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

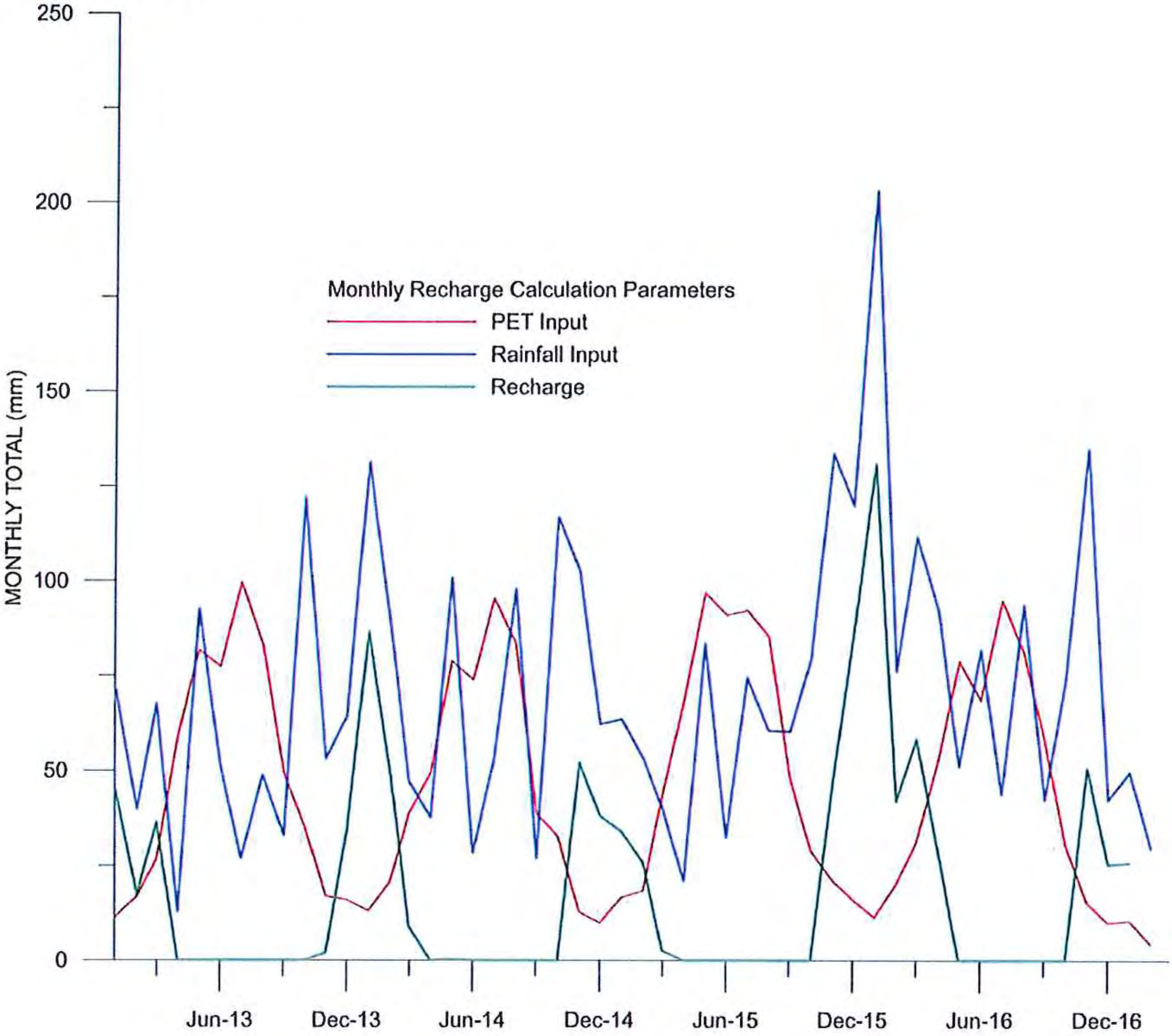

Figure 3.7 Monthly rainfall, PE and recharge used in the transient model run

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

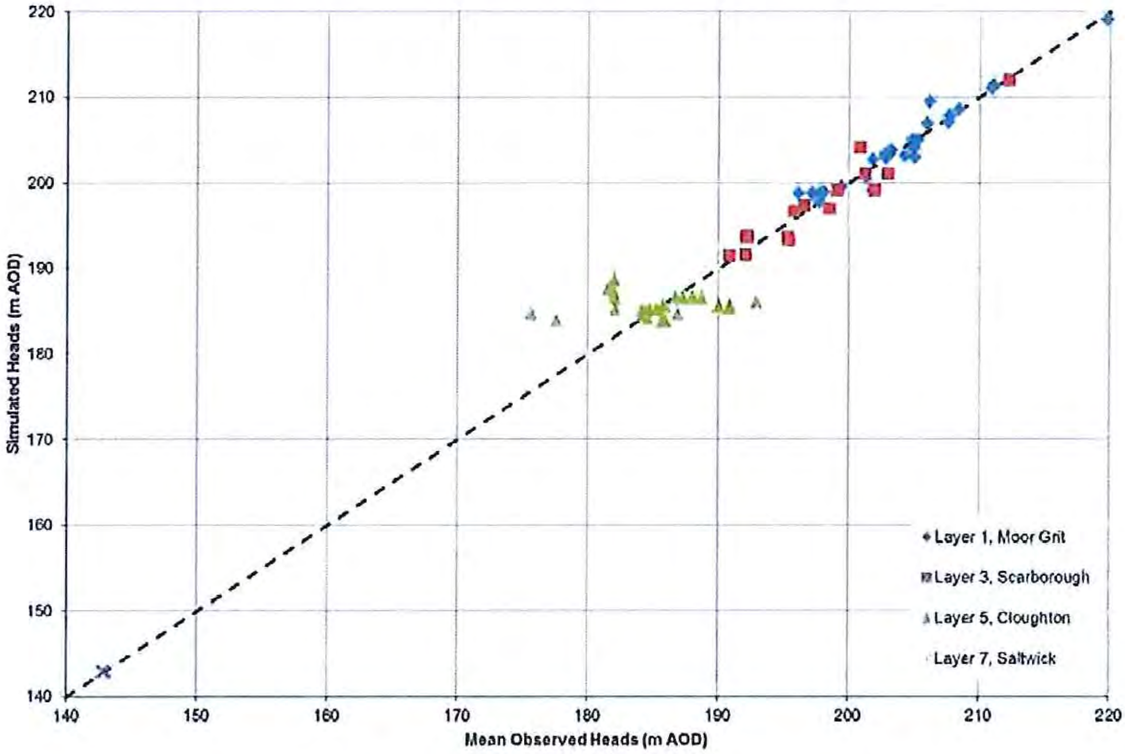

Figure 4.1 Steady state calibration – observed versus simulated groundwater levels (all calibration points)

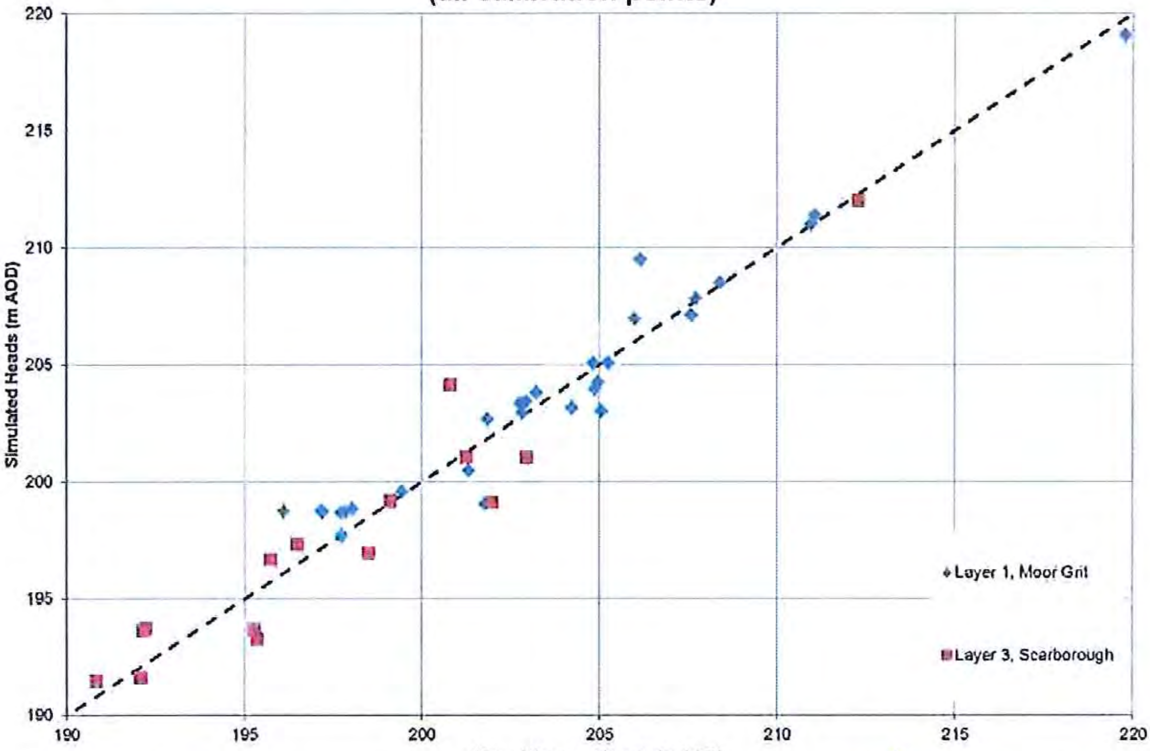

Figure 4.2 Steady state calibration – observed versus simulated groundwater levels (Moor Grit and Scarborough)

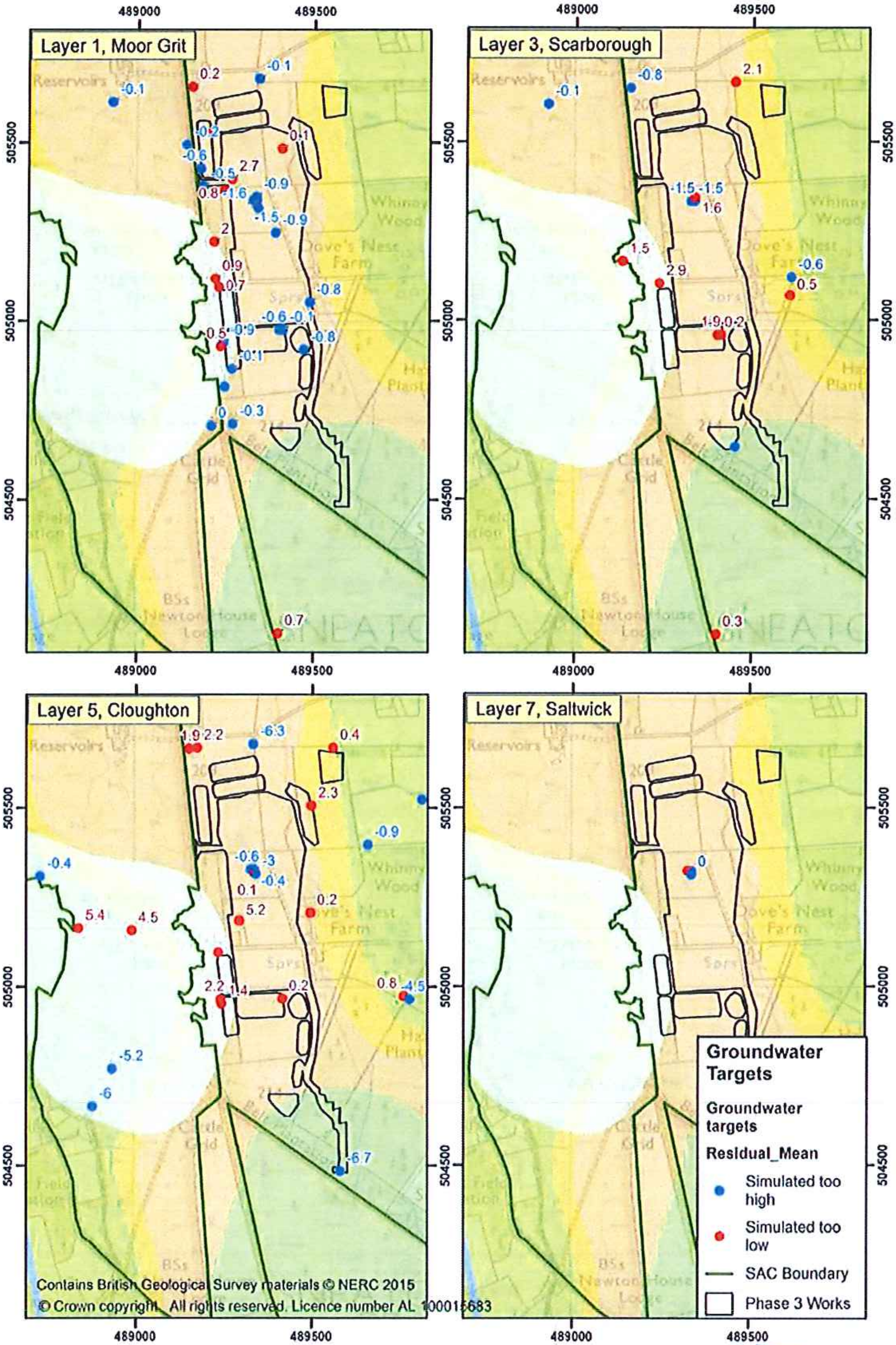

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Figure 4.3 Steady state model – groundwater levels residuals for each model layer

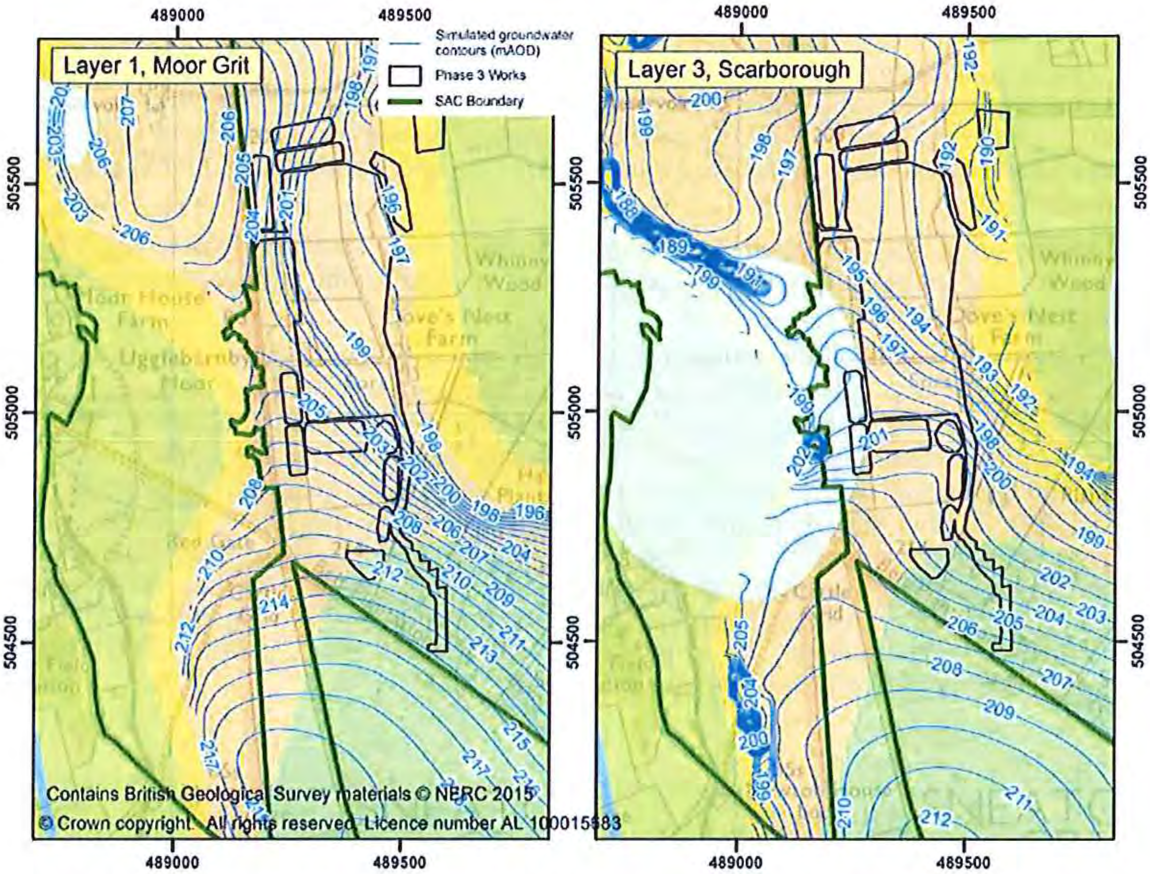

Figure 4.4 Steady state model – Moor Grit and Scarborough groundwater contours

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.

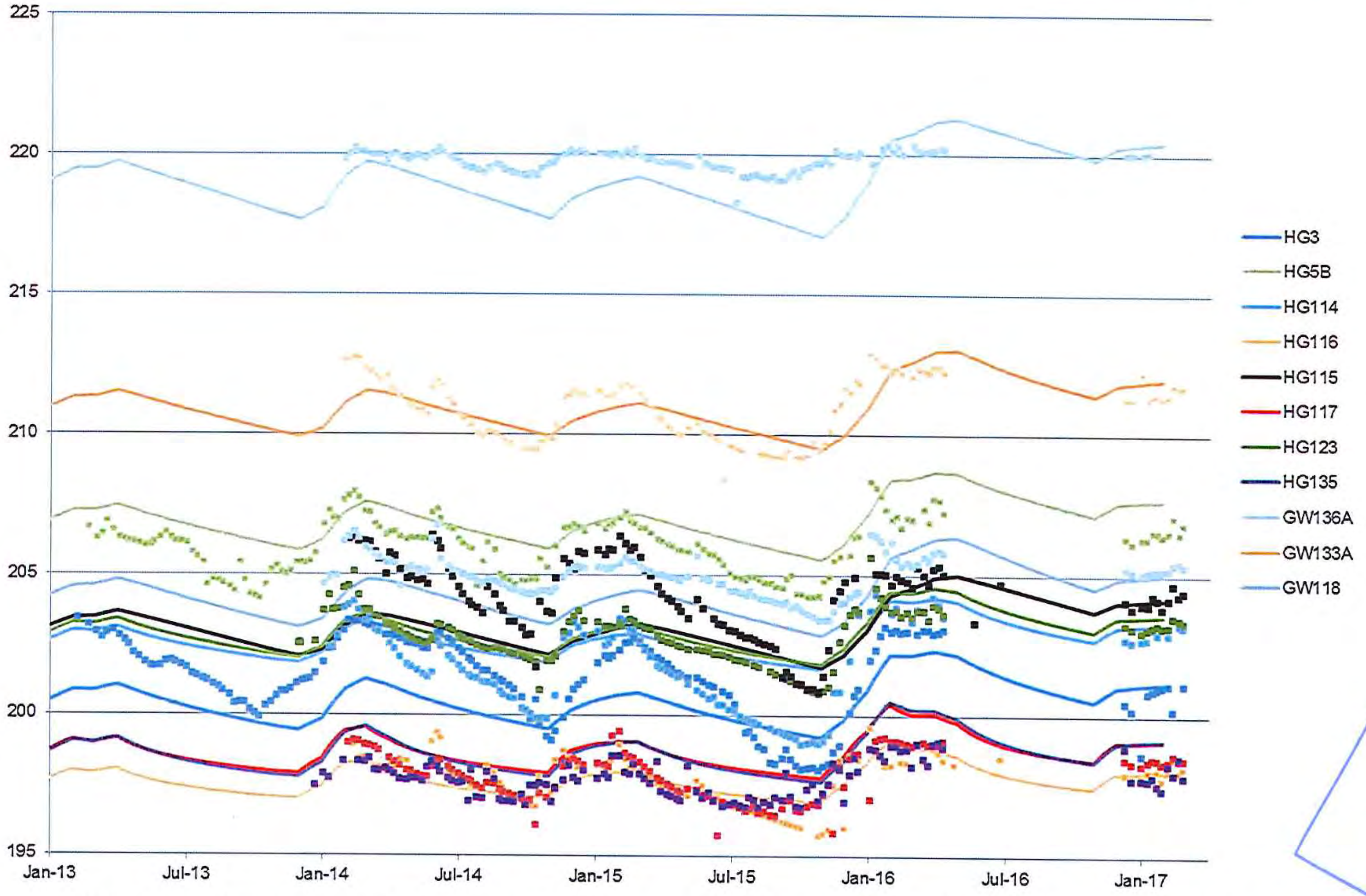

Figure 4.5 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Moor Grit

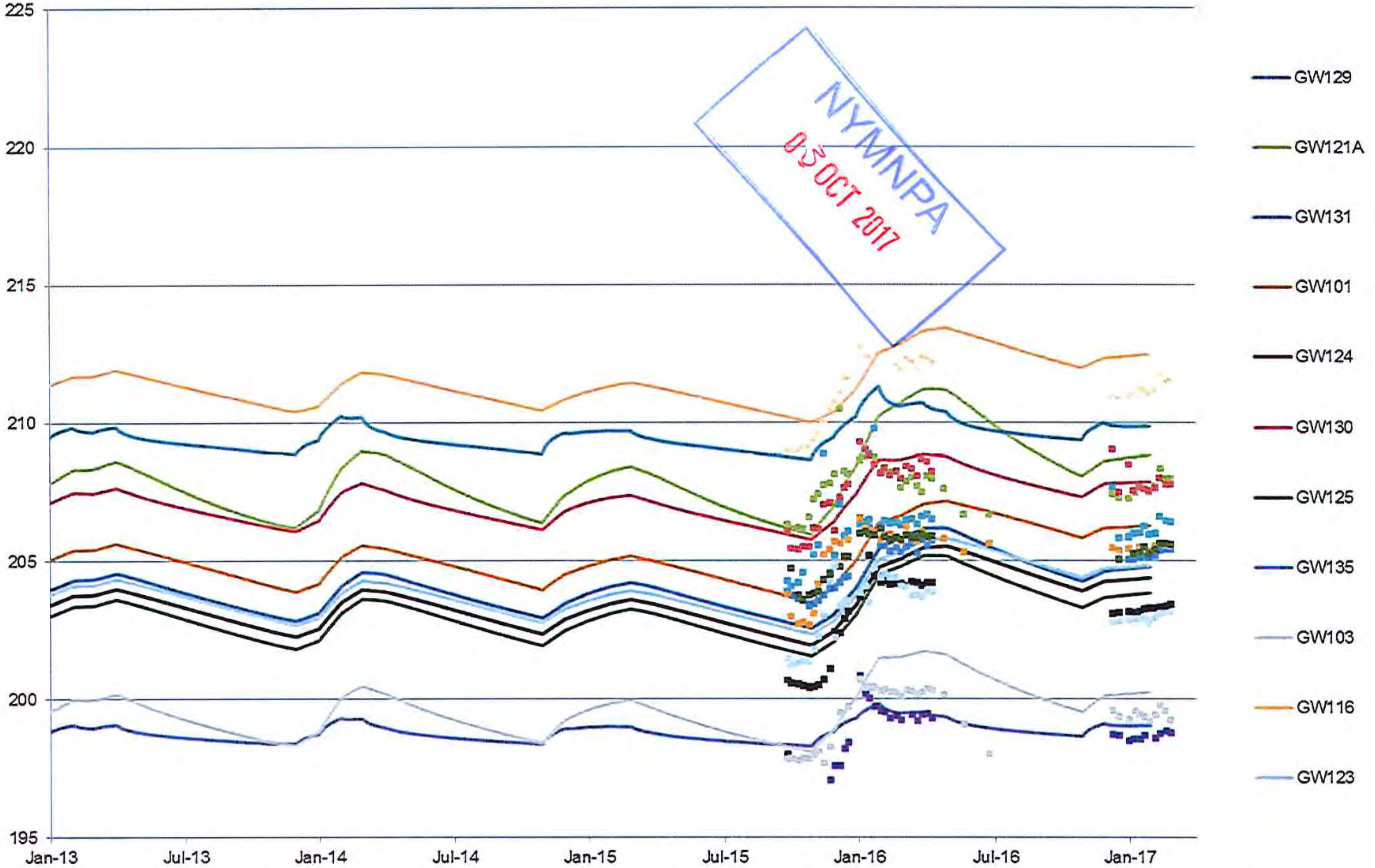

Figure 4.6 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Moor Grit (Phase 4 Stage 2 fieldwork investigation boreholes)

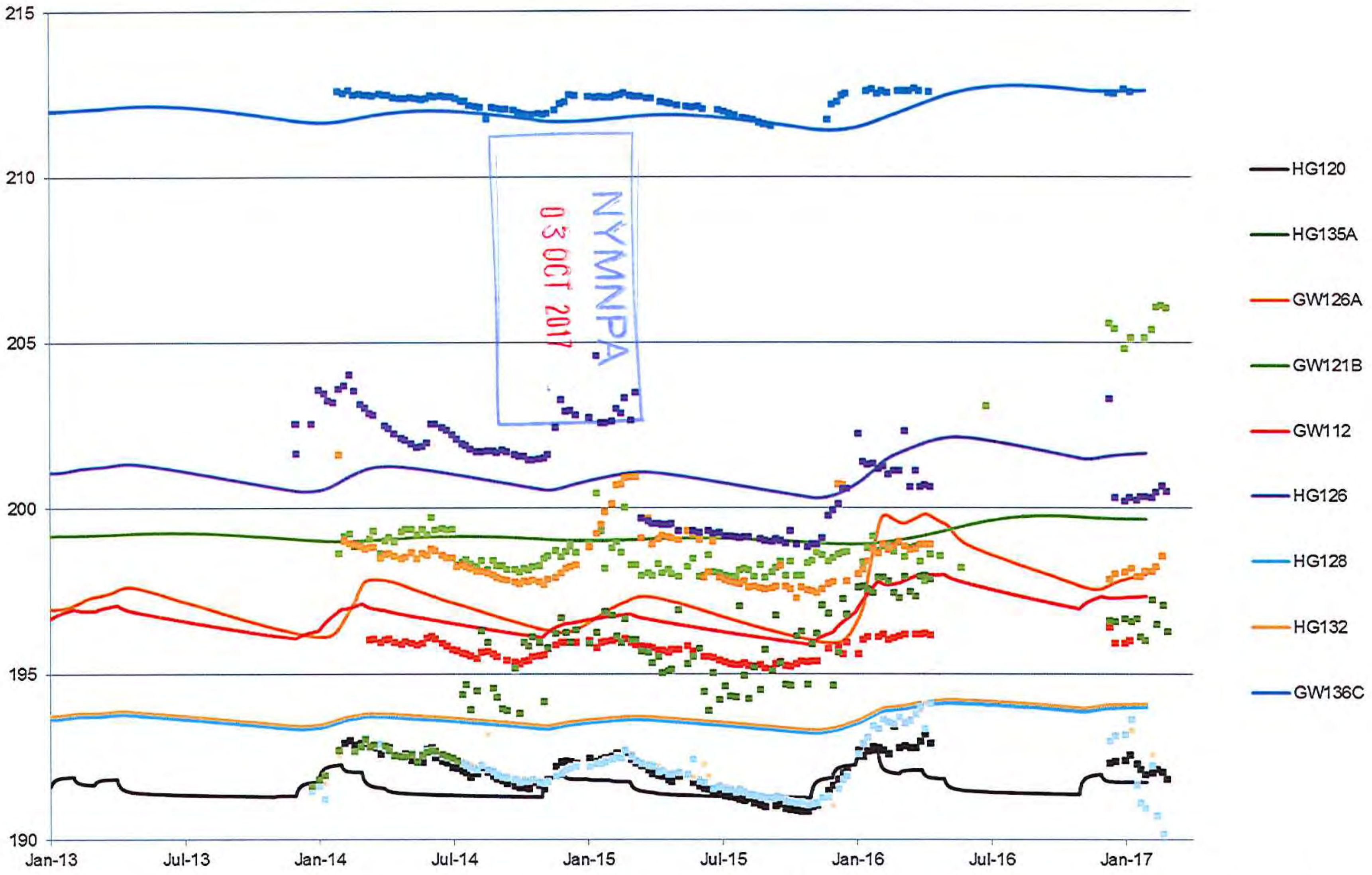

Figure 4.7 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Scarborough

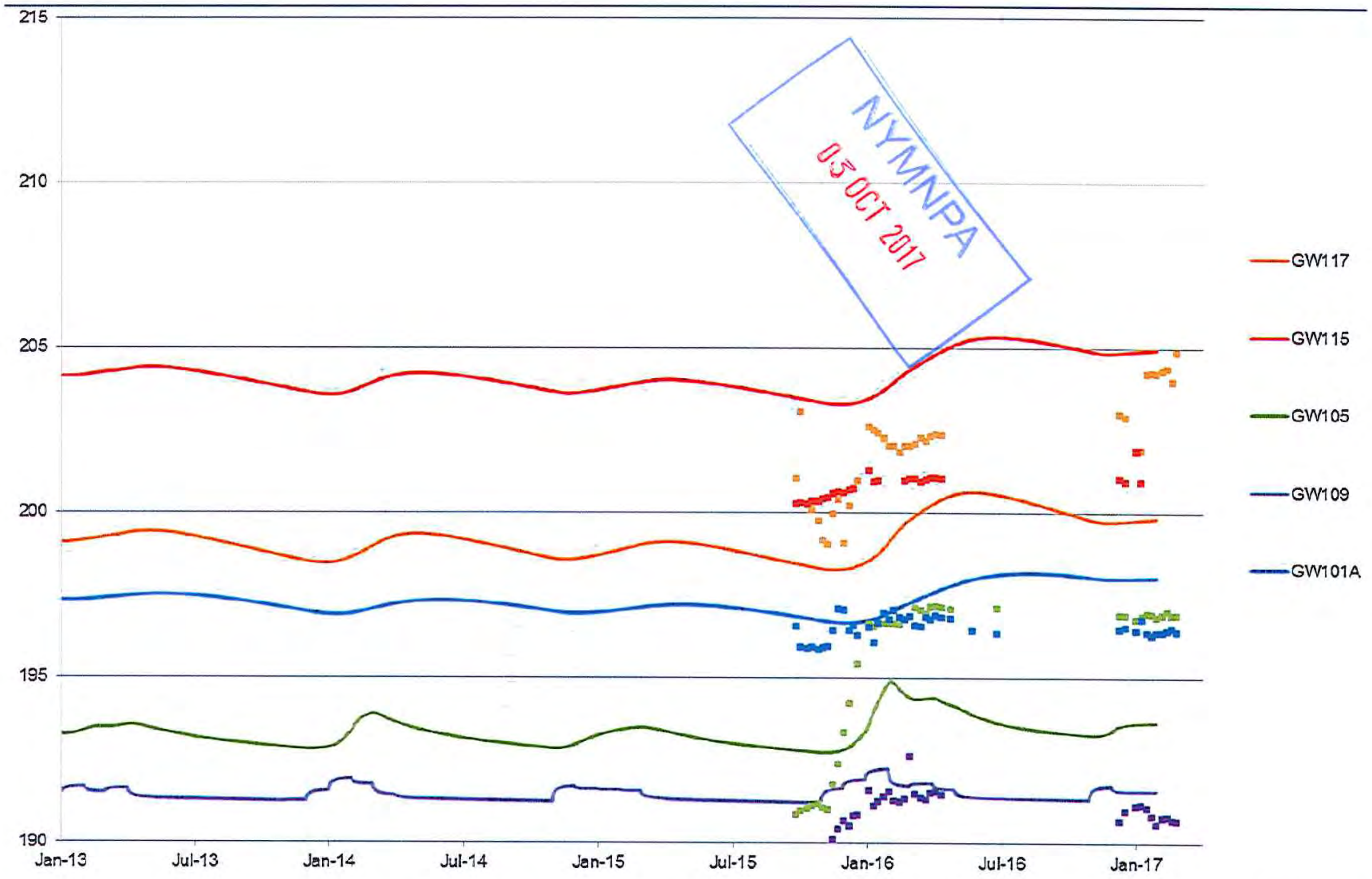

Figure 4.8 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Scarborough (Phase 4 Stage 2 fieldwork investigation boreholes)

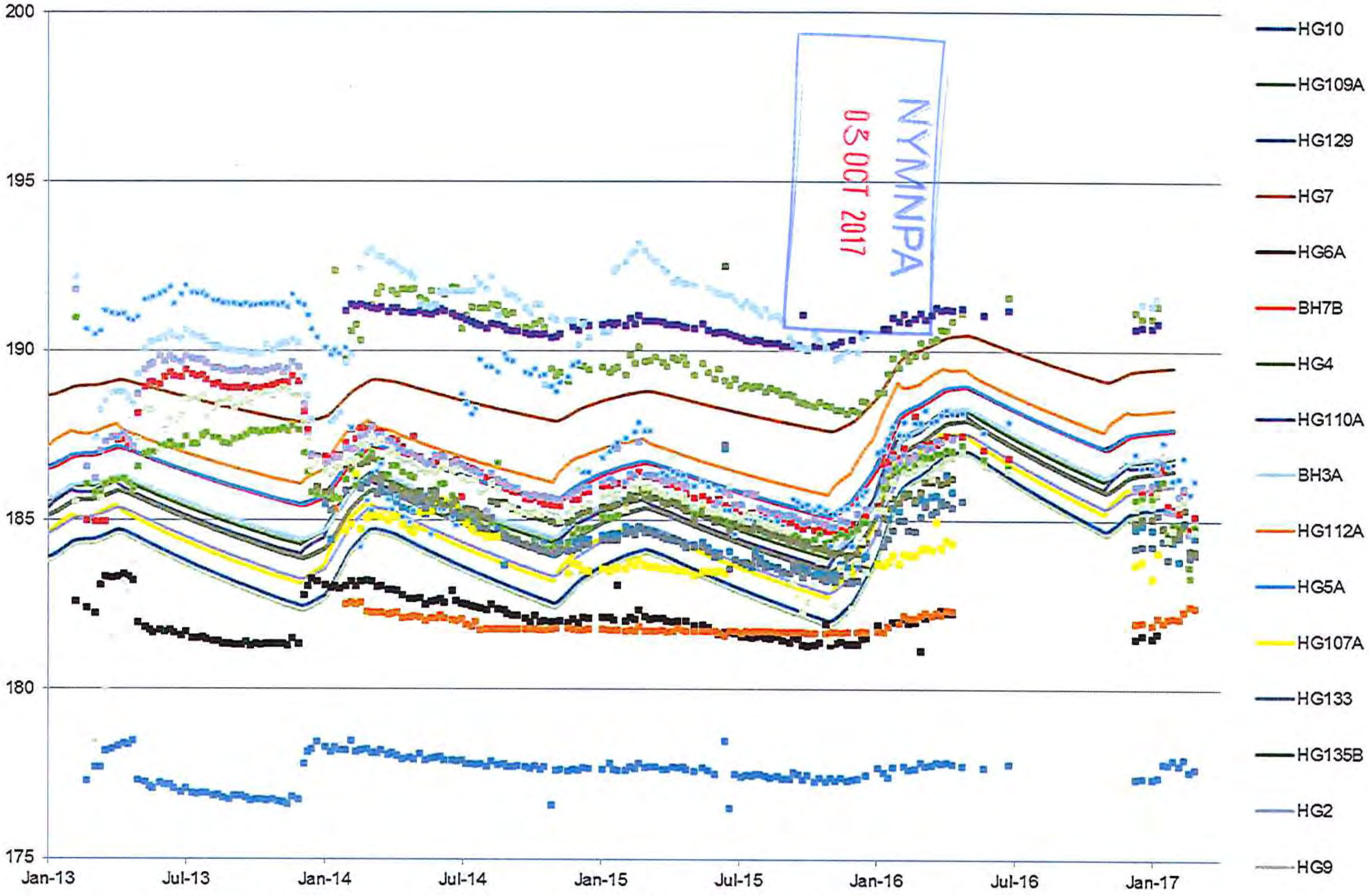

Figure 4.9 Transient model – Comparison of observed (dotted) and simulated (lines)hydrographs, Cloughton

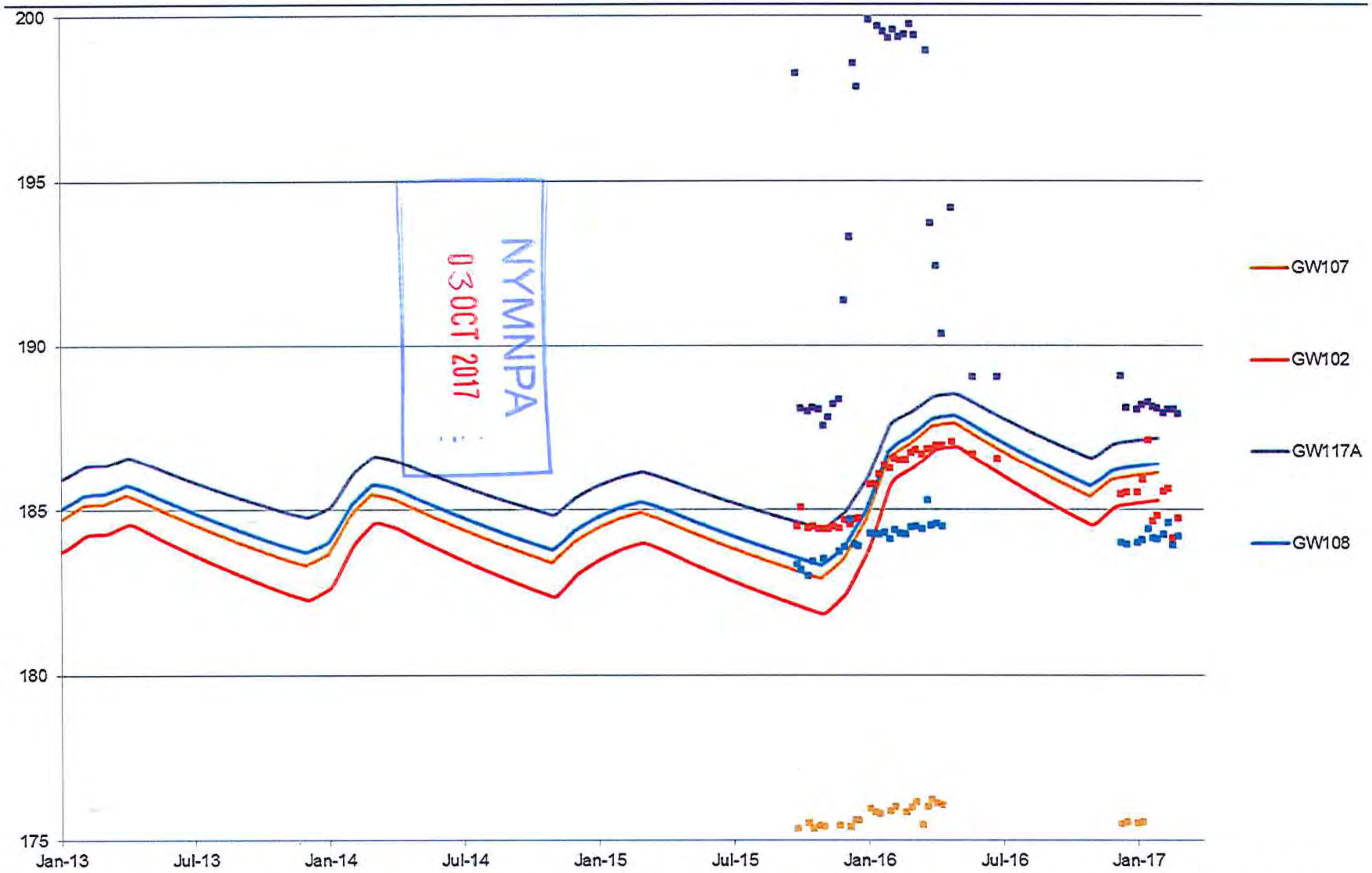

Figure 4.10 Transient model – Comparison of (dotted) and simulated (lines) hydrographs, Cloughton (Phase 4 Stage 2 fieldwork investigation boreholes)

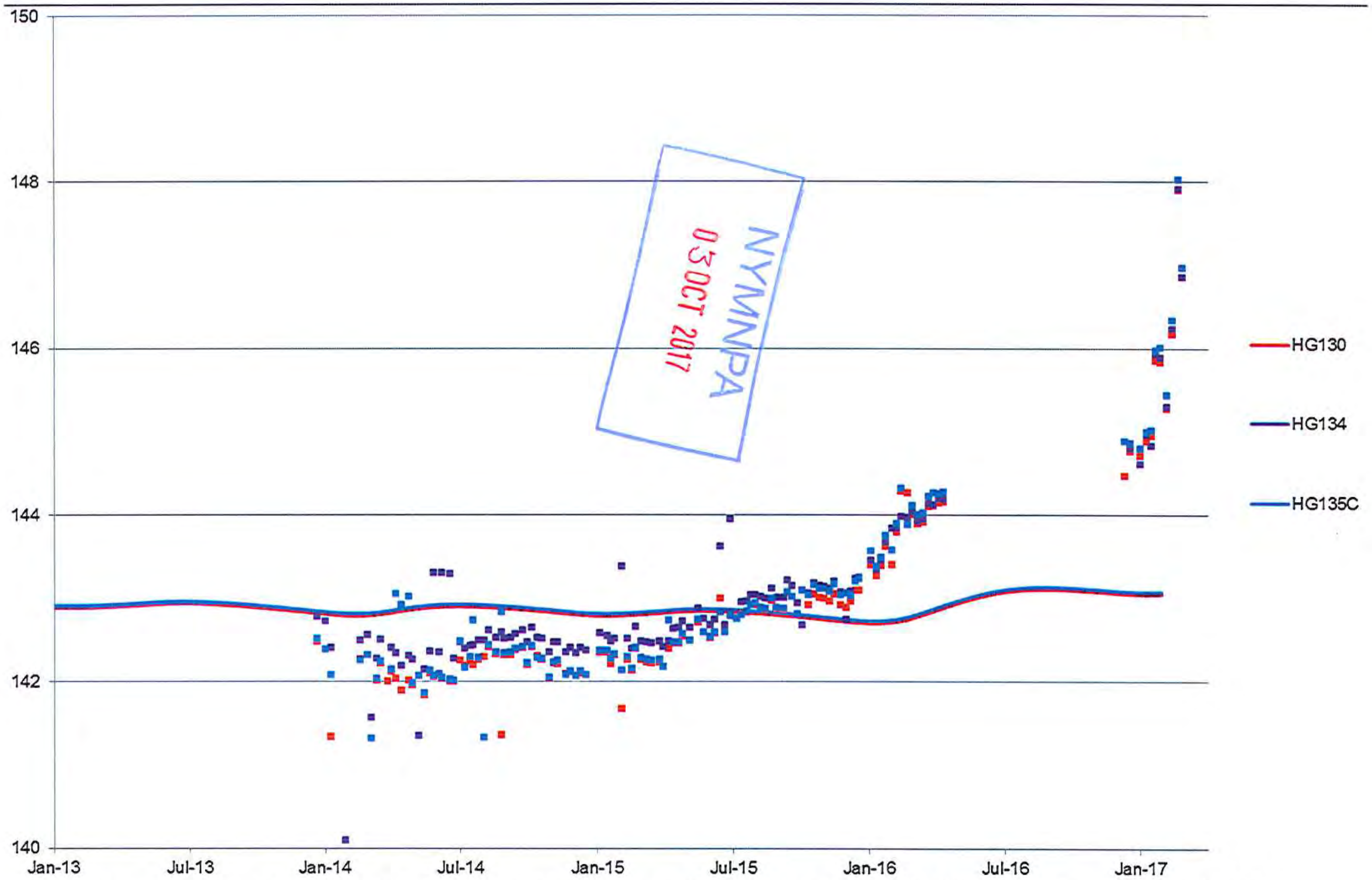

Figure 4.11 Transient model – Comparison of observed (dotted) and simulated (lines) hydrographs, Saltwick

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.

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[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}

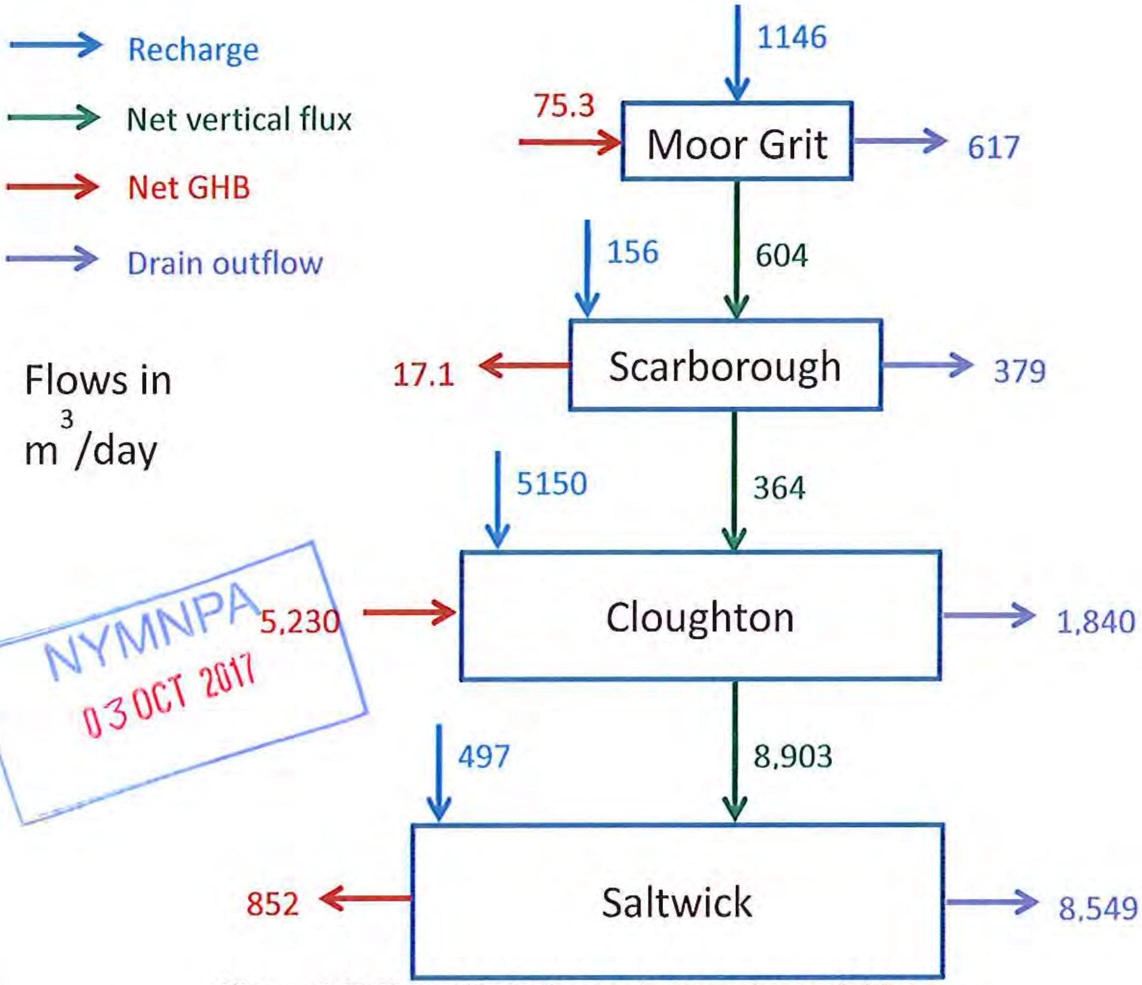

Figure 4.12 Flow chart of water balance by model layer

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.

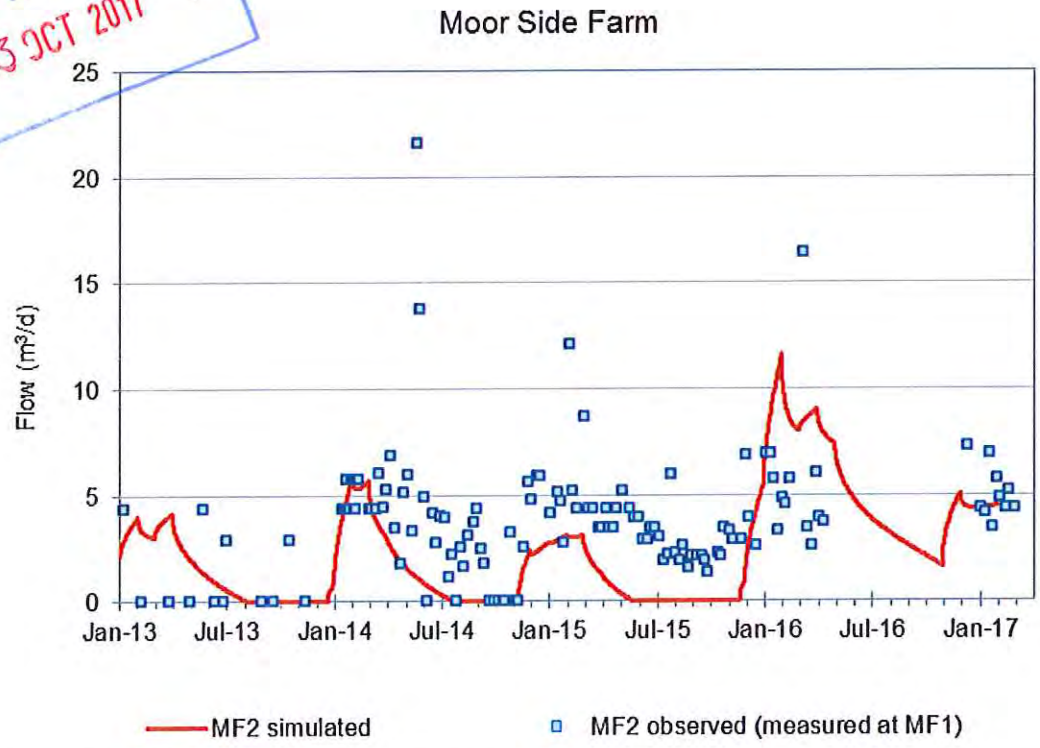

Figure 4.13 Transient model – simulated and observed spring flow at Moor Side Farm spring

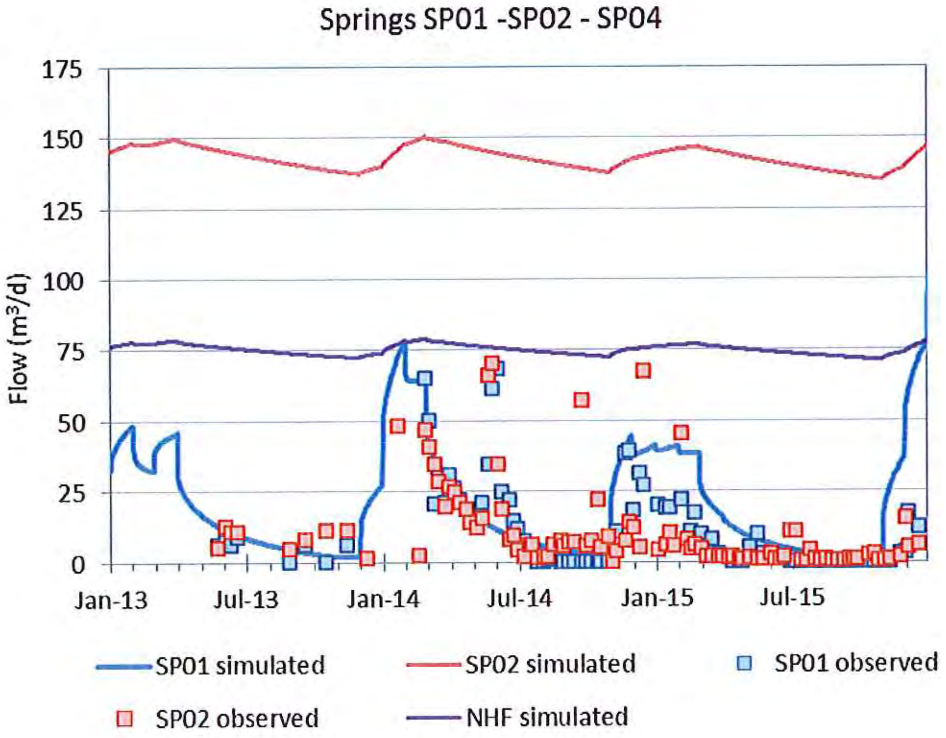

Figure 4.14 Transient model – simulated and observed spring flow at SP01, SP02 and NHF

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

esi Environment Specialists

York Potash Groundwater Model: Section 73 Sensitivity and Uncertainty Analyses

Prepared for York Potash Limited

Report reference: 61415TN4, October 2017

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Author	Chris Woodhouse	
Checked by	Heather Streetly and Barnaby Harding	
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Prepared by
ESI Ltd

New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD, UK

Registered office: New Zealand House, 160 Abbey Foregate, Shrewsbury, SY2 6FD. Registered in England and Wales, number 3212832

CONTENTS

FIGURES

TABLES

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

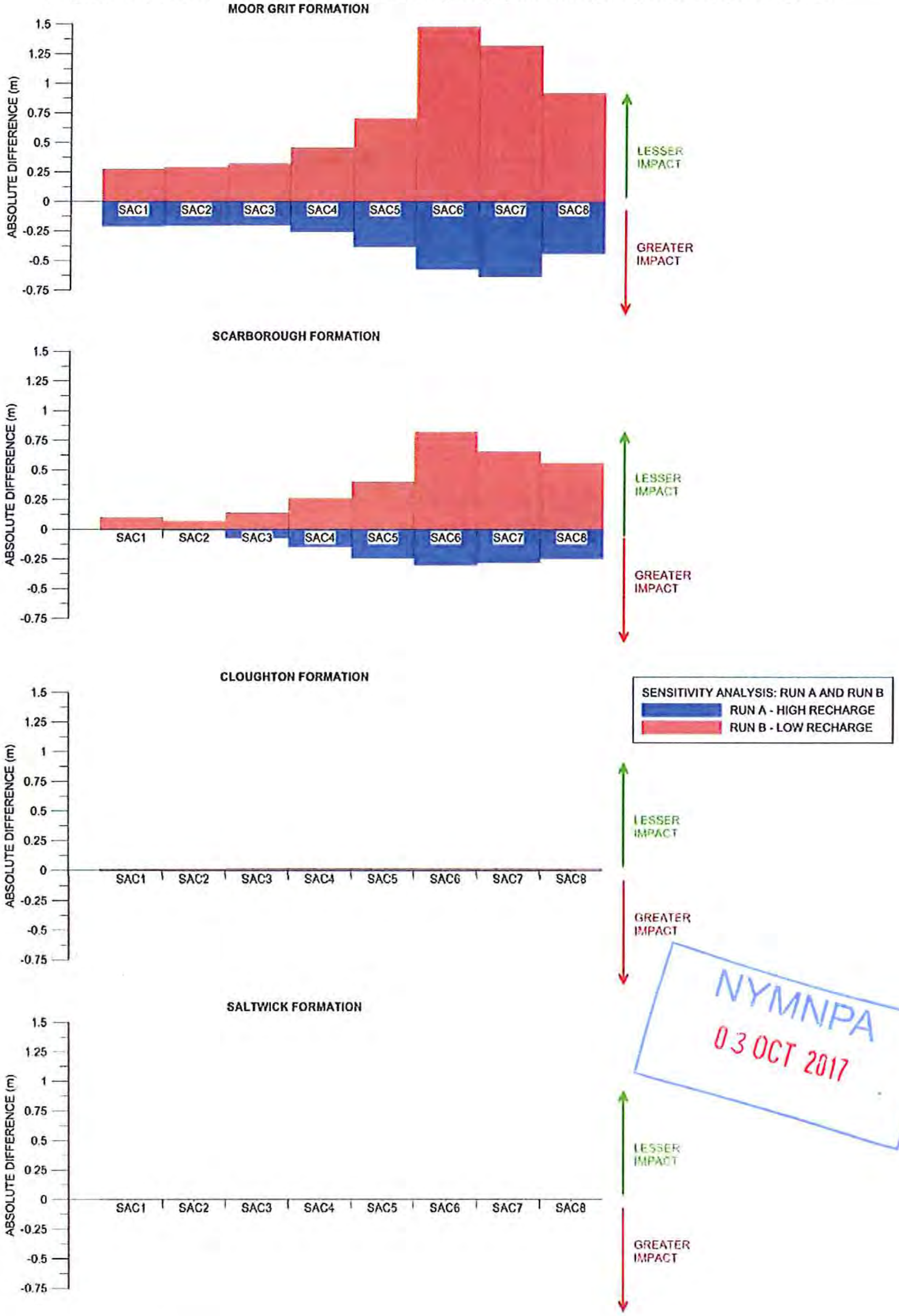
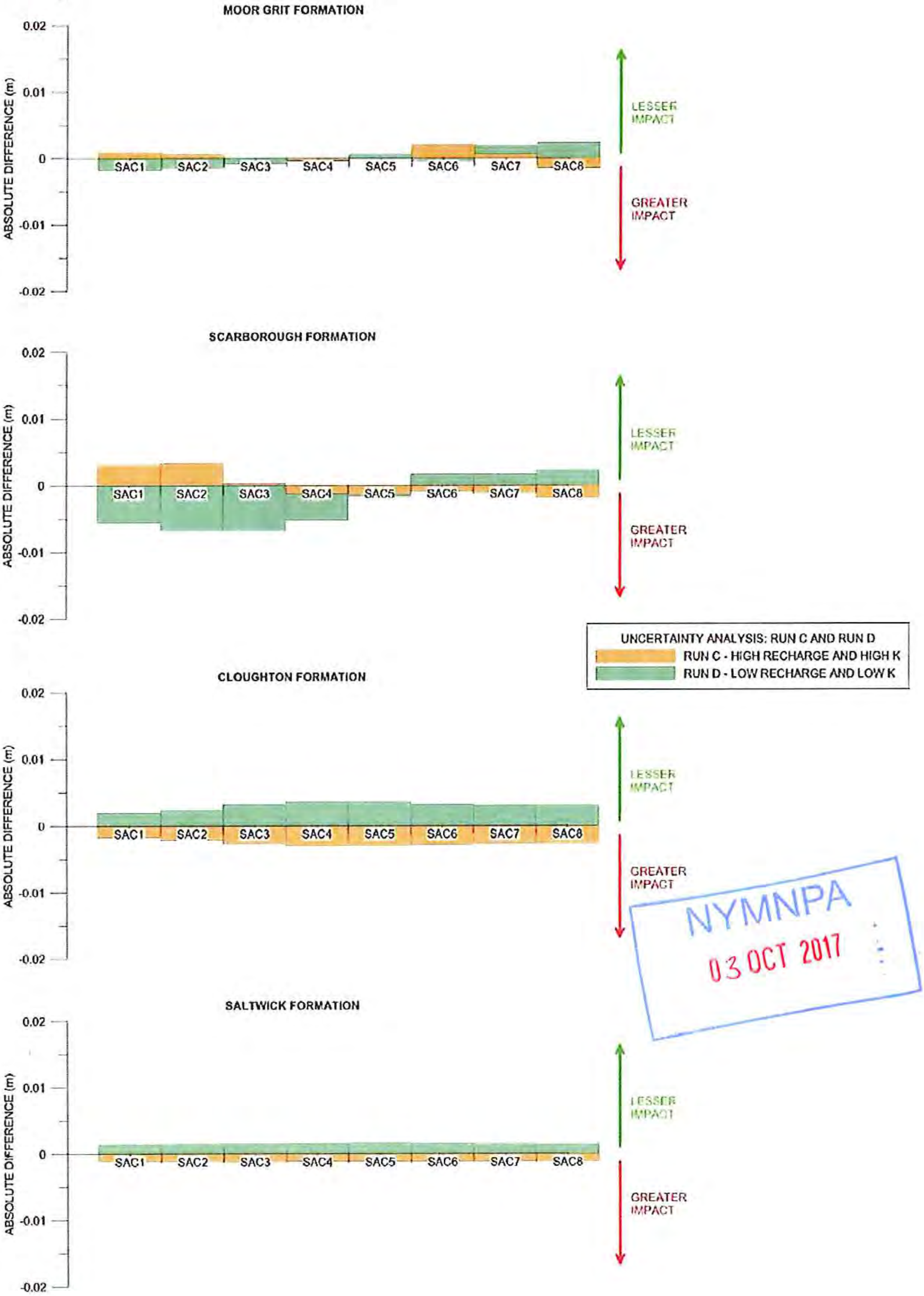


Figure 1.2 Groundwater level uncertainty analysis results for Run C and Run D



Report Reference: 61415TN4
Report Status: Final Report

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.

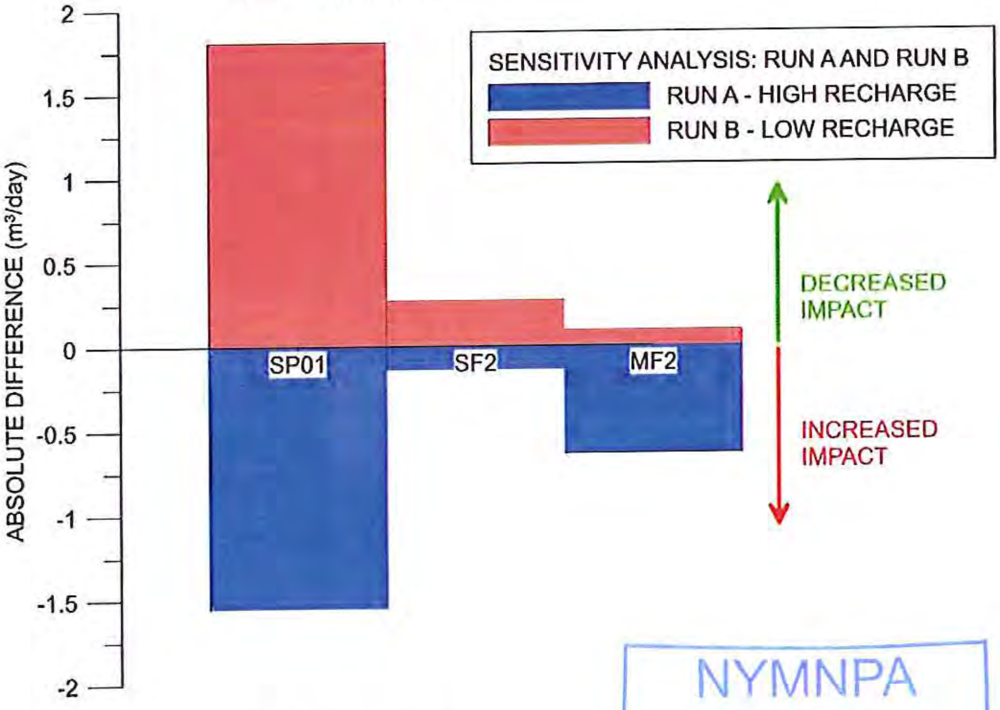
There is clearly model equivalence due to the interplay between the hydraulic conductivity and recharge parameters, and this results in uncertainty in the hydraulic conductivity and recharge parameters. However this uncertainty does not affect the ability of a recharge trench to mitigate the impacts:

- 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.

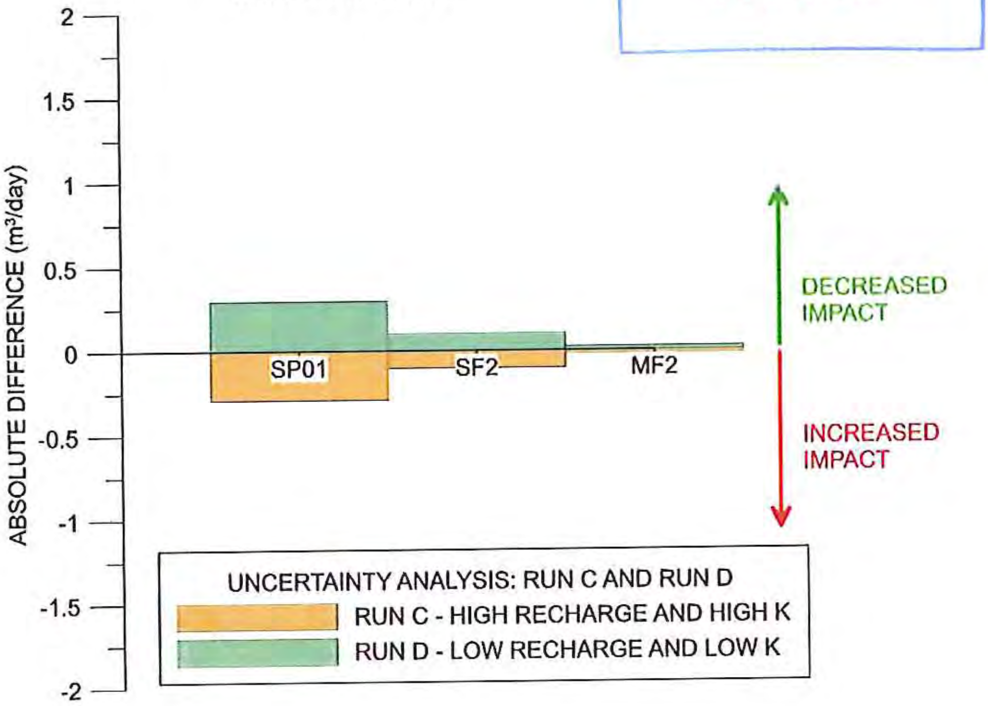
The key uncertainty is whether an adequate proportion of the recharge that is being diverted from the aquifer due to the development can enter the aquifer at the recharge trench. This will depend on local ground conditions around the trench and will need to be resolved with on-site testing.

Figure 1.3 Spring flow analysis results

RUN A AND RUN B



RUN C AND RUN D



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

Dawn Paton

From: Rob Smith
Sent: 11 October 2017 10:37
To: Planning
Subject: FW: Photomontages [NLP-DMS.FID262297]
Attachments: 2307 MH PM04A photomontage 04A_rev01_low res.pdf; 2307 MH PM10A photomontage 10A_rev01_low res.pdf

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From: Amy Farrelly
Sent: 10 October 2017 15:27
To: Rob Smith
Cc: Robert Staniland; William Woods; Aisling Kelly; Hugh Scanlon
Subject: Photomontages [NLP-DMS.FID262297]

Hi Rob

As discussed, please find attached the photomontages for locations 04 (grounds of Whitby Abbey) and 10 (access land at Normanby Hill Top near Coast to Coast walk), covering the last outstanding information for the Section 22 request.

If you require any further information to process, please let me know.

Kind regards, Amy

Amy Farrelly
Senior Planner and Economics Consultant
Lichfields, The St Nicholas Building, St Nicholas Street, Newcastle upon Tyne NE1 1RF

lichfields.uk