

Table 1 – Summary of the North York Moors SAC and SPA designated features

Site Name	Summary of reasons for site designation
North York Moors SAC	The North York Moors SAC covers an area of 44,082ha with a general character of heath and scrub, inland water bodies, bogs and marshes, dry grassland, humid grassland and woodland. It qualifies as a SAC for the following features: • Northern Atlantic wet heaths with *Erica tetralix*, for which this is one of the best areas in the United Kingdom. • European dry heaths, for which this is one of the best areas in the United Kingdom. • Blanket bogs, for which the area is considered to support a significant presence. Natural England has developed conservation objectives for the SAC which aim to avoid the deterioration of the qualifying habitats and the habitats of qualifying species, and significant disturbance of those qualifying species, ensuring that the integrity of the site is maintained and the site makes a full contribution to achieving Favourable Conservation Status of each of the qualifying features.
North York Moors SPA	The North York Moors SPA covers an area of 44,082ha and qualifies under Article 4.1 of the Birds Directive by supporting populations of European importance of the following Annex 1 species: • Golden plover *Pluvialis apricaria*. 526 pairs representing at least 2.3% of the breeding population in Great Britain (at the time of designation in 2001). • Merlin *Falco columbarius*. 40 pairs representing at least 3.1% of the breeding population in Great Britain (at the time of designation in 2001). The conservation objectives of the SPA aim to avoid the deterioration of the habitats of the qualifying features, and significant disturbance of the qualifying features, ensuring that the integrity of the site is maintained and the site makes a full contribution to achieving the aims of the Birds Directive.

4 Assessment of Potential for LSE

4.1.1 The 2014 (Royal HaskoningDHV, 2014) and 2015 (Amec Foster Wheeler, 2015) HRA reports assessed each element of the consented project to determine likelihood of significant effect (LSE) with respect to each relevant qualifying feature for the sites identified. This was undertaken in line with the Planning Inspectorate's Guidance Note 10 (The Planning Inspectorate, 2013) and agreed with Natural England. The same approach has been followed here.

4.1.2 Within the screening stage of this shadow HRA, where LSE cannot be ruled out beyond reasonable scientific doubt, the precautionary principle has been applied and potential for LSE concluded. This ensures that any potential implications for the site(s) are assessed further as part of the Appropriate Assessment (AA) stage (**Section 5** of this report).

4.1.3 The HRA reports were also informed by the findings of several baseline ecological surveys (i.e. botanical, breeding bird and wintering bird surveys) for the Woodsmith Mine site. These surveys (summarised in **Table A1, Appendix A**) were undertaken from October 2011 to October 2012 and during the period February 2013 to January 2014. They were supplemented by a detailed ecological desk-based study and information obtained from stakeholders.

4.1.4 Further surveys for snipe, curlew and nightjar were undertaken in 2016 of areas within and around the Woodsmith Mine site. Although these species are not qualifying features for the North York Moors SAC or SPA, these surveys also provided supplementary information on the underlying habitats and their quality. Full details of these surveys are reported within Phase 2 condition discharge reports (40-RHD-WS-83-EN-SV-0001 and 40-RHD-WS-83-EN-SV-0003).

4.1.5 In addition to ecological surveys, Sirius Minerals has implemented a programme of ground and surface water monitoring, in accordance with the requirements of the planning permission. This is providing weekly and monthly data (as appropriate), within the area of influence of the works, on:

- Groundwater level and quality;
- Spring flows and spring water quality; and
- Surface water flows, quality and geomorphology (at Sneaton Thorpe Beck).

4.1.6 Potentially significant effects that could influence the North York Moors SAC and SPA because of the S73 amendments are identified in **Table 2**.

4.1.7 These identified effects are considered in more detail in a screening matrix (**Table 3**), which sets out relevant considerations and conclusions as to whether there is a LSE on the designated sites.

Table 2 Potentially significant effects associated with the S73 amendments that could affect the North York Moors SAC and SPA

Designated site	Potential effects	Presented in screening matrix (Table 3) as
North York Moors SAC	Direct effect of dust generated during construction activities (e.g. earthworks, use of the haul roads) settling onto the SAC habitats (although prevailing wind is from the south-west).	Dust
	Indirect effects associated with the dry storage of the extracted polyhalite settling onto the SAC habitats.	Dust
	Indirect effects associated with the emissions on and around the Woodsmith Mine site (including from plant and on-site power equipment) and deposition of nitrogen on the SAC habitats.	Nitrogen deposition – onsite plant and power generation
	Indirect effects associated with emissions from road vehicles and deposition on the SAC habitats.	Nitrogen deposition – road traffic movements
	Alteration to groundwater flows affecting water dependent habitats and species within the SAC.	Alteration to groundwater
	Alteration to surface water flows affecting water dependent habitats and species within the SAC.	Alteration to surface water
North York Moors SPA	Indirect effect of dust generated during construction activities (e.g. earthworks, use of the haul roads) settling onto supporting habitats which the SPA birds could use.	Dust
	Indirect effects associated with the dry storage of the extracted polyhalite settling onto supporting habitats which the SPA birds could use.	Dust
	Indirect effects associated with emissions on and around the Woodsmith Mine site (including from plant and on-site power equipment) and deposition of nitrogen on supporting habitats which the SPA birds could use.	Nitrogen deposition – onsite plant and power generation
	Indirect effects associated with emissions from road vehicles and deposition on supporting habitats which the SPA birds could use.	Nitrogen deposition – road traffic movements
	Alteration to groundwater flows affecting water dependent supporting habitats within the SPA.	Alteration to groundwater
	Alteration to surface water flows affecting water dependent supporting habitats within the SPA.	Alteration to surface water
	Disturbance to birds (merlin and golden plover) from noise, vibration and/or visual disturbance.	Disturbance

Table 3 Potential effects of the S73 amendments.

Description of potential effects of the S73 amendments on the North York Moors SAC (*qualifying features are Northern Atlantic wet heaths with Erica tetralix; European dry heaths; and Blanket bogs*) and the North York Moors SPA (*qualifying features are golden plover and merlin*)	**LSE on SAC**	**LSE on SPA**
Dust During the construction phase, potential impacts associated with airborne emissions in the form of dust will be generated from earthworks and vehicles using the haul roads, as well as associated with the dry storage of the extracted polyhalite. A number of dust control measures (e.g. programming of earthworks to avoid dry and/or windy conditions) are proposed and these are set out in the Construction Environmental Management Plan (e.g. 40-RHD-WS-70-EN-NT-002 for Phase 4 construction works, and similar measures will apply to all construction phases). Existing vegetation within the boundaries of Woodsmith Mine, as well as the band of naturally established woodland along the edge of Ugglebarnby Moor, will capture airborne dust. Any deposited material onto this established woodland will then be removed by precipitation and, in combination with the distance of these habitats from the Woodsmith Mine site boundary and the prevailing (south westerly) wind direction, the potential for the deposition of dust onto the qualifying SAC habitats will be low. The S73 amendments do not result in any material changes to the impacts previously identified in respect of the consented scheme, and a LSE can therefore be excluded. Therefore, the conclusion remains the same as that made in the adopted HRA report.	No	No
Nitrogen deposition – onsite plant and power generation Indirect effects arising from vehicle and plant emissions and the deposition of nitrogen on areas of heathland and blanket bogs of the North York Moors could be experienced. Nitrogen deposition rates were considered as part of the 2014 HRA assessment. The S73 amendments will not result in any change to the scenarios considered as part of that assessment. Considering this, in combination with measures to control emissions as outlined in the Construction Environmental Management Plan (eg 40-RHD-WS-70-EN-NT-0002) and the Construction Vehicle and Plant Management Plan (e.g. 40-RHD-WS-70-CI-PL-0005), and information outlined in the Generators Emissions Assessment (e.g. 40-RHD-WS-70-EN-RP-0002), potential effects will be controlled. Consequently, LSE can be excluded. Therefore, the conclusion remains the same as that made in the adopted HRA report.	No	No

Description of potential effects of the S73 amendments on the North York Moors SAC (*qualifying features are Northern Atlantic wet heaths with Erica tetralix; European dry heaths; and Blanket bogs*) and the North York Moors SPA (*qualifying features are golden plover and merlin*)	LSE on SAC	LSE on SPA
Nitrogen deposition – road traffic movements Emissions will be associated with road traffic movements which could result in changes in nitrogen deposition rates. A number of road transport mitigation measures are secured through relevant planning conditions and are documented in the Phase 4 Construction Traffic Management Plan (e.g. 40-RHD-WS-70-CI-PL-004) and the Construction Environmental Management Plan (e.g. 40-RHD-WS-70-EN-NT-0002) submitted in phased discharge of planning conditions applied to the consented scheme. These measures will reduce the impact of emissions from road traffic, and will be applied to the S73 scheme if approved. The S73 amendments do not result in any material changes to the impacts previously identified in respect of the consented scheme, and a LSE can therefore be excluded. Therefore, the conclusion remains the same as that made in the adopted HRA report.	No	No
Groundwater Groundwater and groundwater fed features (e.g. spring flushes) could be affected during construction (through dewatering requirements) and the operation of the consented development, potentially impacting the SAC habitats. A vegetation and mapping survey of Ugglebarnby Moor (PCA, 2014), and associated hydrogeological risk assessment modelling, identified that of all the communities recorded, only those found in the Spring Flush area of the Southern Dry Heath are potentially groundwater dependent. It concluded that the recorded communities are likely to be more a result of topographical features and soil conditions than groundwater conditions (PCA, 2014). However, the potential for changes to the groundwater resource or flow regime to affect these habitats (which are not supporting habitats to the SPA species), whilst low, is present. The S73 amendments do not result in any changes to the potential impacts identified in either the consented scheme or the SES. However, the modelling to date has shown minor changes in the range of seasonal groundwater level fluctuations. As such the potential impact on groundwater flows (and in turn a LSE) cannot be ruled out at this stage.	Yes	N/A
Surface water The consented scheme includes a surface water drainage strategy to mitigate impacts on surface water at the Woodsmith Mine site.	No	N/A

Description of potential effects of the S73 amendments on the North York Moors SAC (*qualifying features are Northern Atlantic wet heaths with Erica tetralix; European dry heaths; and Blanket bogs*) and the North York Moors SPA (*qualifying features are golden plover and merlin*)	LSE on SAC	LSE on SPA
The S73 amendments do not result in any changes to the potential impacts identified in either the consented scheme or the SES. Therefore, there will be no effect on the surface water regime as drainage control measures (e.g. surface water retention ponds) incorporated in the scheme remain unchanged from the currently consented development. This conclusion remains the same as that made in the adopted HRA report.		
Disturbance No evidence of golden plover or merlin has been recorded to date within the Woodsmith Mine site or within the designated habitat that is adjacent to the mine site (up to approximately 1km from the site boundaries). Although no golden plover or merlin have been recorded during breeding bird surveys undertaken to date, consultation with Natural England prior to the 2014 application indicated that both golden plover and merlin have been recorded in these areas previously (although were not recorded during 2012, 2013 or 2014). There remains the potential that they could return to the area. Habitats within the Woodsmith Mine site have been assessed as poor breeding bird habitat and only support a typical range of common bird species; key species are skylark and meadow pipit (PCA, 2014). With respect to lighting, a strategy has been prepared in accordance with RSPB guidance to minimise potential impacts on bird species using both the Woodsmith Mine site and its immediate surroundings. Habitats within the adjacent areas of the SPA (up to 1km from the site boundary) have been assessed as providing poor breeding and foraging habitat for golden plover and merlin (PCA, 2014). It is considered that the habitat within the SPA is unsuitable for these species due to the general age of the established scrub and woodland. Habitats within the wider area do have the potential to support merlin and golden plover. Modelling has shown that noise levels will not exceed the thresholds previously considered for the consented scheme (Lichfields, 2017). These remain below the disturbance thresholds (72dB) for both merlin and golden plover. As noted in the adopted HRA, whilst noise and vibration from construction works at Woodsmith Mine may produce short-term avoidance responses by these species over limited parts of the SPA, they will not result in a significant adverse effect on the current or future levels of use by these species. As such, and together with implementation of measures outlined in the Noise and Vibration Monitoring Plans (NVMP), a LSE will not arise.	N/A	No

5 Appropriate Assessment

5.1.1 The S73 amendments at Woodsmith Mine will not directly affect habitats or species within the boundary of the North York Moors SAC and SPA as all the works are outside the boundaries of this designated site.

5.1.2 The adopted HRA report (Amec Foster Wheeler, 2015 produced on behalf of the NYMNPA) concluded that with the incorporation of appropriate mitigation measures (as provided in **Table 3**), there would be no LSE on the North York Moors SPA. This remains the conclusion for the S73 amendments, as shown in **Table 3**.

5.1.3 The S73 amendments at Woodsmith Mine will not result in a LSE on most of the SAC features, with the exception of potential effects on some potentially groundwater-dependent species found in the 'Spring Flush' area of Ugglebarnby Moor, within the North York Moors SAC.

5.1.4 **Appendix B** to this Shadow HRA report presents a Hydrogeological Risk Assessment of the cumulative, long-term impacts of the Woodsmith Mine development on groundwater levels and spring flows (FWS, 2017). The Hydrogeological Risk Assessment has been informed by the results of quantitative, multi-layered Transient and Dynamic State modelling, undertaken by ESI Limited.

5.1.5 Groundwater management measures incorporated within the design of the permanent mine site development and taken to be 'embedded mitigation' within the modelling, are as follows:

- Within the Shaft Platform and Laydown areas, a natural geological clay barrier or a re-compacted clay liner will be constructed over the Moor Grit aquifer;
- A trench constructed to promote re-infiltration of surface runoff to recharge the Moor Grit Formation up hydraulic gradient of the source area to Moorside Farm Spring; and
- Groundwater drainage areas, beneath Bunds E and F, will collect spring water issues from the Scarborough and Cloughton Formations, for discharge to the attenuation ponds within the main surface water drainage system.

5.1.6 Further detail of these mitigating features is provided in the S73 submission and within **Appendix B**.

5.1.7 As a result of the changes to the shaft platform level being raised above groundwater levels in the Moor Grit aquifer (see **Paragraph 1.1.3**), there is no longer a groundwater management requirement to incorporate the grout curtain and pressure relief drain (within the previously approved scheme) within the S73 submission. As such, these features have been excluded from the quantitative modelling.

5.1.8 The Hydrogeological Risk Assessment concludes that "*the cumulative and long term effects of the development will cause a very low physical change in the groundwater levels in the Moor Grit or Scarborough Formations underlying the hydrogeologically supported Spring Flush ecosystem and a low physical change in the groundwater levels and spring flow rates at the Moorside and Soulsgrave Farm spring water supplies. This very low change in groundwater levels is typically at times of the year when groundwater levels are low and where flow from the Spring Flush has been observed to be intermittent and dominated by contribution of recharge to the Moorside Farm Spring via superficial deposits which would not be affected by minesite development*".

5.1.9 Furthermore, the modelling has also confirmed that there is no requirement for any additional groundwater control measures, including the grout curtain and pressure relief drain.

5.1.10 On the basis of the above, and the detailed information presented in **Appendix B**, it can be concluded that there will be no adverse effect on the integrity of the North York Moors SAC as a result of the proposed changes to the Woodsmith Mine development.

6 References

Amec Foster Wheeler (2015) North York Moors National Park Authority – York Potash Project Habitat Regulations Assessment.

FWS Consultants Limited (FWS) (2017) Hydrogeological Risk Assessment of the Cumulative Long Term Conditions.

INCA (2016a) Breeding bird survey Seaton Moor & Ugglebarnby Moor.

INCA (2016b) Nightjar survey Haxby Plantation & Ugglebarnby Moor.

Lichfields (2017) Woodsmith Mine Supplementary Environmental Statement.

Paul Chester and Associates (2014) York Potash Project Proposed Mine Baseline Ecology Surveys.

Planning Inspectorate (2013). Habitats Regulations Assessment for Nationally Significant Infrastructure Projects. August 2013, Version 5.

Royal HaskoningDHV (2014) York Potash Project Environmental Statement: Part 2, Appendix 11.3 Habitats Regulations Assessment.

Appendix A

Table A1 – Summary of selected ecological baseline surveys undertaken for the Woodsmith Mine site.

Ecological survey	Reference	Description
Phase 1 Habitat Survey (2012)	Proposed Mine baseline ecology surveys report (PCA, 2014)	These surveys followed Joint Nature Conservation Committee (JNCC, 2010) guidance which was extended to include a search for evidence of the presence of, or potential to support, notable and protected species in or adjacent to the Site, as recommended by CIEEM.
NVC survey (2012 and 2013)		A botanical walkover survey of the Site was undertaken and broadly followed the standard methodology for Phase 2 vegetation surveys (National Vegetation Classification, Rodwell, 2000).
Breeding bird surveys (2012, 2013 and 2014)		Breeding bird surveys of the site undertaken in accordance with the Common Bird Census (CBC) methodology, described in Marchant (1983).
Wintering bird survey (2011/12 and 2013/14)		Golden plover and other moorland waders survey followed the Brown and Shepherd (1993) methodology for censusing upland waders.

Appendix B

FWS Geological & Geo-Environmental Consultants

SIRIUS MINERALS PLC – THE NORTH YORKSHIRE POLYHALITE PROJECT

REPORT	HYDROGEOLOGICAL RISK ASSESSMENT OF THE CUMULATIVE LONG TERM CONDITIONS
SITE	WOODSMITH MINE, NORTH YORKSHIRE
DOCUMENT NUMBER	40-FWS-WS-83-PA-RA-0002

1433DevOR296Rev5/September 2017

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PROJECT NUMBER	1433Dev	
PROJECT TITLE	NORTH YORKSHIRE POLYHALITE PROJECT	
CLIENT	Sirius Minerals Plc 7-10 Manor Court Manor Garth SCARBOROUGH YO11 3TU	
REPORT TITLE	Hydrogeological Risk Assessment of the Cumulative Long Term Conditions at Woodsmith Mine, North Yorkshire	
REPORT REFERENCE	1433DevOR296	
DOCUMENT NUMBER	40-FWS-WS-83-PA-RA-0002	
REVISION	**Date**	**Checked**
Final	27/09/2017	RIL

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<u>APPENDICES</u>

HYDROGEOLOGICAL RISK ASSESSMENT OF THE CUMULATIVE LONG TERM CONDITIONS AT WOODSMITH MINE, NORTH YORKSHIRE

1 INTRODUCTION

1.1 General Background

Since approval, detailed in planning permission NYM/2014/0676/MEIA for Woodsmith Mine, modifications have been undertaken to the application documentation to address design amendments. These modifications have included amendment and revision to the foreshafts, substructures, drift portal, tunnel and to the earthworks aspects of the mine surface development.

As part of the Section 73 submission, which detailed these modifications, a hydrogeological risk assessment was compiled by FWS Consultants Ltd on behalf of Sirius Minerals (Ref 1). Subsequent to issue of that report, a meeting was held with the North York Moors National Park Authority and Natural England on 5th July 2017 to discuss the results of quantitative modelling from previous construction phases and the implications to long term groundwater conditions, post-construction. At that meeting it was agreed that, now the broader scheme has been established for the surface mine development, all future hydrogeological risk assessment and modelling would consider and incorporate the cumulative and long term impacts of the final scheme development.

This document has therefore been prepared to provide an assessment of the results of quantitative modelling by ESI (Ref. 2) of the predicted changes to groundwater levels and spring flow rates caused by the cumulative and long term impacts of the finished mine site development.

1.2 Objectives

The purpose of this document is to:-

- Provide details of the hydrogeology of the site and adjacent areas.
- Provide details of the finished mine site development.
- Provide an assessment of the quantitative multi-layered hydrogeological modelling conducted to analyse the potential magnitude of the impacts of the finished landform on groundwater levels and spring flows.
- Identify, where appropriate, any additional hydrogeological mitigation measures that may be warranted as part of the development.

2 DATA SOURCES

The data considered within this report are from the following sources:-

Hydrogeological Data

- Hydrogeological Baseline Report for the Woodsmith Mine, North Yorkshire 2012 to 2016 (1975OR01; Ref. 3).
- Hydrogeological Risk Assessment For the Section 73 Works At Woodsmith Mine, North Yorkshire (1433DevOR226 Rev2 July 2017 Ref. 1).
- ESI Ltd, 2017 - York Potash: Groundwater Modelling to evaluate the cumulative and long – term impact of the operational development corresponding to the Section 73 Application, Report No. 61415R9 D2 (Ref. 2; included as Appendix 2).

Development Details Presented in the Section 73 Application

The following Section 73 construction development details have been considered within this hydrogeological risk assessment, as provided by Sirius Minerals, Arup and Cartwright Pickard.

3 DETAILS OF THE LONG TERM OPERATIONAL MINESITE LANDFORM

3.1 General Description

This report presents a hydrogeological risk assessment of the long term condition of the completed mine site development for the maximum size of the landscaped bunds included in the Section 73 submission, as shown on Arup Drawing 40-ARI-WS-71-CI-DR-1036, 40-SMP-WS-10-PA-DT-0001 and YP-P2-CX-509.

The Operational Phase development comprises earthworks and substructures, penetrating the superficial deposits and bedrock, which interact with the groundwater system. A summary drawing of the key long term operational construction and earthworks elements is presented in Drawing 1433DevOD292. Presented below is a summary of the operational elements impacting on the groundwater system and the hydrogeological regime post development.

The long term earthworks and site surfacing elements interacting with the groundwater system will include the following:-

- Earthworks to create the lined ponds, areas of hardstanding including the Shaft Platform and the welfare areas will reduce infiltration into the ground surface.
- Landscaped Bunds A, B and G will be constructed of extractive material and will incorporate surface water drainage reducing infiltration into the ground surface.
- Landscaped Bunds C, D, E and F will be constructed of extractive material and will have a geocomposite drainage layer above a designed capping and lining system reducing infiltration into the ground surface.

The principal long term substructure elements interacting with the groundwater system will include the following.

- Lined shaft basement construction features at the Service Shaft and Production Shaft to around 5.5 m below ground level will locally impede groundwater flows in the Moor Grit Aquifer.

- Two diaphragm walls at the Service and Production shafts, with outside diameters of 37.8 m and 34.8 m extending to a depth of 60 m into the Ellerbeck Formation and their associated 11m diameter shafts together with the 11.05m diameter MTS shaft extending to a depth of 120m into the Whitby Mudstone. These structures will create local impedance to groundwater flows in the Ravenscar Formation aquifers.

3.2 Groundwater Management Measures

Groundwater management measures incorporated within design of the permanent mine site development, are as follows:-

- Within the Shaft Platform and Laydown areas, a natural geological clay barrier or a re-compacted clay liner are constructed over the Moor Grit aquifer.

- A re-infiltration trench, collecting runoff from the catchment area on Bund C as illustrated in Arup Drawing YP-P2-CX-509, will promote re-infiltration of surface runoff to recharge the Moor Grit Formation up hydraulic gradient of the source area to Moorside Farm Spring.

- Groundwater drainage areas, beneath Bunds E and F, will collect spring water issues from the Scarborough and Cloughton Formations, for discharge to the attenuation ponds within the main surface water drainage system.

As part of this development, now that the Shaft Platform has been raised above groundwater levels in the Moor Grit aquifer, there is no longer a groundwater management requirement to incorporate the grout wall and relief drain from the approved scheme within the Section 73 submission. As such, the modelling presented in this report has considered the Section 73 scheme, excluding the grout wall and relief drain.

3.3 Duration of Operation

For the purpose of this hydrogeological risk assessment, it has been assumed that the duration of minesite operation will be such that steady state long term average conditions will establish. Model results therefore represent cumulative long term average (LTA) effects of the mine site development and the re-infiltration trench on the groundwater system. These predicted effects are the worst case precautionary maximum expected long term average change under the imposed recharge condition.

4 MINESITE HYDROGEOLOGICAL CONDITIONS

4.1 Introduction

From the geometry and construction details of the completed mine development, presented in Section 3, and the baseline hydrogeological conditions determined for the site (Ref. 1), the following sections present an overview of the interaction between aquifer conditions, the completed development surface and the below ground structures.

Within this Section, reference is made to specific groundwater monitoring well locations, as shown in Drawing 1433DevOD292.

4.2 Geology

4.2.1 General

Presented below is a summary of the superficial deposits and strata within the Ravenscar Formation that form the sensitive aquifers impacted on by the surface mine development. Drawing 1433DevOD292 (Appendix 1) illustrates the substructures, zones of no and low recharge, and groundwater management measures on the geological plan of the minesite and the adjacent Ugglebarnby and Sneaton Low Moor areas.

4.2.2 Superficial Deposits

Within the SAC, the soils consist of topsoil and peat, while on the minesite there is a thin covering of topsoil. The superficial deposits across the minesite and the moorland areas of the SAC consist of sandy gravelly clay (Glacial Till) to depths between 1.4m to 4.7m bgl, generally thinning towards the southeast of the minesite, and containing frequent sand lenses at the base of this unit.

4.2.3 Long Nab Member

The Long Nab Member underlies the south of the minesite and Sneaton Low Moor. It comprises weathered grey or orange/yellow fine to medium grained sandstone over a thin (0.2m to 0.45m thick) layer of dark grey mudstone.

4.2.4 Moor Grit Member

The Moor Grit Member un-conformably overlies the Scarborough Formation and comprises a grey, iron-stained fine to medium grained cross bedded sandstone with occasional medium to coarse gravel to pebble beds, discontinuous argillaceous beds and thin coal laminations within the mid-section of this unit. The upper part of this sandstone unit is distinctly weathered to de-structured, whilst the lower part of the sandstone unit is only partially weathered. This sandstone unit ranged in thickness from 2.3m to 13.2m and the discontinuous argillaceous units within the mid-section ranged from 1m to 4m in thickness. The base of the Moor Grit has a maximum dip of approximately 2° to the east beneath the SAC moorland and Woodsmith Mine, forming a shallow basin-like structure.

4.2.5 Scarborough Formation

The Scarborough Formation comprises three horizontal to sub-horizontal bedded weak to very weak, partially to distinctly weathered units including an upper moderately to highly fractured mudstone or siltstone, a grey-green sandstone/siltstone mid-section unit and a basal mudstone unit. To the west of the site, in the northern part of Ugglebarnby Moor (HG106A/GW121B), the lower argillaceous unit is a light to dark grey sandy argillaceous limestone with shell fragments.

The upper mudstone/siltstone unit is on average 2m thick. The middle sandstone unit ranges in thickness from 0.3m to 5.7m and the lower mudstone ranges in thickness from 0.05 to 9m. The upper mudstone unit is discontinuous, especially towards the northern boundary of the

Woodsmith Mine. The base of the Scarborough Formation dips at a relatively shallow angle of around 1° to the east beneath the SAC and Woodsmith Mine, forming a basin-like structure.

4.2.6 Cloughton Formation

The Cloughton Formation comprises a series of interbedded sandstones and mudstones with occasional siltstones of between 23.5m to 52m thick. Beneath Ugglebarnby Moor, the Cloughton dips at a relatively shallow angle (1 to 5°) to the east, becoming roughly horizontal beneath, and to the east of, the Woodsmith Mine.

The upper part of the Cloughton Formation comprises a weak to extremely weak weathered mudstone of between 1 to 5m thick, which thickens to the south. This overlies a medium strong to strong, partially to distinctly weathered, fine to medium grained sandstone, containing interbedded mudstone and occasional coaly and carbonaceous beds, particularly towards the base. The total thickness of this sandstone-dominated Formation ranges from 11.2 to 33.1m. The Formation becomes more sandy and thicker towards the south, with fewer mudstone beds. In the central part of the minesite, the sandstone sequence contains a higher proportion of mudstone/siltstone beds. The base of the Cloughton is dominated by an interbedded mudstone/siltstone sequence, of between 20 to 25m thick.

4.2.7 Eller Beck Formation

The Eller Beck Formation comprises 4 to 7 m of fine to medium sandstone, with a basal shale and ironstone unit (Ref. 30).

4.2.8 Saltwick Formation

The Saltwick Formation was between 37 to 40 m thick and comprises a series of interbedded sandstones, mudstones and siltstones, with some thin coals, with an upper argillaceous unit, a middle arenaceous unit and then a basal argillaceous unit.

4.3 Landform and Structures Forming the Operational Development

4.3.1 Hydrogeological Development Considerations

As illustrated in Drawing 1433DevOD292 (Appendix 1) the final development of Woodsmith Mine will entail the following construction zones and substructure elements that will impact on groundwater flows and recharge within the Ravenscar aquifers:

<u>Zones of No Recharge</u>

- The tiered Shaft Platform and the Laydown areas will either have a hardstanding or landscaped surface underlain by an insitu natural or enhanced clay geological barrier overlying the Moor grit aquifer. These surfacings will restrict surface water recharge into the underlying bedrock.

- The Welfare Unit and access road will have hardstanding surfacing underlain by predominantly cohesive Glacial Till overlying the Long Nab and Moor Grit aquifers. This surfacing will restrict surface water recharge into the underlying bedrock.

- The surface water drainage ponds and attenuation basins will have a landscaped surface underlain by insitu or engineered clay overlying the Moor Grit, Scarborough or Cloughton aquifers. This surfacing will restrict surface water recharge into the underlying bedrock.
- Landscaped bunds C, D, E and F will have a capping and lining system that will restrict surface water infiltration into the underlying Moor Grit and Scarborough aquifers.

Zones of Low Recharge

- Landscaped Bunds A, B and G, and general landscaped areas across the site will have a soil cover and a surface water drainage system that will reduce but not inhibit permeation of surface water ingress into the underlying Glacial Till overlying the Long Nab, Moor Grit, Scarborough and Cloughton aquifers.

Substructure Elements

- The diaphragm walling and shaft structures to the Production, Service and MTS shafts will form permanent and low permeable structure's that locally impact on groundwater flows in the Moor Grit, Scarborough, Cloughton and Saltwick aquifers.

- The basement structure's to the Production and Service Shafts will form permanent and low permeable structure's that locally impact on groundwater flows in the Moor Grit aquifer.

Permanent Groundwater Management Measures

- The re-infiltration trench constructed around Bund C will enable surface water runoff, collected from within the capping system to soakaway into the Moor Grit strata.

- The two groundwater drainage areas beneath Bunds E and F collect local surface water issues from the Scarborough Formations.

4.3.2 Aquifer Conditions

From the results of the ground investigation and the baseline groundwater monitoring, a summary is provided in Table 1 overleaf of the aquifer units, the interpreted groundwater surface, design permeability characteristics and water quality conditions that characterise the hydrogeological conditions within the zones of no and low recharge and substructure elements associated with the final development landform.

Table 1 Aquifer and Groundwater Conditions within Principal No and Low Recharge Zones and around Substructure Elements

	Development Area		Southern Working Platform	South Shaft Platform	North Shaft Platform	Welfare Facility	Bund C and Re-Infiltration Trench	Basement substructures
	Development Level	**m AOD**	**~208**	**203.00**	**203.5**	**202**	**211 to 214**	**203**
Superficials	**Current Ground Level**	**m AOD**	204.1 to <203.5 Platform construction incorporating clay barrier	203.1 to <202.5 Shaft Platform construction incorporating clay barrier	203.5 Shaft Platform construction incorporating clay barrier	202	209 to 212	203
Superficials	**Groundwater Conditions**	**m AOD**	none	none	spring water supplies at water seepage at 202.0	None	None	None
Moor Grit	**Top & Base Level of Aquifer**	**m AOD**	203.8 to 197.38	(GCBH9) ~200.4 to 192.0	(GCBH07) ~202.0 to 193.0	~200	197 to 210	193 to 202
Moor Grit	**Inferred Groundwater Surface (Winter, Summer & Mean levels)**	**m AOD**	~197.98 to 206.13	Winter ~200 Summer ~198	Winter 198.6 to 203.0, average 201.7 Summer 198.3 to 202.9, Mean 200.4 (HG115 & HG116)	Winter ~200 Summer ~198	Winter ~209 Summer ~205 (GW130 &131)	Winter 197.5 to 200.6, average 198.9 (BHs 505 & 507)
Moor Grit	**Aquifer Design Permeability**	**m/s**	Most Likely 1.3 x10^{-5} m/s					
Moor Grit	**Water Quality**		Good					
Scarborough Formation	**Top and Base Level of Upper Aquitard Unit**	**m AOD**		~192.0-191.5	~193 to 191.5			193.0 to 192.1
Scarborough Formation	**Upper Aquitard Design Permeability**	**m/s**	Most Likely 4.0 x 10-6 m/s					
Scarborough Formation	**Elevation of Mid-Section Permeable Aquifer**	**m AOD**		~191.5 to 188.3	~191.5 to 188.0			192.1 to 189.5
Scarborough Formation	**Inferred Groundwater Surface**	**m AOD**		~195	NIA			190.9 to 193.6
Scarborough Formation	**Aquifer Design Permeability**	**m/s**	Most Likely 1.3 x 10^{-5} m/s (Fractures 5.2 x 10^{-4} m/s)					
Scarborough Formation	**Water Quality**		Good					
Scarborough Formation	**Elevation of lower Aquitard Unit**	**m AOD**		~18.3 to 184.5	~188.0 to 184.0			192.1 to ~185.5
Scarborough Formation	**Lower Aquitard Design Permeability**	**m/s**	Most Likely K_h 2 x 10^{-6} m/s, K_v 1 x 10^{-8} m/s					

NIA = No Information Available

5 RECEPTORS

5.1 Receptor Sensitivity

The sensitivity of groundwater receptors has been assessed in terms of their ability to accommodate physical or chemical change and on the impact any change may have on a regional or local ecological or other environmental system. By adopting this approach to the qualitative assessment, the most sensitive receptors are determined to be those with very limited or no capacity to accommodate physical and/or chemical change that are of very high importance as a groundwater resource. Conversely very low sensitivity receptors are those that can generally tolerate physical and/or chemical changes and are of low importance as a groundwater resource. Groundwater receptor characteristics and receptor examples are detailed in Table 2 below:-

Table 2 – Sensitivity Evaluation

Sensitivity	Groundwater Receptor Characteristics	Receptor Examples
Very High	• has very limited or no capacity to accommodate physical or chemical changes • supports internationally important ecological, amenity or landscape features	• licensed public water supply or major industrial abstractions (e.g. SPZ 1/2) • licensed/unlicensed abstractions and springs providing potable water supply, for which there is no alternative source (e.g. mains water) • designated SAC, SPA, or Ramsar site with fauna or flora that are hydrogeologically supported from groundwaters within rock aquifers • surface water bodies supporting the above
High	• has limited capacity to accommodate physical or chemical changes • supports nationally important ecological amenity or landscape features	• designated 'Principal Aquifer' • licensed/unlicensed abstractions and springs providing potable water supply, for which an alternative source (e.g. mains water) is available • SSSI, NNR with fauna or flora that are hydrogeologically supported from groundwaters within rock aquifers • designated SAC, SPA, or Ramsar site with fauna or flora that are supported from both surface runoff and groundwaters within superficial or rock aquifers • surface water bodies supporting the above
Medium	• has limited capacity to accommodate physical or chemical changes • supports regionally important ecological, amenity or landscape features	• designated 'Secondary A (or Undifferentiated) Aquifer' • regionally important wildlife sites with fauna or flora that are hydrogeologically supported from groundwaters within rock aquifers • non-potable licensed abstractions • surface water bodies supporting the above or classified as Good under Water Framework Directive
Low	• has moderate capacity to accommodate physical or chemical changes • supports locally important ecological, amenity or landscape features	• non-potable unlicensed abstractions • local wildlife sites (LNR, SNCI, RIGS), country parks with flora hydrogeologically supported from groundwaters within rock aquifers • designated SAC, SPA, or Ramsar site with fauna or flora that are not hydrogeologically supported from groundwaters within rock aquifers • surface water bodies supporting the above or classified as Moderate under Water Framework Directive

Sensitivity	Groundwater Receptor Characteristics	Receptor Examples
Very Low	• generally tolerant of and can accommodate physical or chemical changes • supports no features of significant ecological, amenity or landscape value	• designated 'Secondary B Aquifer' or 'Unproductive Strata' • surface waters with no important, dependent receptors • SSSI, NNR with fauna or flora that are not hydrogeologically supported from groundwaters within rock aquifers

All groundwater level, spring flow and water quality data referred to in this report is presented in detail in the revised Hydrogeological Baseline Report (Ref. 1) from which five types of groundwater receptors have been identified in the vicinity of the Woodsmith Mine that could be impacted on by its long term operational condition. These are streams, springs, private water supplies, the Special Areas of Conservation containing potentially groundwater-supported terrestrial ecosystems, and controlled waters in sensitive aquifers comprising the Secondary A Aquifers, as summarised in Table 3 below.

Table 3 – Receptor Sensitivity

Type	Receptor	Sensitivity
Sensitive Aquifers	Moor Grit Member	Medium
	Scarborough Formation	Medium
	Cloughton Formation	Medium
	Saltwick Formation	Medium
Base Flow Springs	Doves Nest Farm Spring (DNS1)	Very Low
	Ugglebarnby Moor Spring (SP01)	Very Low
	Springs Northwest of Ugglebarnby Moor (SP02, SP03)	Very Low
	Springs North of Woodsmith Mine (SP04)	Very Low
	Springs North of Woodsmith Mine (KHF)	Very Low
Spring Water Supplies	Moorside Farm Spring (MF2)	High
	Soulsgrave Farm Spring (SF2)	High
	Newton House Farm Spring (NHF1)	High
Groundwater Abstractions	Sneaton Low Moor Caravan Park	High
Ecological Receptors	Ugglebarnby Moor Northern Dry Heath Area	Low
	Ugglebarnby Moor Central Wet Heath Area	Low
	Ugglebarnby Moor Southern Dry Heath Area	Low
	Ugglebarnby Moor Southern Spring Flush	High
	Sneaton Low Moor Dry Heath Area	Low
Surface Waters	Sneaton Thorpe Beck	Low
	Little Beck	Medium

From the previous hydrogeological risk assessments (Ref 1, 4, 5, 6, and 7), the principal sensitive hydrogeological receptors identified in close proximity to the operational mine will include; the two springs used for domestic water supplies at Moorside and Soulsgrave farms and the Spring Flush ecosystem.

As the springs provide unlicensed potable water supplies, for which an alternative source (e.g. mains water) is available, they are considered as of "High" sensitivity.

With regards to the Spring Flush area, in the original hydrogeological risk assessment submitted in support of the Planning Application (Ref 1), this was categorised in 2014 as of "Very High" sensitivity" on the basis that it was a hydrogeologically supported terrestrial ecosystem within an

SAC designated area. Subsequent baseline and construction phase monitoring between 2014 and 2017 has demonstrated that this ecosystem is however, sustained by a combination of surface water runoff, and seasonal and intermittent spring flows that are sourced from both superficial glacial soils and the Moor Grit aquifer. This is demonstrated in the Hydrogeological Baseline Report that shows that rainfall recharge is the predominant process with the Moor Grit aquifer providing a secondary ephemeral source of recharge. This is supported by the ecological survey undertaken by Paul Chester Associates (Ref. 4) that the plant life is maintained by topography and surface water from rainfall.

As such, in view that this terrestrial ecosystem is partially supported by surface runoff and only intermittently sustained by spring groundwater flows from the rock aquifer, it is categorised as of "High" sensitivity in terms of its sensitivity to hydrogeological conditions.

In addition to these receptors of "High" sensitivity, down hydraulic gradient of the bunds to the east of the development are the Moor Grit, Scarborough and Cloughton Secondary A aquifers, which are characterised as of medium sensitivity.

6 QUALITIVATIVE HYDROGEOLOGICAL RISK ASSESSMENT

A qualitative hydrogeological risk assessment was presented in the FWS report (Ref 1), in respect of the completed Section 73 amended mine development, which provided a summary evaluation of the potential physical and chemical impacts of the long term operational condition of the mine site on the above sensitive hydrogeological receptors. That report concluded that for the operational condition the magnitude of physical and chemical effects of the modified mine surface development on the ecological, spring and Secondary A aquifer receptors would remain as negligible to minor. As part of the Permit application, pollution modelling of the final footprint of the bunds would be undertaken.

Presented in Section 7 of this report are the results of the quantitative modelling undertaken to evaluate the long term cumulative effects of the surface mine development works on groundwater levels and spring flows and their impacts on Moorside Farm Spring, Soulsgrave Farm Spring and to the Spring Flush area of the SAC.

7 QUANTITATIVE HYDROGEOLOGICAL MODELLING

To evaluate the magnitude of the potential adverse impacts on groundwater levels and to spring flows sustaining the sensitive receptors, identified in Section 5, quantitative Dynamic and Steady State modelling has been carried out by ESI Ltd (ESI) in the following two principal stages:-

- Stage 1 – Calibrating a "Base Case" model to represent the predevelopment baseline conditions.
- Stage 2 - Evaluation of the cumulative hydrogeological physical effects of the long term operational mine development to highlight potentially unacceptable adverse impacts on the key sensitive receptors and to determine whether additional mitigation measures are warranted.

In the following sections, details are provided on the conceptual models developed to evaluate the impact of the long term operational mine development, the groundwater modelling approach adopted and the model runs undertaken. The results of the multi-layered quantitative analysis of the simulated physical changes in groundwater levels in the Moor Grit and Scarborough aquifers and of the spring flowrates at Moorside Farm and Soulsgrave Farm springs, are summarised in Section 7.4 of this report and present in full in Appendix 2.

7.1 Conceptual Models

Full details of the conceptual hydrogeological model are given in Section 2 and 3 of the ESI report (Appendix 2), including geological cross-sections of the site showing the aquifer units affected by the development.

7.1.1 Pre-Construction Baseline Conditions

The model area is shown in Figure 2.1 for the Moor Grit aquifer and Figure 2.2 for the Scarborough aquifer (Appendix 2). The model has an active area of approximately 3.7 km east-west, 6.2 km north-south and the model grid cells are 20 m x 20 m in size. A refined grid area, where the model cells are 2 x 2 m in size, was adopted for the re-infiltration trench location west of Bund C and the reduced recharge areas into the Moor Grit created by the Shaft Platform, the Working Platform and Batching Plant surfaced areas, and by the landscaped bunds.

The superficial deposits, which are primarily cohesive and of a low permeability, are considered as non-aquifer units and cannot be modelled. As such, the model does not apply to the superficial deposits present on both the minesite and the SAC, and the simulated changes in groundwater levels are representative of those occurring in Moor Grit and Scarborough aquifers only.

The external model boundaries for the two main aquifer units are shown in Figure 2.1 and 2.2 (Appendix 2). The Moor Grit and Scarborough have drain cells to the west, north and east, with a recharge boundary to the south. The drain cells are used to simulate both spring discharges and discharge from the aquifer outcrop edges (which include transfers from an upper to a lower aquifer unit).

7.1.2 Construction Conditions

The long term mine construction features that are expected to impact on groundwater levels and spring flows have been simulated in the following worst case model. The conservative assumptions made on the construction elements are listed below and illustrated in Drawing 1433DevOD292 Appendix 1 and Figures 2.1 and 2.2 of ESI's model Appendix 2.

1. Areas occupied by bunds C, D, E and F, lined ponds, areas of hardstanding and buildings, the laydown area, welfare area, and shaft platforms have been treated as "No Recharge Zones."

2. Areas of bunds A, B and G, capped with restoration soils only, are treated as with a conservative reduced recharge of 10% of background recharge (equivalent to 20 mm/a).

3. Lined shaft basement construction features at the Service Shaft and Production Shaft to around 5.5 m below ground level have been modelled as impermeable. To more accurately represent the basements in the model, layer one (the Moor Grit Formation) was

split in half to form two layers and the no flow boundary condition for the basement was only added to the uppermost layer.

4. Three diaphragm walls at the Service, Production and MTS shafts, with outside diameters of 37.8 m, 34.8 m and 11.05 m respectively. Each of these diaphragm walls will be 1.2 m thick and will be installed to 60 m depth keyed into the Ellerbeck Formation. These have been simulated as No Flow boundaries to the base of the Cloughton Formation.

5. Three lined shafts to 120 m depth and 11 m diameter at each of the three shaft locations. These have been simulated as No Flow boundaries to the base of the Saltwick aquifer.

6. A re-infiltration trench that will collect runoff from the catchment shown in Arup Drawing YP-P2-CX-509 and recharge into the Moor Grit Formation. The re-infiltration trench is assumed to be excavated into the Moor Grit Formation rock head. An upper limit to the recharge along this trench was calculated based on the catchment area (approximately 6.5 ha) of the re-infiltration trench and effective precipitation. To prevent groundwater flooding along the re-infiltration trench, drain cells were placed along the trench outline in layer one.

7.2 Modelling Approach

The groundwater modelling has been undertaken using the USGS numerical finite difference groundwater model code MODFLOW-2005, using the Groundwater Vistas 6 (GV6) interface. A modified version of MODFLOW-2005 (MODFLOW-USG) called MODFLOW-USG, has also been used which allows for the use of unstructured grids. The following model runs were undertaken for both the pre-development base case and post-development models:

- One steady state model run with background recharge at calibrated levels. This run was undertaken to determine the Long Term Average (LTA) change in groundwater levels and spring flows as a result of the construction features forming the post-development landform; and

- One dynamic steady state model run to determine the maximum and minimum changes in spring flows and groundwater levels through a typical year using a typical synthetic recharge sequence to allow typical seasonal changes in water levels to be shown.

Full details of the model construction, parameter setting, input parameters and model calibration are presented in ESI's report (Appendix 2).

7.3 Steady State and Dynamic Conditions Modelled

For the long term steady state conditions, the post development construction features have been imposed onto the pre-development base case model. In addition, surface water discharge into the re-infiltration trench was decreased from the maximum calculated value for the catchment until unacceptable groundwater flooding was not observed in the model. The recharge rate for the model cells, representing the re-infiltration trench, was calculated to be 27,710 mm/a (approximately 140 times background recharge) at steady state conditions. This was then used in the model to obtain the steady state post-development model results that are representative of Long term Average (LTA) post-development conditions.

For evaluation of the long term average seasonal variation conditions, the dynamic steady state base case and post-development steady state models were both converted to transient simulations and run for several years until dynamic steady state had been achieved. For the purposes of this study, dynamic steady state is defined as the point at which the amplitude of seasonal groundwater fluctuations does not change. From this modelling, it was determined that dynamic steady state conditions could develop after a period of six years after completion of the operational landform.

For the dynamic model runs the initial heads derived from the steady state models were used. A synthetic recharge sequence was derived from MORECS data and long term monthly rainfall at Whitby to model a total annual recharge equivalent to the steady state calibrated model recharge of 200 mm/a. Zero recharge was applied over the summer period (June to September, inclusive), which is consistent with rainfall experienced on site during recent summers. On a similar basis a synthetic sequence was developed to represent monthly recharge into the re-infiltration trench with low recharge during summer months and high recharge over the winter months (November to March) so that the total annual recharge was equivalent to that used in the steady state model.

To enable evaluation of the magnitude of physical impacts at the key sensitive groundwater receptors described above, the following existing monitoring locations and dummy points were considered in the simulations, as shown in Figure 3.1 and 3.2 (Appendix 2) for the Moor Grit and Scarborough aquifers respectively:-

- Spring Flush Receptor: the impacts on groundwater level changes in the Moor Grit strata were considered by simulated changes at Assessment Points SAC 6, 7 and 8 (at well GW133A/HG111A) and at existing wells GW130 and 131.
- Moorside Farm Spring Receptor: the impacts on groundwater level changes in the Moor Grit strata were considered by simulated changes at Assessment Points SAC 6, 7 and 8 (at well GW133A/HG111A) and at existing wells GW130 and 131.
- Soulsgrave Farm Spring Receptor: the impacts on groundwater level changes in the Scarborough strata were considered at the intermediate well position GW112/HG119 from the simulated impacts on spring flows at SF2.

7.4 Model Results

Impacts on Ground Water Levels

The results of the Steady State modelling have been compared with the baseline conditions for the Moor Grit and Scarborough Formations. This shows that the greatest fall in groundwater levels in the Moor Grit occurs in two depressions and is counteracted by the re-infiltration trench in the centre of the site that locally increases groundwater levels between the areas of reduced and zero recharge.

Decreases in groundwater level reach approximately 2 m to the north west of the Shaft Platform and 2.9 m around Bunds C and D, and the Welfare area. Due to the relatively large areas of no recharge zones, the steady state decline in groundwater levels is simulated to cover almost the entire minesite area, except local to the re-infiltration trench. Around the Spring Flush and

Moorside Farm Spring area, this effect reduces to a fall in groundwater levels of less than 0.05 m due to the recharge to the spring source sustained by the re-infiltration trench.

From the dynamic state modelling of seasonal changes in the Moor Grit aquifer, which sustains the Moorside Farm Spring and the Spring Flush terrestrial ecosystem, the following changes in ground water levels are simulated to occur at the locations shown in Figure 3.1 (Appendix 2):-

- A 1.03m to 1.81 m rise in groundwater levels (between March to January) above baseline conditions SAC 6 located 200m from Moorside Farm Spring.

- A 0.61m to 1.25m rise in groundwater levels (between April to January) to above baseline conditions at SAC 7 located 115m from Moorside Farm Spring.

- A 0.07m to 0.19m fall in summer groundwater levels at GW133A located 80m from Moorside Farm Spring.

- A 0.17m to 0.32m fall in summer (July to September) groundwater levels at SAC 8 located 125m from Moorside Farm Spring.

- A negligible <0.05m fall in groundwater levels at Moorside Farm Spring.

As illustrated by the baseline data (Drawing 1433DevOD232 Appendix 1), during the summer to autumn period, groundwater levels in the Moor Grit at Moorside Farm Spring (GW133A / HG111A) typically fluctuate by around 1.5m. The modelling locations that best represent the groundwater level changes immediately uphydraulic gradient of the spring and forming its primary source area are best represented by the triangle of modelled nodes at MF2 at the spring, GW113A 80m to the southeast, SAC 8 125m south west and SAC 7 115m to the north east (Figure 3.1 Appendix 2). From this triangle of nodes, the simulated groundwater level changes over the summer autumn period at SAC 7 and 8 around 120m, uphydraulic gradient of the spring, will vary between a minimum rise of 0.61m to a maximum fall of 0.32m at SAC 8. This indicates that the re - infiltration trench will provide adequate recharge into the Moor Grit Aquifer. This demonstrates that the simulated groundwater level change in the Moor Grit Aquifer at the spring is very low in comparison with the magnitude of seasonal variation in the groundwater levels at this location. Therefore, as the spring is sourced primarily from runoff from the superficial deposits, with only a minor contribution from the Moor Grit Aquifer, the small change in groundwater levels caused by the minesite development will have no significant impact to spring flows. This condition is supported by the results of the spring flow rate simulations discussed below and equates to a local very low magnitude of change against the natural baseline seasonal variation, which is considered to represent a negligible significance of impact on this receptor.

In the Scarborough aquifer, the simulated groundwater level changes at GW136, within the same zone of groundwater level impact as the spring at Soulsgrave Farm, demonstrate a steady state impact of 0.27m. When compared with the annual seasonal groundwater level fluctuation monitored in the Scarborough in HG119/GW112 and GW 115, of 1.3m and 1.5m respectively (Ref. 1), this equates to a local low magnitude of change against the natural baseline seasonal variation, which is considered to represent a minor significance of impact on this receptor.

<u>Impacts on Spring Flow Rates</u>

As illustrated in Figure 3.9 (Appendix 2) and demonstrated from the baseline hydrogeological monitoring (Drawing 1433DevOD232 Appendix 1), the long term changes in recharge to Moorside Farm spring is simulated to cause a very low reduction in spring flow rate over the May to October period of up to 4.9×10^{-3} l/s (0.42 m^3/day). As illustrated in Drawing 1433DevOD232, during this summer to autumn period of low recharge conditions, baseline monitoring has typically recorded intermittent spring flow rate discharges at this location of around 0.03 l/s, although varying between no flow and peak of 0.06 l/s, which is a very small change in comparison with the measured seasonal range in flow rates. Such a very low reduction in spring flow rate over the May to October period of up to 4.9×10^{-3} l/s would be beyond the resolution of measurement in the field, and would therefore not be noticeable either too the domestic water supply or the spring flush area.

Simulated reductions in spring flow rate changes at Soulsgrave Farm Spring due to the long term changes in recharge to the Scarborough Formation are simulated to cause a relatively consistent very low reduction in spring flow rates of up to 6.2×10^{-3} l/s (0.54 m^3/day). Baseline monitoring has determined that seasonal flows vary between 0.1 and 1.0 l/sec during the winter months, 0.02 and 0.7 l/sec during the spring months, no flow to 0.6 l/sec during the summer months, and no flow to 0.53 l/s during the autumn months. As such, the simulated changes in spring flows at this location, caused by the proposed long term operational conditions is less than 1% of the measured winter season fluctuation in flow rates and less than 10% of the measured summer seasonal range in flow rates. Such changes would be beyond the resolution of measurement in the field, and would therefore not be noticeable.

7.5 Conclusions

The results of the multi-layered Transient and Dynamic State modelling undertaken by ESI has determined that the cumulative and long term effects of the development will cause a very low physical change in the groundwater levels in the Moor Grit or Scarborough Formations underlying the hydrogeologically supported Spring Flush ecosystem and a low physical change in the groundwater levels and spring flow rates at the Moorside and Soulsgrave Farm spring water supplies. This very low change in groundwater levels is typically at times of the year when groundwater levels are low and where flow from the Spring Flush has been observed to be intermittent and dominated by contribution of recharge to the Moorside Farm Spring via superficial deposits which would not be affected by minesite development.

On the basis of this modelling, it has been confirmed that there is no requirement for any additional groundwater control measures to be implemented as part of the final minesite development to mitigate physical impacts on groundwater levels or spring flow rates on sensitive receptors.

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5 FWS Consultants Ltd, 2017 Hydrogeological Risk Assessment for the Phase 2 Works at Doves Nest Farm Minesite, North Yorkshire (1433OR27).

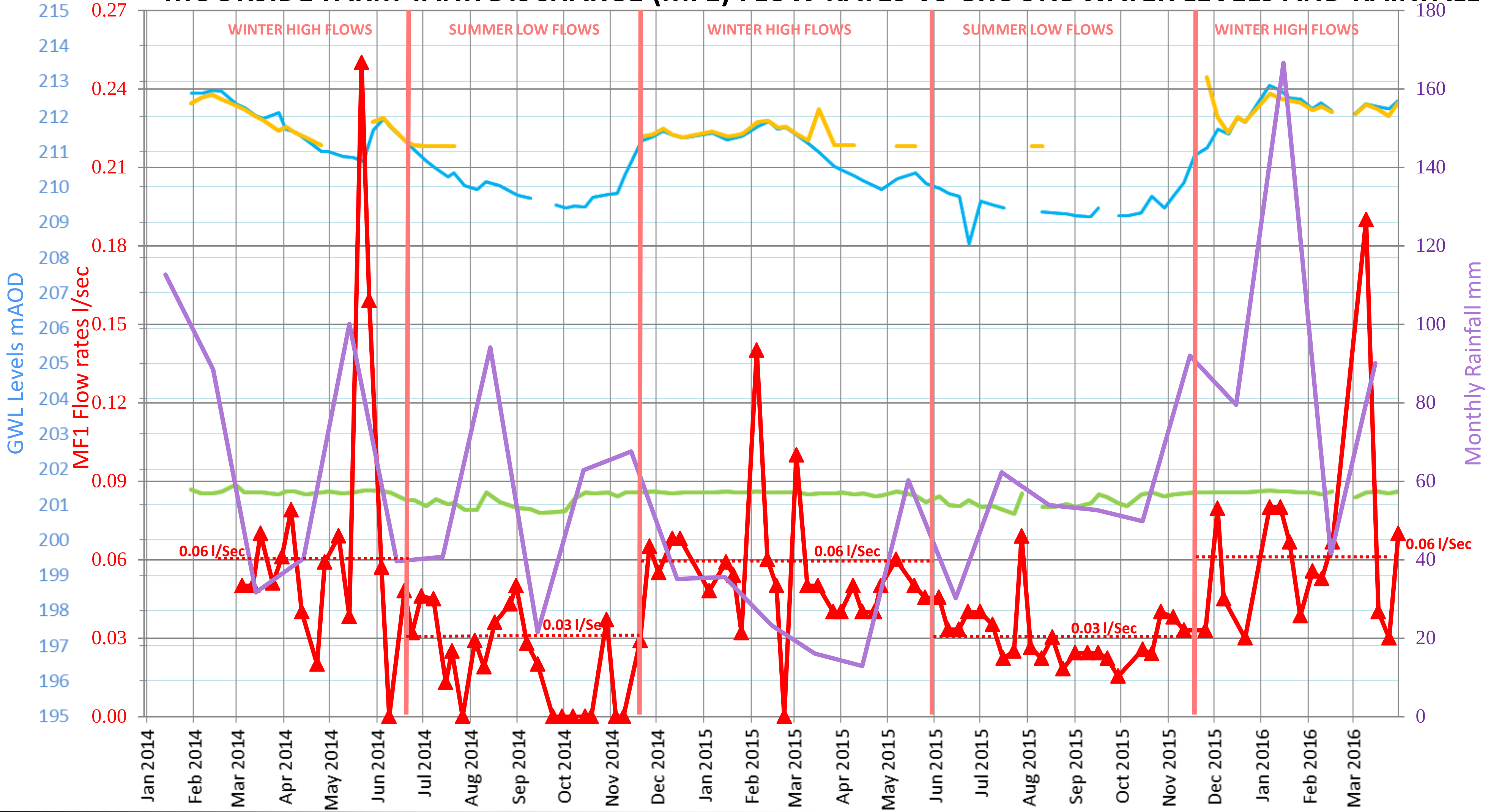
6 FWS Consultants Ltd, 2017 Hydrogeological Risk Assessment for the Phase 3 Works at Doves Nest Farm Minesite, North Yorkshire (1433OR175).

7 FWS Consultants Ltd, 2017 Hydrogeological Risk Assessment for the Phase 4 Works at Doves Nest Farm Minesite, North Yorkshire (1433OR205).

APPENDIX 1

DRAWINGS

MOORSIDE FARM TANK DISCHARGE (MF1) FLOW RATES VS GROUNDWATER LEVELS AND RAINFALL



NOTES / KEY

DISCHARGE FLOW RATES FROM SPRING FED TANK OVERFLOW (MF1)

SEASONAL AVERAGE FLOW RATES AT MF1

GROUNDWATER LEVEL IN MOOR GRIT UP HYDRAULIC GRADIENT OF MF2 (HG111A)

GROUNDWATER LEVEL IN SUPERFICIAL DEPOSITS UP HYDRAULIC GRADIENT OF MF2 (HG111)

GROUNDWATER LEVEL IN SUPERFICIAL DEPOSITS DOWN HYDRAULIC GRADIENT OF MF2 (HG112C)

MONTHY RAINFALL (WHITBY METEOROLOGICAL DATA

DRAWING TITLE	Moorside Farm Tank Discharge (MF1) Proxy for Moorside Farm Spring (MF2) Flow Rates VS Groundwater Levels and Rainfall
PROJECT TITLE	York Potash Project
CLIENT	Sirius Minerals plc.
STATUS	FINAL
PROJECT NUMBER	1433Dev
DRAWN BY	CB
DATE	December 2016
SCALE	NOT TO SCALE
DRG. No.	1433DevOD232Rev1

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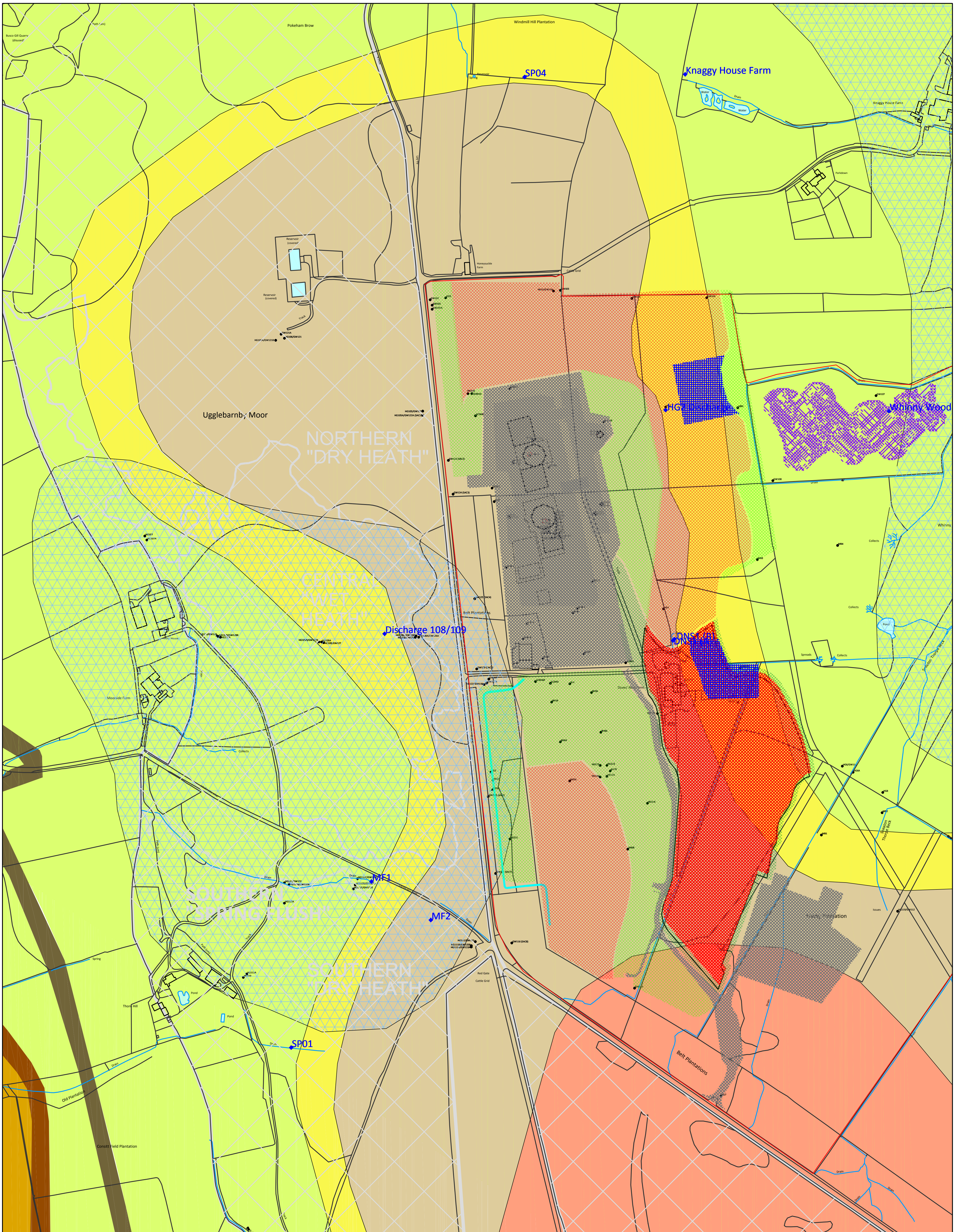

NOTES / KEY

SITE OWNERSHIP BOUNDARY
NYM SAC

SURFACE WATER
BOREHOLES GCBH01
HYDROGEOLOGICAL RECEPTORS MF2

AREAS OF NO RECHARGE
Shaft Platform & Welfare
NHNI MWFs Bunds
Ponds

AREAS OF POTENTIAL RECHARGE
Inert Bunds

GEOLOGY
GLACIAL TILL
LONG NAB
MOOR GRIT
SCARBOROUGH FORMATION
CLOUGHTON & SALTWICK FORMATION
ELLER BECK FORMATION
DOGGER FORMATION
WHITBY MUDSTONE

GROUNDWATER DRAINAGE

REINFILTRATION TRENCH

DRAWING TITLE	GEOLOGICAL PLAN AND EXPLORATORY HOLE LOCATIONS WITH MINESITE
PROJECT TITLE	YORK POTASH PROJECT
CLIENT	SIRIUS MINERALS PLC
STATUS	FINAL
PROJECT NUMBER	1433Dev
DRAWN BY	PG
DATE	AUGUST 2017
SCALE	1:5,000@A3/1:2,500@A1
DRG. No.	1433DevOD292

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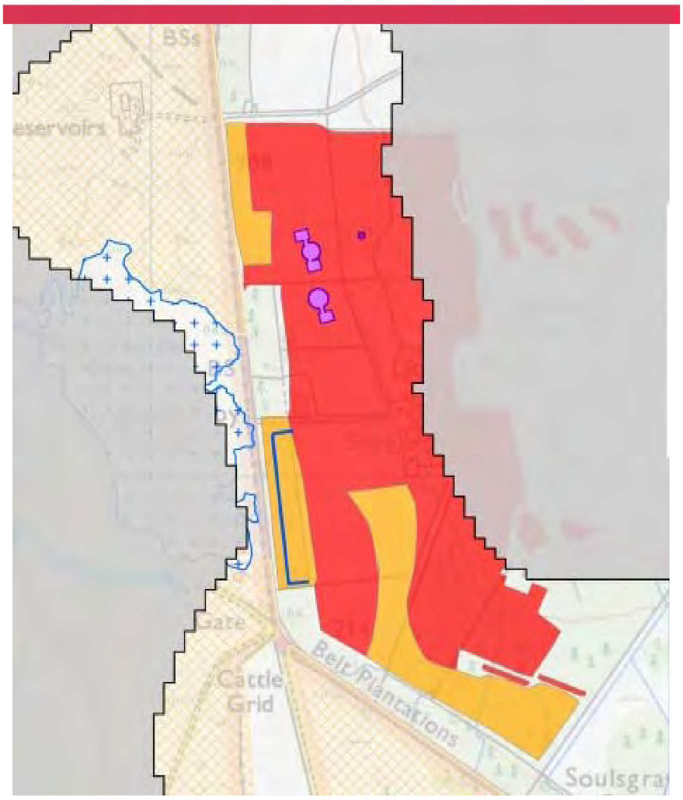
APPENDIX 2

QUANTITATIVE MODELLING



Groundwater Modelling to evaluate the long-term impact of the Woodsmith mine development to meet Section 73 Application requirements

Groundwater Modelling to evaluate the long-term impact of the Woodsmith mine development to meet Section 73 Application

Prepared for

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Report reference: 61415R9 D2, October 2017
Report status: Final Report

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Groundwater Modelling to evaluate the long-term impact of the Woodsmith mine development to meet Section 73 Application

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61415R9. Final Report

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Revision record:

Issue	Report ref	Comment	Author	Checker	Reviewer	Issue date	Issued to
1	61415R9 D1	Draft report for external review	CDW	HRS	MJS	16/08/2017	Richard Izatt-Lowry (FWS)
2	61415R9 D2	Draft report for external review	CDW	HRS	MJS	17/08/2017	Richard Izatt-Lowry (FWS)
3	61415R9	Final Report	CDW	BCH	BCH	2/10/2017	Richard Izatt-Lowry and Jennifer Cooke (FWS)

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APPENDICES

1 INTRODUCTION

1.1 Background

Since approval of the scheme detailed in planning permission NYM/2014/0676/MEIA at Woodsmith Mine, modifications have been undertaken to the application documentation to address design amendments. These modifications have included amendment and revision to the foreshafts, substructures, drift portal, tunnel and to the earthworks aspects of the mine surface development.

This document presents the results of groundwater modelling undertaken to evaluate the long term impacts on groundwater levels and spring flows caused by the final operational minesite development landform, incorporating the current development design changes to the substructures and earthworks elements as detailed in the Hydrogeological Risk Assessment for the Section 73 Works at Woodsmith Mine (FWS 2017).

1.2 Scope and Objectives

ESI Limited (ESI) has been engaged by FWS Consultants Limited (FWS) to simulate the long term effects of the final operational mine site development.

This modelling report has been undertaken to evaluate the long term impact on groundwater levels and spring flows using the updated model to provide supplementary information, in support of the Section 73 Application.

The scope of work undertaken for this modelling includes:

- Generating new predictive groundwater flow models to account for the long term mine construction elements as shown in ARUP drawings. 40-ARI-WS-71-CI-DR-1036, 40-SMP-WS-10-PA-DT-0001 and YP-P2-CX-509.
- Processing the groundwater model results to determine predicted groundwater level and spring flows changes at neighbouring receptors with a focus around the Spring Flush area of the Ugglebarnby Moor Special Area of Conservation (SAC), and spring flows from Moorside Farm and Soulsgrave Farm springs;
- Sensitivity and uncertainty analyses to assess the suitability of the model results obtained; and
- Production of a groundwater modelling report to reflect the long term construction elements and modelling results (this report).

1.3 Data Sources

The updated groundwater flow model as described by ESI (2017a) has been adapted and used to predict the long terms effects of the mine works to meet Section 73 requirements. This has been undertaken using the following data sources:

- York Potash: 2017 Groundwater Model Update (ESI, 2017a) (Appendix A); and
- ARUP drawings. 40-ARI-WS-71-CI-DR-1036, 40-SMP-WS-10-PA-DT-0001 and YP-P2-CX-509.

1.4 Report Outline

This report is split in the following manner:

- Section 2 includes a description of the relevant long term construction elements, how these have been incorporated in the model and the model runs undertaken.
- Section 3 presents figures and tables to show simulated changes in groundwater levels and spring flows from the predicted baseline conditions due to the final landform and mine site construction features, as documented in the Section 73 Application.

- Section 4 provides a summary of the conclusions and key results.
- Appendix B provides details of the sensitivity and uncertainty analyses undertaken as part of this modelling work.

2 PREDICTIVE SCENARIOS

2.1 Modelled Construction Features

The long term mine construction features are shown ARUP drawings. 40-ARI-WS-71-CI-DR-1036, 40-SMP-WS-10-PA-DT-0001 and YP-P2-CX-509. Features of the design that are expected to impact on groundwater levels and spring flows have been simulated in the model. These elements are listed below and further details are presented in FWS (2017).

1. Areas occupied by lined soil storage bunds, lined ponds, areas of hardstanding and buildings, the laydown area, welfare area, and shaft platforms.
2. Reduced recharge zones covering soil storage areas capped with restoration soils only.
3. Lined shaft basement construction features at the Service Shaft and Production Shaft to around 5.5 m below ground level.
4. Three diaphragm walls at the Service, Production and MTS shafts, with outside diameters of 37.8 m, 34.8 m and 11.05 m respectively. Each of these diaphragm walls will be 1.2 m thick and will be installed to 60 m depth keyed into the Ellerbeck Formation.
5. Three lined shafts to 120 m depth and 11 m diameter at each of the three shaft locations.
6. A recharge trench that will collect runoff from the catchment shown in Arup Drawing YP-P2-CX-509 and direct that runoff to recharge the Moor Grit Formation. This includes areas covered by adjacent soil bunds, that act as no and reduced recharge zones in the model.

These construction elements were represented in the model as follows and are shown in figures 2.1 and 2.2:

1. Areas occupied by construction features listed in point one (above) were represented in the model as no (zero) recharge zones.
2. Reduced recharge zones were applied to bunds that are to be capped with restoration soils. A conservative reduced recharge of 10% of background recharge (equivalent to 20 mm/a) was applied to these bunds.
3. Basement shaft construction features were simulated using the MODFLOW No Flow boundary condition. This makes the lined basements impermeable in the model. To more accurately represent the basements in the model, Layer one (the Moor Grit Formation) was split in half to form two layers. Elevations of the bottom of Layer one/top of Layer two at the Production and Service shafts were locally modified to be 199 m AOD and 197.5 m AOD respectively which are approximately 5.5 m below ground level at these locations and the no flow boundary condition for the basement was only added to the uppermost layer.
4. The diaphragm walls were also simulated as No Flow boundaries in the model to the base of the Cloughton Formation (Layer five in the previous model but Layer six in this model due to the split of the original Layer one into two layers).
5. Each of the shafts was simulated to the base of the model (Layer eight) using the No Flow boundary condition.
6. The recharge trench was incorporated as a new recharge zone, assuming that the trench is dug down to the Moor Grit Formation rock head. This high recharge zone was added along the length of the proposed trench and set at one nested grid cell (2 m) in width. An upper limit to the recharge to this trench was calculated based on the catchment area (approximately 6.5 ha) of the recharge trench and effective

precipitation. To prevent groundwater flooding along the recharge trench, drain cells were placed along the trench outline in Layer one. This was to prevent flooding when some or all of the recharge applied cannot enter the model. These drain cells were set at 0.2 m above ground level, to allow for the fact that calibrated groundwater levels in this area are around 0.2 m above observed mean levels. Further details on how the recharge rate was calculated are provided in Section 2.3.

In order to more accurately incorporate these construction features, the nested grid was extended 140 m (seven parent grid cells) to the south compared to the previous model.

Figure 2.1 and Figure 2.2 show the modelled construction features represented in the Moor Grit and Scarborough formations respectively.

Figure 2.1 Modelled construction features represented in the Moor Grit Formation

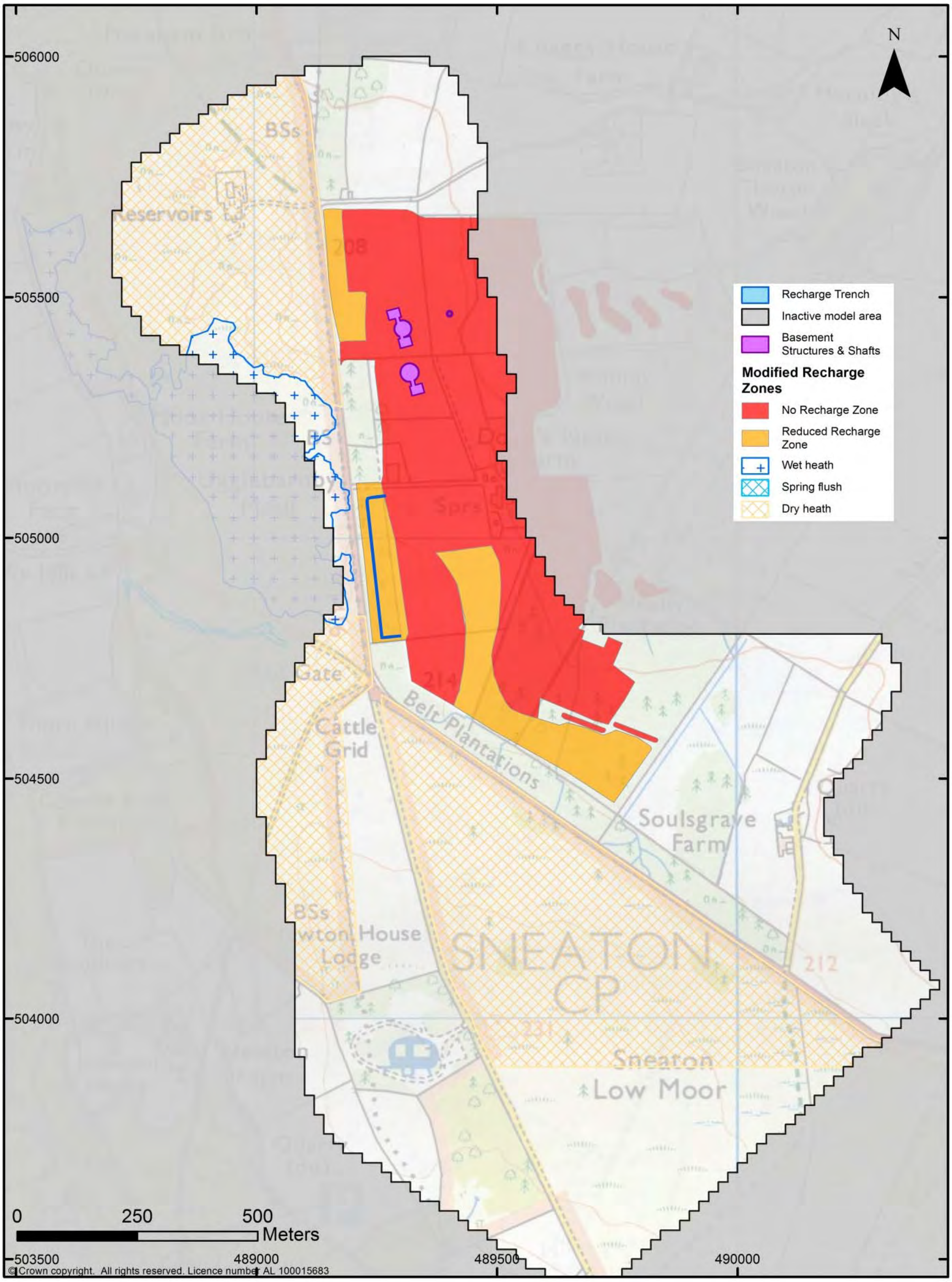
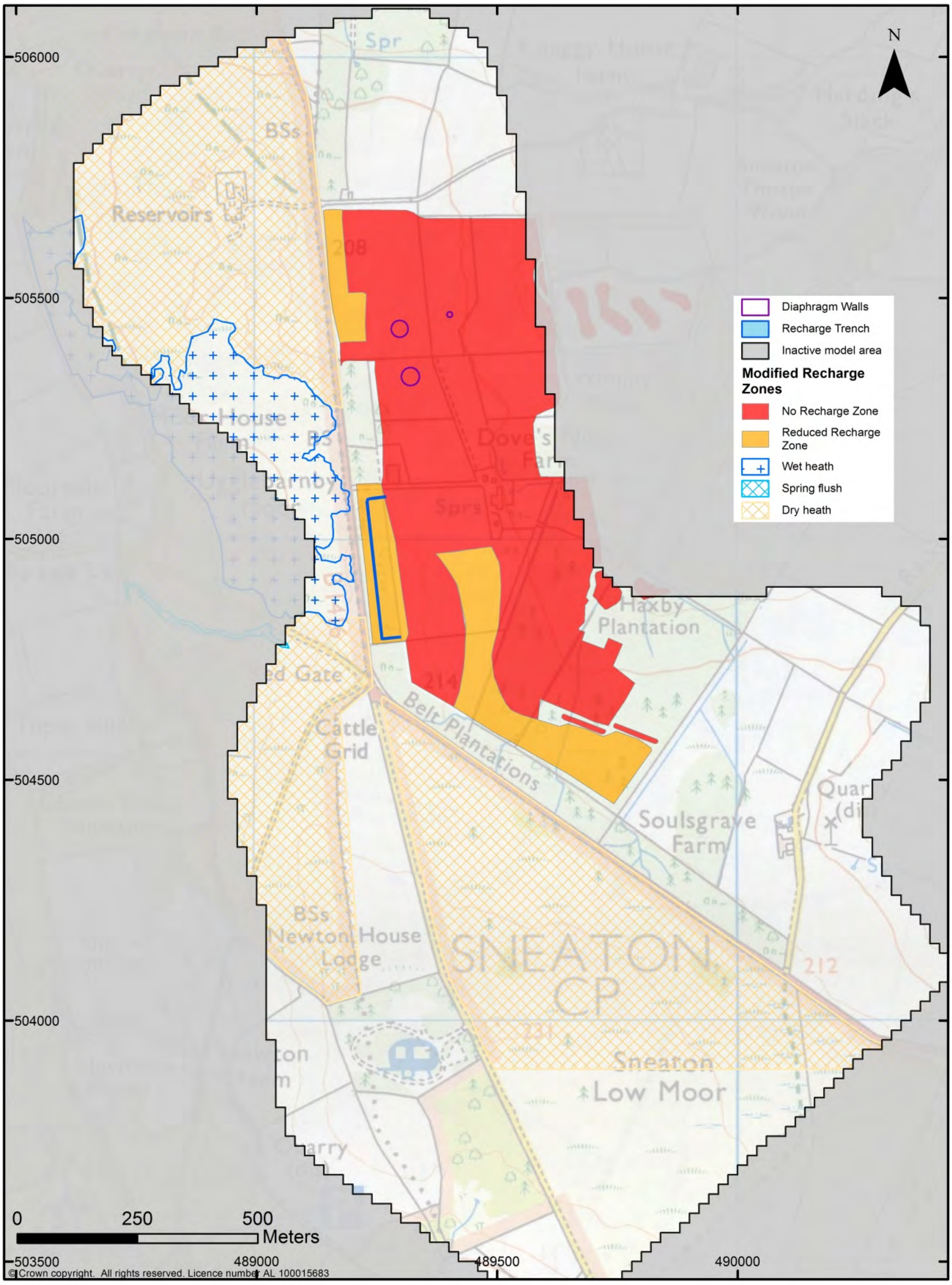


Figure 2.2 Modelled construction features represented in the Scarborough Formation



2.2 Base Case Model

A number of changes to the model structure have been made to allow construction features to be simulated. The incorporation of these structural changes themselves (as opposed to the construction features that they allow to be modelled) does not result in significant changes to model results. To remove any small effect that this may have, these changes were also made to the previous calibrated base case model (ESI, 2017b) to ensure that the only differences between the post-development model and updated base case model (including no construction features) were due to the modelled construction features. The changes are as follows:

- Extending the refined nested grid to the south by 140 m;
- Positioning MODFLOW Drain cells over the course of the proposed recharge trench; and
- Dividing Layer one (representing the Moor Grit) into two layers, split evenly except around the proposed basement structures which were set at 199 m AOD and 197.5 m AOD around the proposed locations of the Production Shaft and Service Shaft respectively.

These changes to the model did not materially affect the steady state calibration with respect to groundwater levels and spring flows.

2.3 Groundwater Model Runs

2.3.1 Overview

In order to simulate the effects of the long term construction works on the Moorside Farm Spring and the Spring Flush area of Ugglebarnby Moor SAC, the following model runs were undertaken for both the pre-development base case and post-development models:

- One steady state model run with background recharge as per the calibrated base case steady state model. This run was undertaken to determine the Long Term Average (LTA) change in groundwater levels and spring flows as a result of the construction features forming the post-development landform; and
- One dynamic steady state model (see Section 2.3.3) run to determine the maximum and minimum changes in spring flows and groundwater levels through a typical year using a typical synthetic recharge sequence to allow typical seasonal changes in water levels to be shown.

Further details on how these runs were undertaken are set out below. Table 2.1 provides a summary of the model runs that have been undertaken.

Table 2.1 Summary of model runs undertaken

Model Run Number	Name	Type
1	Pre-development Base Case SS	Steady state
2	Post-development SS	
3	Pre-development Base Case DSS	Dynamic Steady state
4	Post-development DSS	

2.3.2 Steady state model runs

Amendments were made to the pre-development base case model (which includes no post-development features) as described in Section 2.2 and this model was run with the results being taken as representative of LTA baseline conditions.

To this base case model, the post-development construction features described in Section 2.1 were incorporated to form the post-development steady state model.

Surface water discharge into the recharge trench was decreased from the maximum calculated value for the catchment until unacceptable groundwater flooding was not observed in the model. The maximum recharge was calculated by using mean annual effective precipitation data from MORECS (for period 2013 – 2017) and multiplying this by the catchment area to obtain the maximum runoff rate (approximately 1 l/s). This was then input into the model and several runs undertaken to determine the point at which groundwater flooding in the post-development model was not significantly greater in terms of extent and magnitude than in the base case simulation.

Some of the runoff from the recharge trench catchment over the winter months from October to March, will be diverted into the main surface water drainage system as the modelling indicates that the recharge trench will not be able to accept all of runoff from the catchment. The modelling assumes that most of the effective precipitation over the catchment during summer will be diverted to the recharge trench. The recharge rate for the model cells representing the recharge trench was calculated to be 27,710 mm/a (approximately 140 times background recharge) at steady state. This was then used in the model to obtain the steady state post-development model results that are representative of LTA post-development conditions.

2.3.3 Dynamic steady-state model runs

In order to achieve dynamic steady state (defined below), the base case and post-development steady state models were both converted to transient simulations and run for several years until dynamic steady state had been achieved. For the purposes of this study, dynamic steady state is defined as the point at which the change in the amplitude and elevation of seasonal groundwater fluctuations is insignificant. Once the difference in adjacent groundwater level peaks and troughs had reached < 0.01 m at key locations in the model, dynamic steady state was assumed to have been reached. This point was six years into the model run for both post-development and base case runs.

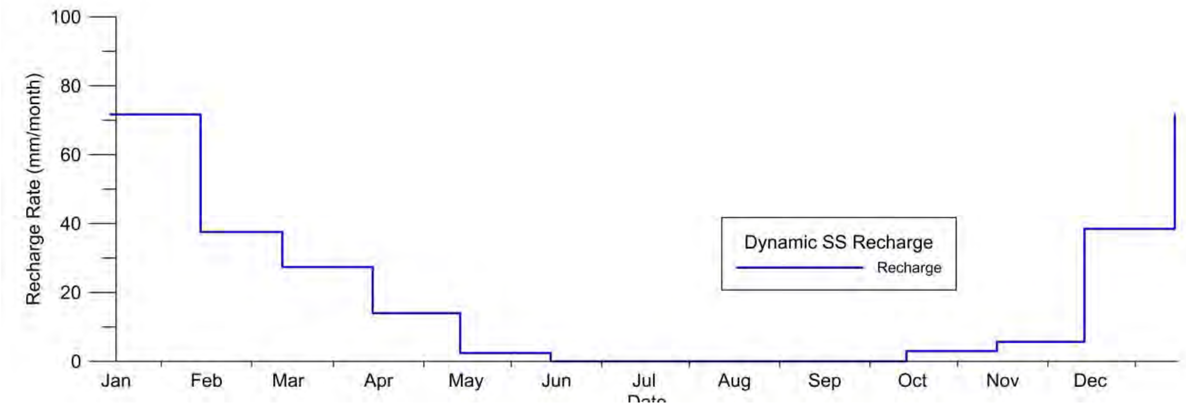
For the two dynamic steady state model runs, initial heads were taken as the steady state groundwater heads from the equivalent steady state models. A synthetic recharge sequence was used as shown in Figure 2.3. This has been derived based on Met Office MORECS data (for the period 2013 – 2017) and long term monthly rainfall at Whitby for the period 1971 – 2000, and has been scaled so that total annual recharge is equivalent to the steady state calibrated model recharge of 200 mm/a. Zero recharge was applied over summer (June to September, inclusive), which is consistent with rainfall and PET data for previous summers.

A synthetic sequence was also devised for recharge to the recharge trench. This allows recharge to enter the trench at the rate of effective precipitation during summer (when heads are lower) and was assigned over the winter months (November to March) so that the total annual recharge was equivalent to that applied to the recharge trench in the post-development steady state model. Recharge is non-zero over summer to the recharge trench, because it is assumed that all runoff will be directed towards the recharge trench and infiltration will be rapid thereby not allowing additional time for evaporation.

An allowance has not been made for possible climate change influences on recharge because the purpose of this modelling exercise is to compare changes in groundwater levels and spring flows to measured baseline conditions. Potential climate change impacts should not be assessed as these will not be caused by the proposed development.

Future climatic conditions are unknown. As a result, transient modelling using a recharge sequence based on measured rainfall data has not been undertaken, because the purpose of this modelling is to determine the LTA impacts of the construction features. No effort has been taken to model the impact on spring flows and groundwater levels of low or high recharge periods beyond that expected in a typical winter or summer.

Figure 2.3 Synthetic background recharge sequence used for dynamic steady state



3 RESULTS OF PREDICTIVE SCENARIOS

3.1 Assessment Points

Changes in groundwater level simulated by the steady state and dynamic steady state models as a result of the long term construction features have been assessed at certain assessment points, chosen to be located close to the Moorside Farm Spring (MF2) habitat of the SAC and Soulsgrave Farm Spring (SF2). The locations of the assessment points are illustrated in Figures 3.1 and 3.2 for the Moor Grit and Scarborough formations respectively and are listed in Table 3.1.

Target locations with the prefix GW correspond to actual monitoring points installed by FWS (FWS, 2016) as opposed to theoretical assessment locations. Changes in groundwater levels are of most interest for this study, and therefore the absolute levels and residuals to measured groundwater levels at the assessment points are of lesser importance. The updated model is considered to be fit for the required purposes and suitable for predicting changes in groundwater levels in the Moor Grit and Scarborough formations.

Figure 3.1 Assessment locations in the Moor Grit Formation

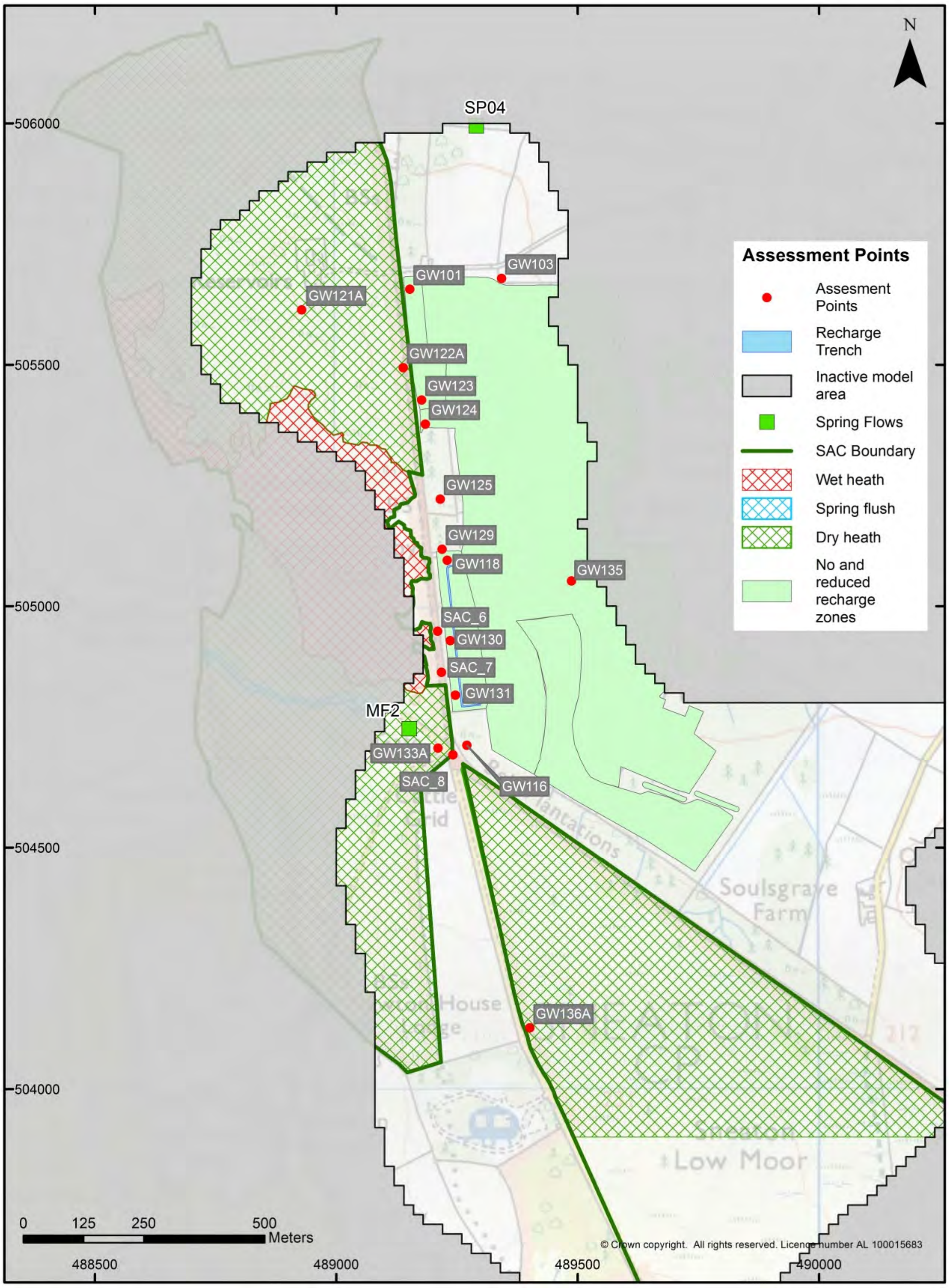


Figure 3.2 Assessment locations in the Scarborough

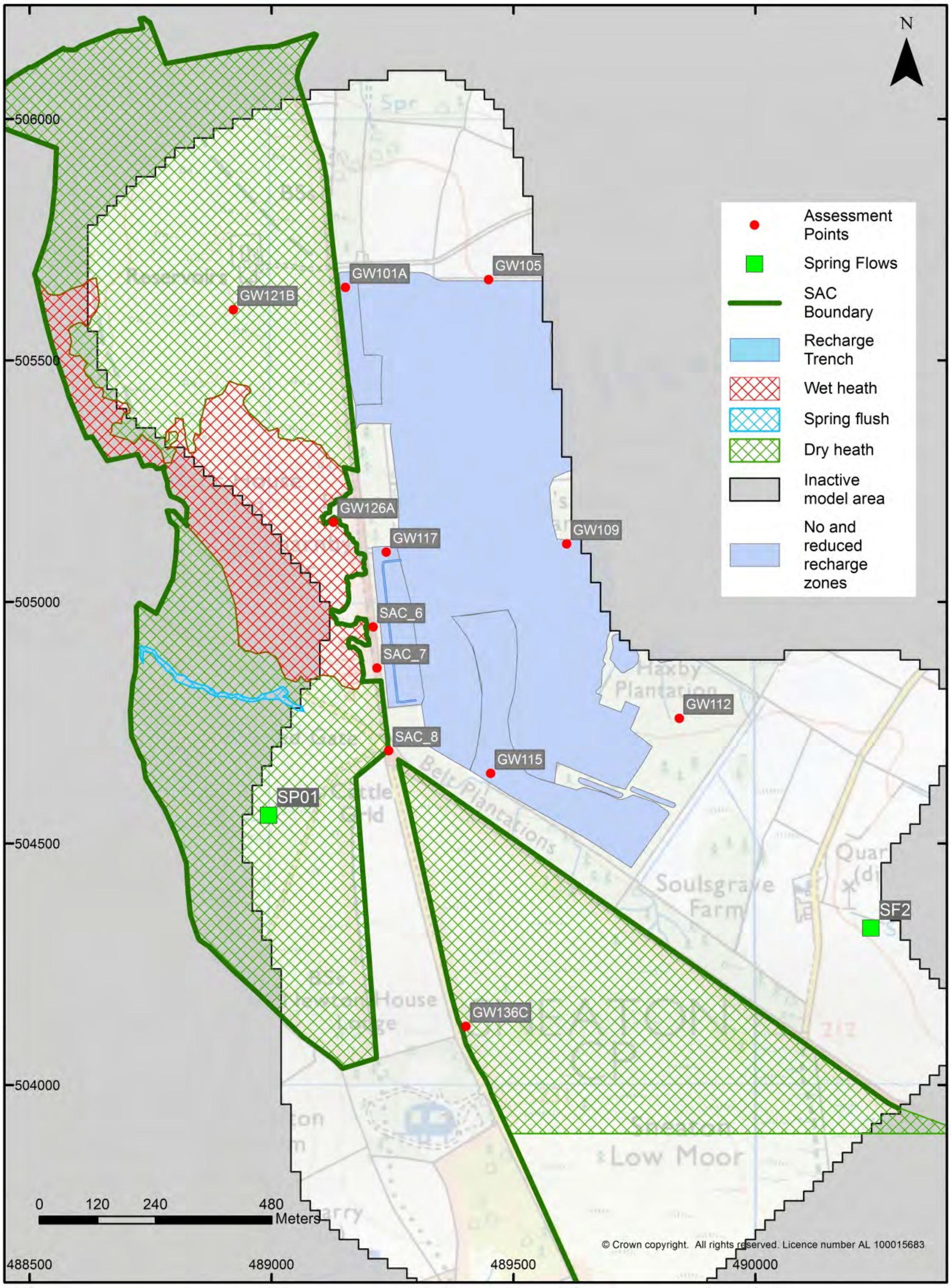


Table 3.1 Predictive scenario assessment points

Name	Easting	Northing	Ground level (m AOD)	Response zone (m bgl) / unit
Moor Grit Formation				
GW101	489153	505657	206.8	2 - 9.75 m
GW103	489343	505679	203.4	3 - 8.5 m
GW116	489271	504712	213.0	2.7 - 9.6 m
GW118	489230	505095	208.9	4.0 - 14.5 m
GW121A	488929	505614	211.7	3.4 - 6.6 m
GW122A	489139	505494	208.3	3.5 - 13.0 m
GW123	489177	505427	208.9	6 - 12.8 m
GW124	489184	505377	209.7	5 - 13.2 m
GW125	489216	505222	206.5	4.1 - 8.5 m
GW129	489219	505118	207.6	3.4 - 9 m
GW130	489236	504929	209.7	2 - 10.8 m
GW131	489247	504815	211.5	1.9 - 10.5 m
GW133A	489211	504706	213.0	2.0 - 10.0 m
GW135	489487	505052	202.3	3.4 - 8 m
GW136A	489401	504126	224.1	6.5 - 9.3 m
SAC_6	489210	504948	-	Moor Grit
SAC_7	489218	504863	-	Moor Grit
SAC_8	489242	504692	-	Moor Grit
MF2	489150	504745	-	Moor Grit
Scarborough Formation				
GW101A	489153	505651	206.7	10.8 - 13 m
GW105	489449	505667	197.4	8 - 10 m
GW109	489610	505120	193.4	4.2 - 6.6 m
GW112	489843	504759	197.2	8.75 - 6.2 m
GW115	489453	504645	209.3	11 - 14 m
GW117	489237	505103	208.7	14.2 - 16.5 m
GW121B	488921	505605	211.6	4.0 - 14.0 m
GW126A	489128	505165	203.4	6.5 - 10.0 m
GW136C	489402	504121	224.3	11.0 - 16.8 m
SAC_6	489210	504948		Scarborough
SAC_7	489218	504863		Scarborough
SAC_8	489242	504692		Scarborough
Spring Flows				
MF2	489151	504746	210	Moor Grit
SP04	489290	505995	195.6	Moor Grit
SP01	Distributed along western model border		Variable	Moor Grit
SF2	490239	504325	196.8	Scarborough
SP02	488336	505814	145	Cloughton
SP03	488473	506115	162.4	Cloughton
NHF	488866	504006	174.3	Cloughton

3.2 Calculation Details

All groundwater level changes and difference contour plots presented in the subsequent sections are calculated differences between the pre-development base case model (with no construction features) and the post-development model (including construction features). In each case, the base case model has been run under the same background recharge conditions. Negative changes are representative of a post-development fall in groundwater levels or decline in spring flows relative to the base case, whilst positive values indicate a post-development rise.

3.3 Model Results

3.3.1 Effects on groundwater levels

Figure 3.3 and Figure 3.4 show contour plots of changes in groundwater level between the base case and post development model runs (model runs 1 and 2) at steady state in the Moor Grit and Scarborough formations respectively. **Error! Reference source not found.** shows a north east to south west cross section through the model that passes through the Production Shaft and towards the Spring Flush area of the SAC. These plots represent the LTA changes in groundwater level simulated by the steady state model.

Figure 3.3 and Figure 3.5 show that the greatest falls in groundwater level in the Moor Grit are located in the centre of the no recharge areas, as expected. Figure 3.3 shows that the decline is separated into two depressions. This is caused by the recharge trench that locally increases groundwater levels and counteracts the effects of reduced and zero recharge zones. Decreases in groundwater level reach approximately 2 m in the centre of the northern depression and 2.9 m in the centre of the southern depression. The drop in groundwater levels reduces to around 0.9 m between the two main depressions. Due to the relatively large areas of no recharge, the decline in groundwater levels covers almost the entire model area (except around the recharge trench). Around the Spring Flush and Moorside Farm Spring area, this effect is less than 0.05 m.

The combination of the no recharge zones and the recharge trench causes a rise in groundwater levels along the alignment of the recharge trench, of up to 2.3 m over an area approximately 490 m long and 140 m wide. However, as mentioned above, the effects of the recharge trench spread to the east causing the groundwater decline to be split into two main depressions.

In the Scarborough Formation (Figure 3.4 and Figure 3.5), the pattern of groundwater level change is similar to that in the Moor Grit, with two main areas of groundwater fall in the north and south and a rise at the location of the recharge trench. The overall magnitude is lower because the no recharge zones that are responsible for the declines in groundwater level mostly affect the Moor Grit Formation rather than the Scarborough Formation.

The greatest groundwater level decline in the Scarborough Formation is in the south, where levels are predicted to drop by up to around 1.3 m. The shape of the groundwater level rise in the Scarborough Formation is approximately semi-circular, with increases generally reaching no more than 0.5 m.

A layer of mudstone lies between the Moor Grit and Scarborough formations, and this affects the pattern of groundwater level response in the Scarborough Formation in two ways:

- Where the mudstone is thinner, the groundwater effect in the overlying Moor Grit can be transmitted more readily to the Scarborough Formation.
- Where this layer is thicker, recharge from the overlying Moor Grit cannot access the Scarborough Formation as easily (due to the low permeability and thickness), and this reduces any decrease in groundwater level caused by the reduced and no recharge zones in the post development model.

These variations in mudstone thickness may also cause isolated increases and decreases in groundwater level around the model area although most of these are thought to be model artefacts (see below).

The modelled thickness of the upper mudstone layer is based on borehole log data. The simulated mudstone layer is broadly thinner towards the eastern edge of the model and thickest in the north west. However, there are local spatial variations in thickness.

Although the effects of each of the construction feature have not been assessed individually in isolation, the diaphragm walls and basement structures appear to affect the groundwater system only very locally. These construction features are of relatively small area in comparison to the model and the effects on groundwater flow, such as backing up or diversions, are limited and local. In the base case model, some of the area around the basement structures is simulated to be dry, and this does not change in the post-development simulations.

Figure 3.3 and Figure 3.4 show some small patches of groundwater level increases or decreases that are isolated and in which the change in water level is much greater than effects in the surrounding area. These features mostly occur along the eastern edge of the Moor Grit and around the eastern and western edges of the Scarborough Formation. These changes are caused by cells drying out (due to the no recharge zones) or re-wetting (due to the recharge trench) in the post-development model compared to the base case model which is saturated in these areas. As such the results in these areas should be treated as model artefacts; these results do not imply significant areas of groundwater level decline or increases caused by the proposed development.

Predicted changes in groundwater level in the deeper Cloughton and Saltwick formations were always < 0.1 m and generally < 0.05 m. The low permeability intervening mudstone layers significantly dampen the transmission of effects from the construction features to these deeper layers.

Figure 3.3 Contour plot of change in groundwater levels at steady state in the Moor Grit Formation (difference between model runs 1 and 2)

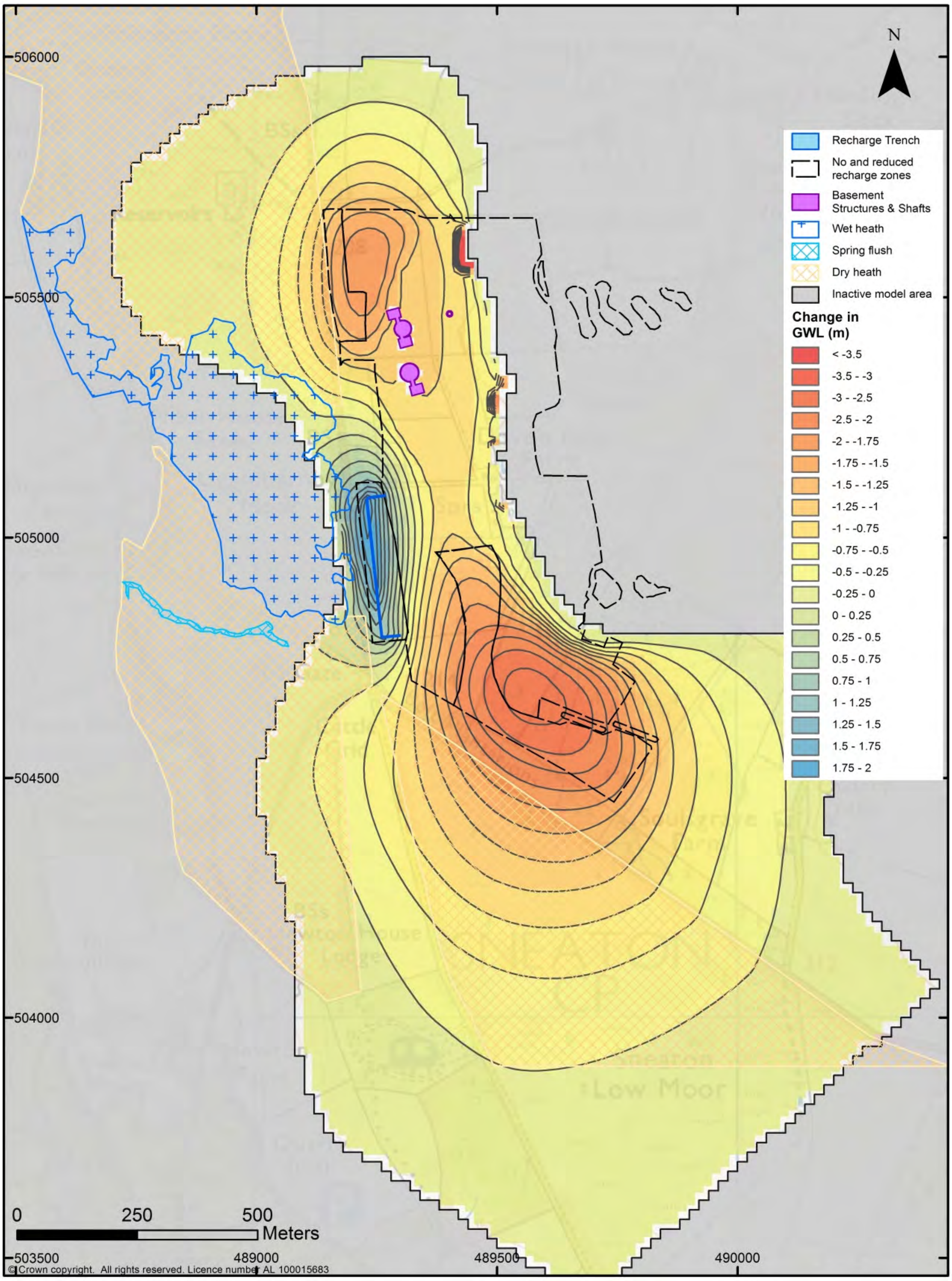


Figure 3.4 Contour plot of change in groundwater levels at steady state in the Scarborough Formation (difference between model runs 1 and 2)

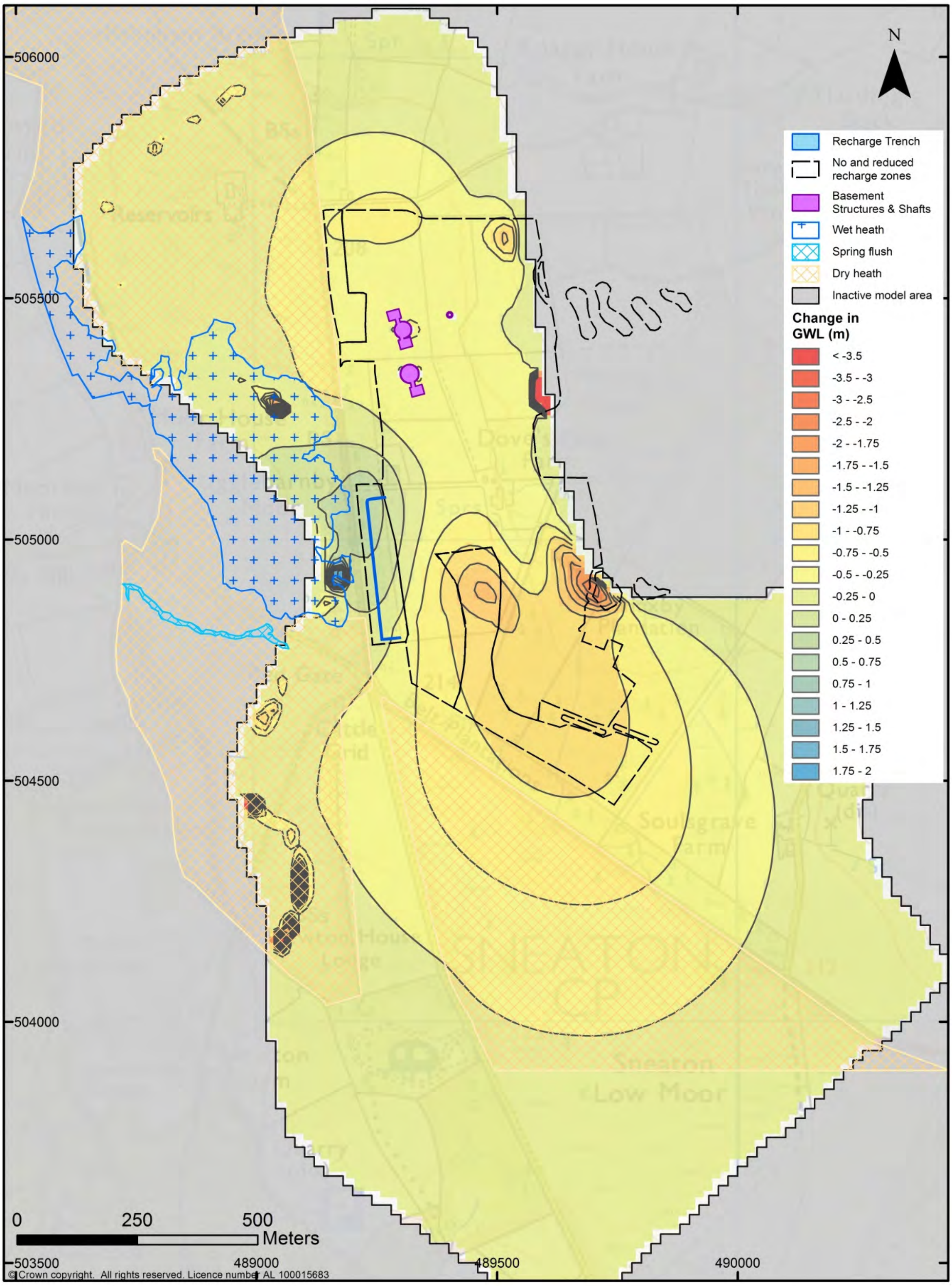
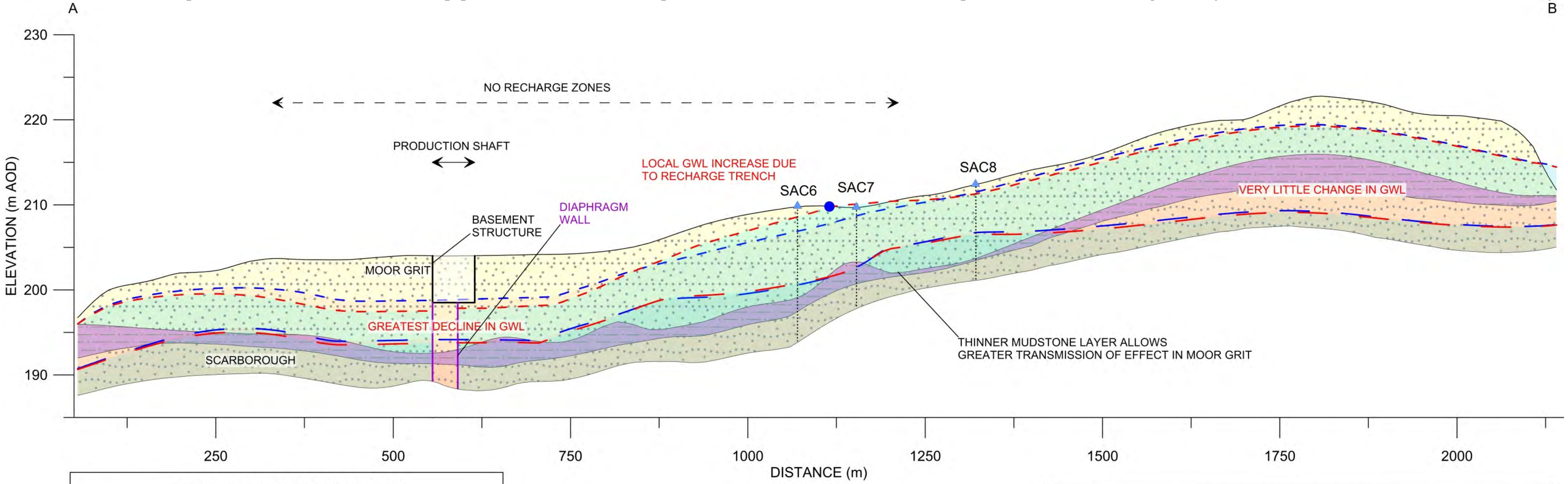
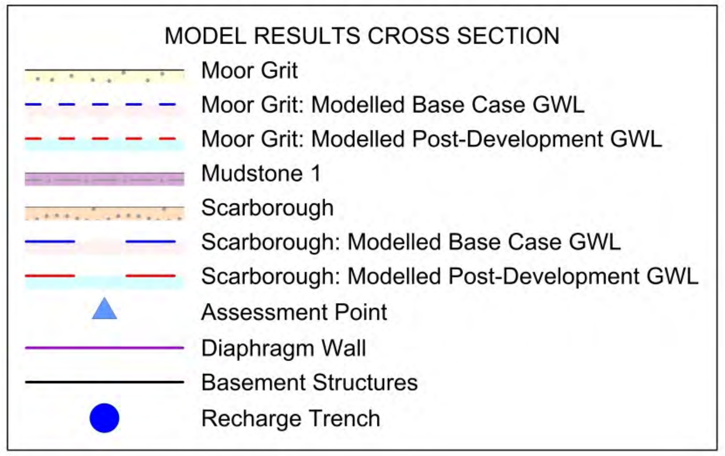


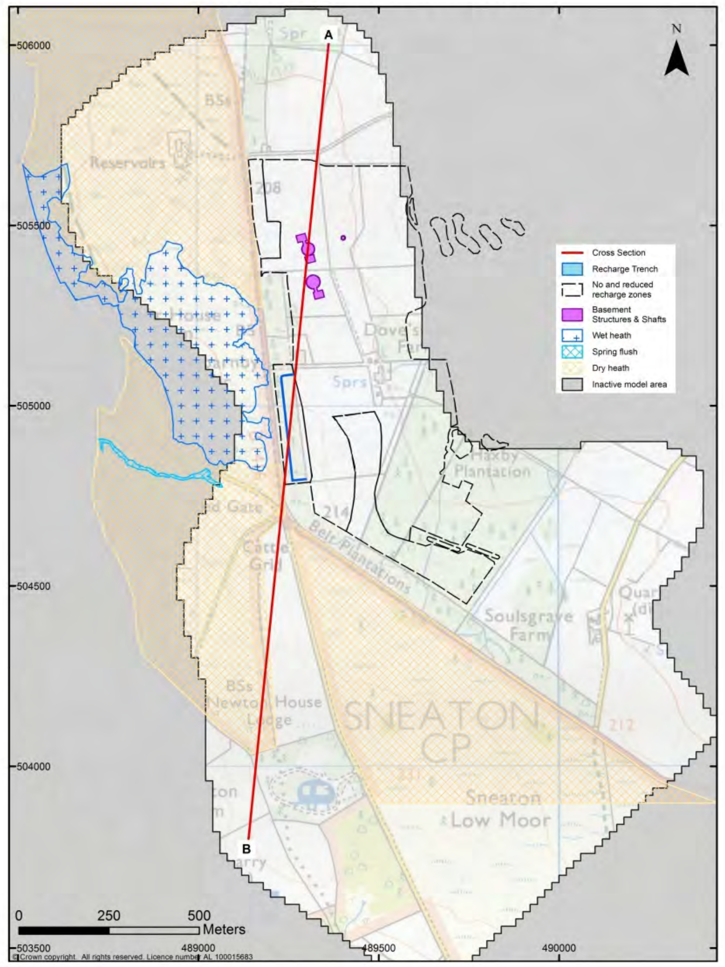
Figure 3.5 Cross section showing groundwater level changes in the Moor Grit and Scarborough formations at steady state (difference between model runs 1 and 2)





- VERTICAL EXAGERATION: 1:12
- RESULTS FROM LONG TERM STEADY STATE RUN
- GREATEST DECREASE IN GWL AROUND THE PRODUCTION SHAFT
- LOCAL INCREASE IN GROUNDWATER LEVELS AROUND RECHARGE TRENCH DUE TO GREATER RECHARGE
- ESTIMATED CHANGE IN SCARBOROUGH LESS THAN THAT IN MOOR GRIT

CROSS SECTION LOCATION



Figures 3.6 to 3.8 show time series of changes in groundwater levels under dynamic steady state conditions at locations lying on a transect between the main construction works and the Moorside Farm Spring. A summary of results from the dynamic steady state model is provided in Table 3.2, this includes maximum and minimum changes in groundwater levels over the fluctuations in the dynamic steady state run period. These plots show groundwater level time series for the post-development and base case conditions together with a groundwater level difference time series plot. A two year period is shown on the graphs and the repeating cycles indicate that dynamic steady state has been achieved.

Groundwater levels in the Moor Grit Formation show a fall at GW101 and GW124 compared to the base case (**Error! Not a valid bookmark self-reference.**). Maximum groundwater level falls occur over winter when recharge is greatest in the base case simulation and the difference in recharge inflows between the two models is at its greatest. Similarly, minimum falls in water levels occur over summer period when recharge reduces to zero and the difference in recharge between the two models is at a minimum.

Figure 3.7 shows that groundwater levels are simulated to rise at SAC6 and SAC7 due to the effect of the recharge trench which is located close to these assessment points. The rise in groundwater level is greatest following summer and before winter at which point the increase drops off. This is because recharge in the post-development model is greater than the base case model during the summer months due to the effect of the recharge trench which sources water running off from adjacent soil bunds. By December, this situation reverses as winter recharge increases and groundwater levels in post-development model run 4 increase to a lesser degree than in the base case model run 3. The recharge trench also causes the summer troughs to be less pronounced. Heads at SAC8 show a consistent drop compared to baseline conditions, with very little seasonal fluctuation. Levels at MF2 are moderated by the MODFLOW Drain cell level in the model (representing the spring) and consequently show very little seasonal variation and only a very small change in levels.

Figure 3.8 shows dynamic steady state hydrographs from the Scarborough Formation. Close to the recharge trench, at SAC6, levels are simulated to increase. However, levels decrease at SAC8 and show variable behaviour at SAC7; generally decreasing slightly over winter and increasing over summer due to the recharge trench. Amplitudes of change in the Scarborough Formation are less than in the Moor Grit Formation because the construction features directly affect the Moor Grit Formation and the shafts in the Scarborough Formation have only a minor impact on groundwater levels.

Figure 3.6 Simulated change in groundwater level at GW101 and GW124 in the Moor Grit Formation at dynamic steady state (difference between model runs 3 and 4)

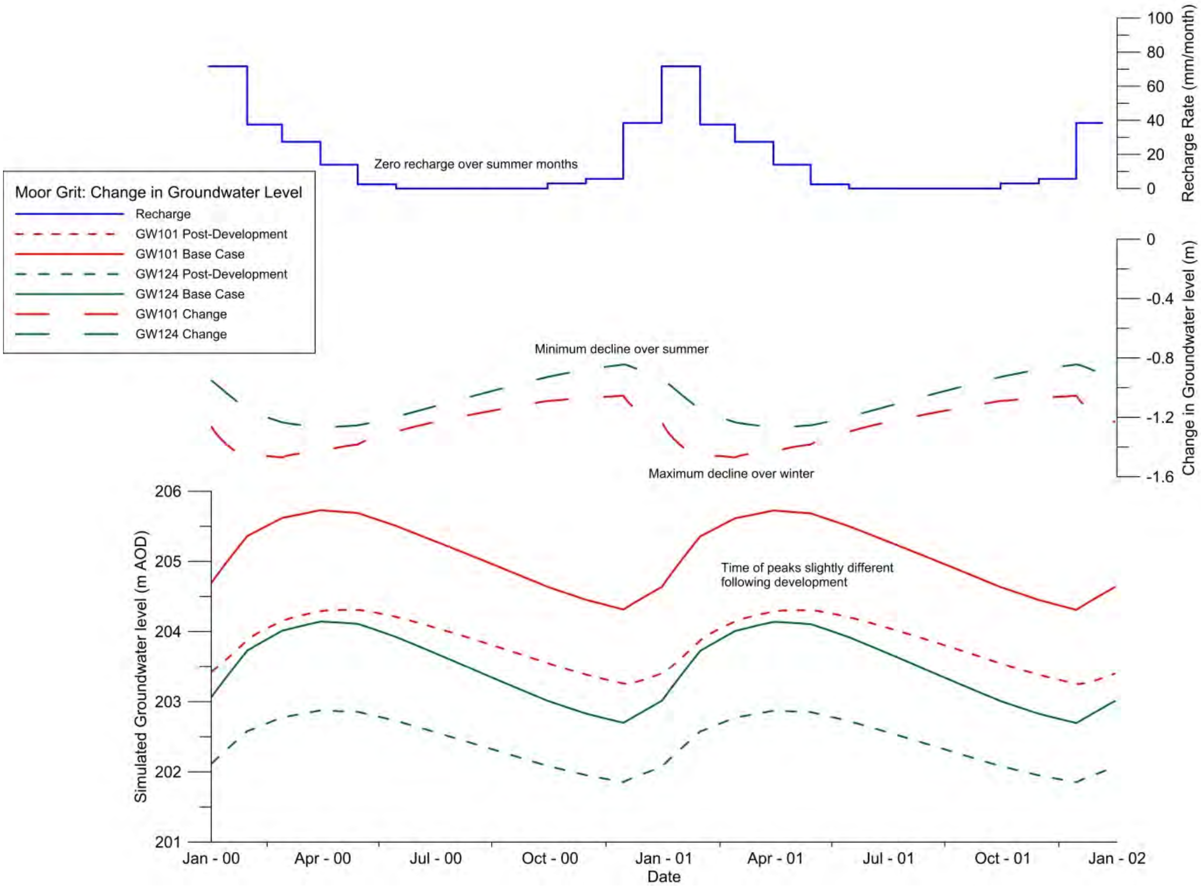


Figure 3.7 Change in groundwater level at SAC6, SAC7, SAC8 and MF2 in the Moor Grit Formation at dynamic steady state (difference between model runs 3 and 4)

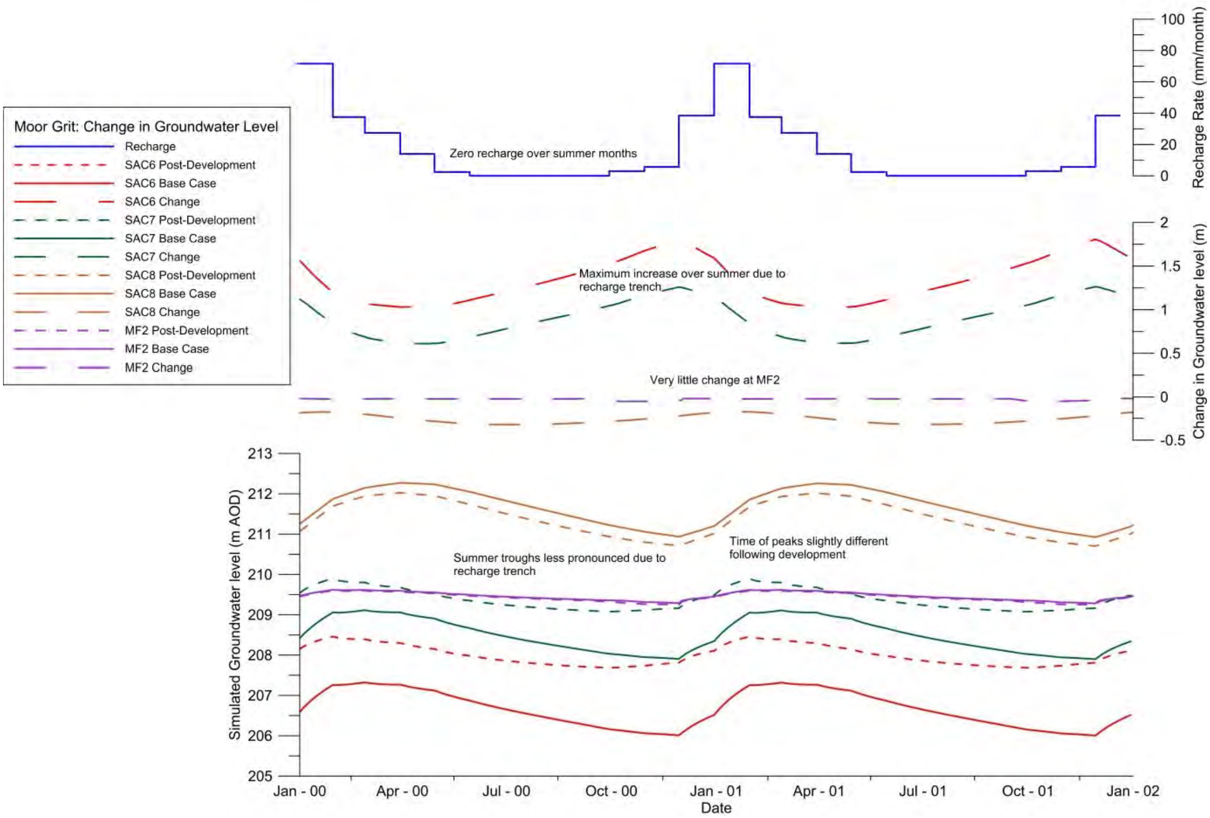


Figure 3.8 Simulated change in groundwater level at SAC6, SAC7 and SAC8 in the Scarborough Formation at dynamic steady state (difference between model runs 3 and 4)

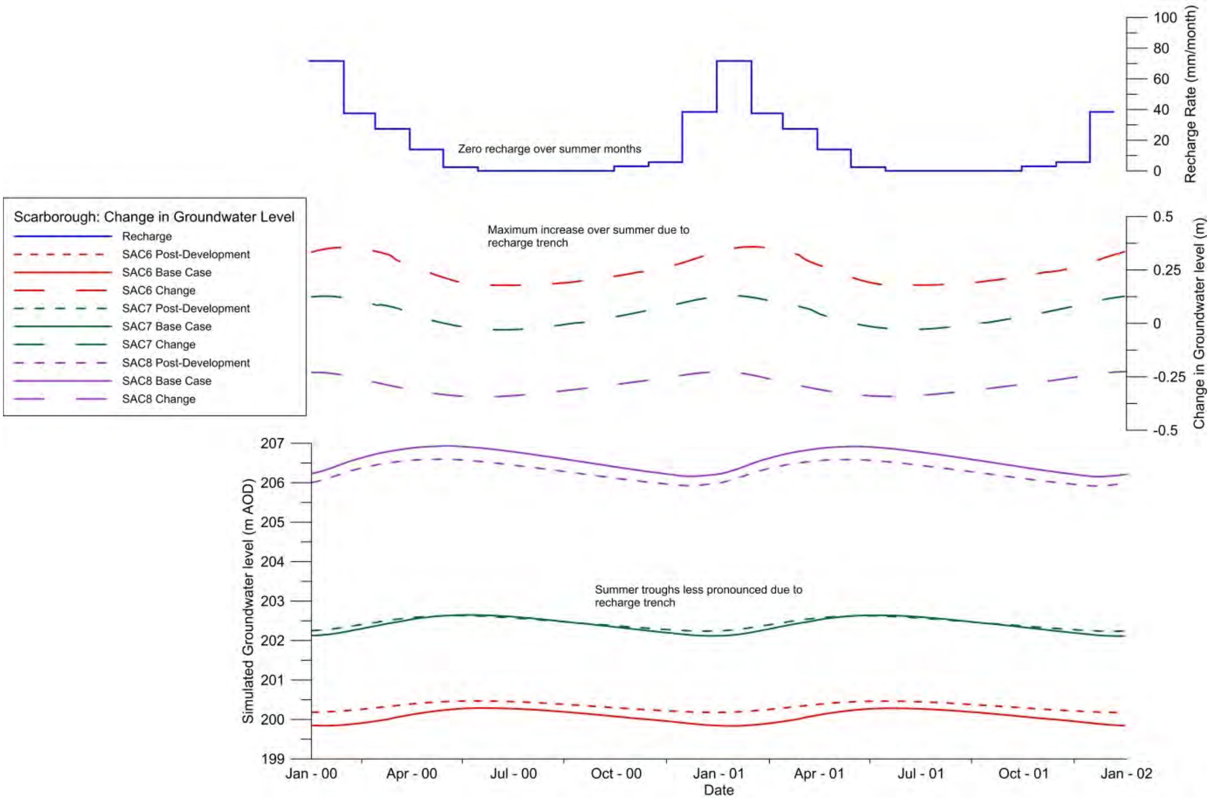


Table 3.2 Range of changes in groundwater level (m) at dynamic steady state assessment points for each transient simulation

Name	Easting	Northing	Minimum Change (m)	Maximum Change (m)
Moor Grit Formation				
GW101	489153	505657	-1.05	-1.48
GW103	489343	505679	-0.74	-1.23
GW116	489271	504712	-0.13	-0.39
GW121A	488929	505614	-0.11	-0.16
GW122A	489139	505494	-1.03	-1.41
GW123	489177	505427	-1.04	-1.76
GW124	489184	505377	-0.84	-1.27
GW125	489216	505222	0.10	-0.19
GW129	489219	505118	0.82	1.32
GW130	489236	504929	1.42	2.41
GW131	489247	504815	-0.04	-0.08
GW133A	489211	504706	-0.07	-0.19
GW135	489487	505052	-0.24	-1.00
GW136A	489401	504126	-0.40	-0.54
SAC_6	489210	504948	1.03	1.81
SAC_7	489218	504863	0.61	0.61
SAC_8	489242	504692	-0.17	-0.32
MF2	489150	504745	-0.02	-0.05
Scarborough Formation				
GW101A	489153	505651	-0.44	-0.58
GW105	489449	505667	-0.18	-0.58
GW109	489610	505120	-0.04	-0.43
GW112	489843	504759	-0.37	-0.57
GW115	489453	504645	-0.63	-0.91
GW117	489237	505103	0.23	0.50
GW121B	488921	505605	-0.09	-0.14
GW126A	489128	505165	0.03	0.17
GW136C	489402	504121	-0.26	-0.27
SAC_6	489210	504948	0.18	0.36
SAC_7	489218	504863	-0.03	0.13
SAC_8	489242	504692	-0.23	-0.34

3.3.2 Effects on spring flows

Changes in spring flows between the base case model and the post-development model at MF2, SF2 and SP01 are shown in **Error! Not a valid bookmark self-reference.**. **Error! Not a valid bookmark self-reference.** also shows the modelled variations in spring flows at dynamic steady state in MF2 in the base case and post-development model runs. Maximum and minimum changes in spring flow at dynamic steady state are summarised in Table 3.3.

Spring flow changes in MF2 and SP01 are greatest at the start of winter. This is caused by the lag time between the start of spring flows in winter in the base case (where spring flow starts earlier due to greater recharge) and post-development models. This lag time is due to the decline in groundwater levels caused by the no recharge zones meaning that the modelled groundwater levels take slightly longer to reach the drain stage. Less of a seasonal fluctuation in effect is predicted at SF2 because this spring is sited in the Scarborough Formation where groundwater levels fluctuate to a lesser extent.

The predicted maximum decrease in spring flows at MF2 is 0.42 m³/day (4.9 x 10^{-3} l/s), whilst the decrease at SP01 is predicted to be 2.29 m³/day (0.026 l/s). Such small decreases in spring flow are not measurable in the field.

Figure 3.9 Simulated change in spring flows at key receptors at dynamic steady state (difference between model runs 3 and 4)

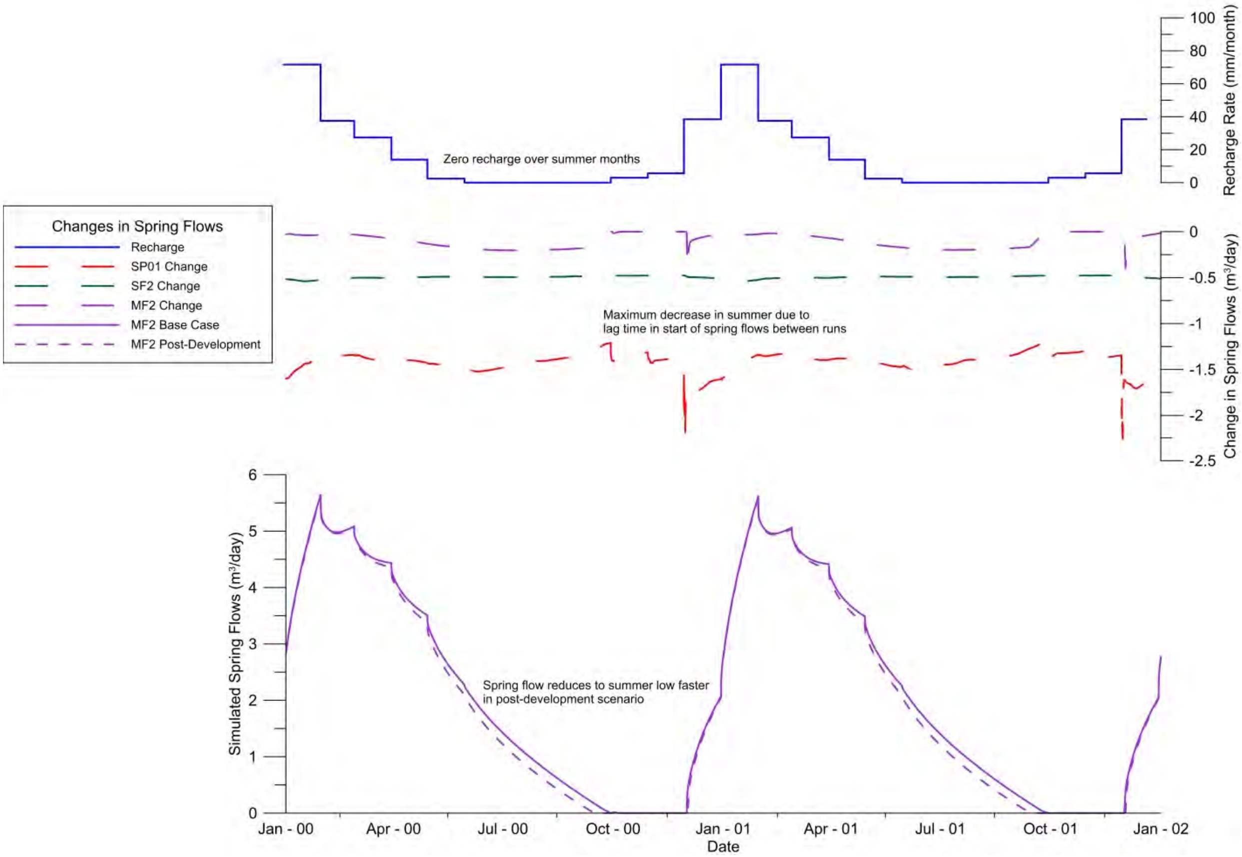


Table 3.3 Range in modelled changes in simulated spring flows at dynamic steady state

Name	Easting	Northing	Maximum difference in spring flows (m³/day)	Minimum difference in spring flows (m³/day)
Moor Grit Formation				
MF2	489151	504746	-0.42	0
SP04	489290	505995	-0.12	0
Scarborough Formation				
SF2	490239	504325	-0.54	-0.48
SP01	Distributed along western model border		-2.29	-1.2
Cloughton Formation				
SP02	488336	505814	-0.20	-0.16
SP03	488473	506115	-0.21	-0.17
NHF	488866	504006	-0.11	-0.07

3.4 Sensitivity and Uncertainty Analyses

Sensitivity and uncertainty analyses have been completed to test issues of model equivalence and the sensitivity. High and low recharge runs have been undertaken to test sensitivity to recharge and combined high and low recharge and hydraulic conductivity runs have been undertaken to test model equivalence and uncertainty. Appendix B contains details of how the runs were undertaken, a presentation of full results and discussion of these analyses.

Increasing or decreasing background recharge causes a corresponding increased or decreased contrast in recharge between the base case and post-development runs and this is responsible for the increased or decreased changes in groundwater levels and flows. If climate change increases LTA recharge compared to baseline recharge, spring flows and groundwater levels in the post-development scenario could be higher than baseline measured flows. Therefore, there will be less of an impact on levels and flows when compared to the baseline conditions. This sensitivity to recharge does not therefore detract from the predictions of the calibrated model, which focuses on the impacts on spring flows and groundwater levels relative to baseline current recharge conditions.

Equivalence exists in the model due to the interplay between the hydraulic conductivity and recharge parameters[1], which results in some uncertainty in these parameters (Appendix B). However, this uncertainty does not affect the ability of a recharge trench to mitigate the impacts because:

- At the main receptors (MF2, SF2 and spring flush area), the reduction in groundwater levels caused by reduced recharge and the increase in groundwater levels caused by the recharge trench are affected by the same key parameters (hydraulic conductivity and recharge).
- If the hydraulic conductivity of the aquifer between the recharge trench and the MF2 is lower than that simulated, then the rise in groundwater levels from the recharge trench will be lower, but also the impact from the development will be lower. Therefore, these effects counteract each other, the extent of this counteraction is however uncertain.
- If climate change causes rainfall to be higher than in the base case, this will generate more runoff and there will be more runoff available to apply to the recharge trench and thus mitigate the increased impact under the high recharge scenario. This relies on the capacity of the groundwater system to accept recharge.

The key uncertainty is whether an adequate proportion of the recharge that is being diverted from the aquifer due to the development can enter the aquifer at the recharge trench. This will depend on local ground conditions around the trench and will need to be resolved with on-site testing.

3.5 Model Limitations

The calibrated model is suitable for making indicative long term predictions of changes in spring flows and groundwater levels caused by the development of the mine site as part of environmental permitting requirements. However, there are limitations in the predictive capabilities of the groundwater flow model, these are as follows:

- Climate change is expected to alter rainfall patterns and this will likely also affect seasonal recharge. Accordingly, the recharge sequence used to simulate effects may not be applicable to long term future recharge variations. This could alter predicted effects as is shown by the sensitivity to recharge. However, the recharge sequence

[1] i.e. there are various combinations of recharge and hydraulic conductivity that result in very similar simulated groundwater levels in the calibration (an increase in recharge requiring a corresponding increase in hydraulic conductivity to simulate the same groundwater levels). However, some constraints on these values are provided by the extensive field testing of hydraulic conductivity on site and the calibration of the model to observed spring flows as discussed in previous reports is considered most appropriate.

used is representative of the baseline recharge and the predicted effects of the post-development construction features should all be related to baseline conditions.

- The limited effects on groundwater levels and flows at MF2 are dependent on the Moor Grit Formation accepting recharge from the recharge trench and this recharge being capable of supporting spring flows at MF2. Recharge to the recharge trench in the calibrated post-development model was varied to ensure that unacceptable flooding did not occur and this indicated that the recharge trench can accept the modelled recharge rate. However, the model is most suitable for simulating large scale processes rather than conditions at the scale of the recharge trench. In reality, the recharge rate that the recharge trench can accept will be dependent on local scale ground conditions and the resulting rise in groundwater levels at springs will be dependent on the transmissivity between the spring and the recharge trench. These parameters are uncertain in this area and are beyond the resolution of the model. In order to increase the acceptable recharge rate and minimise effects on neighbouring receptors it may be necessary to artificially enhance permeability around the trench. It would be appropriate to conduct infiltration testing, or similar, to test the connection between the MF2 spring and recharge trench to establish a suitable recharge rate that will result in the required groundwater level to support the springs.

4 CONCLUSIONS

The updated calibrated groundwater flow model has been used to simulate the long term effects on groundwater levels and spring flows caused by the construction features detailed in FWS (2017) compared to the base case.

Based on the groundwater modelling work undertaken, the following conclusions have been made:

- Groundwater levels in the Moor Grit and Scarborough formations across the model domain generally decrease as a result of the bunds which are modelled as no/reduced recharge areas except for levels close to the recharge trench in the west of the model. This feature causes the declines due to the no/reduced recharge zones to be concentrated in two depressions in the centre of the model to the north and centre of the model to the south. Very little change in water level is simulated in the formations underlying the Scarborough Formation.
- The predicted impacts of the development on near surface groundwater levels and flows are virtually all caused by the reduction in recharge and it is predicted that there will be no significant impact from the presence of shafts /basements acting as barriers to flow.
- The largest declines in groundwater levels generally occur away from the recharge trench and in winter when there is a greater contrast between recharge in the post-development and base case simulations. Around the recharge trench the opposite is true, and the higher recharge in the summer relative to the base case has the effect of reducing the amplitude of seasonal groundwater fluctuations. These results are conditional on sufficient recharge being accepted at the recharge trench.
- Around the Spring Flush and Moorside Farm Spring area, the groundwater level decline is simulated to be less than 0.05 m. Spring flows at the Moorside Farm spring are predicted to decrease by a maximum of 0.42 m^3/day and those at SP01 by 2.29 m^3/day. These maximum spring flow rate changes are anticipated to occur at the start of the winter period due to a lag time caused by the post-development decline in groundwater levels. These flow reductions of such a low magnitude that they will not be measurable in the field.

5 REFERENCES

ESI (2016) York Potash Phase 2 Works Model Update, ESI Ltd, Report Ref: 61415R5, December 2016

ESI (2017a) York Potash Phase 3 Works Model Update, ESI Ltd, Report Ref: 61415R6 Revision01, March 2017

ESI (2017b) York Potash: 2017 Groundwater Model Update, ESI Ltd, Report Ref: 61415R7, May 2017

FWS (2017) Hydrogeological Risk Assessment for the Section 73 Planning Submission for the North Yorkshire Polyhalite Project. Ref 1433DevOR226 Rev 2 July 2017

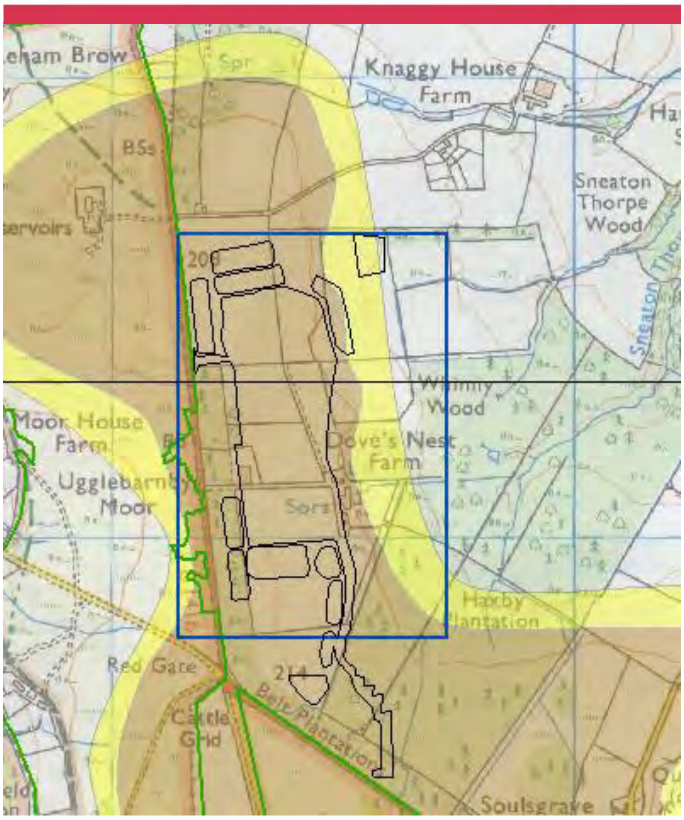
FWS (2016). Revised Hydrogeological Risk Assessment Phase 2 Site Preparatory Works at Doves nest Farm Mine Site, North Yorkshire 1433devOR27/December 2016.

FWS (2014) Hydrogeological risk assessment of the mine site development at the Dove's Nest site, North Yorkshire, FWS Consultants Ltd, 1433MineOR24/Draft/May 2014

APPENDICES

APPENDIX A

York Potash: 2017 Groundwater Model Update Report



York Potash: 2017 Groundwater Model Update

York Potash: 2017 Groundwater Model Update

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Report reference: 61415R7, May 2017
Report status: Final Report

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York Potash: 2017 Groundwater Model Update

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61415R7. Final Report

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Revision record:

Issue	Report ref	Comment	Author	Checker	Reviewer	Issue date	Issued to
1	61415R7 D1	Draft report for external review	CDW	BCH	BCH	20/4/2017	Richard Izatt-Lowry (FWS)
2	61415R7	Final report	CDW	BCH	BCH	25/5/2017	Richard Izatt-Lowry (FWS)

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1 INTRODUCTION

1.1 Background

In September 2014, the York Potash Planning Application was submitted which incorporated the Hydrogeological Baseline Report (FWS, 2014), Hydrogeological Risk Assessment (FWS, 2014a) and groundwater modelling appendix (ESI, 2014). Following receipt of planning consent for the mine in 2015, baseline groundwater level and spring flow monitoring has continued.

Development of the mine site is to be undertaken in phases. ESI has used the existing groundwater model to assess the impact of the Phase 2 Works and Phase 3 Works on spring flows and groundwater levels (ESI, 2016 and 2017). In readiness to assess the impact of the proposed Phase 4 Works, this model has been updated and re-calibrated to take account of new geological, groundwater level and spring flow data.

1.2 Scope and Objectives

ESI Limited (ESI) has been engaged by FWS Consultants Limited (FWS) to update and re-calibrate the existing groundwater flow model. The scope of work undertaken for this modelling work includes:

- Comparing the existing model elevations against all borehole data and revising the model where necessary with a focus on the upper four layers (Moor Grit and Scarborough Formation aquifers and associated mudstones);
- Re-calibration of the updated model to take account of new groundwater level and spring flow data focussing on the upper four layers; and
- Production of a standalone groundwater model report to cover the model updates and re-calibration (this report).

1.3 Data Sources

The original model was constructed using information sources that are outlined in ESI (2014b). These modelling updates have been undertaken using the sources of data listed below:

- Geological borehole logs provided by FWS including:
    - Phase 4 Stage 2 borehole logs
    - Phase 5 borehole logs
- Spring flow and groundwater level data provided by FWS up to March 2017; and
- York Potash Multi-Layer Model Report (ESI, 2014b).

Note that all figures in this report show the modelled Phase 3 Works no recharge zones used by ESI (2017). This is to illustrate the relationship between aspects of the model and the proposed mine site development.

1.4 Report Outline

This report includes the following:

- A summary of the conceptual understanding of the Site and surrounds (Section 2);
- A description of the model construction is summarised in Section 3;
- A discussion of model calibration is presented in Section 4; and
- A summary of the conclusions and key results is provided in Section 5.

2 CONCEPTUAL MODEL

This section briefly discusses the features of the conceptual model relevant to the groundwater model. This conceptual model has been formulated based on information presented in the most recent Hydrogeological Baseline Report (FWS, 2016a). The Hydrogeological Baseline Report is in turn based on previous reports (FWS, 2013; 2014), but has been updated with groundwater level, spring flow data up to March 2017 and drilling results from Phase 4 Stage 2 and Phase 5 borehole drilling. The conceptual model summary outlined below is for context only and further detail can be found in the most recent hydrogeological risk assessment report (FWS, 2017).

2.1 Geology

Superficial deposits are present across the Site. These drift deposits are generally clays of varying composition but they can contain significant thicknesses (> 0.5 m) of sand. In the vicinity of the Site superficial deposits are typically between 1 and 4 m thick. Around Ugglebarnby and Sneaton Low Moor SACs they vary in thickness from around 1.5 to 4.7 m, with the lesser thicknesses seen around Sneaton Low Moor to the south of the Site.

Bedrock geology at the Site comprises a series of relatively thin alternating Jurassic sandstones and siltstones/mudstones of the Ravenscar Group. The Whitby Mudstone is a thick, low permeability unit which forms the effective base of the sequence in terms of the local groundwater system. A summary of the sequence is provided in Table 2.1.

Table 2.1 Summary of the geological units and thicknesses underlying the Site

Stratigraphic Unit	Thickness at the Site (m)	Description
Long Nab Member	1.5 to 1.75	Sandstone with mudstone at base
Moor Grit Formation	2.3 to 13.2	Two sandstone units with intermediate mudstone/siltstone
Scarborough Formation	9 to 13	Three units – upper mudstone/siltstone; middle sandstone/siltstone; lower basal mudstone/sandy limestone
Cloughton Formation	23.5 to 52	Mudstone unit over sandstone
Ellerbeck Formation	4 to 7	Sandstone with basal ironstone
Saltwick Formation	37 to 40	Two mudstone/siltstone units with intermediate sandstone
Whitby Mudstone	72	Mudstone

These units are sub-horizontal, and dip at a low angle towards the east and north. When combined with topography, this results in the younger units cropping out to the south and older units cropping out as the land slopes northwards (towards the River Esk) and the stream valleys to the east and west. The Whitby Mudstone does not outcrop in the vicinity of the Site.

The solid geology units that outcrop beneath the Ugglebarnby and Sneaton Low Moor SACs are the Long Nab Member (Sneaton Low Moor only), Moor Grit, Scarborough, and Cloughton formations. These are the key formations with respect to indirect groundwater impacts on the SACs. The moisture contents in the soils at the SACs are predominantly dependent on groundwater within the superficial deposits upon which they sit rather than groundwater within the underlying solid geology aquifers (FWS, 2016a and b). Locally however, it is reported by FWS (FWS, 2016a and b) that in the northern part of the spring flush area underlain by Moor Grit strata, groundwater from these aquifers contributes to soil moisture within this area of this SAC.

The assessment of indirect impacts of groundwater level changes in the solid geology aquifers on groundwater levels within the superficial deposits is beyond the scope of this modelling exercise and is not discussed within this report.

2.2 Hydrology and Hydrogeology

2.2.1 Springs and surface water

Several discrete but generally very small springs have been identified near the Site. Figure 2.1 shows the location of these springs. With the exception of SP02, SP03 and NHF (all sourced from the Cloughton Formation), these springs are not thought to flow continuously throughout the year (FWS, 2016a). Monitoring of spring flow at the springs further supports this assertion.

The key groundwater discharge of relevance to this study is Moorside Farm Spring (MF2) and the associated spring flush area of the SAC. A proportion of the flow from the spring at MF2 provides the spring water that feeds a domestic storage tank, whilst the remaining (and larger) proportion forms the water source to the spring flush area within Ugglebarnby Moor SAC (FWS, 2016a). Due to the nature of the groundwater discharge, no flow rates can be monitored at the groundwater discharge point (MF2). However, flow rates have been measured for the storage tank discharge (MF1) and it is evident that spring MF2 is unlikely to provide a continuous flow of groundwater to the storage tank at MF1. As MF1 is a storage tank for drinking water used by two properties, a zero flow from MF1 does not directly represent a zero flow of groundwater from spring MF2 (FWS, 2014).

Based on their location and elevation and recent hydrochemical analysis (FWS, 2016a), the springs appear to drain the superficial deposits, Moor Grit, Scarborough Formation and Cloughton Formation (see Figure 2.1). Hydrochemical analysis of the spring waters suggests that Moorside Farm Spring (MF2) and Moorland Spring (SP01) may derive a proportion of their water from the superficial deposits. It is possible that these springs are independent to some degree from the underlying bedrock geology groundwater systems (FWS, 2016a). Further details of the springs and the formations from which they are believed to derive are given in FWS (2016a).

From the monitoring data available, flows in the springs are generally very small and highly variable and they are frequently dry over the summer. Exceptions to this are SP02 and SP03 which drain the Cloughton Formation and have been observed to flow continuously during the monitoring period. Measured flow rates (for the period January 2013 to March 2016) are summarised in Table 2.2.

Remaining groundwater discharges have been identified as follows:

- Dove's Nest Farm Spring (DNS1) – baseflow to Sneaton Thorpe Beck;
- Soulsgrave Farm Spring (SF2) – baseflow to Soulsgrave Slack, and associated storage tank (SF1);
- Ugglebarnby Moor Spring (SP01) – groundwater discharge in Ugglebarnby Moor SAC;
- Northern Springs (SP02, SP03 and SP04); and
- Newton House Farm (NHF) – licensed groundwater abstraction 2/27/29/149.

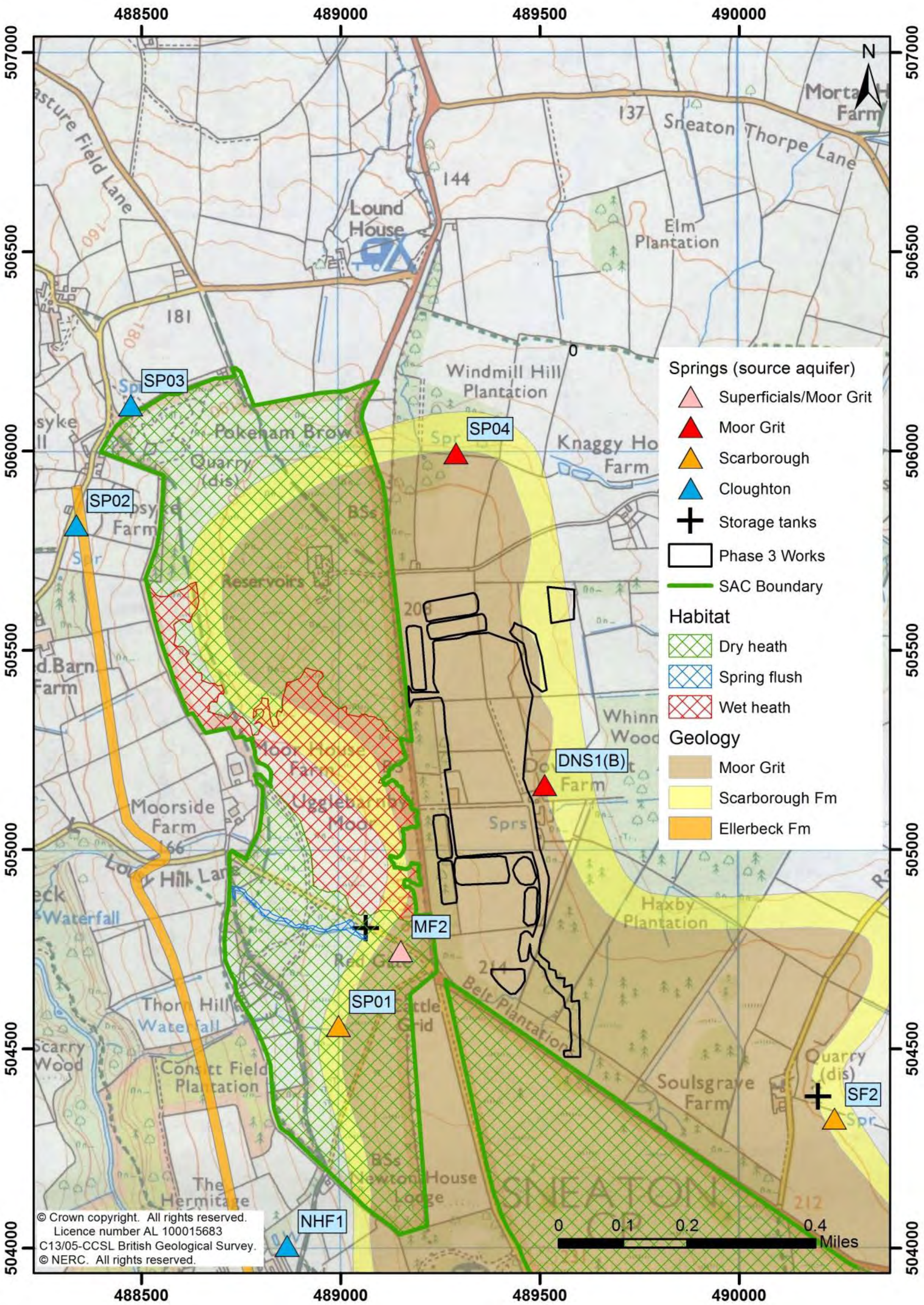


Figure 2.1 Location of known springs and source aquifer

Table 2.2 Measured flow rates for springs in vicinity of Dove's Nest site

Spring ID	Easting	Northing	Name	Source aquifer	Measured flow (m^3/d)
SP01	488994	504558	Moorland spring	Superficials/Moor Grit	0 – 68
SP02	488336	505814	Hempsyke spring	Cloughton	0 – 70
SP03	488473	506115	Quarry spring	Cloughton	10 – 2,321
SP04	489290	505995	Windmill Hill Plantation spring	Moor Grit	Not measured
NHF	488866	504006	Newton House Farm	Cloughton	Not measured
SF1	490198	504380	Soulsgrave Farm Tank	-	-
SF2	490239	504325	Soulsgrave Farm Spring	Scarborough	0 – 97
MF1	489063	504803	Moorside Farm Tank**	-	-
MF2	489151	504746	Moorside Farm Spring	Superficials/Moor Grit	0 – 22*
DNS1	489510	505070	Dove's Nest Farm	Moor Grit	0 – 432

*Flow at MF2 measured at MF1

**A small amount of flow is taken off from the tank for domestic supply to two properties. Assuming a maximum of 8 inhabitants this would not be expected to exceed ~1 to 1.5 m^3/day.

Although not confirmed in the field, it is also expected that more diffuse spring flow/seepage occurs around the outcrop boundaries of the higher permeability units. These springs and seepages represent one of the discharge components for the groundwater system in the area.

Run-off and spring flow are directed to the Little Beck to the west, the Wash Beck and Buskey Beck to the north or the Rigg Mill Beck and its various tributaries to the east. These ultimately feed into the River Esk which flows eastwards and is located to the north of the site.

2.2.2 Groundwater levels and flow

Groundwater level monitoring at the Site demonstrates a degree of hydraulic separation between the individual thin sandstone aquifer horizons. This is consistent with a low vertical hydraulic conductivity (K_v) for the aquitard layers (ESI, 2014a). There is a steep downward vertical hydraulic head gradient driven by recharge to the uppermost layers. Evidence for this is given by higher units having higher groundwater levels. For example, between the Moor Grit and Scarborough aquifers there is a difference in groundwater levels of around 5 m; between Scarborough and Cloughton it is around 7 m; and between Cloughton and Saltwick it is around 40 m. Generally, groundwater levels in the underlying aquifer are below the base of the overlying aquifer. This means that there is unlikely to be any significant effect on heads in one layer from changes in head in a vertically adjacent layer. This was demonstrated during the pumping tests (ESI, 2014a).

There is a smaller degree in variation of groundwater levels within individual layers[1]. The highest observed groundwater levels occur in the south and a groundwater high appears to run from south to north in the Moor Grit and Scarborough formations. This groundwater high runs closer to the western outcrop boundary of the aquifers than the east and consequently flow over much of the aquifer extent (including the Site) has an easterly component. This is presumably due to the springs on the eastern outcrop being lower than in the west, due to the slight north easterly dip.

In the Cloughton and Saltwick formations there are fewer monitoring points to confirm the pattern of groundwater flow. However, the data that are available are consistent with a similar flow pattern in these units.

The drivers for these groundwater flow patterns include:

- Recharge that occurs across the outcropping aquifer units,
- Vertical fluxes between units (either via leakage through the underlying aquitards or via downwards flow through the more weathered zones of these layers at the edge of outcrop); and
- The presence of springs, seeps and watercourses to the west, north, and east resulting from steeply dipping ground levels intersecting the groundwater surface in each of the aquifers.

2.2.3 Recharge Processes

Recharge is expected to occur through the superficial deposits and into the outcropping aquifer units and weathered feather edges of mudstone layers. It is likely that some spatial variation in recharge exists due to the variable nature and thickness of the superficial deposits. However, this cannot be confirmed on the basis of available information. Along with reduced superficial deposit thicknesses, higher groundwater levels in the vicinity of Sneaton Low Moor could be caused by the effects of uniform recharge over the widest part of the outcropping aquifer (i.e. further from discharge points) or a minor perched layer. Recharge rates applied to the groundwater model are discussed in more detail in Section 3.6.

Although vertical hydraulic conductivities of the intervening aquitard layers are estimated to be very low (ESI, 2014a), if allowed to drain under unit hydraulic gradient, it is possible to provide enough water via vertical flow to sustain groundwater levels in aquifer units below the outcropping unit. For example, under free-draining conditions, an aquitard with K_v of 10^{-9} m/s (consistent with the results of the pumping tests and the observed lithology of the aquitards) would allow vertical throughflow of around 30 mm/a irrespective of thickness. It is therefore considered likely that recharge occurs to the outcropping aquifers and that this then supports groundwater levels in the underlying formations through slow vertical leakage. Under these circumstances, whilst the various aquifer units are to some extent hydraulically disconnected, the rate of recharge still exerts an important control on groundwater heads in confined aquifers.

[1] NB Some of the variation within individual layers may reflect vertical hydraulic gradients within the layer as much as horizontal variations

3 MODEL CONSTRUCTION

This section describes the construction and parameters adopted for the final calibrated steady state and transient models. The model was constructed using the United States Geological Survey (USGS) numerical finite difference groundwater model code MODFLOW-2005 (Harbaugh, 2005) within the Groundwater Vistas 6 (GV6) interface. A modified version of MODFLOW-2005, called MODFLOW-USG (Panday *et al.* 2013), has been used which allows for the use of unstructured grids such as nested grids.

Two baseline models have been constructed;

1. Steady state calibration model – calibrated to average groundwater levels and spring flows. Whilst no structural changes have been made to this model in the current phase of work, results have been compared to average level/flow based on the full data series from January 2013 to March 2017. Results are presented in Section 4.1.1.
2. Transient calibration model – model with monthly stress periods for a 49 month period (January 2013 to January 2017 inclusive) calibrated to monitored groundwater levels and spring flows. Initial conditions for the transient model have been taken from the steady state model. Results are presented in Section 4.1.2.

In general, the steady state model was a useful pre-cursor to the transient model, but the latter is more robust, particularly with respect to the representation of the intermittent spring flows. Except for recharge (Section 3.6), model construction is identical for both the steady state and transient models.

3.1 Approach to Modelling

The original approach to modelling was discussed extensively with the relevant regulators and their technical experts during discussions about the original scoping model. Based on these discussions it was concluded that, although accurate modelling of thin layered aquifers and the associated small intermittent springs is challenging, this was an important exercise to carry out in order to provide confidence in the decision making.

As with any modelling exercise, it important to recognise that there will be uncertainties associated with the following aspects:

- Interpretation of the data used in the model;
- Conceptual understanding of the key processes and translation of those conceptual processes into the numerical model; and
- Uncertainties associated with the developed model as developed such as numerical and/or calibration issues.

These uncertainties should not detract from recognising that a carefully developed groundwater flow model is likely to be the most effective tool for exploring the likely effect of various development scenarios on the local groundwater system.

The steepest variation in measured groundwater levels in the local system is in the vertical plane and it was considered essential that the new, layered groundwater model should replicate these as accurately as possible. The shallower hydraulic gradients within individual layers are less well constrained (e.g. by lateral extent of monitoring) and are more prone to small scale variability in response to local variations in aquifer properties (e.g. variations in thickness, sediment nature and fracturing) and vertical gradients within layers.

In the absence of detailed information about this spatial variation in properties, the initial approach adopted in the model was to maintain uniform properties within individual layers. This approach is consistent with that generally adopted for regional groundwater models developed by the Environment Agency. However, despite concerted attempts to calibrate using globally uniform parameter values, it was not possible to achieve a satisfactory calibration and a decision was made to adopt spatial variation (see Sections 3.5.1).

Notwithstanding the decision regarding the use of spatial variation, it is well understood within the groundwater modelling community that models are generally more reliable at predicting changes between model scenarios rather than in achieving fit to absolute values.

3.2 Model Grid

The model location and dimensions are shown in Figure 3.1. Model origin is at NGR 487700 503200 with dimensions 3.7 km (east-west) and 6.2 km (north-south).

Model grid cells are set to 20 x 20 m size across the model, and are refined to 2 x 2 m across the Site area using a rectangular nested grid and the functionality of MODFLOW-USG (see Figure 3.1). This localised refinement allows for more accurate representation of construction features associated with mine site development.

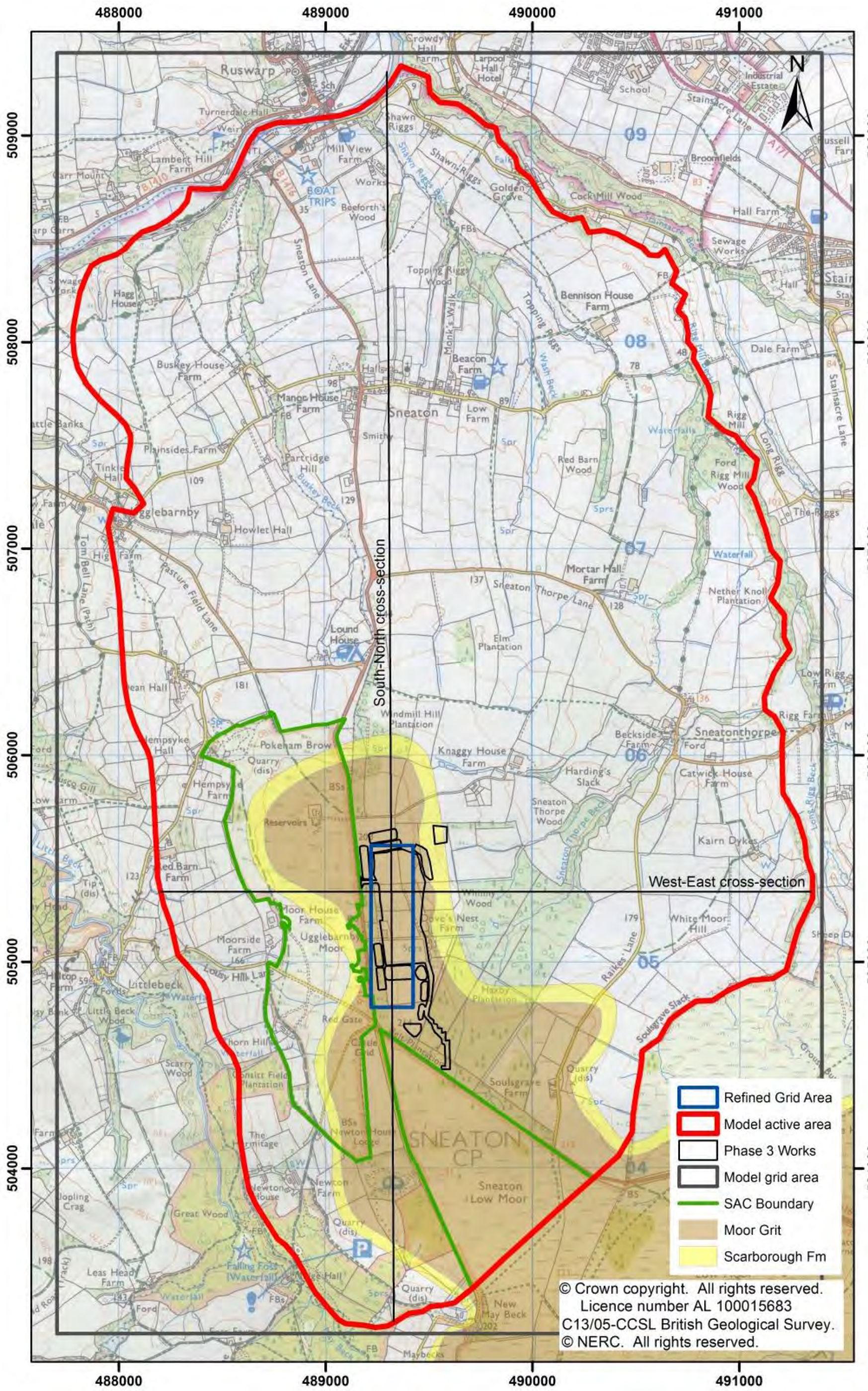


Figure 3.1 Model extent

3.3 Model Layers

The model comprises seven layers representing four aquifer units and three intervening aquitard units (Table 3.1). The lateral extent of each layer corresponds to either the aquifer/aquitard extent or the active extent of the model and is discussed further in Section 3.4.

Superficial deposits at the Site have not been explicitly included in the model as a hydrogeological unit (i.e. calibrated hydraulic conductivity of the Moor Grit does not allow for the superficial units). However, the upper surface of layer one represents the ground surface meaning that the modelled Moor Grit layer does include the superficial deposits even though the properties of these have not been directly simulated. This should be considered when groundwater level changes in the vicinity of the SACs are presented. Rather, the superficial deposits are accounted for when calculating and calibrating recharge estimates. Only a small amount of additional storage is represented by the more porous superficial deposits in reality than is allowed for in the model. Therefore, this makes the model more conservative with respect to changes in groundwater levels.

As discussed in Section 2.1, moisture content in the soils at the SAC is predominantly dependent on groundwater within the superficial deposits rather than within the underlying bedrock aquifers. The assessment of indirect impacts of groundwater level changes in the solid geology aquifers on groundwater levels within the superficial deposits is beyond the scope of the modelling exercise. However, where the model is simulating groundwater discharge from the modelled layers within the SAC (e.g. along the line of outcrop of the Moor Grit and Scarborough Formation to the west of the Site), the model can be considered to represent part of the hydrological system on which the SAC is partly dependent. One such discharge area is the Spring Flush area, where the groundwater supported flora are understood to be located (Appendix 5 of FWS (2016b)).

Table 3.1 Model layers and typical elevation at Phase 3 construction area

Layer	Modelled Strata	Hydrogeological characteristics	Approximate Top elevation at Phase 3 construction area (m AOD)
1	Moor Grit	Aquifer	200 – 211
2	Mudstone (MS1)	Aquitard	191 – 204
3	Scarborough	Aquifer	188 – 200
4	Mudstone (MS2)	Aquitard	187 – 197
5	Cloughton	Aquifer	182 – 196
6	Ellerbeck Formation	Aquitard	132 – 163
7	Saltwick	Aquifer	118 – 145

Elevation of model layers was determined using a range of data sources as follows:

- Borehole logs – stratigraphic divisions based on available borehole logs across the Site area were provided by FWS.
- OS OpenData Terrain50[2] - topography data with a 50 m grid resolution.
- Outcrop geology based on BGS Solid and Drift Map for Whitby and Scalby (Sheet 35 and 44; BGS, 1998).

[2] Contains Ordnance Survey data © Crown copyright and database right [2014]

- Pilot points – since no data were available between the Site area and the eastern model boundary, points with estimated elevation based on mean thickness were used along the eastern model boundary in the Cloughton, Ellerbeck and Saltwick formations to constrain the interpolation from the Site eastwards. This ensured that an adequate thickness was maintained for these formations in the absence of data to indicate otherwise.

Elevations based on borehole data were used directly in the derivation of model layers as known elevation points. Borehole log data were also used to calculate mean thickness for each formation, and these thicknesses were used to supplement the dataset in formations where borehole data was limited. Topography data were used in combination with the BGS map of outcrop geology to extract surface elevation at outcrop for each aquifer unit. Spatial interpolation between known or estimated points was then used to create the model surfaces. Following interpolation, checks were made to ensure a minimum layer thickness of 0.1 m and corrections made where necessary.

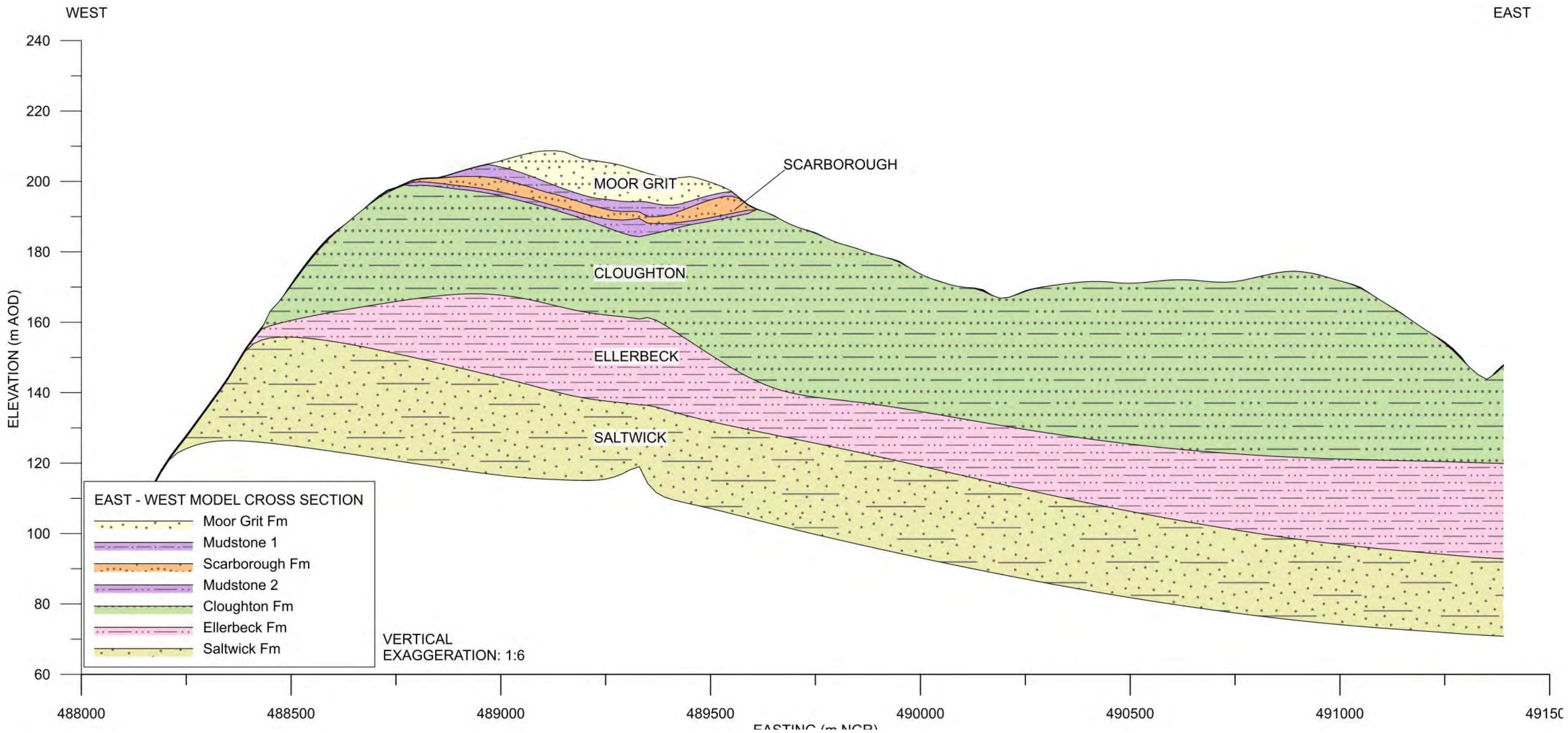
The geometry of the uppermost four layers has been updated to incorporate Phase 4 and Phase 5 field investigations. Refinement of model layer elevations has been focussed on these shallow layers, because the construction works modelled to date will have the greatest effect on groundwater levels at these depths and changes in these layers have the greatest potential for environmental impact. Some differences between the new field investigations and modelled layer elevations were identified in the deeper Cloughton and Ellerbeck formations. However, amending these much deeper layers would have a negligible impact on the model results at shallower depths. Adjusting the model elevations in these areas would improve the model calibration for these layers, and it is recommended that this exercise is undertaken in future before deeper construction works are modelled

Elevations of the upper and lower surfaces of the Mudstone (MS2) layer in areas where borehole log data was sparse were constrained to ensure that thickness is ≥ 1 m across the model, consistent with the geological data (FWS, 2017). Similarly, the thickness of the modelled Scarborough Sandstone layer was constrained to ensure that it does not exceed 6.5 m.

The lateral extent of mudstone units MS1 and MS2 was taken to be broadly similar to that of the Scarborough Formation sandstone. The Ellerbeck Formation outcrop was assumed to extend northwards beyond that mapped separating the Cloughton and Saltwick aquifer units.

Typical west-east and south-north cross-sections through the Site area are shown in Figure 3.2 (see Figure 3.1 for section lines). Layer elevations are more variable in the vicinity of the Site where data coverage is high (broadly within the box in Figure 3.1) whereas interpolation from the Site to model boundaries is typically more linear. This local-scale variability in layer elevations at the Site is an artefact of interpolation between nearby borehole logs and reflects inconsistencies, such as in borehole interpretation, and is an artificial effect of the model rather than the actual geology. These inconsistences have no consequence for the simulation of groundwater flow.

The Moor Grit Formation (Layer one in the model) was assigned as MODFLOW layer type 1, which means that the layer is treated as unconfined with transmissivity changing with alterations in saturated thickness. The storage coefficient used for this layer type is constant. All other layers were assigned as MODFLOW layer type 3, which allows transmissivity of the model cells to vary with saturated thickness. This layer type also allows the storage coefficient used by MODFLOW to alternate between confined and unconfined values depending on whether the layer is confined or unconfined.



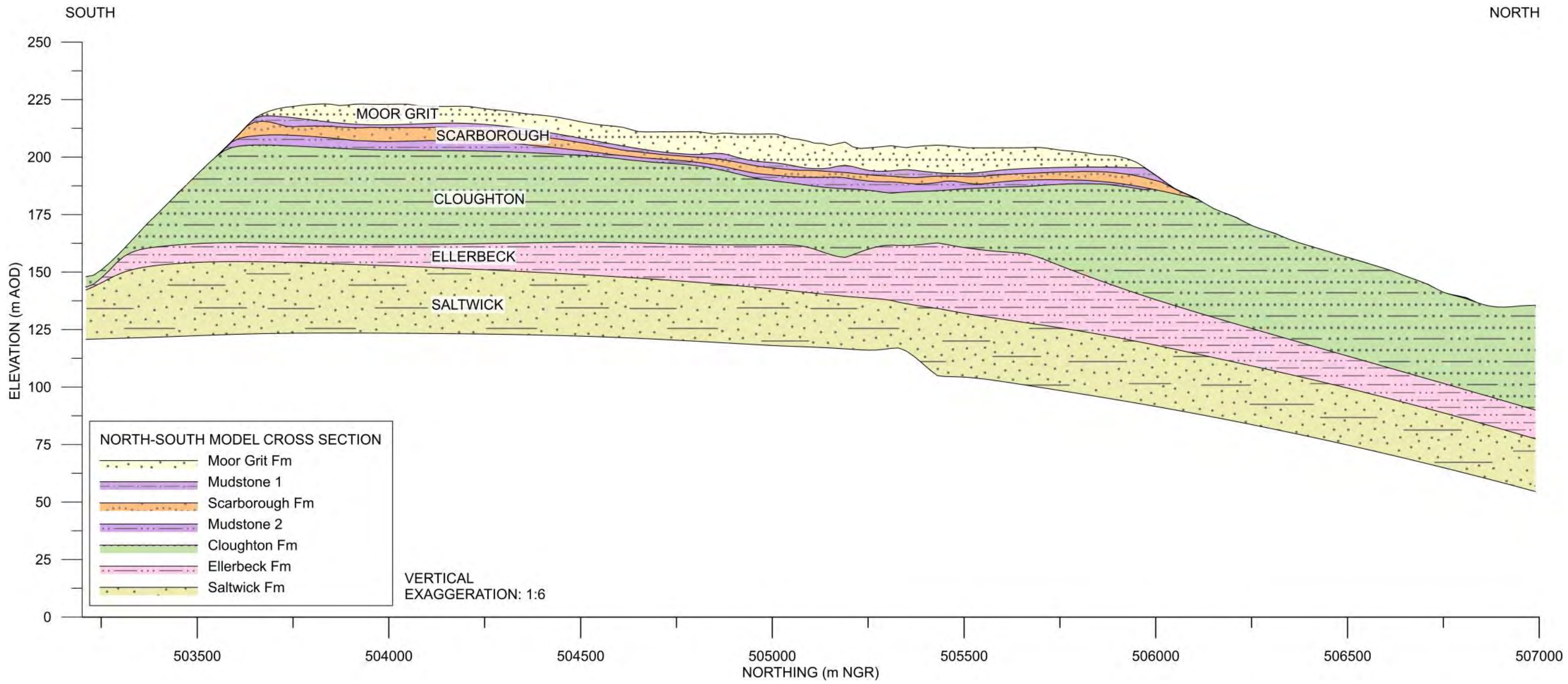


Figure 3.2 Cross-sections of model geometry (top is east—west section and bottom is north – south section). See Figure 3.1 for cross section locations

3.4 Model Boundaries

3.4.1 External boundaries

The active area of the model varies for each layer depending on the spatial extent of the aquifer/aquitard unit (see Figure 3.3). All model cells outside the active model area in each layer have been set to no flow. All lateral boundaries in aquitard units have also been set to no flow.

Due to the potential for inflow and/or outflows, the southern boundary of the model has been set as a MODFLOW General Head Boundary (GHB). This has been set approximately parallel with the groundwater flow direction in the Moor Grit and Scarborough Formation (broadly based on contours presented in FWS, 2016a).

Based on existing information on groundwater levels in the lower aquifer units, heads in the Cloughton and Saltwick were set at approximately 5 m and 60 m respectively below those in the Scarborough Formation (based on the average difference in groundwater level at monitored locations). Hydraulic conductivity is also specified for GHBs, constraining inflow and/or outflow from the aquifer, and has been set sufficiently high to ensure that the permeability of the aquifer unit is the controlling factor for inflows and/or outflow (see Section 3.5).

Remaining boundaries in the Moor Grit and Scarborough units were defined along the respective outcrop boundaries (see Figure 3.3) and are represented using MODFLOW Drain cells. Similarly, the western limits of the Cloughton Formation (defined by the Ellerbeck Formation) and the Saltwick Formation are represented using MODFLOW Drain cells.

MODFLOW Drain cells permit water to discharge from the aquifer when heads are above a specified stage level but do not allow water to enter the aquifer. At aquifer edges these therefore represent the presence of springs and seepages which are known to exist (although exact locations for all but a few are unknown). Known spring locations have also been represented explicitly and will be discussed further in Section 3.4.2.

For external model boundaries, Drain stage has been set at or slightly above the base of the relevant aquifer unit and hydraulic conductivity (K) was initially set so as not to be a limiting factor on discharge (i.e. higher, than aquifer hydraulic conductivity). During the process of model calibration, it was necessary to modify Drain K to aid model calibration. The Drain K distribution has been simplified compared to the previous version of the model without impacting on model calibration. In both the Moor Grit and Scarborough, Drain K was increased to the east of the Site (coincident with the high aquifer K zone – see Section 3.5.1). Drain K was also increased around part of the northern boundary, also coincident with the high aquifer K zone. The distribution of Drain K is shown in Figure 3.4 below.

During calibration of the original model, heads in the Cloughton and Saltwick units could not be maintained at observed levels due to high discharge from the western boundaries. Therefore, in order to achieve calibration Drain K was reduced in these layers and this distribution of Drain K has been maintained here. The northern boundary of both the Cloughton and Saltwick aquifer units has been set as MODFLOW Drain cells along the River Esk to represent possible discharge from the aquifer to the river. Drain stage is set 0.5 m below topography and hydraulic conductivity was reduced below that of the respective aquifer unit during model calibration to maintain heads in the aquifer.

The eastern boundary is set as no flow along Rigg Mill Beck, a surface watercourse over 1.5 km from the Site. This is considered to be sufficiently distant from the Site that any boundary effects are of limited significance to levels at the Site.

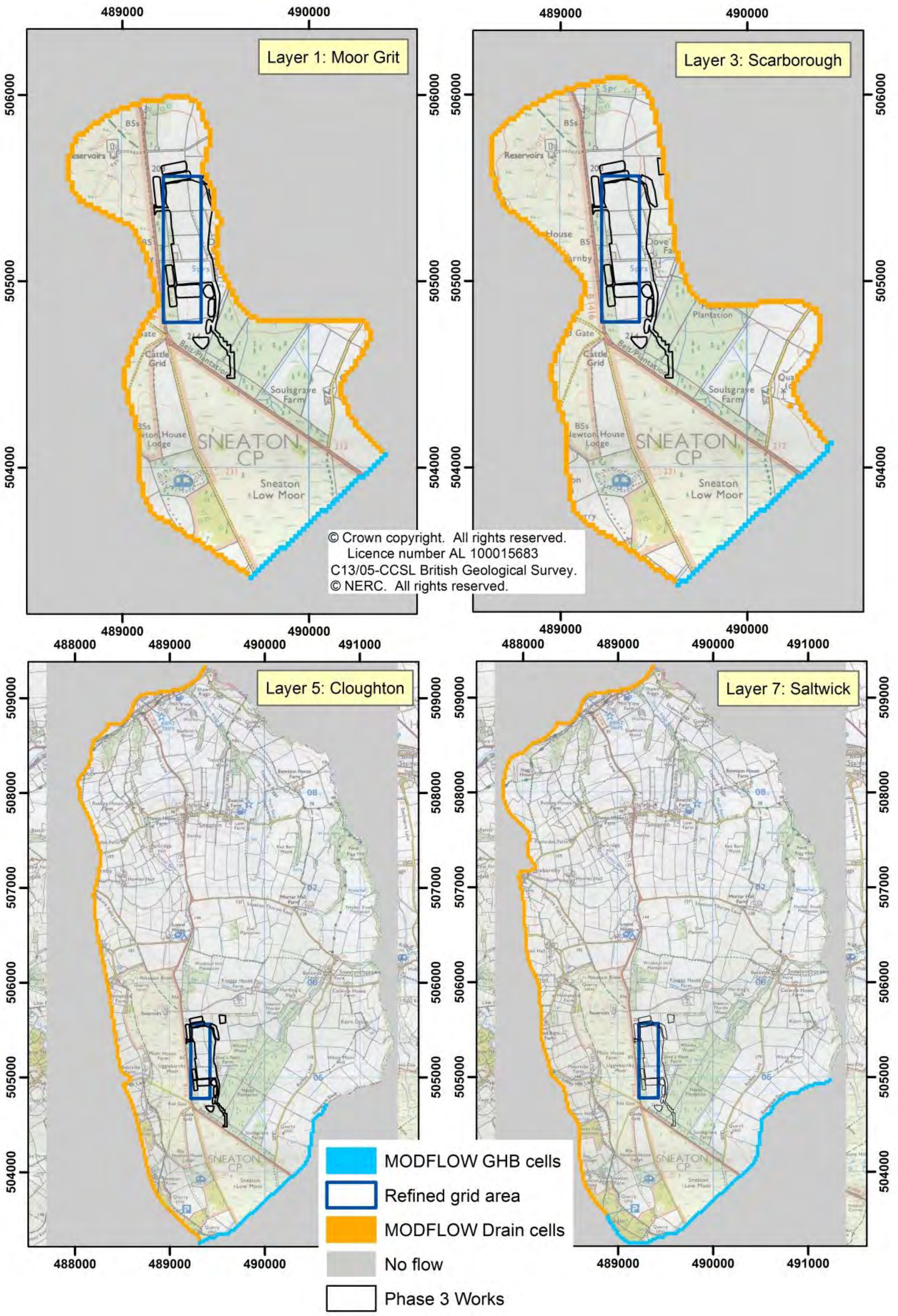


Figure 3.3 External model boundaries

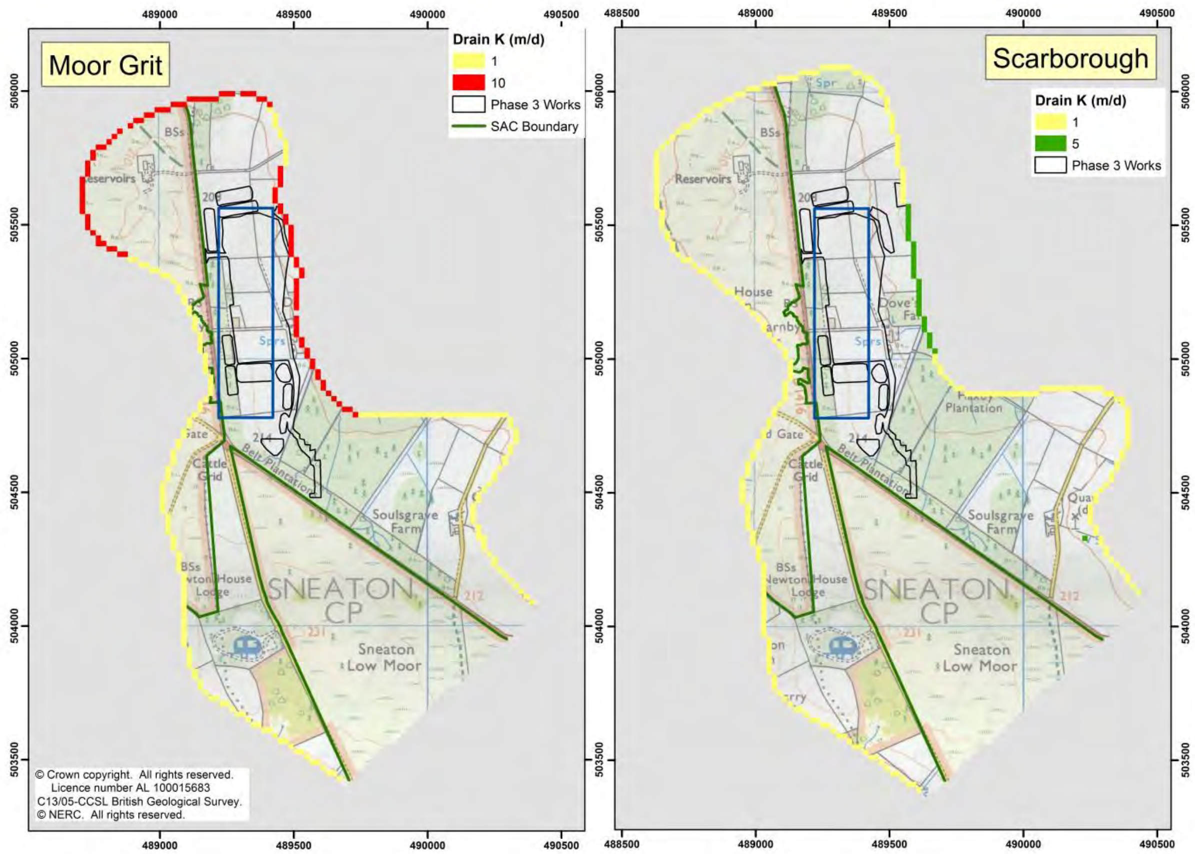


Figure 3.4 Modelled Drain K values in the Moor Grit and Scarborough Formations

3.4.2 Internal boundaries

<u>Springs</u>

Discrete springs which have been identified in the vicinity of the Site (see Figure 2.1) have also been modelled using MODFLOW Drain cells. Flow at most these groundwater discharges is intermittent (see Section 2.2.1).

The surveyed and modelled elevation of the springs is given in Table 3.2. All spring elevations were initially set at the surveyed elevation in the model. Drain stage at DNS1, SF2 and MF2, was lowered during model calibration to achieve spring flows consistent with measured flows.

SP02 was raised to 151.9 m AOD, which corresponds to the modelled base of the Cloughton Formation. Drain K applied to modelled springs is set higher than the other external boundary drain cells to force water to discharge at these known spring locations.

SP01 was simulated at the base of the Moor Grit Formation along the outcrop boundary in layer one of the model. The spring was simulated as being distributed along this model edge representing a series of seeps and springs rather than one discrete spring location. Due to this distributed representation in the model, hydraulic conductivity of this drain boundary has been set to equal 1 m/day,

Table 3.2 Details of springs included in the model

Spring ID	Name	Surveyed elevation (m AOD)	Modelled elevation (m AOD)	Source aquifer (FWS, 2016a)
SP01	Moorland spring	Various along western edge of model at base of Moor Grit		Superficials/Moor Grit
SP02	Hempsyke spring	145.00	151.9	Cloughton
SP03	Quarry spring	162.42	162.42	Cloughton
SP04	Windmill Hill Plantation Spring	195.55	195.55	Moor Grit
NHF	Newton House Farm	174.32	174.32	Cloughton
SF2	Soulsgrave Farm Spring	196.78	193.75	Scarborough
MF2	Moorside Farm Spring	210.02	209.25	Superficials/Moor Grit
DNS1	Dove’s Nest Farm	199.00	198.45	Moor Grit

Drilling platform

Exploration drilling platforms for SM11 (South Shaft) and SM14 (North Shaft) were constructed in the northern area of the Site prior to drilling (November/December 2012). These consist of dolomite hardcore (of thickness from 0.3 to 0.9 m) and have an approximate base level of 201.5 m AOD. Given the high permeability of this material relative to the Moor Grit, these have been represented in the Moor Grit using MODFLOW Drain cells. These Drain cells allow water to drain out to a stage level of 201.5 m AOD. The Drain cells have been set with a high conductance in the green shaded area shown in Figure 3.5 below.

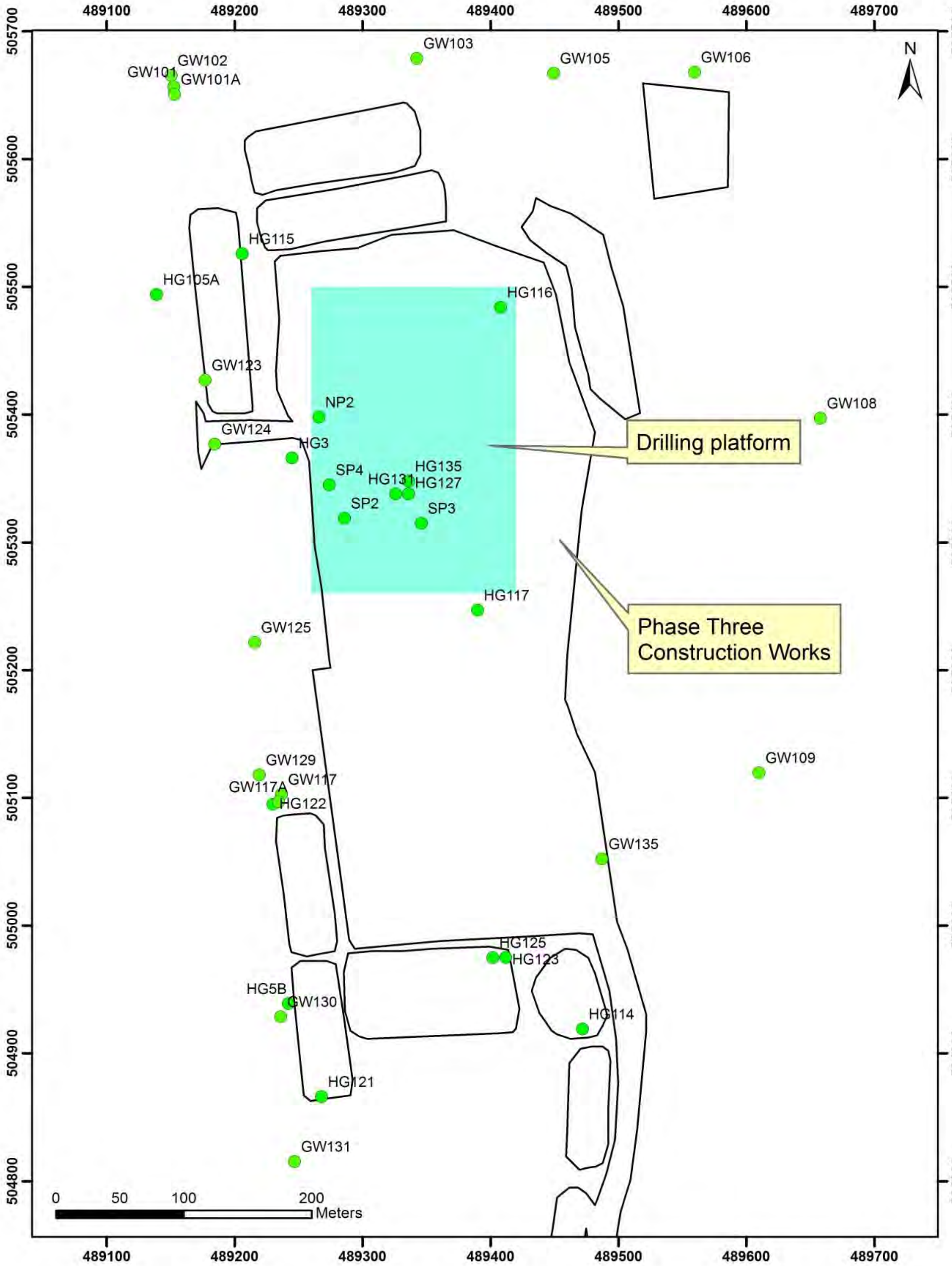


Figure 3.5 Location of MODFLOW Drain cells representing drilling platform

3.5 Hydraulic Parameters

3.5.1 Hydraulic conductivity

Aquifer hydraulic conductivity (K_h and K_v) values were based on the results of pumping tests (as reported in ESI, 2014a) and packer tests and variable head tests undertaken as part of the Phase 4 Stage 2 fieldwork investigations, as reported by (FWS, 2016a). These results are summarised in Table 3.3. Aquitard hydraulic conductivity values were determined to be at least two orders of magnitude lower than typical values of aquifer K_h (ESI, 2014a). Aquitard K_v was an important parameter for model calibration and will be discussed further in Section 4. For simplicity, the hydraulic conductivity distribution in the aquitards has been set as isotropic.

In the Cloughton and Saltwick formations, aquifer hydraulic conductivity has been set to a uniform, isotropic value (as shown in Table 3.3). In the Moor Grit and Scarborough formations, variable hydraulic conductivity zones were required to aid model calibration. Anisotropy has been incorporated into the Moor Grit Formation in the model, representing less flow in the west-east dimension than south-north.

Hydraulic conductivity zones for the Moor Grit and Scarborough formations are shown in Figure 3.6 and summarised in Table 3.3.

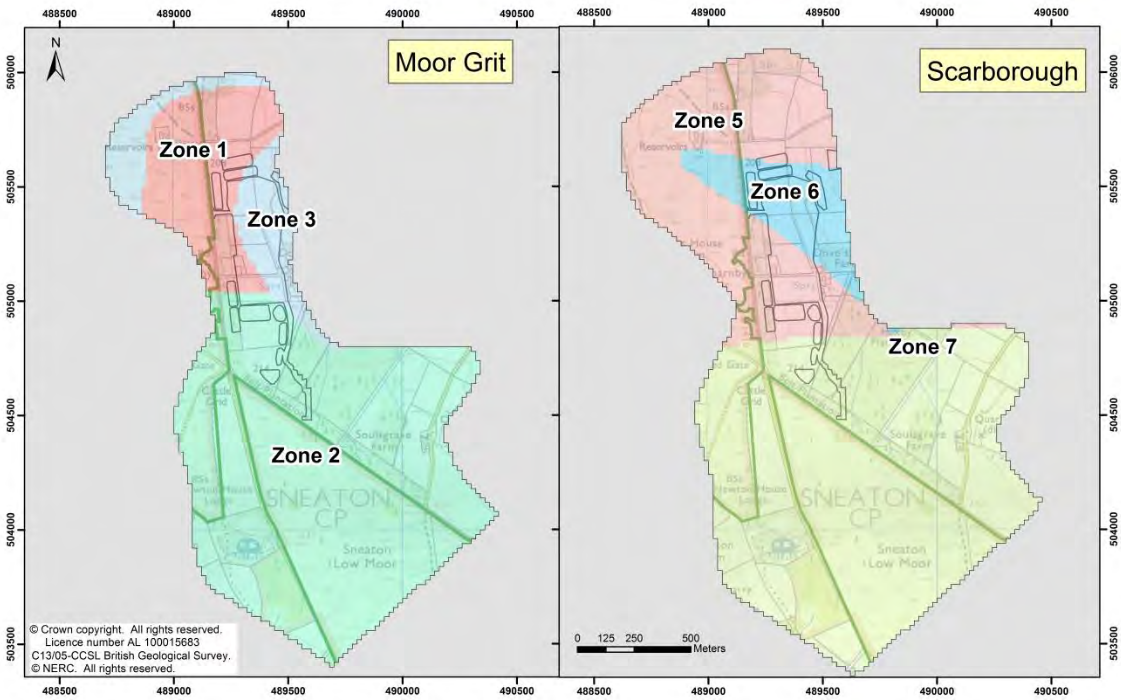


Figure 3.6 Modelled hydraulic conductivity zones in the Moor Grit and Scarborough formations

The results of the pumping tests shown in Table 3.3 are discussed in more detail in the pumping test report (ESI, 2014a). Further details on the other hydraulic testing are available in the Hydrogeological Baseline Report (FWS, 2016a). These results suggest the possibility of anisotropy and spatial variation in K_h. In particular, the results from the Scarborough Formation show a range of several orders of magnitude which may be attributable to the local presence of fissures. It was therefore considered reasonable, after first attempting to achieve calibration using isotropic and spatially uniform parameter values, to explore spatial variation and anisotropy.

In order to achieve a satisfactory calibration, it was necessary to amend the zone boundaries in both the Scarborough and the Moor Grit formations slightly from the previous model. The most significant changes are adding an additional area of high permeability Zone 1 in the north-west of the Moor Grit and adding in a new permeability zone (Zone 7) in the southern part of the Scarborough Formation.

Table 3.3 Hydraulic conductivity – field measurements and modelled values

Layer	Zone	Strata	Hydrogeological characteristics	Estimated K_h range (m/s): Pumping tests*	Estimated K_h range (m/s): Packer tests**	Estimated K_h range (m/s): Variable head tests**	Modelled: K_x (m/s)	Modelled: K_y and K_z (m/s)
1	1	Moor Grit	Aquifer	1×10^{-7} – 3×10^{-6}	3.40×10^{-7} - 3.80×10^{-5}	3.2×10^{-7} - 2.10×10^{-6} 4.32×10^{-7} - 2.99×10^{-5} (MG and SB)	2.3×10^{-6}	5.8×10^{-6}
	2						3.5×10^{-6}	6.9×10^{-6}
	3						4.6×10^{-5}	1.2×10^{-4}
2	4	Mudstone (MS1)	Aquitard	Unknown	1.20×10^{-6} to 5.20×10^{-6}	2.6×10^{-7} - 5.2×10^{-5} (aquifer and aquitard) 4.32×10^{-7} - 2.99×10^{-5} (MG and SB)	6.9×10^{-10}	6.9×10^{-10}
3	5	Scarborough	Aquifer	7×10^{-7} (unfissured)- 1×10^{-3} (fissured)	6.08×10^{-6} - 3.20×10^{-5}		1.2×10^{-6}	1.2×10^{-6}
	6						2.3×10^{-5}	2.3×10^{-5}
	7						8.1×10^{-6}	8.1×10^{-6}
4	8	Mudstone (MS2)	Aquitard	Unknown	1.10×10^{-7} - 2.70×10^{-5}	1.11×10^{-9} to 6.97×10^{-7}	2.0×10^{-10}	2.0×10^{-10}
5	9	Cloughton	Aquifer	2×10^{-4} – 8×10^{-4}	2.33×10^{-5} - 3.25×10^{-5} (fractured siltstone) 6.45×10^{-5} - 1.21×10^{-4} (fractured sandstone)	1.09×10^{-7} (CL and SB aquitard) 1.70×10^{-6} - 5.68×10^{-5} (MG, SB, CL)	2.3×10^{-4}	2.3×10^{-4}
6	10	Ellerbeck Formation	Aquitard	Unknown	8.54×10^{-7} - 1.76×10^{-6}		1.0×10^{-9}	1.0×10^{-9}
7	11	Saltwick	Aquifer	2×10^{-5} – 5×10^{-5}	3.20×10^{-5} - 5.75×10^{-5}	2.0×10^{-7} (aquifer and aquitard)	2.0×10^{-5}	2.0×10^{-5}

*Based on pumping tests (see ESI, 2014a) **FWS, 2016.

3.5.2 Storage

The calibrated storage parameters are shown in Table 3.4.

Table 3.4 Storage parameters used in the model

Layer(s)	Formation(s)	Specific Yield	Specific Storage
1	Moor Grit Formation	0.01	0.01
2 - 7	Scarborough, Cloughton and Saltwick formations	0.01	0.001

Unconfined specific yield was set to 0.01 (1%) for all layers, while specific storage was chosen to vary with depth. Specific storage was set to be an order of magnitude lower in the layers underlying the Moor Grit in order to better replicate the observed seasonal variations in groundwater level.

3.6 Recharge

The Environment Agency's Water Framework Directive Recharge Calculator Version 2.63 (Environment Agency, 2007) has been used for assessing the transient variation in recharge at the Site. This tool is based on a water budget approach which estimates the direct (e.g. infiltration recharge) and indirect (e.g. run-off recharge) components of recharge. It includes estimations of effective rainfall, actual evapotranspiration and run-off (dependent on soil type, surface geology and land use) to determine actual recharge to an aquifer.

A recharge time series for the transient model has been calculated by inputting daily rainfall and potential evapotranspiration (PE) data into the recharge calculator. Recharge in the model has been updated by obtaining daily rainfall and PE data for the period from 1 January 2013 to 12 February 2017 (provided by the Met Office for MORECS Square 87).

The resultant transient time series indicated an annual recharge of between 161 mm/a and 402 mm/a (based on clay soil type and 'rough grass/moor' land use), with the actual recharge dependent on superficial deposit thickness and likelihood of bypass flow[3]. The high upper value of the range is due to an exceptionally high recharge of 157 mm in January 2016, and a more typical upper recharge is expected to be around 350 mm. Given that a proportion of recharge will remain in the superficial deposits, the actual recharge to the bedrock aquifers will be towards the lower end of the middle of this range.

Recharge in the steady state model has been set to 5.48×10^{-4} m/d (200 mm/a) during the process of model calibration. For the reasoning outlined above, this is considered to be a representative average value of recharge for the period to which the steady state model has been calibrated. In the transient model, the daily recharge sequence determined by the recharge calculator was summed on a monthly basis and factored to sum to an annual recharge of 200 mm/a (based on the steady state calibration) whilst maintaining the seasonal recharge variability. The exceptionally high January 2016 recharge of 157 mm was excluded when factoring the recharge for the transient run. This was to prevent recharge at other times of the model run from being reduced to a greater degree.

In the model, recharge has been applied only to outcropping aquifer units and is zero where aquitard layers outcrop. The transient recharge time series is shown in Figure 3.7 and is compared to monthly rainfall and PE. There is generally no recharge simulated between April and October as PE is generally higher than rainfall during these months. As rainfall begins to exceed PE in the autumn, the soil moisture deficit is satisfied and recharge to

[3] Determines Hydrology of Soil Type (HOST) class (see Boorman, D.B. and Hollis, J.M. Hydrology of Soil Types: A hydrologically-based classification of the soils of England and Wales).

groundwater can begin. Recharge is relatively low over the 2014/15 winter, and peaks during the 2016/17 winter.

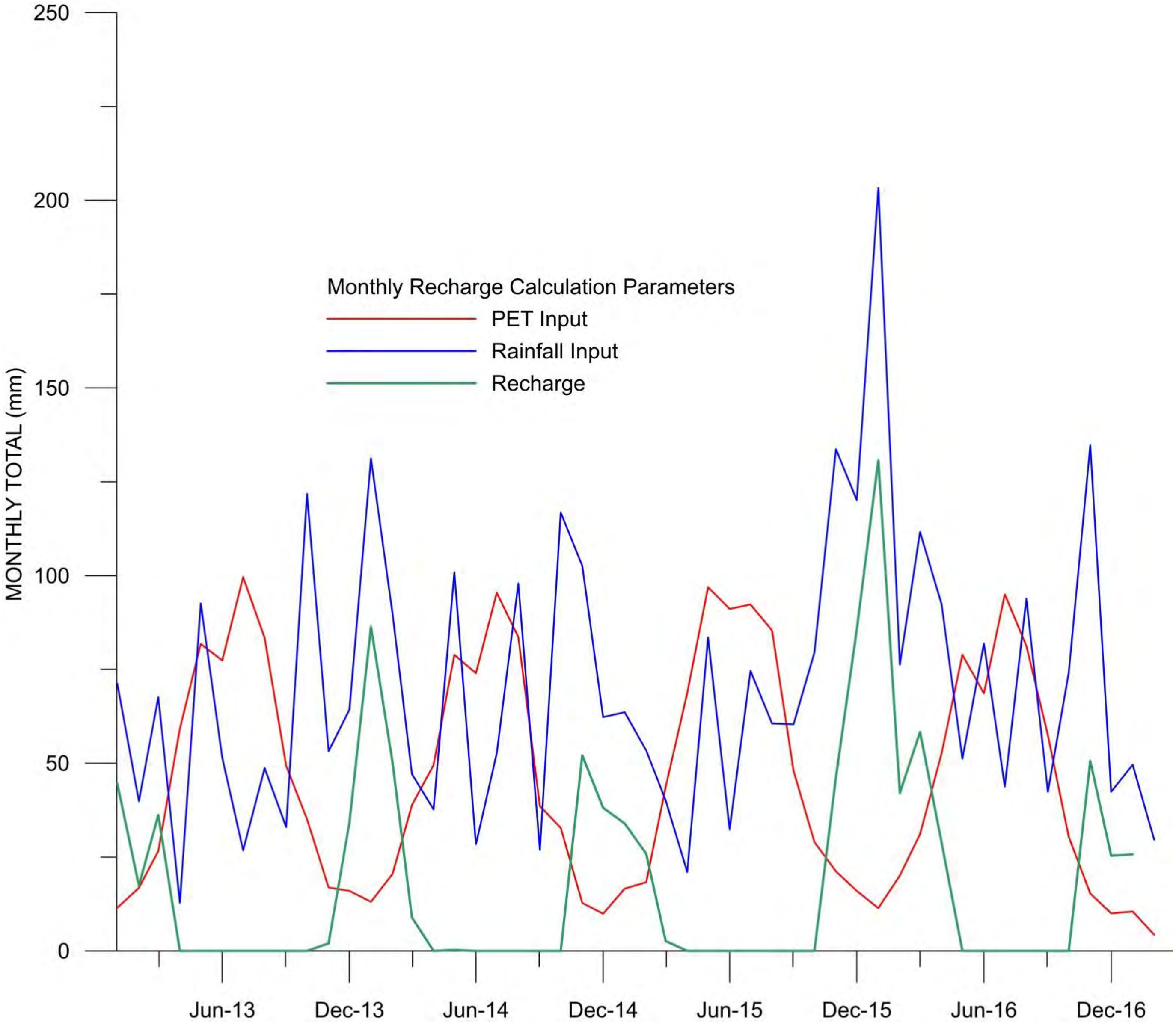


Figure 3.7 Monthly rainfall, PE and recharge used in the transient model run

4 MODEL CALIBRATION

Steady state and transient 'best estimate' calibration is discussed in this section. The steady state calibration focused on constraining the range of likely recharge and hydraulic conductivity and provided a 'best estimate' of typical heads to use as initial conditions for the transient run. Using a steady state model for calibration initially, rather than a transient model, significantly reduced the time required for model runs.

Transient calibration then focused on determining likely ranges of specific yield (unconfined) and specific storage (confined). Due to the intermittent nature of the small springs in the upper horizons, it is considered that the results of the transient model are more appropriate for reaching conclusions regarding the potential effect of the proposed development on the local groundwater system.

Both steady state and transient calibrations initially focussed on the period January 2013 to May 2014 (ESI, 2014b) and have since been extended to January 2017. Because the model layer elevations were revised based on the new field data, it was necessary to re-calibrate the model.

Model calibration as part of this phase of modelling was focused on achieving a model that is fit for purpose for the following objective:

- Assessment of the effects of the proposed development on the Moorside Farm spring (MF2)/Spring Flush within Ugglebarnby Moor SAC.

As discussed in Section 3.1, the primary focus of the calibration was to simulate the steep vertical hydraulic gradients at the Site. Additionally, it was important to simulate the transient behaviour of the springs although, due to their intermittent nature, there were challenges with model cells drying that needed to be overcome to achieve this. Accurate simulation of hydraulic gradients (and water levels) within individual layers was difficult to achieve. As discussed in Section 3.1, it is considered that the main strength of the model is in simulating the difference between two scenarios (i.e. change in flows or groundwater levels in response to construction activities) more reliably than the simulation of the absolute values.

4.1 Groundwater levels

Calibration to groundwater levels has focused on enabling the assessment of the effects of the proposed development on groundwater levels within Ugglebarnby Moor SAC.

4.1.1 Steady state calibration

Steady state groundwater level calibration targets have been set based on mean recorded groundwater levels during the period January 2013 to March 2017 at 72 observation boreholes. Phase 4 boreholes were included, but not Phase 5, because groundwater levels in these boreholes are yet to equilibrate following drilling. A complete dataset for this time period is not available for all observation boreholes, with monitoring at some locations within the Ugglebarnby Moor SAC only starting in January/February 2014. Groundwater level data from the Phase 4 boreholes is only available from September 2015 to March 2017. Average levels for these locations are therefore only representative of those for this period.

Although average recorded levels provide a good indication of spatial variation in groundwater levels, the steady state model does not capture seasonal fluctuations. The transient model is essential for assessing how potential impacts vary seasonally.

Plots of observed versus simulated heads for the steady state calibration for all layers are shown in Figure 4.1, and for the Scarborough and Moor Grit formations only in Figure 4.2. Residuals for each model layer are presented spatially in Figure 4.3. A negative residual (labelled blue in Figure 4.3) indicates that simulated heads are greater than mean levels, whereas a positive residual (labelled red in Figure 4.3) indicates that simulated heads are below mean levels. Residual summary statistics are provided in Table 4.1 for the 72 boreholes used in the model as calibration targets. Boreholes drilled as part of the Phase 4

Stage 2 fieldwork investigations have also been included, even though observed data are only available since September 2015. The calibration statistics and plots indicate that model calibration is good particularly within the Moor Grit and Scarborough formations, where the main receptors are located. There is also a good match to mean observed levels in the Saltwick Formation. The match to levels in Cloughton Formation is similar to that achieved previously. In order to improve the calibration in this layer, further work involving updated elevations, and new permeability zones would be required.

Simulated steady state groundwater contours for the Moor Grit and Scarborough formations are provided in Figure 4.4.

Table 4.1 Residual summary statistics for steady state model calibration

Statistic	**All layers**	**Moor Grit**	**Scarborough**	**Cloughton**	**Saltwick**
Number of observations	72	29	15	25	3
Range in mean of observations (m)	77.0	23.6	21.4	17.3	0.31
Absolute residual mean (m)	1.7	0.89	1.32	3.06	0.1
Scaled residual standard deviation (m)	0.97	0.93	0.93	0.022	0.03
Normalised sum of square residuals	72	30	15	25	3
Minimum residual (m)	-9.1	-3.34	-3.3	-9.1	-0.14
Maximum residual (m)	6.9	2.72	2.87	6.9	0.16

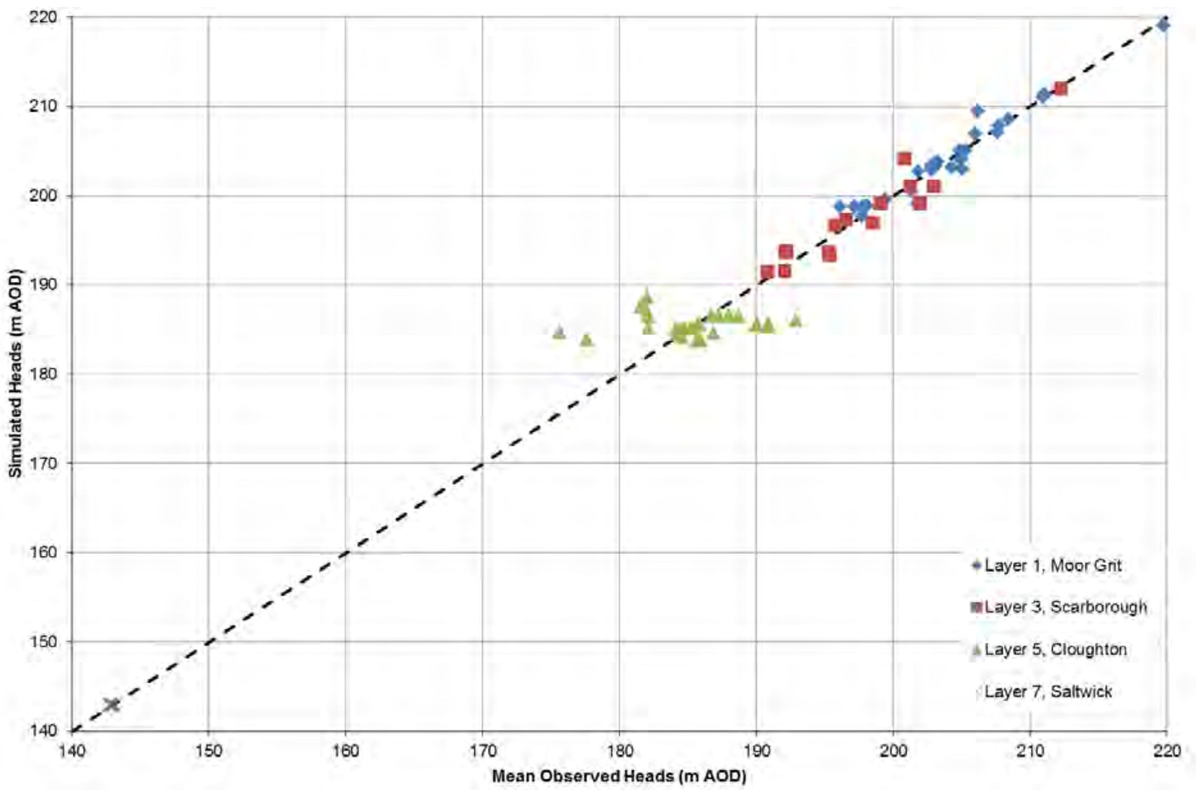


Figure 4.1 Steady state calibration – observed versus simulated groundwater levels (all calibration points)

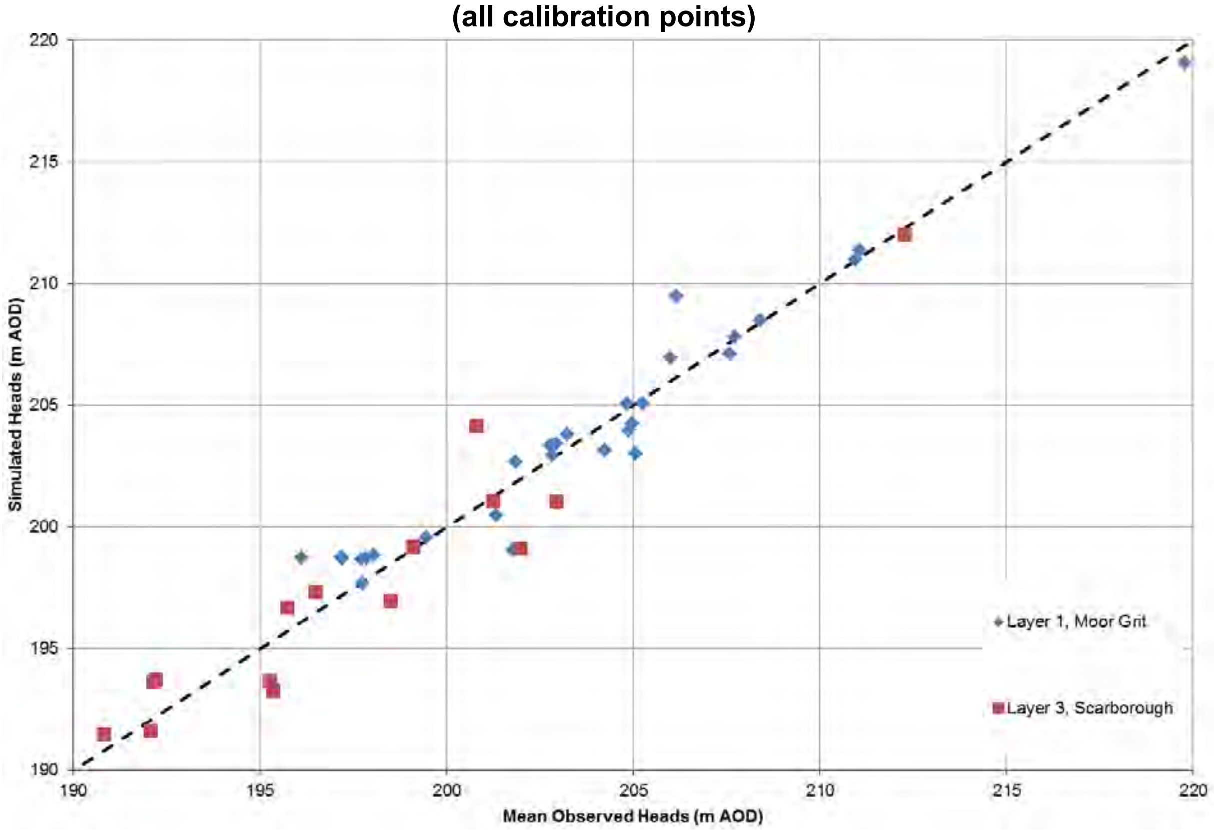


Figure 4.2 Steady state calibration – observed versus simulated groundwater levels (Moor Grit and Scarborough)

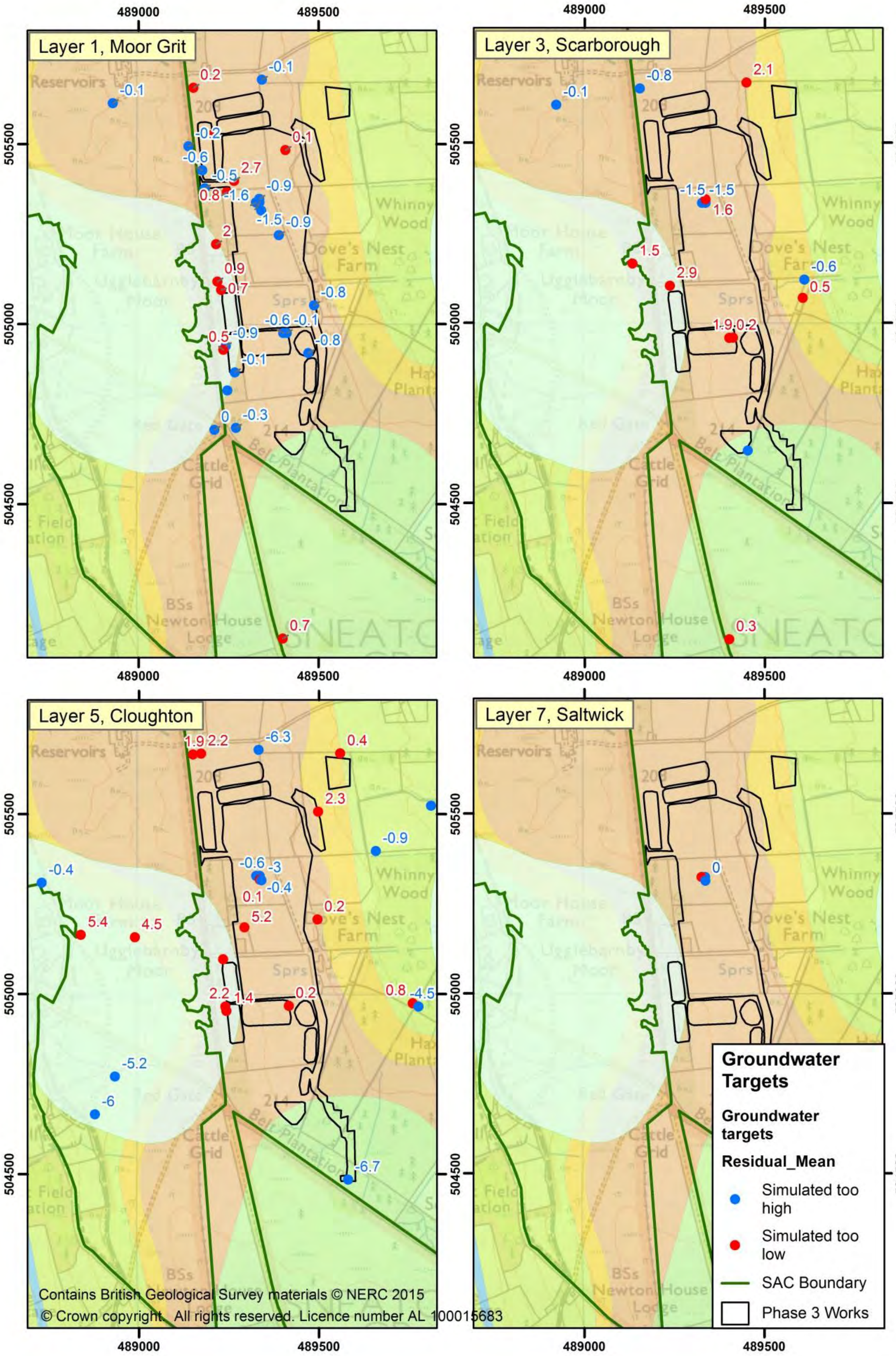


Figure 4.3 Steady state model – groundwater levels residuals for each model layer

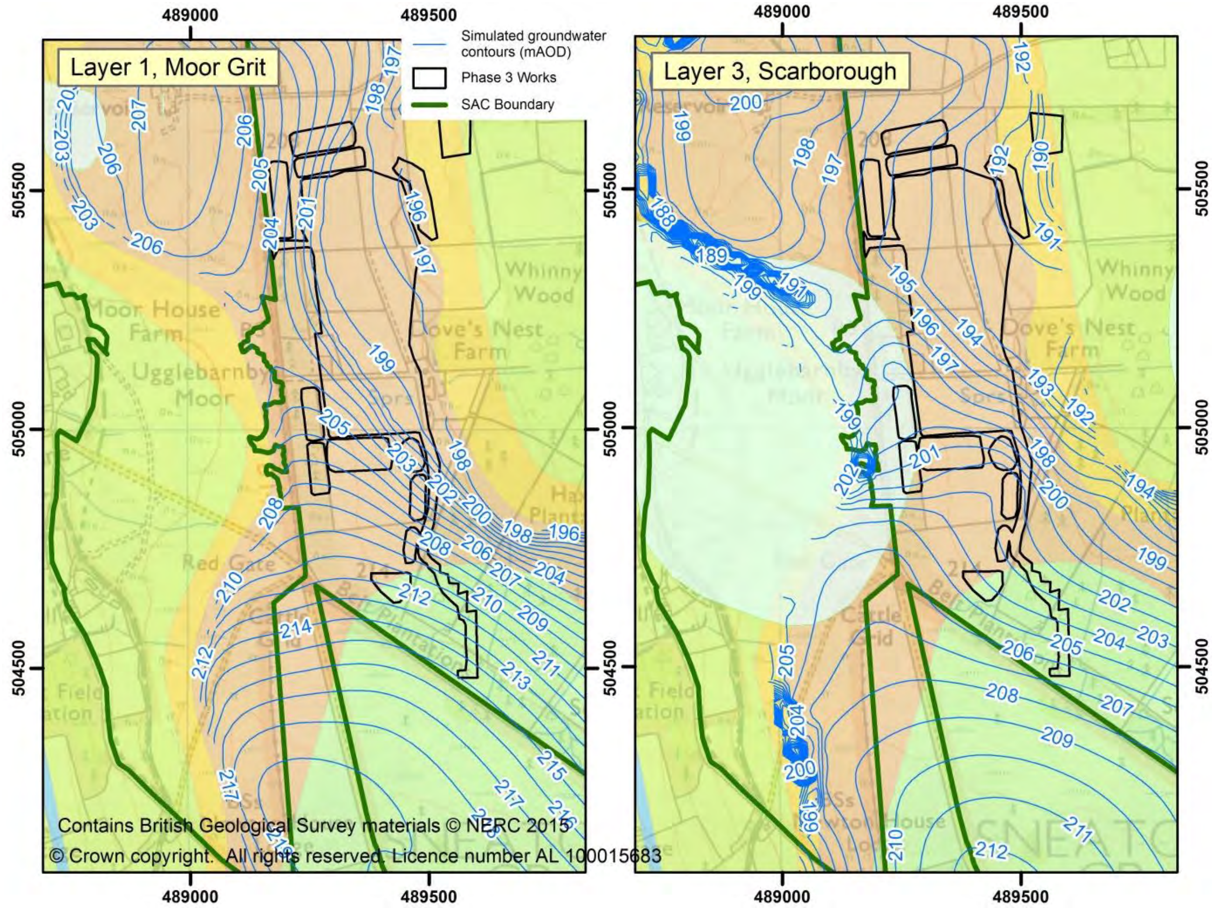


Figure 4.4 Steady state model – Moor Grit and Scarborough groundwater contours

Residuals and groundwater contours for the Moor Grit and Scarborough formations show that a reasonable overall fit to observed heads and groundwater flow directions has been achieved. Where there is a relatively large change in the residual (and particularly where this changes from negative to positive) over a relatively short distance, this may be suggestive of local-scale processes which are not simulated in the model. Possible reasons for this are local perching due to lithological variation (including fractures), a heterogeneous hydraulic conductivity distribution, and vertical head gradients within the aquifer.

Despite concerted attempts, it was not possible to achieve adequate calibration using spatially uniform and isotropic parameters. In particular, the transition from relatively steep east-west gradients to the very flat gradient found along the eastern side of the model in the vicinity of the main shaft platform could only be simulated by inclusion of a high K zone in the eastern area (zones 3 and 6 in Figure 3.6). The adoption of slightly lower K_x compared to K_y in the Moor Grit aquifer (zones 2 and 3) prevented the flattening of east-west gradients in this area that would have resulted from the higher K eastern zone. Over the Scarborough Formation (zones 5 - 7), an isotropic K distribution produced an adequate calibration. Inclusion of variable hydraulic conductivity zones and anisotropy in the Moor Grit has allowed both the south-north and west-east gradients to be better replicated by the model.

Overall, representing the complex hydrogeological system using a multi-layered model has enabled the simulation of hydraulic separation between aquifer units and the vertical hydraulic gradients are well reproduced. Whilst some simulated heads are slightly too high and some too low within individual horizons, the calibrated steady state model successfully simulates the large range of heads between the various layers (i.e. the high degree of hydraulic separation). This updated model is therefore viewed as being a credible representation of the layered aquifer from this perspective. This vertical hydraulic separation is also replicated by the transient model (Section 4.1.2).

4.1.2 Transient calibration

Transient calibration to groundwater levels was carried out by comparing simulated heads with weekly manual dips undertaken at the Site for the period January 2013 to January 2017. Updating the model and re-calibrating allowed a satisfactory fit to the more recent groundwater level data, particularly in the Moor Grit and Scarborough formations, to be achieved.

Observed (dots) and simulated (solid lines) hydrographs are shown in Figure 4.5 to Figure 4.11. Results from the transient runs are generally in keeping with the observed fluctuations in groundwater levels.

Critical for transient modelling is the fit to the amplitude of groundwater level variations which are controlled by storage coefficients. Model calibration was therefore achieved through changes to specific yield (unconfined aquifers) and/or specific storage (confined aquifers). Observed and simulated groundwater level trends and the range of variation are well matched, particularly in the Moor Grit and Scarborough aquifers (e.g. HG135 at the Site and GW133A). Within the Cloughton Formation, the calibration has been improved and the model approximately matches the observed seasonal variations. As with the Moor Grit and Scarborough aquifers this may reflect spatial variation in hydraulic properties. However, the focus of the model is in determining the impacts on receptors that are linked to the Moor Grit and Scarborough aquifers. The quality of calibration in the Cloughton and Saltwick formations is considered adequate for this purpose.

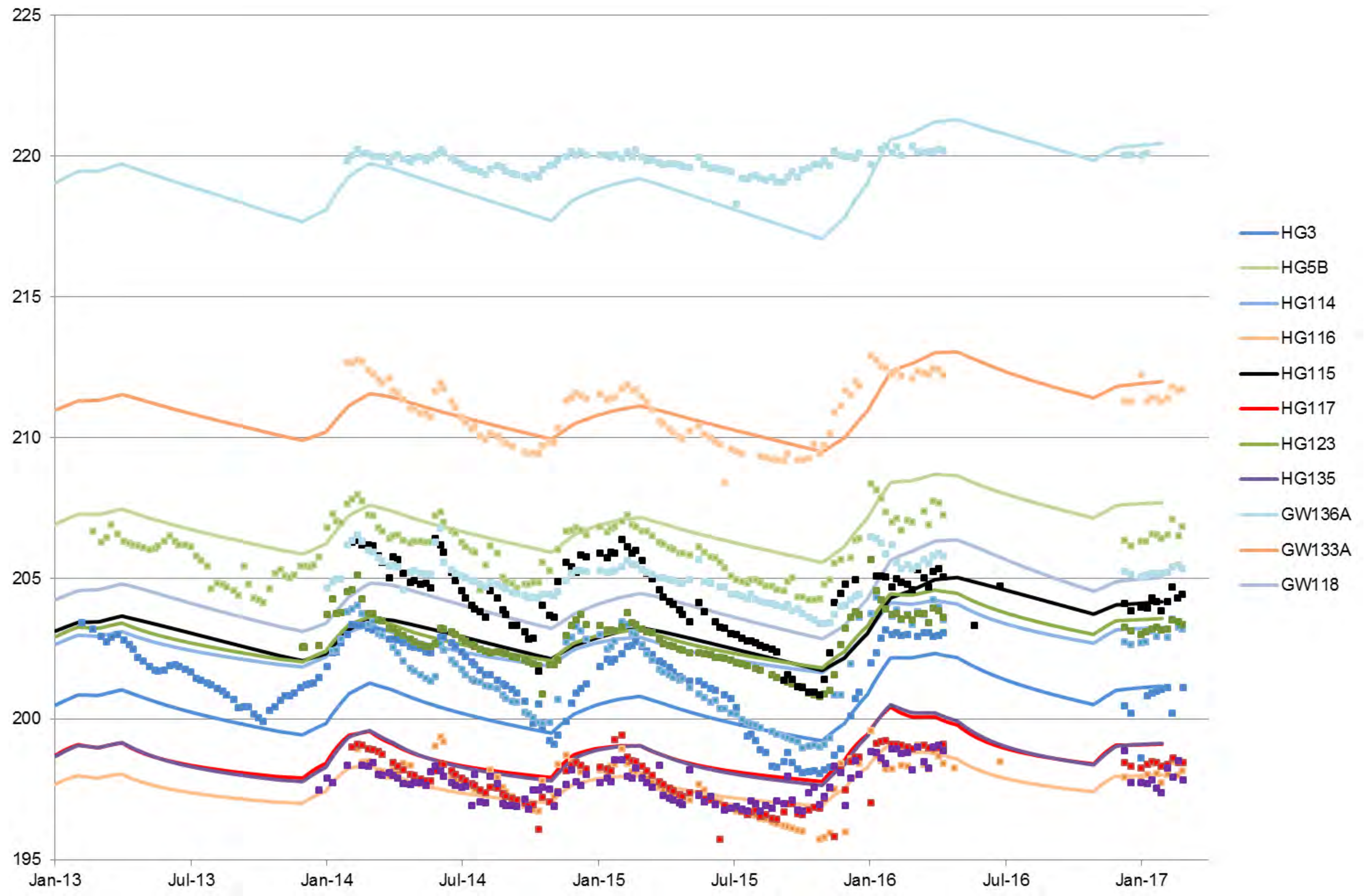


Figure 4.5 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Moor Grit

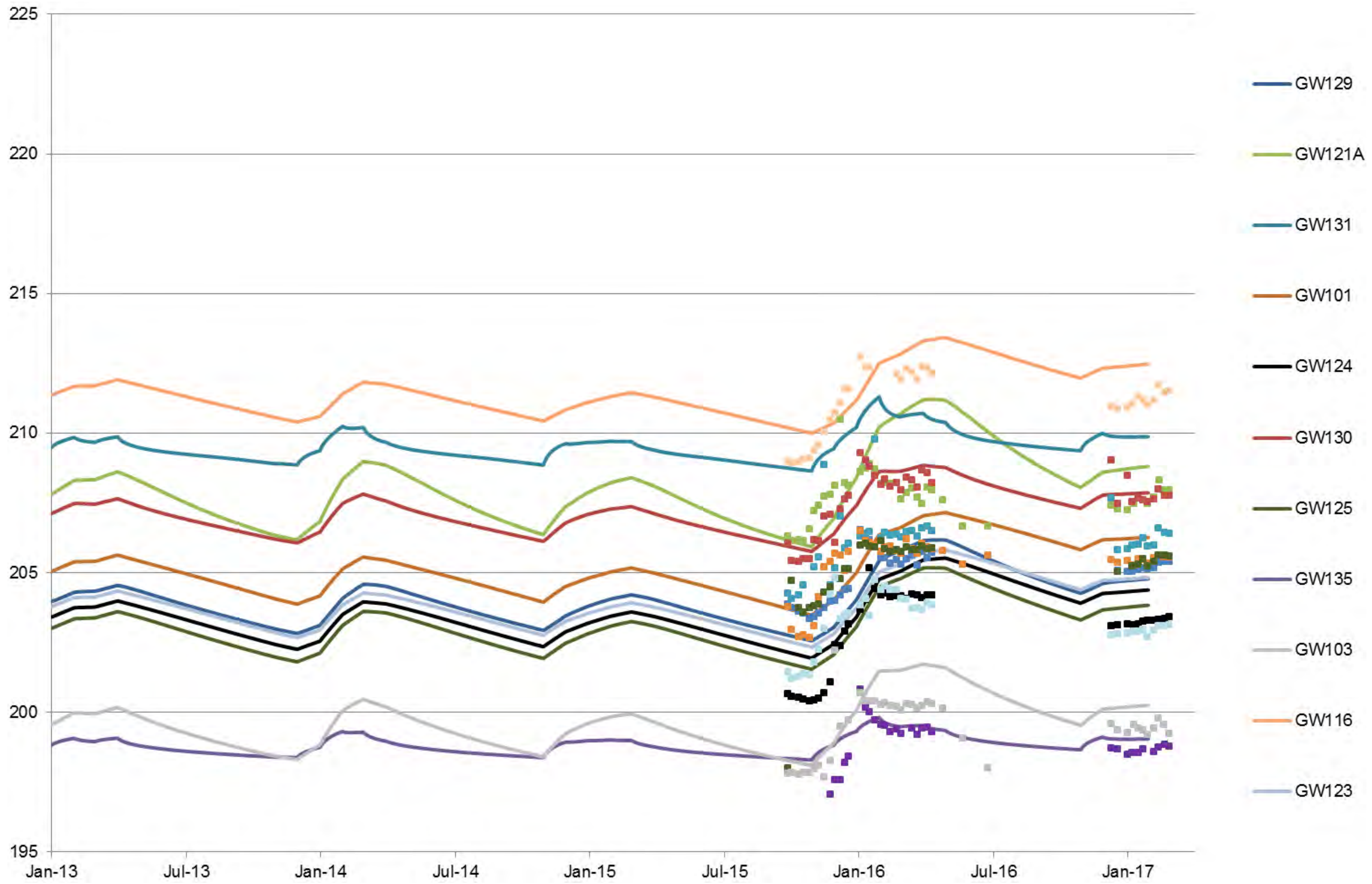


Figure 4.6 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Moor Grit (Phase 4 Stage 2 fieldwork investigation boreholes)

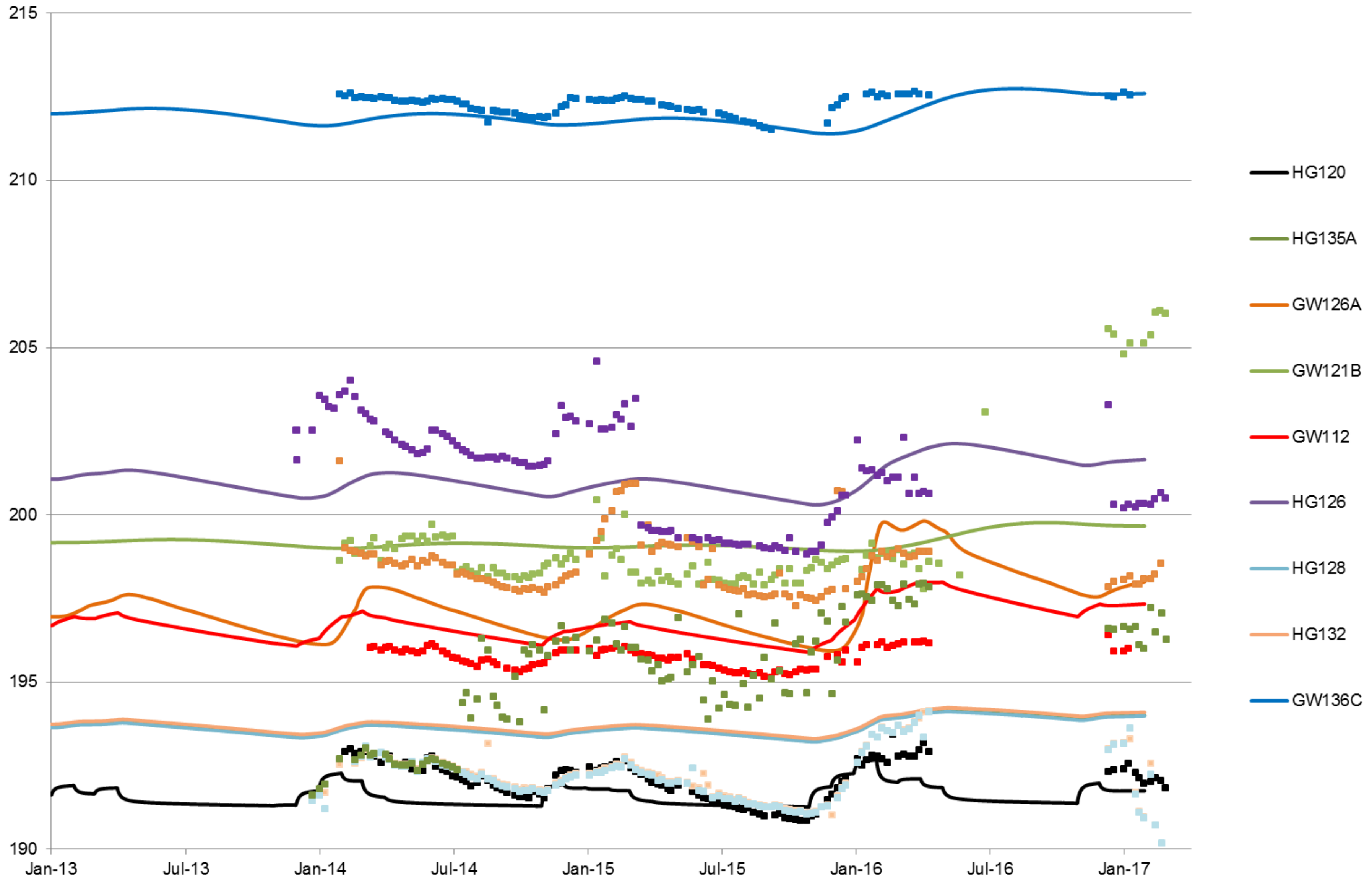


Figure 4.7 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Scarborough

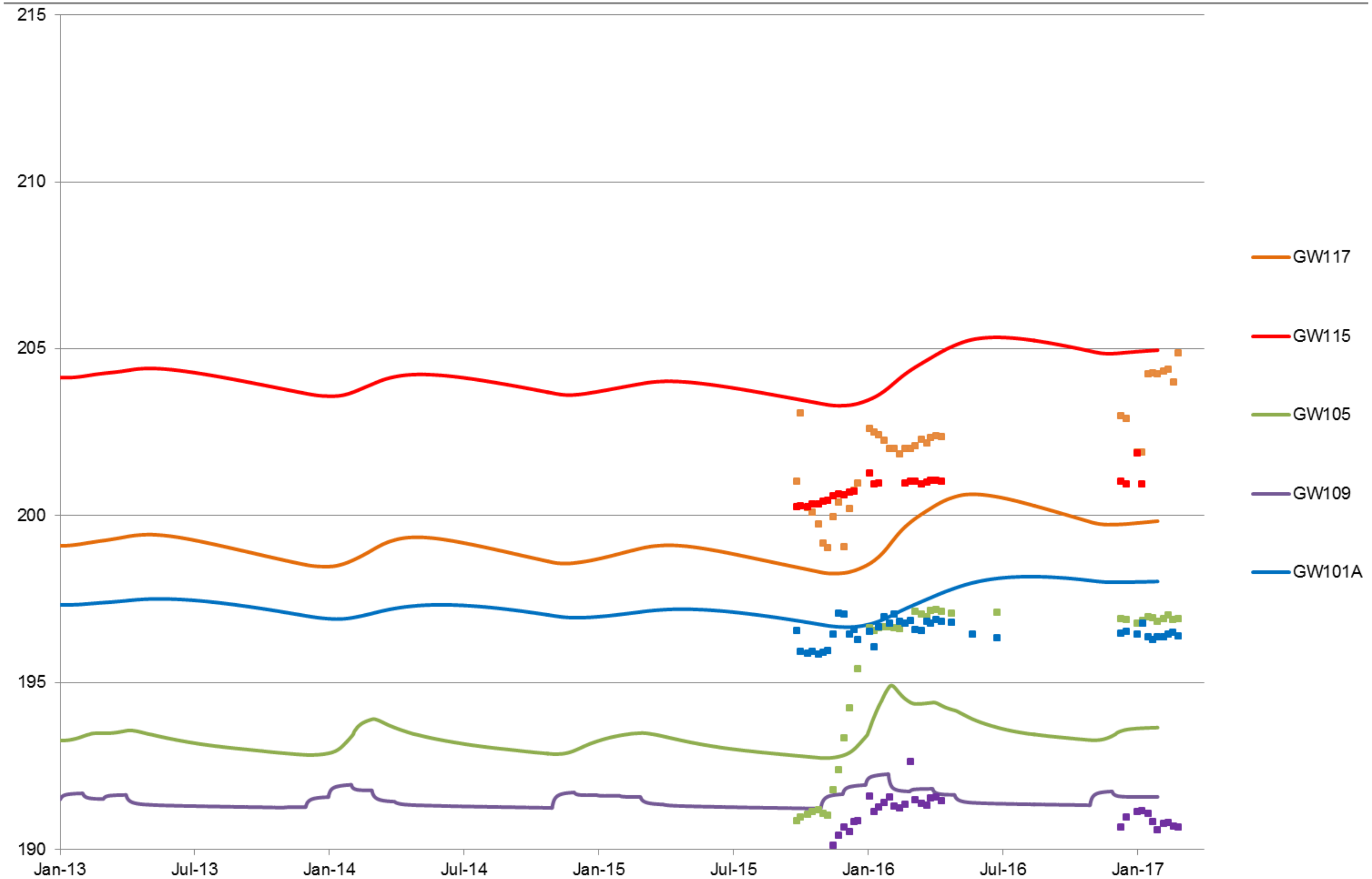


Figure 4.8 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Scarborough (Phase 4 Stage 2 fieldwork investigation boreholes)

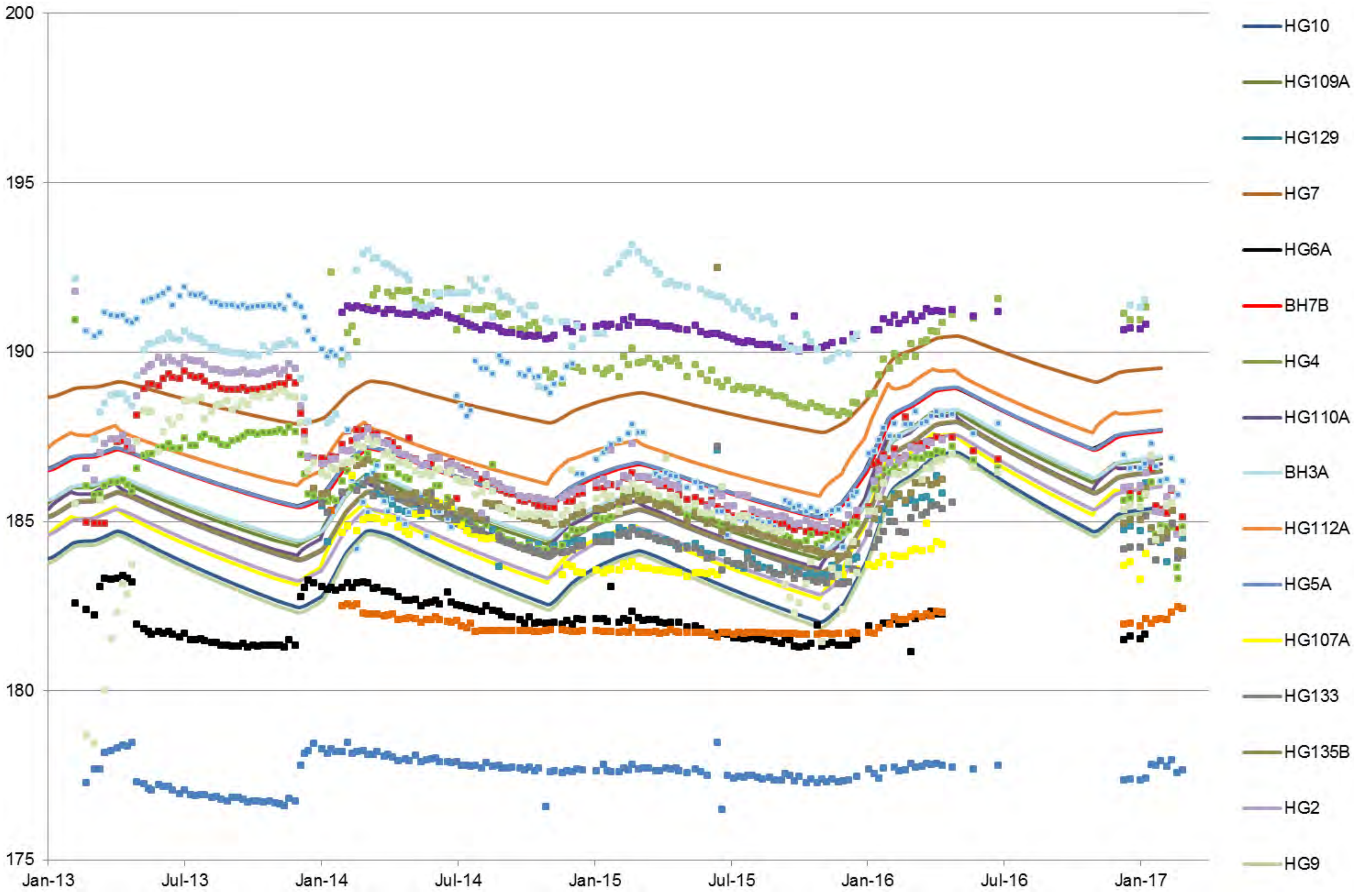


Figure 4.9 Transient model – Comparison of observed (dotted) and simulated (lines)hydrographs, Cloughton

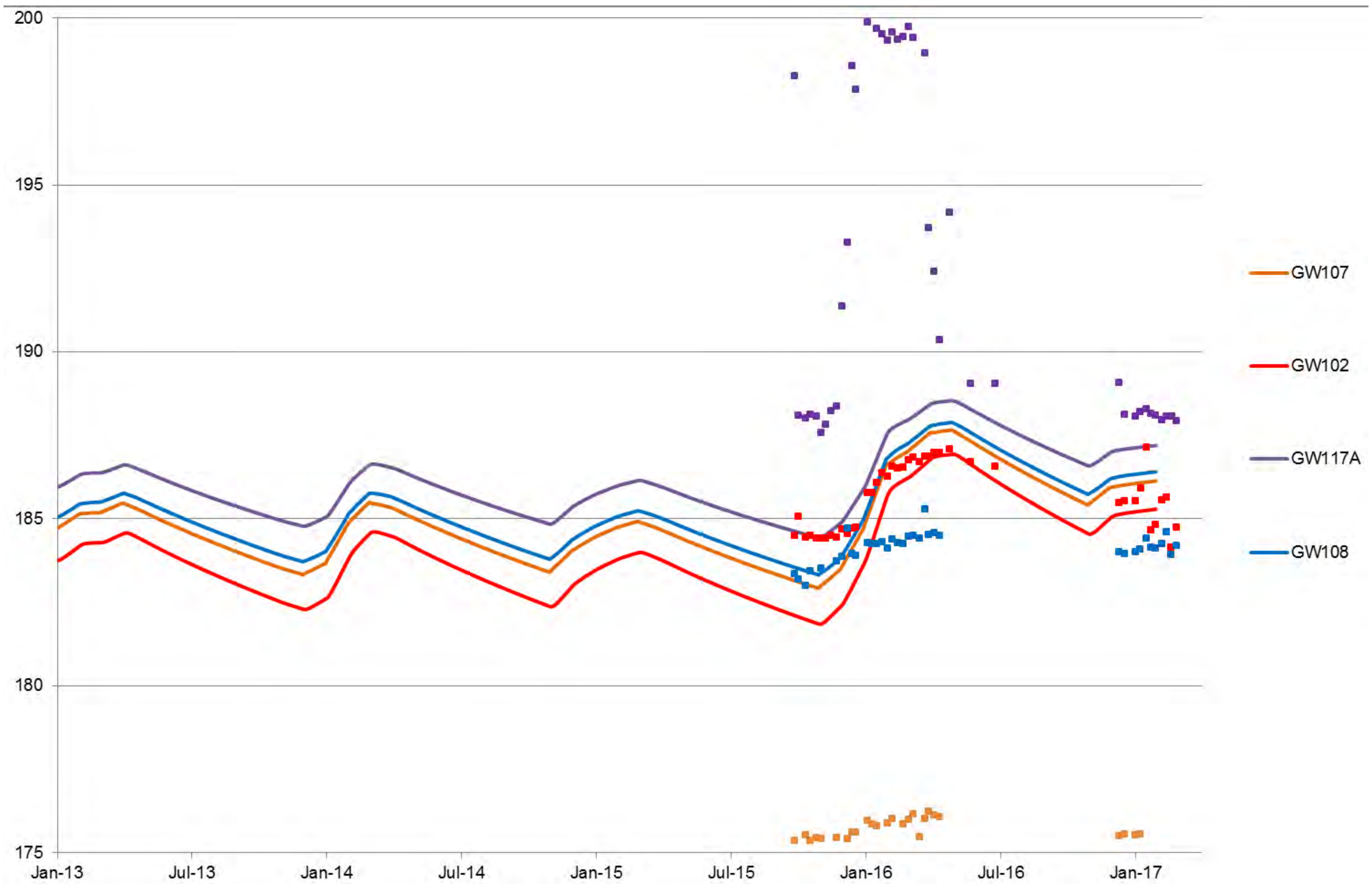


Figure 4.10 Transient model – Comparison of (dotted) and simulated (lines) hydrographs, Cloughton (Phase 4 Stage 2 fieldwork investigation boreholes)

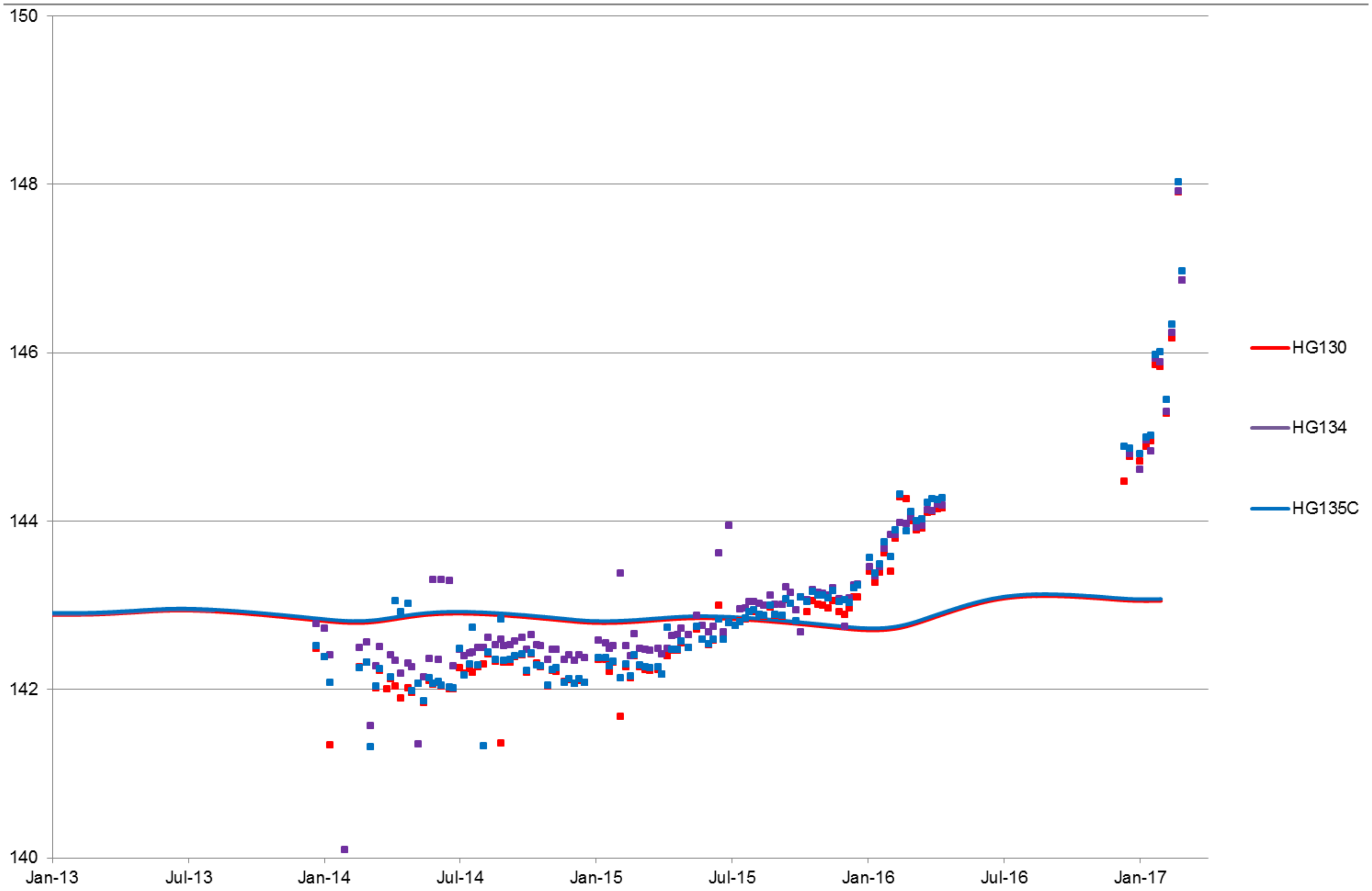


Figure 4.11 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Saltwick

4.2 Water Balance

Achieving hydraulic separation between aquifer layers in the model required a sensitive balance between recharge to outcropping aquifer formations and vertical flux between intervening aquitard layers. Despite the very low vertical hydraulic conductivity of aquitard layers, vertical flux between aquifer units dominates over horizontal flow (except in the Moor Grit). This is due to the large surface available over which vertical fluxes can occur. This does not suggest a high degree of connection between aquifer units.

For a given amount of recharge, vertical flux has to be sufficiently high to permit a sufficient amount of water to enter lower aquifer layers, but low enough to prevent drying of upper aquifer layers. This is illustrated by the water balance for the steady state model which is differentiated by model layer and presented in Table 4.2. Figure 4.12 shows this water balance for the steady state model in the format of a flow chart.

Approximately 49% of water flowing into the Moor Grit (via recharge and from the GHB) is released through the base and flows vertically to the underlying Scarborough Formation. This is either through the intervening aquitard layer, or by more diffuse downward seepage around the edge of the outcrop[4]. The remaining 51% of inflow is discharged via spring flow or diffuse seepage. Lateral outflows from the Moor Grit and Scarborough formations are in part constrained by calibration to observed spring flow (plus an allowance for diffuse seepage) and are discussed further in Section 4.3.

The lower aquifer layers are fed both by vertical flux from upper layers and GHB inflow. As with the Moor Grit, this is released via vertical flow into the lower layers or diffuse flow around the outcrop boundary.

[4] The latter process is not formally represented in the model but, if occurring, would be captured during calibration by use of a slightly higher K_v in the underlying aquitard which, it is considered, would make the model generally conservative with respect to the assessment of effects of deeper dewatering activities on these shallow horizons.

Table 4.2 Steady state water balance by model layer

	Inflow (m^3/d)	Outflow (m^3/d)	Error (%)
Layer 1 (Moor Grit)			
Bottom	0.98	605	
GHB	101.6	26.4	
Drain	-	617	
Recharge	1146	-	
Total	1,249	1,249	*-3.8×10^{-7}*
Layer 2 (MS1)			
Top	605	0.98	
Bottom	0.98	605	
Total	606	606	*-5.6×10^{-8}*
Layer 3 (Scarborough)			
Top	605	0.98	
Bottom	0.03	364	
GHB	31.1	48.2	
Drain	-	379	
Recharge	156		
Total	793	793	*-3.1×10^{-8}*
Layer 4 (MS2)			
Top	364	0.03	
Bottom	0.03	364	
Total	364	364	*3.4×10^{-8}*
Layer 5 (Cloughton)			
Top	364	0.03	
Bottom	3.09	8,906	
GHB	6,009	779	
Drain	-	1,840	
Recharge	5,150		
Total	11,526	11,526	*-1.5×10^{-5}*
Layer 6 (Ellerbeck Formation)			
Top	8,906	3.09	
Bottom	3.09	8,906	
Total	8954	8909	*-4×10^{-9}*
Layer 7 (Saltwick)			
Top	8,906	3.09	
GHB	163	1014	
Drain	-	8,549	
Recharge	497	-	
Total	9,567	9,567	*-8×10^{-7}*

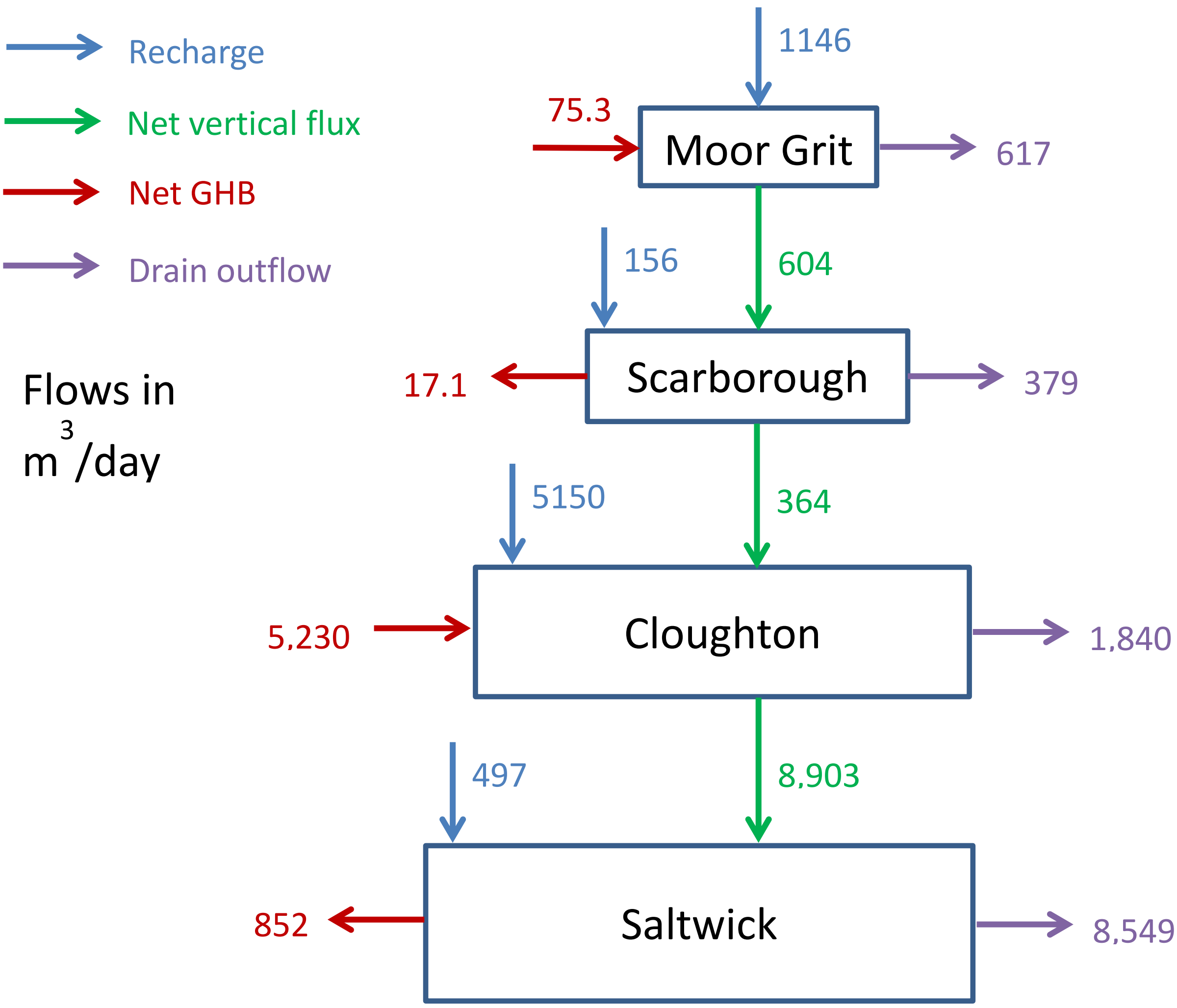


Figure 4.12 Flow chart of water balance by model layer

4.3 Spring flows

4.3.1 Steady state calibration

As discussed in Section 3.4.2, a number of springs were represented in the model using MODFLOW Drain cells. Spring flows simulated in the steady state model are summarised in Table 4.3. The full ranges of spring flows measured to date are given in Table 4.3 for comparison to the simulated flows.

In general, the steady state model simulates broadly the right amount of average flow at the various springs. However, because the springs are intermittent, it may be realistic to assume that some springs may be dry under steady state conditions. In this case the transient model provides a better approximation to flow (Section 4.3.2).

Flow at the Moorside Farm Spring (MF2) was simulated to be 1.9 m^3/day at steady state. Measured flows in the spring have varied from 0 – 22 m^3/day. Steady state represents long term average conditions; and this flow rate is considered reasonably representative of those conditions. Flow at SP01 was simulated as the western edge of the Moor Grit in the model, as is discussed above.

Table 4.3 Steady state model – observed and simulated spring flow

Spring ID	Name	Source aquifer	Model layer	Measured flow (m^3/d)	Simulated flow (m^3/d)
SP01	Moorland spring	Superficial deposits/Moor Grit	3	0 – 68	24.2
SP02	Hempsyke spring	Cloughton	5	0 – 70	145
SP03	Quarry spring	Cloughton	5	10 – 2,321	97.5
SP04	Windmill Hill Plantation Spring	Moor Grit	1	Not measured	0
NHF	Newton House Farm	Cloughton	5	Not measured	76.2
SF2	Soulsgrave Farm Spring	Scarborough	3	0 – 97	15.4
MF2	Moorside Farm Spring	Superficials/Moor Grit	1	0 – 22*	1.9
DNS1	Dove’s Nest Farm	Moor Grit	1	0 – 432	0.3
	Moor Grit outcrop edge				590
	Scarborough outcrop edge				365
	Cloughton outcrop edge				678
	Saltwick outcrop edge				2,549
	Discharge to River Esk				6,844
	Drilling platform				0

*Flow at MF2 measured at MF1

4.3.2 Transient calibration

Simulated transient and observed spring flows at Moorside Farm are shown in Figure 4.13 and those for SP01, SP02 and SP04 are shown in Figure 4.14. On this plot, simulated flows (averaged over a one month model stress period) are compared to spot observed flows which are recorded at a given time instance. As a result a direct (or quantitative) comparison is not appropriate. It is known that the spring flows are flashy and respond rapidly to rainfall events (FWS, 2016a). Whether this flashy nature is captured in measured flows depends on the date gauging is carried out. Similarly, observed flows may have a run-off component which will not be captured by the model.

Despite this, a reasonable fit to spring flows at Moorside Farm Spring (MF2) is achieved and the transient model is considered to be suitable for assessing the effects of the proposed development on spring flow at MF2 (as set out in the model objectives).

Flows in SP02 are overestimated, as they were with the previous calibration. This is because the spring is in the Cloughton Formation, and the calibration is less good in this formation.

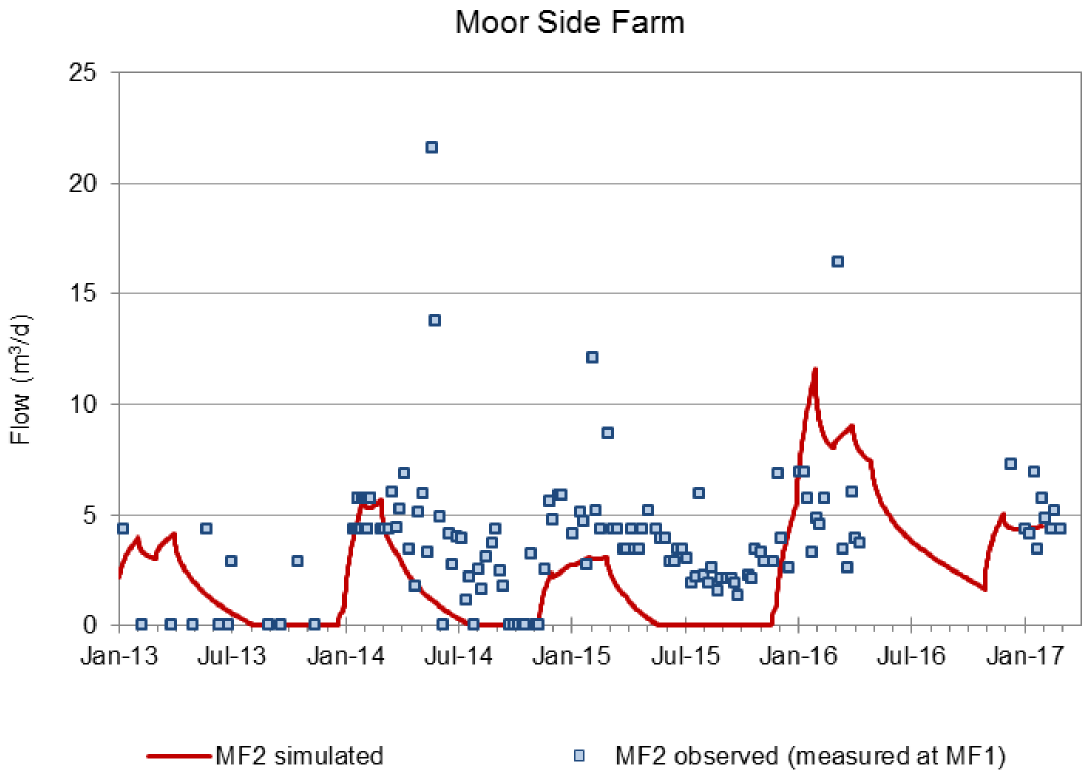


Figure 4.13 Transient model – simulated and observed spring flow at Moor Side Farm spring

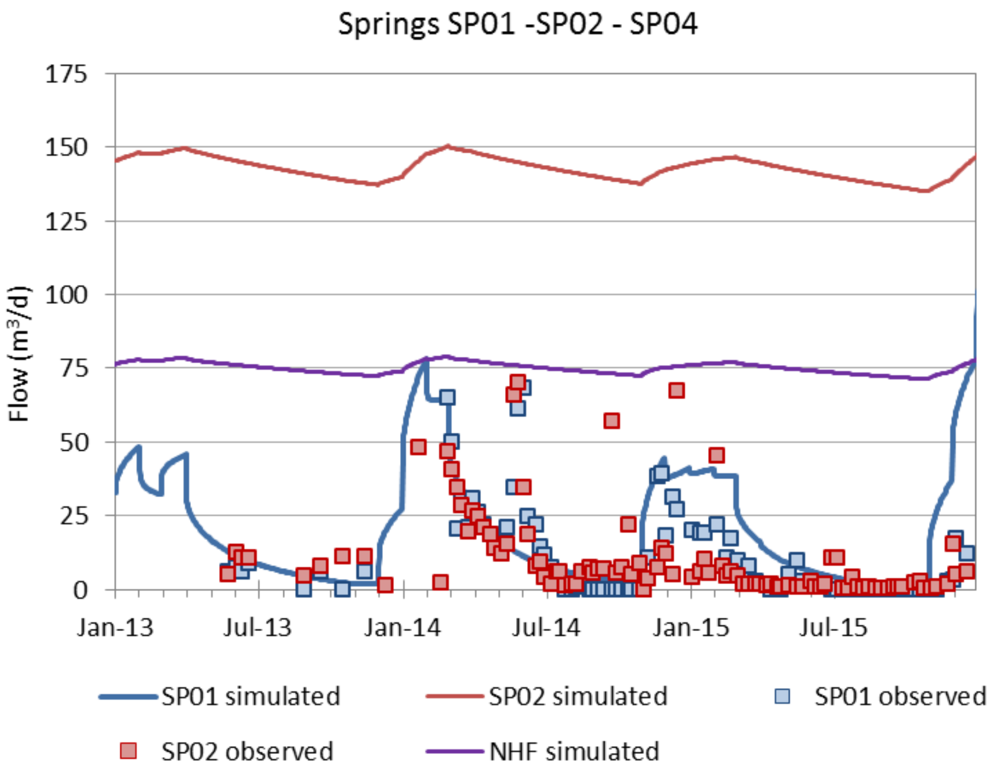


Figure 4.14 Transient model – simulated and observed spring flow at SP01, SP02 and NHF

4.4 Summary of Model Credibility and Appropriate Use

The updated multi-layered, transient model that has been developed from the extended baseline data is considered to represent an improvement on the previous model (ESI, 2016). The model should be continually updated as new data becomes available.

The model is particularly good at the following:

- Simulating the steep vertical hydraulic gradients observed between the various thin aquifer layers on Site accurately; and
- Simulating the seasonally intermittent flows in the key springs effectively.

Whilst the quality of fit between observed and simulated is variable across the model area, this is not considered to be a significant limitation on its use in predictive mode as models are generally accepted to represent the differences between two scenarios more reliably than the simulation of absolute heads and flows.

The update to the model undertaken specifically for predicting the effects of the future works has produced an adequate degree of model calibration to groundwater levels and spring flow.

The model is thus considered to be an appropriate tool for use in assessing the likely effect of future proposed works on the local groundwater systems.

5 CONCLUSIONS

Following recent drilling and collection of the latest groundwater level and spring flow data, the existing multi-layer groundwater model of the York Potash mine head development has been reviewed and updated. The model has been re-calibrated to transient conditions using all available data over the 2013 - 2017 period of groundwater level and spring flow monitoring. Calibrated model results are consistent with measured spring flow and groundwater levels to January 2017. The objective of the model calibration focussed on achieving a model that is fit for assessing the effects on groundwater levels in the Moor Grit and Scarborough aquifers underlying Ugglebarnby Moor SAC. Potential impacts on flows from Moorside Farm Spring and to the Spring Flush area are of greatest interest.

In re-calibrating the model, it was necessary to deviate slightly from field parameters, as was the case with the previous model. Non-uniform zones of hydraulic conductivity and anisotropy are used to simulate the spatial variability in heads. The K_h values used for each of the aquifer units are consistent with the results obtained from pumping tests (ESI, 2014a).

Pumping tests demonstrated that the K_v of the aquitards was very low. The K_v of each of the aquitards layers was further constrained by model calibration. The vertical leakage through these layers must be sufficiently low to support the observed steep vertical hydraulic gradients. Despite the permeability being very low (of the order of 10^{-9} and 10^{-10} m/s) the K_v values of the aquitards are still sufficient to allow a reasonable vertical groundwater flux under free-draining conditions (30 mm/a for a K_v of 10^{-9}). It is therefore possible to support the groundwater levels in each of the aquifer units by allowing a certain amount of the recharge at the surface to exit through the base. By comparison, the flux through the southern boundary is relatively small.

Elevations of the upper four layers of the model have been updated to account for drilling data that has become available since 2014. The lower three layers have not been updated, and it is recommended that if future works at the Site are to impact on groundwater levels in these layers that the layer elevations are changed to match the most recent drilling data.

Given the changes to elevations of the upper four layers, it was necessary to re-calibrate the model to the more recent groundwater level and spring flow datasets. Changes to aquifer properties and boundary conditions were undertaken to achieve an acceptable fit to observed levels and flows. Again, this calibration was focussed on levels in the upper four layers (mostly the Moor Grit and Scarborough formations). There is a reasonable match to absolute levels in the steady state calibration model, and the transient model appropriately matches seasonal variability in both levels and spring flows.

In summary, the model is considered to be appropriately calibrated for the purposes required:

- The model simulates the steep vertical hydraulic gradients observed between the various thin aquifer layers on Site accurately; and
- The model simulates the flashy, intermittent flows in the key springs effectively.

The model does not capture all the spatial variability in groundwater levels within individual horizons accurately due to local heterogeneity. However, this is not considered to be a significant limitation on its predictive use as models are generally considered to represent the differences between two scenarios (e.g. baseline and predictive) more reliably than the simulation of absolute flow and groundwater level. The model is thus considered to be an appropriate tool for use in assessing the likely effect of the proposed development on the local groundwater systems.

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APPENDIX B

Section 73 Sensitivity and Uncertainty Analyses

York Potash Groundwater Model: Section 73 Sensitivity and Uncertainty Analyses

Prepared for York Potash Limited

Report reference: 61415TN4, October 2017

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1 SENSITIVITY AND UNCERTAINTY ANALYSES

1.1 Background

This technical note relates to sensitivity and uncertainty testing undertaken on the York Potash groundwater flow modelling undertaken as part of Section 73 requirements (ESI, 2017a). This technical note should be read in conjunction with that report.

1.2 Overview

Given the uncertainties involved in modelling an area of complex hydrogeology, it is important to undertake sensitivity and uncertainty analyses to validate the conclusions reached using the calibrated York Potash groundwater flow model. These conclusions are presented in the Section 73 groundwater modelling report (ESI, 2017a), and this technical note should be read in conjunction with that report. Base case and post-development steady state model run pairs have been used to check the changes in groundwater level along the boundary of the Ugglebarnby Moor Special Area of Conservation (SAC) at assessment points SAC1 to SAC8.

Results from these analyses can then be used to identify sensitive parameters and model equivalence issues. Model runs were carried out using a steady state model and the conclusions are therefore considered to be more reliable for groundwater level changes than for spring flows (due to the intermittent flow of the springs).

The main source of model equivalence and uncertainty in the calibrated values relates to the interplay between hydraulic conductivity and recharge in the eight model layers. Recharge and hydraulic conductivity were therefore the focus of these analyses. Results of these model runs only look at the impact attributed to the development (i.e. differences between base case and post-development scenarios) rather than absolute groundwater levels predicted by the model. Groundwater levels under low and high recharge conditions will be predicted to be lower and higher in the model respectively. The differences in heads and spring flows between the base case and post-development runs could be more or less depending on how the model adjusts to changes in recharge and hydraulic conductivity.

The predicted impacts of the development on near surface groundwater levels and flows are virtually all caused by the reduction in recharge and it is predicted that there will be no significant impact from the presence of shafts /basements acting as barriers to flow.

1.3 Model Runs

A summary of the model runs undertaken is provided in Table 1.1. Run A and Run B represent estimated high and low annual recharge values based on monthly rainfall at Whitby for the period 1971 – 2000 (chosen to represent the long term average). The purpose of these runs is to test the sensitivity of the results predicted by the model to changes in recharge. During this time, lowest rainfall was recorded in 1972 (325 mm) and the highest in 2000 (744 mm). Low and high annual recharge was calculated by assuming that the calibrated recharge of 200 mm/year is the recharge that would occur during a year with rainfall equal to the long term average rainfall at Whitby (558 mm/year). The calibrated recharge was then factored up and down based on differences between long term average rainfall and high and low rainfall values. This produced recharge estimates ranging from 116 – 267 mm/year. However, the groundwater model encountered numerical stability issues with a low annual recharge of 116 mm/year and therefore run B was completed using a slightly higher annual recharge of 134 mm/year. This corresponds to the lowest annual recharge predicted by MORECS data from 2013 to 2016 (ESI, 2017b).

The MORECs data shows a high recharge of 336 mm/year that occurred in 2016. This has not been used in the sensitivity analysis because based on the long term Whitby rainfall record, this appears to be an extreme event. Testing sensitivity to such extreme and rare events, is not appropriate in a steady state model which is representative of long term average conditions.

Runs C and D represent an uncertainty of ± 20% in the calibrated long term average recharge of 200 mm/year and calibrated hydraulic conductivity in all model layers. The principle purpose of these runs is to test potential uncertainties in the model results arising from model equivalence. In any groundwater flow model, there is some equivalence in model solutions; particularly in models where the flows are poorly constrained, the recharge and hydraulic conductivity can be varied to give a very similar model calibration to groundwater heads. Therefore, hydraulic conductivity has therefore also been changed by the same factor as the recharge. Horizontal and vertical hydraulic conductivity for all model layers have been modified however, the ratios remain the same.

The base case calibration in runs C and D has been checked and compared to the calibrated model. The calibration in both runs C and D appears reasonable and therefore these results are suitable for testing model equivalence issues.

The steady state post-development models include all of the Section 73 construction features as described in ESI (2017a). Recharge to the recharge trench is unchanged from the calibrated model in runs A and B but has been increased and decreased respectively by 20% in runs C and D. All other construction features remain unchanged from the calibrated post-development model. The reason for this is that runs A and B are designed to test the final post-development model to changes in recharge in isolation that might be brought about by climate change, whilst runs C and D have been designed to test model equivalence. Therefore, for runs C and D recharge to the recharge trench has been changed in the same manner as in the final model to minimise impacts on the Moorside Farm Spring without increasing the risk of groundwater flooding.

Table 1.1 Model uncertainty and sensitivity runs

Run Pair	Description	Background Recharge (mm/year)	Change in recharge and hydraulic conductivity[1] in all model layers
Calibrated model	Models as described in ESI (2017a)	200	0%
Run A	High annual recharge	267	+33%
Run B	Low annual recharge	134	-33%
Run C	High annual recharge and hydraulic conductivity	240	+20%
Run D	Low annual recharge and hydraulic conductivity	180	-20%

[1]Vertical and horizontal

Results of the sensitivity and uncertainty analyses in the following sections are presented as a series of bar charts showing ‘absolute difference’. This absolute difference has been calculated using the following equation:

$$Absolute\ difference\ (m) = Change_{Run\ X} - Change_{Calibrated\ Model}$$

Where:

Change refers to the change in groundwater levels or spring flows between the base case and post development model pairs for each of the sensitivity/uncertainty and calibrated model runs; and

Run X refers to each of the uncertainty and sensitivity run pairs (i.e. Run A etc.).

A negative absolute difference means that the model run predicts a greater decline or lesser increase in groundwater levels or spring flows than the calibrated model (i.e. a greater impact). A positive absolute difference means that the uncertainty run predicts a smaller decline or greater increase in groundwater levels or spring flows than the calibrated model (i.e. a lesser impact). An absolute difference of zero means that the same change is predicted by the uncertainty run and the calibrated model.

Absolute differences in Runs A and B provide an indication of the sensitivity of the model results to long term fluctuations in seasonal recharge. Runs C and D give an indication of the uncertainty of the model results with regard to issues of model equivalence.

1.4 Groundwater Levels

Figure 1.1 and

Figure **1.2** present the predicted absolute differences for runs A and B and runs C and D respectively. Differences in the level of effect between the sensitivity/uncertainty run pairs and the calibrated model run pair are greatest for Run A and Run B for the shallower Moor Grit and Scarborough formations. This shows that the model results are sensitive to long term recharge variations. Absolute differences for Run pairs C and D are all smaller than ± 0.02 m. This shows that uncertainties in results due to non-uniqueness of the model calibration are small. However, the uncertainty in recharge and hydraulic conductivity and the small differences in the results from runs C and D indicate that the predictions are only valid if the recharge trench accepts the modelled recharge rate.

Generally, under high (Run A) and low (Run B) annual recharge conditions, the results indicate a greater impact under high recharge conditions and a lesser impact under low recharge conditions. This is in part because the recharge to the recharge trench has not been modified and it is relatively lower and higher in the high and low recharge runs respectively. If there is a higher recharge rate (i.e. from increased rainfall) then more water will be available from runoff to supply the recharge trench so Run A represents a worst case scenario. This does however rely on the recharge trench being capable of accepting a greater recharge rate than that modelled without causing unacceptable groundwater flooding.

Figure 1.1 Groundwater level sensitivity analysis results for Run A and Run B

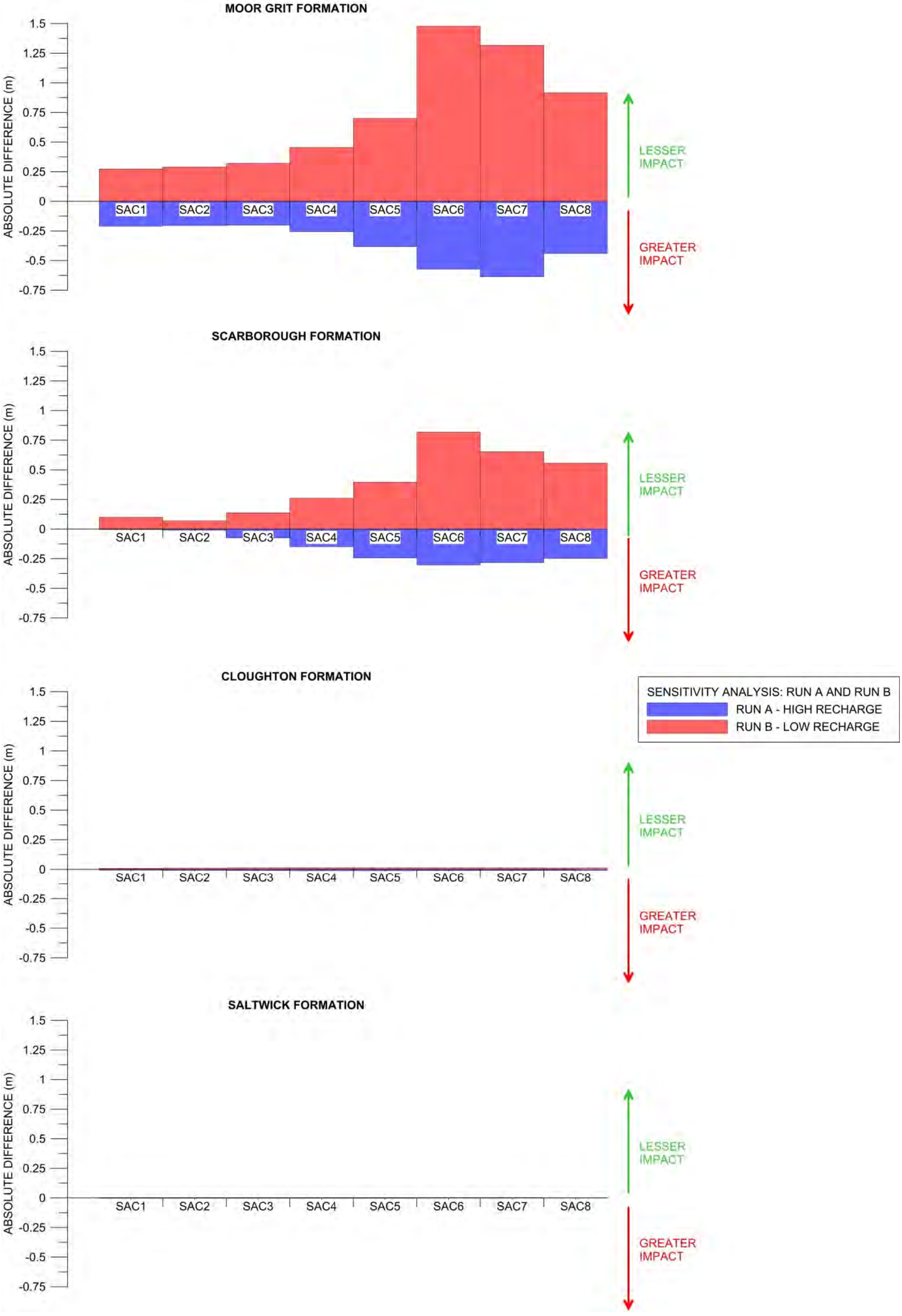
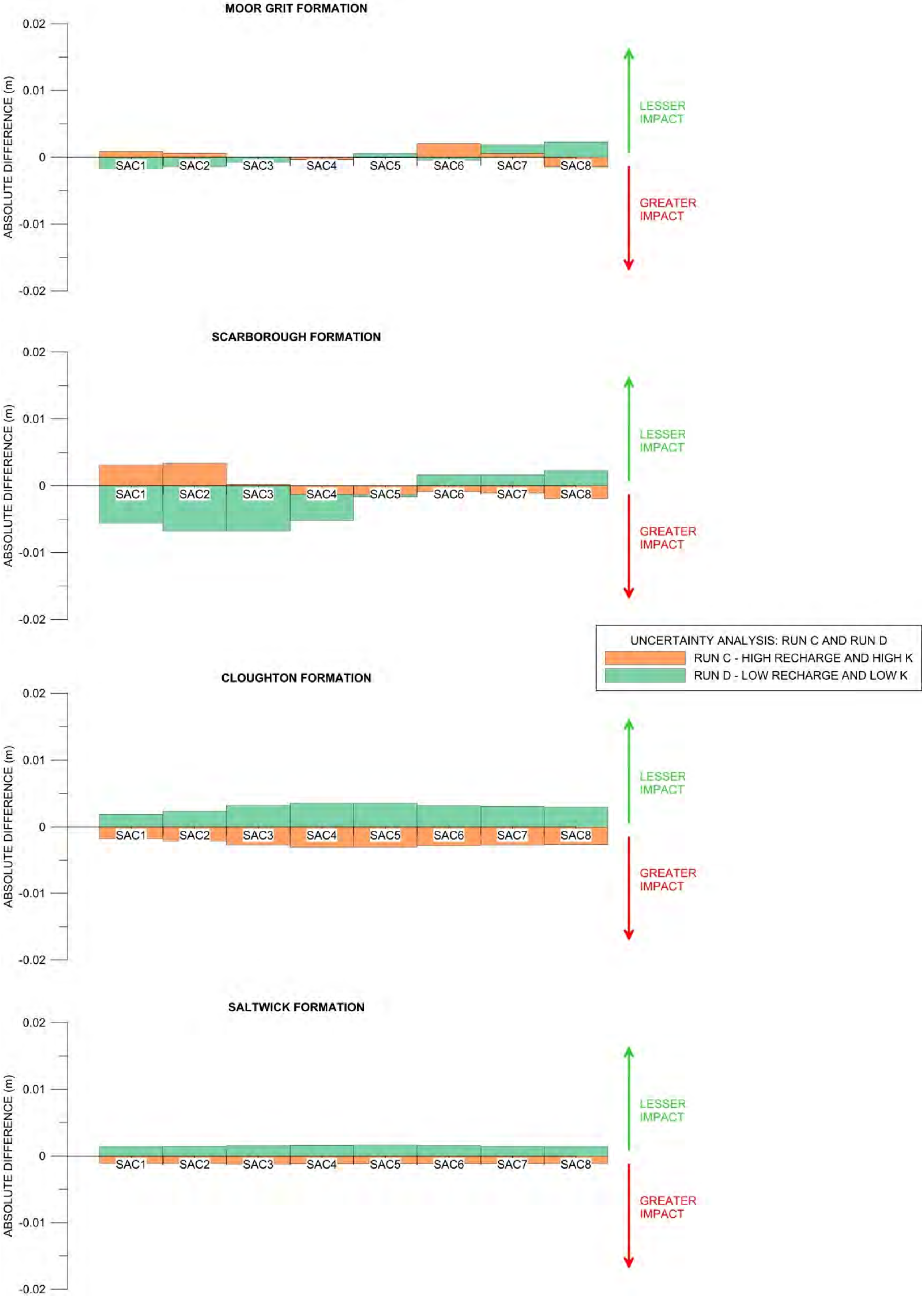


Figure 1.2 Groundwater level uncertainty analysis results for Run C and Run D



1.5 Spring and Boundary Flows

Figure 1.3 shows the sensitivity and uncertainty analysis results for spring flows. As for groundwater levels, only negligible absolute differences of < 0.3 m^3/day were identified for spring flows in Runs C and D. This demonstrates that uncertainties in the model results regarding model equivalence are small. However, as is mentioned above these results rely on the recharge trench being capable of accepting the recharge simulated in the model runs.

An increase in effect of 0.64 m^3/day (0.007 l/s) was predicted by high recharge Run A at the Moorside Farm Spring compared to the calibrated model run pair. Such a decrease in flow would be beyond the scale of measurement. These results indicate that during periods of unusually high recharge, such as over a wet winter, the decrease in spring flow is likely to be greater, with the opposite being true over dry periods. However, the actual increase in impact is too small to be measureable.

1.6 Conclusions

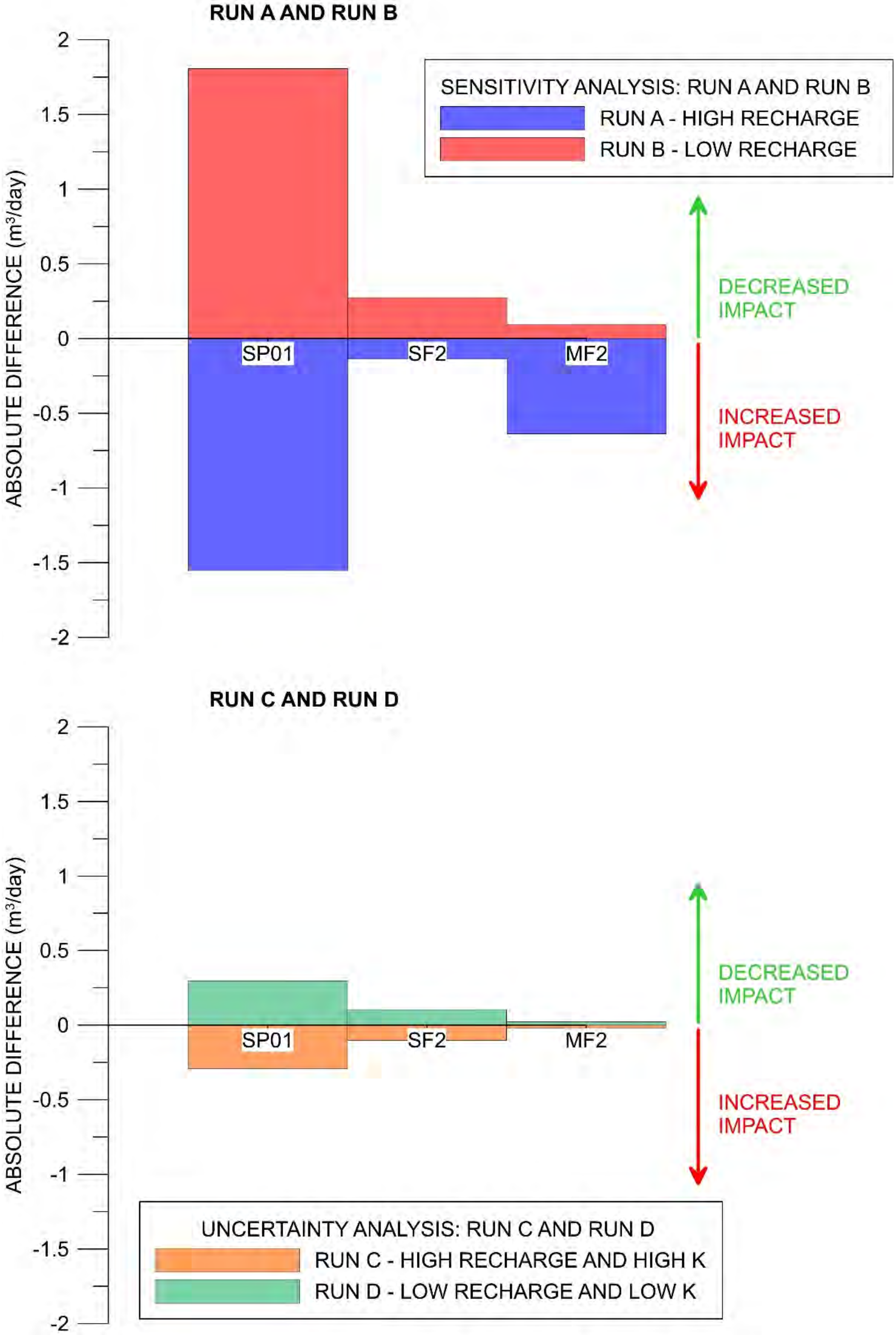
Increasing or decreasing background recharge causes a corresponding increased or decreased contrast in recharge between the base case and post-development runs and this is responsible for the increased or decreased changes in groundwater levels and flows. If causes climate change increases long term average recharge, spring flows and groundwater levels in the post-development scenario will be higher than baseline measured flows. Therefore, there will be less of an impact on levels and flows when compared to the baseline conditions. This sensitivity to recharge does not therefore detract from the predictions of the calibrated model, which focus on the impacts on spring flows and groundwater levels relative to baseline current recharge conditions.

There is clearly model equivalence due to the interplay between the hydraulic conductivity and recharge parameters, and this results in uncertainty in the hydraulic conductivity and recharge parameters. However this uncertainty does not affect the ability of a recharge trench to mitigate the impacts:

- At the main receptors (Moorside Farm Spring and Soulsgrave Farm Spring and spring flush area), the reduction in groundwater levels caused by reduced recharge and the increase in groundwater levels caused by the recharge trench are affected by the same key parameters (hydraulic conductivity and recharge).
- If the hydraulic conductivity of the aquifer between the recharge trench and the Moorside Farm Spring is lower than that simulated, then the rise in groundwater levels from the recharge trench will be lower, but also the impact from the development will be lower. Therefore these effects counteract each other, the extent of this counteraction is however uncertain.
- If the climate change causes rainfall to be higher this will generate more runoff and there will be more runoff available to apply to the recharge trench and thus mitigate the increased impact under the high recharge scenario. This relies on the capability of the groundwater system to accept recharge.

The key uncertainty is whether an adequate proportion of the recharge that is being diverted from the aquifer due to the development can enter the aquifer at the recharge trench. This will depend on local ground conditions around the trench and will need to be resolved with on-site testing.

Figure 1.3 Spring flow analysis results



2 REFERENCES

ESI (2017a) York Potash: Section 73 Groundwater Modelling, ESI Ltd, Report Ref. 61415R9, August 2017

ESI (2017b) York Potash: 2017 Groundwater Model Update, ESI Ltd, Report Ref: 61415R7, May 2017