A303 – Amesbury to Berwick Down

Stage 4 – Groundwater Monitoring 2018-19 Conceptual Model Review

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Highways England Approval

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List of Outstanding Issues and Information			
Outstanding issue/info.	**Section/Paragraph**	**Responsibility**	**Action**

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Chapter **Pages**

1 Introduction

1.1.1 The groundwater aspects of the Environmental Statement (ES) comprised a Groundwater Risk Assessment (GRA) appendix (Highways England, October 2018. A303 Amesbury to Berwick Down TR010025. 6.3 Environmental Statement Appendices. Appendix 11.4 Groundwater Risk Assessment).

1.1.2 The GRA collated available information on geology, hydrogeology and groundwater chemistry from previous phases of ~~authors,~~ground investigation ~~data~~, and the Wessex Basin conceptual study (EA, 2011), and compiled a hydrogeological conceptual model for the study area.

1.1.3 Groundwater monitoring data in the area of the road alignment used in the development of the conceptual model was limited to that collected during previous investigations, generally between 2002 and 2006, and new data collected during the development of the ES in 2017-18.

1.1.4 This report considers monitoring data from 2018-19 following the installation of additional monitoring boreholes and gathered subsequent to submission of the DCO application in order to inform development of the detailed design.

1.1.5 Interpretation of potential preferential flow horizons from geophysics was given in the GRA and additional interpretation has been reported separately in A303 – Amesbury to Berwick Down Stage 4 – Implications of 2018 Ground Investigations to the Groundwater Risk Assessment (February 2019).

1.1.6 Interpretation of aquifer properties from pumping tests conducted in 2018 were reported in A303 – Amesbury to Berwick Down Stage 4 – Stonehenge Area Pumping Test 2018 Interpretative Report (January 2019).

1.1.7 A comparison of the pumping tests results with those described in the GRA and the implications for the risk assessment groundwater modelling was reported in A303 – Amesbury to Berwick Down Stage 4 – Implications of 2018 Ground Investigations to the Groundwater Risk Assessment (February 2019).

1.1.8 Therefore this report focuses on groundwater levels, flow directions and groundwater chemistry.

2 Current Conceptual Model

2.1 Groundwater Level and Flow

2.1.1 A summary of the conceptual model from the GRA is as follows.

2.1.2 Groundwater flow in the Chalk aquifer in the study area is generally from north to south with flow at high groundwater levels converging towards the River Till in the west of the study area and towards the River Avon in the east of the study area. The groundwater discharges naturally as baseflow to the Rivers Avon and Till.

2.1.3 The groundwater elevation contours (Figure 3.8 in GRA) show groundwater flow direction varies seasonally. Flow is generally north-south at lower groundwater levels discharging to the River Avon at the end of the Stonehenge Bottom dry valley. At high groundwater levels flow turns south easterly on the eastern side of Stonehenge Bottom to discharge to the River Avon near Amesbury and downstream. On the western interfluve (Stonehenge Down) groundwater turns south westerly to the River Till and Wylye.

2.1.4 The seasonal fluctuations in the groundwater level tend to be less in the dry valleys (between 8m and 10m) than below topographic divides (about 15m) as the storage capacity is usually greater beneath dry valley systems, than in the interfluve areas. Boreholes located close to the active rivers in the groundwater discharge regions show a limited seasonal fluctuation (about 2m).

2.1.5 Groundwater levels in the Chalk aquifer respond rapidly to recharge events at the surface due to a low storage capacity, and significant changes in groundwater level can occur over short periods of time.

2.1.6 Chalk transmissivity is typically greater beneath the dry valleys compared to the interfluve zones. Preferential groundwater flow zones beneath dry valleys result in the enhanced development of fissuring within the Chalk.

2.1.7 Groundwater baseflow enters the rivers as seepages rather than at discrete springs. A number of springs have been identified in the study area associated with the margins of the superficial deposits in the River Avon valley at Durrington, West Amesbury, Gallows Hill and Amesbury.

2.2 Groundwater Chemistry

2.2.1 The Chalk groundwater is of a calcium bicarbonate type, with chemistry generally consistent with the BGS baseline data. There is little variation in the groundwater quality across the study area. Only nitrate and turbidity concentrations exceeded the DWS in groundwater samples collected in 2018.

2.2.2 Natural sources are postulated for elevated sulphate, dissolved phosphate and arsenic concentrations compared to the BGS baseline, with elevated nitrate and ammoniacal nitrogen likely to be related to the general agricultural land use in the study area. Elevated concentrations of chloride and sodium reported for historic data could be due to road salt.

2.2.3 The dominant calcium carbonate chemistry of the Chalk is likely to generate a precipitated form of phosphorus rather than a soluble form. The general low concentration of orthophosphate measured in the groundwater is in contrast to higher concentrations measured in the River Avon. This suggests that the origin of the phosphorus in the surface water is natural discharges from the Upper Greensand rather than the Chalk upstream of the study area.

3 2018-19 Groundwater Monitoring

3.1 Data Availability

3.1.1 Monitoring data described in the GRA was generally limited to the boreholes near the road alignment and Environment Agency regional observation boreholes.

3.1.2 As there was a limited spatial extent to the monitoring there was no discussion of groundwater level seasonal differences between the boreholes that may enhance the conceptual understanding of the Chalk aquifer in different parts of the study area.

3.1.3 This report provides recent monitoring data from across the study area and offers an interpretation of behaviour and considers this in the context of the pumping test findings and the GRA conceptual model.

3.2 Groundwater Level Trends

3.2.1 The monitoring borehole data for all sites in 2018-19 is given in Figure 1. It shows a range of responses from the summer recession and autumn low point, to the winter groundwater level rise.

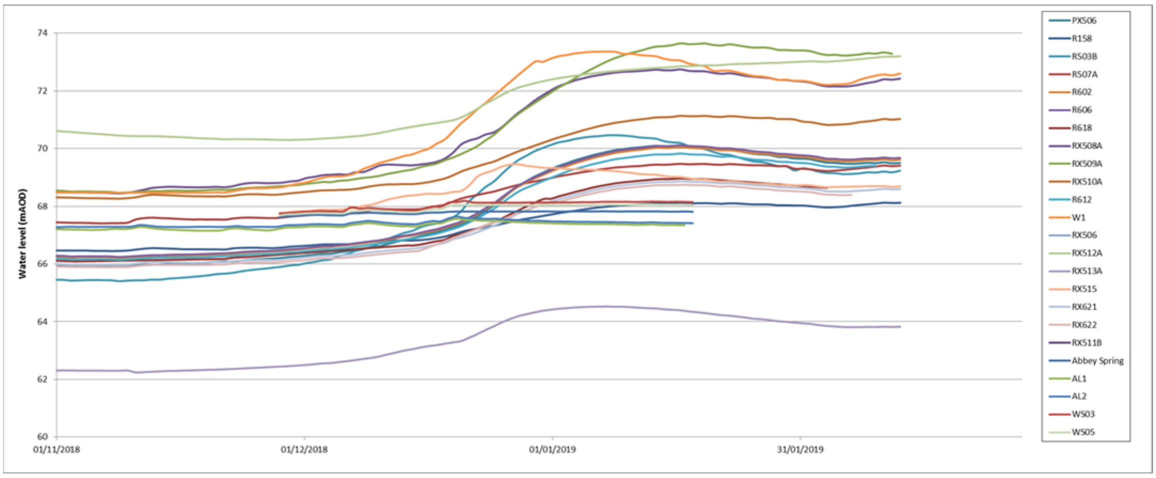


Figure 1 Groundwater Level Monitoring 2018-19 Seasonal Low and Rise

3.2.2 There are a variety of responses with some steep and rapid while others are slower but similar in overall magnitude, while others are more subdued.

3.2.3 At a larger scale the varying responses through the 2018 recession and recovery into 2019 can be observed.

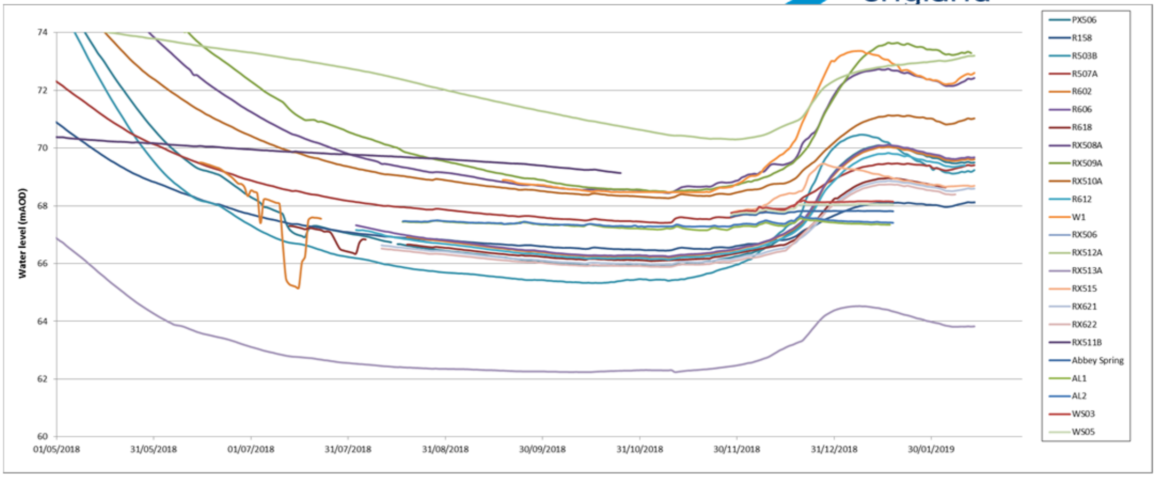
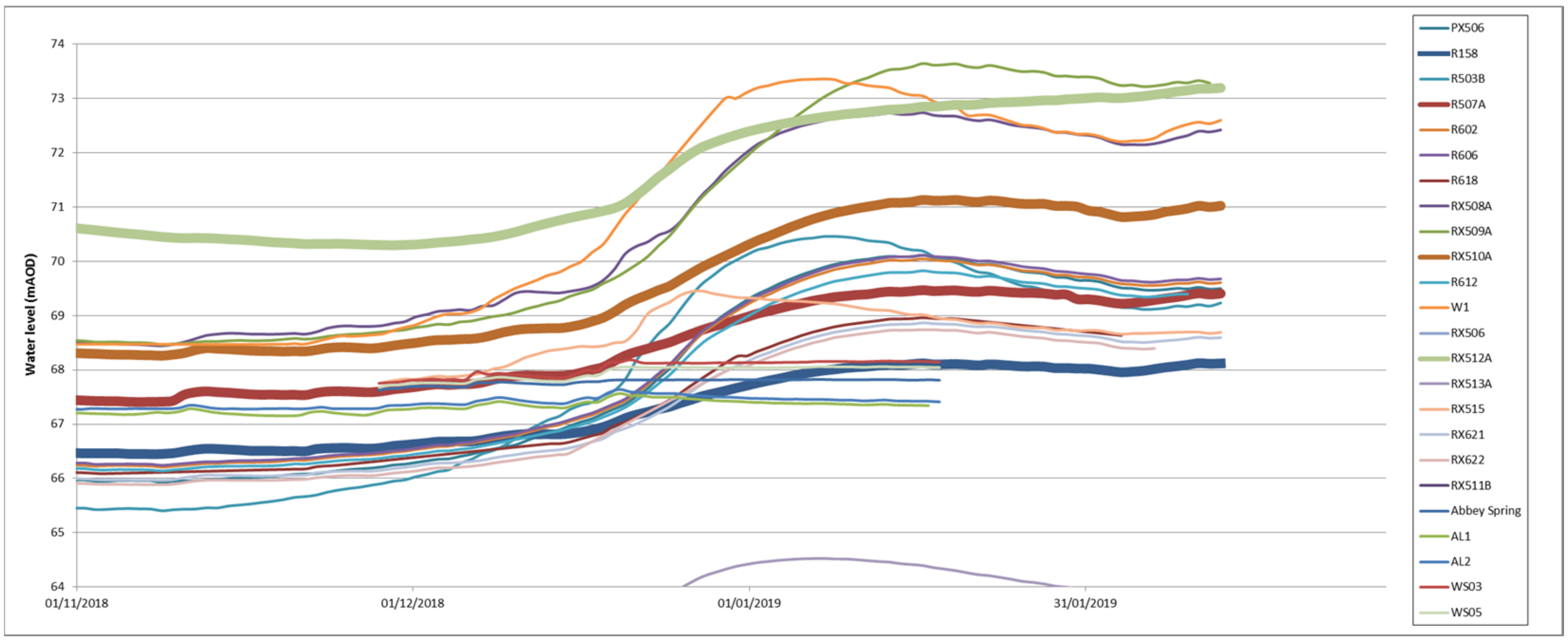


Figure 2 Groundwater Level Monitoring 2018-19 Recession and Recovery

3.2.4 The groundwater level responses can be grouped into several categories. Figure 3 highlights the boreholes showing a similar pattern of behaviour within the context of all Highways England monitoring sites in the study area.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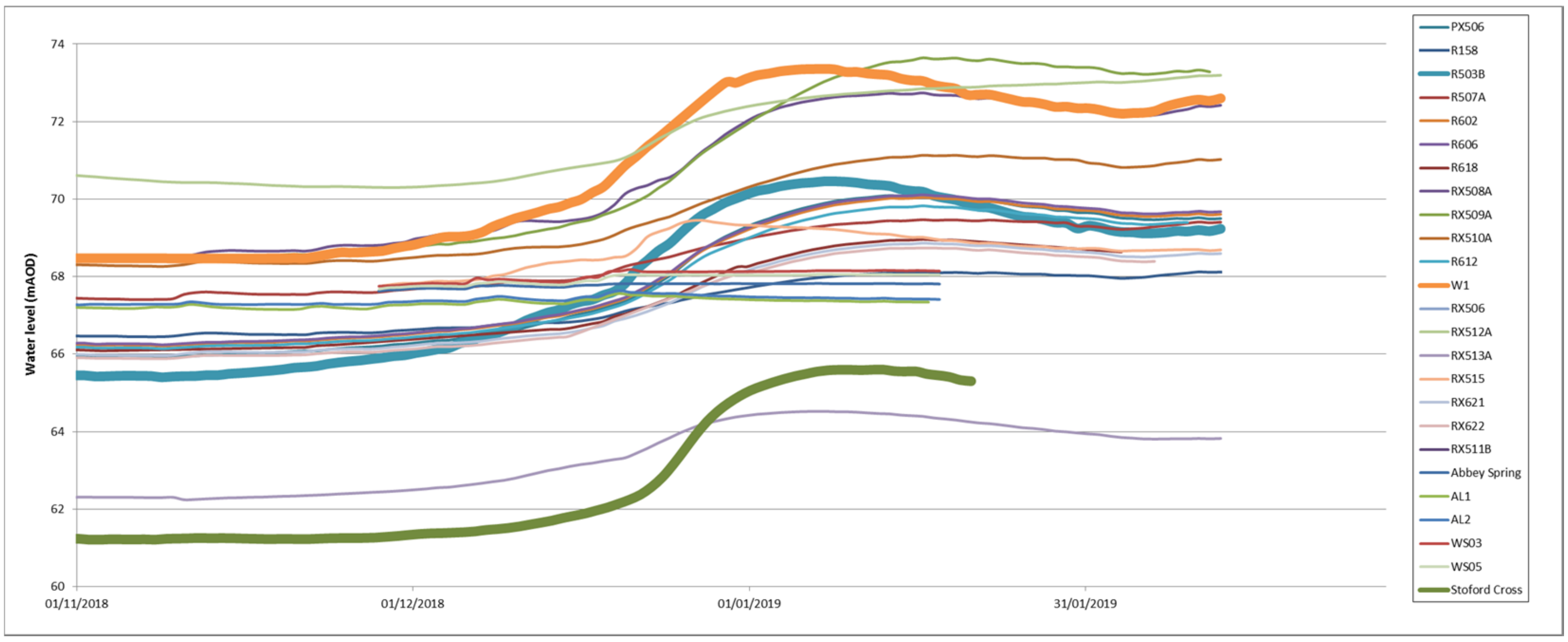
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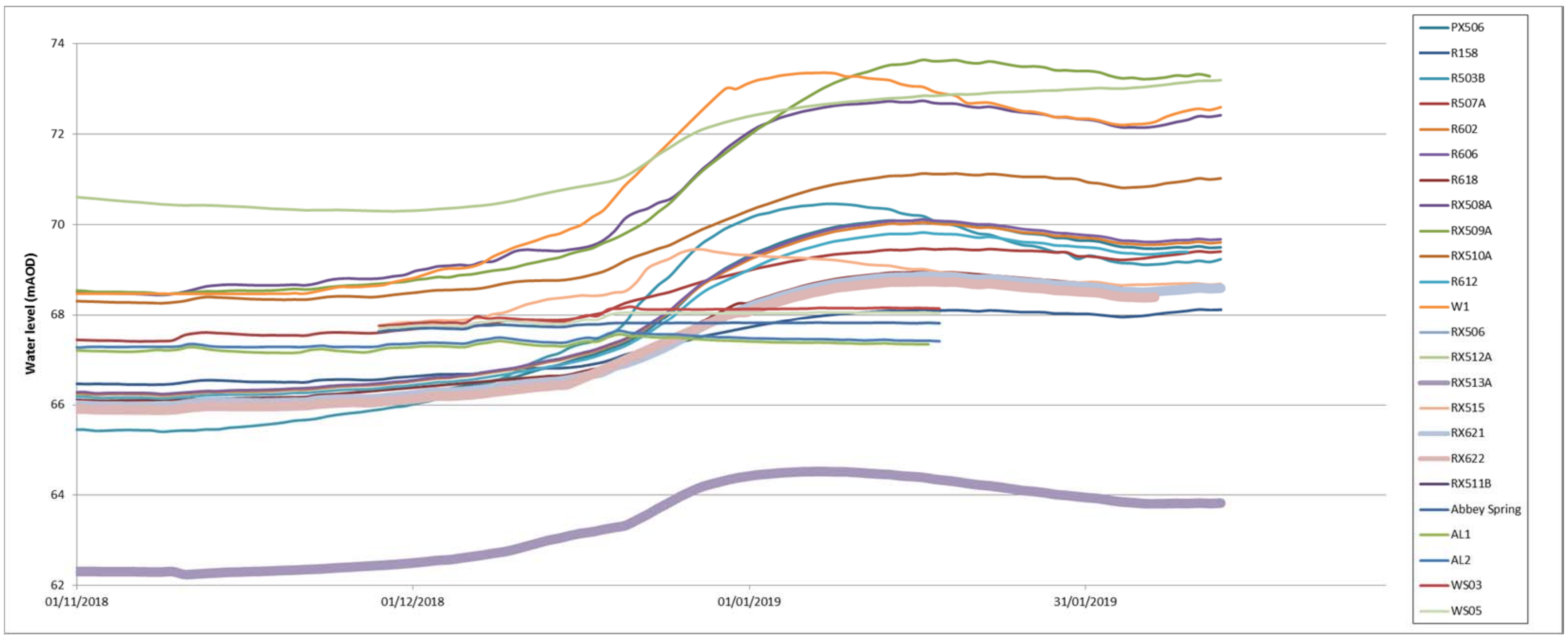
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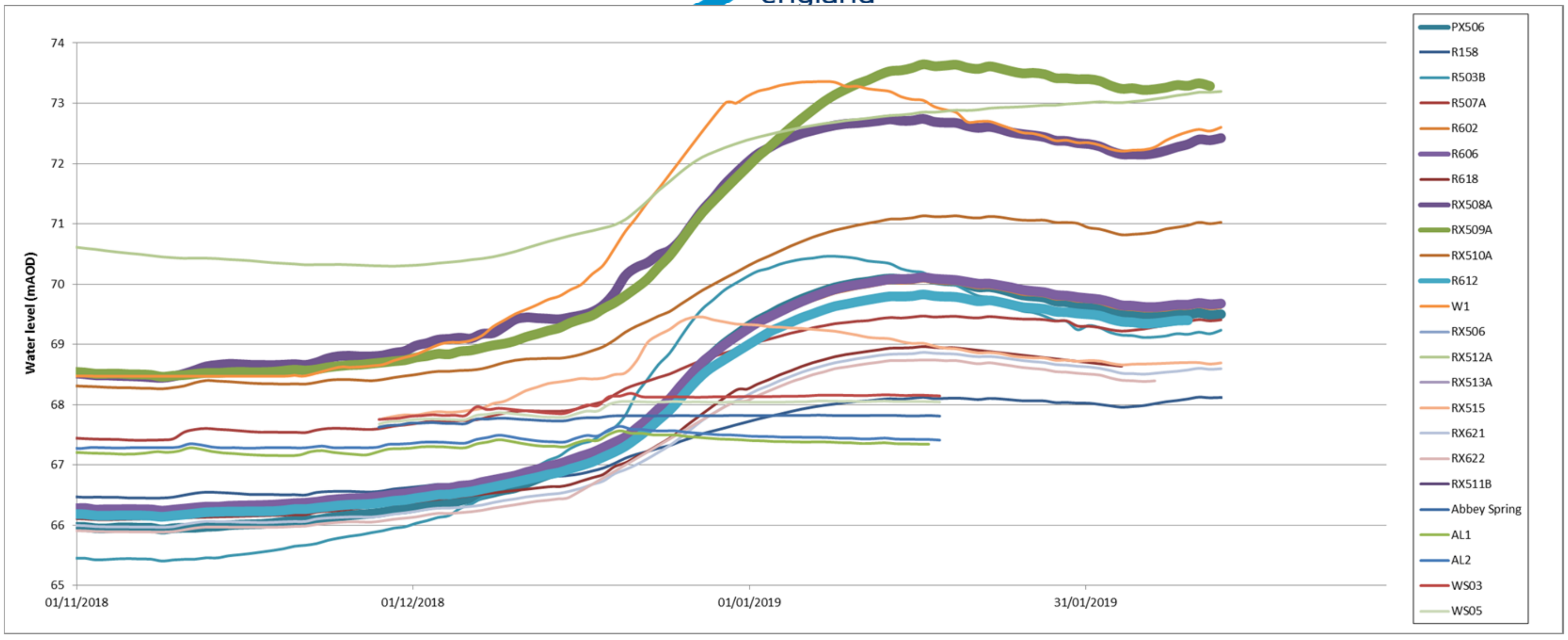

Figure 3 Groundwater Level Trends Groups

3.2.5 The locations of the boreholes grouped together in the figures above are given in Appendix A.

3.2.6 Most boreholes in the interfluve between the rivers Avon and Till-Wylye exhibit a rise in water levels from the low point in 2018 to the current monitoring data in February 2019 of 3-5m. One set of boreholes exhibit a rise of 2m. These boreholes are situated within Stonehenge Bottom valley where the pumping test interpretation calculated higher transmissivity and storage properties than for the surrounding Chalk (Figure A1).

3.2.7 Of the majority of boreholes that show a more pronounced seasonal change, some rise rapidly and plateau, while other rise more gradually. There is also variation in the timing of the rise in water levels, with those rising most rapidly also commencing their rise approximately one week earlier.

3.2.8 Those rising most rapidly are situated in Stonehenge Down. In this area the pumping test interpretation indicated that transmissivities are lower on average than for the eastern interfluvial Chalk area, Coneybury Hill; while both interfluvial areas have a similar range of storage values but Stonehenge Down has a lower average overall. This groundwater response is consistent in Stonehenge Down from the road alignment south to Stoford Cross (Figure A2).

3.2.9 East of Stonehenge Bottom valley boreholes show a more gentle rise from the autumn low and to date (February 2019) have not risen as much, approximately 3m compared to 5m on Stonehenge Down (Figure A3).

3.2.10 The pumping test east of Stonehenge Bottom at Coneybury Hill (south of these boreholes), found an overall higher average transmissivity than the Stonehenge Down pumping test with on average, higher storage properties. These aquifer properties could explain the gentler and slightly delayed rise in groundwater levels in response to recharge compared to the Stonehenge Down interfluvial Chalk.

3.2.11 The exception is RX512 which shows this gentler and slightly delayed rise but is located north of the road alignment on Stonehenge Down. This location is at the head of a dry valley descending to the River Till. Assuming this dry valley has a higher transmissivity and storage as recorded in the Stonehenge Bottom pumping tests, then this location could also be expected to have a less pronounced water table rise.

3.2.12 The fourth group of groundwater level responses have a rapid rise in groundwater level but it is delayed compared to those boreholes that rise rapidly on Stonehenge Down (Figure A4). These are all located on the Stonehenge Down interfluvial Chalk but are close to Stonehenge Bottom. These responses may be delayed as higher transmissivity and storage in the nearby dry valley provides additional storage for recharge and the ability for groundwater to flow more rapidly down gradient, which may limit the rate of rise in the near-valley interfluve when recharge commences, until the valley Chalk is saturated.

3.2.13 The exception is RX509 which shows the same rate of rise as others in this group but continues to rise after the others have plateaued. This may be because this location is further from the dry valley and located near a dry valley tributary compared to the other sites near the main Stonehenge Bottom valley. This may mean it has lower transmissivity and storage compared to the other near valley sites, but greater than the Stonehenge Down interfluve sites in Figure A2.

3.2.14 Faulting in the Stonehenge Bottom area shown on BGS geological maps and shown in cross sections (Mortimore 2012 & 2017) may have an influence on groundwater level trends. The pumping test report described faulting or fracture zones as potential recharge boundaries where some pumping test data indicated high transmissivities.

3.2.15 Faulting in the Stonehenge Bottom area may be the mechanism for the higher transmissivity chalk, while the GRA described the general observation that dry valleys tend to have higher transmissivities.

3.2.16 The fault throw juxtaposes different chalk units against one another in the valley, which if there are differing transmissivities at a local scale, may have led to preferential flow on the more permeable side, which would further enhance the transmissivity in the valley compared to the interfluve.

3.2.17 The numerical model (Annex 1 to the GRA) replicates the groundwater flow and level behaviour described in the GRA at a catchment scale by means of the aquifer properties understood at the time combined with a river network based on accurate river bed level measurements.

3.2.18 Faulting may also have a role in groundwater behaviour at a local scale but the data indicates this potential influence fits within the overall flow regime described in the GRA.

3.3 Groundwater Flow Directions

3.3.1 Interpolated groundwater contours from November 2018 representing the low point of the recession shows the groundwater flows direction to be generally north to south with flow toward the south east in the eastern part of the interfluve to the River Avon, and on the western side to the south west toward the rivers Till and Wylye.

3.3.2 Interpolated groundwater contours from April 2018 representing the high point in the data to date shows groundwater flow in the eastern interfluve to be more easterly than the low groundwater levels, though still toward the south east.

3.3.3 The seasonal change in groundwater level is consistent with the GRA conceptual model with flow directions very similar overall, while every year can be expected to vary to some degree with different antecedent conditions and recharge. A comparison of the flow directions given in the GRA and interpolated from recent monitoring is given in Figure A5.

3.3.4 Consequently, the catchment areas to springs discussed in the GRA are unchanged.

3.3.5 Groundwater flow directions toward the rivers Avon, Till and Wylye where discharge as baseflow supports river flows, also shows no significant change with the new monitoring data compared to that described in the GRA.

3.4 Groundwater Chemistry

3.4.1 A wider range of pH, temperature and electrical conductivity was measured during 2018-19 than the ranges published in the GRA.

3.4.2 The pH recorded during the sampling rounds from January 2018 to February 2019 ranged between 7.15 and 8.37 pH units, temperature ranged between 6.1 and 17.6 °C, and electrical conductivity ranged between 393µS/cm and 867µS/cm.

3.4.3 The data has shown concentrations of cyanide, lead, nitrate, nickel, iron and sodium exceeding the relevant DWS in a small number of samples. Nitrate, iron and turbidity exceeded the DWS on several occasions in groundwater samples collected and analysed in 2018-2019. Total PAH and Benzo(a) pyrene exceeded DWS and UKTAG standards in one sample, RX512A, over the 2018-2019 monitoring period. Nitrite exceeded the DWS standard in RX631 in 2018.

3.4.4 Average concentrations of ammoniacal nitrogen, chloride, nitrate, phosphorus, and sulphate exceeded the mean BGS baseline in over 10% of the samples taken, compared to 6% at the time of the GRA.

3.4.5 More boreholes recorded elevated sodium and chloride than described in the GRA. Concentrations of chloride and sodium were significantly higher than the regional maximum at W1 and CP4, R503B, W137, RX631 and RX634, while CP2 and W617 had higher concentrations of sodium, although the magnitude of this is less than W1 and CP4.

3.4.6 Sulphate, nitrate and ammoniacal nitrogen were reported as exceeding the BGS baseline at several locations in the GRA. Additional exceedances were recorded at several new monitoring sites, as well as nitrite.

3.4.7 Arsenic, lead and aluminium were reported as exceeding the BGS baseline at several locations in the GRA. Arsenic also exceeds the BGS baseline in many of the new monitoring sites, as well as antimony and copper.

3.4.8 The concentration of dissolved phosphorus was lower than the mean BGS regional concentration (40ug/l) in all samples described in the GRA. One location W601 recorded 70µg/l in recent sampling.

3.4.9 Orthophosphate (soluble reactive phosphorus) concentrations reported in the GRA were less than the detection limit of 0.03mg/l in all samples. In the new boreholes three locations: borehole RX514A, situated approximately 3km south west of the scheme alignment, recorded a concentration of 0.56mg/l; borehole RX511, located at Winterbourne Stoke next to the River Till, recorded 0.04mg/l; and borehole RX506, located near Larkhill, recorded 0.04mg/l.

4 Implications for Groundwater Risk Assessment and Environmental Statement

4.1.1 New monitoring data has given more detail to variations in groundwater behaviour in the Chalk aquifer in the study area. This detail fits within the overall conceptual model of groundwater flow from north to south and discharge to the rivers Avon and Till-Wylye.

4.1.2 Groundwater level seasonal changes have been shown to vary with hydrogeological setting as described in the GRA. The groundwater level data from 2016-19 is outside the time range of the groundwater model, but when plotted against the long term simulated groundwater levels it can be seen that the observed groundwater levels from the new boreholes are at levels predicted by the model to within approximately 2m across a range of years with varying climate (Appendix B).

4.1.3 The modelled groundwater levels at these new observation locations also show different timings of response to the onset of recharge, and different trough to peak level amplitude in accordance with the groupings described in Section 3.2, in the context of the model time and spatial scale.

4.1.4 There is no significant deviation between the new observation data and the modelled groundwater level that would suggest the model is not simulating an important control on groundwater behaviour in the study area.

4.1.5 Groundwater flow directions interpolated from the recent groundwater level data are very similar to the flow directions interpreted from typical high and low groundwater levels provided in the GRA from the Wessex Basin Conceptual Study.

4.1.6 Groundwater chemistry sampling between 2018 and 2019 shows that more determinands at more locations are above either DWS or the BGS baseline concentrations than were reported in the GRA.

5 Conclusions

5.1.1 The new groundwater monitoring data has supplemented the conceptual understanding presented in the GRA.

5.1.2 The findings confirm the existing conceptual understanding and the groundwater model replicates the new observation data well in the context of the model time and spatial scale.

5.1.3 The supplementary data confirms the findings presented in the GRA and the inputs to the groundwater model used to assess impacts.

5.1.4 Therefore the monitoring data and enhanced conceptual understanding does not change the findings of the GRA or the significance of effects reported in the ES.

6 References

Environment Agency, 2011. Wessex Basin Groundwater Modelling Study. Phase 4 Final Report. February 2011

Highways England, October 2018. A303 Amesbury to Berwick Down TR010025. 6.3 Environmental Statement Appendices. Appendix 11.4 Groundwater Risk Assessment

Highways England, January 2019. A303 – Amesbury to Berwick Down Stage 4 – Stonehenge Area Pumping Test 2018 Interpretative Report

Highways England, February 2019. A303 – Amesbury to Berwick Down Stage 4 – Implications of 2018 Ground Investigations to the Groundwater Risk Assessment

Mortimore, 2012. Making sense of Chalk: a total-rock approach to its Engineering Geology. The Eleventh Glossop Lecture

Mortimore, 2017. Stonehence Unexpected Geology. Proceedings of the Geologists' Association

Appendix A New Groundwater Level Data

Figure A1 Subdued groundwater level variations in Stonehenge Bottom valley

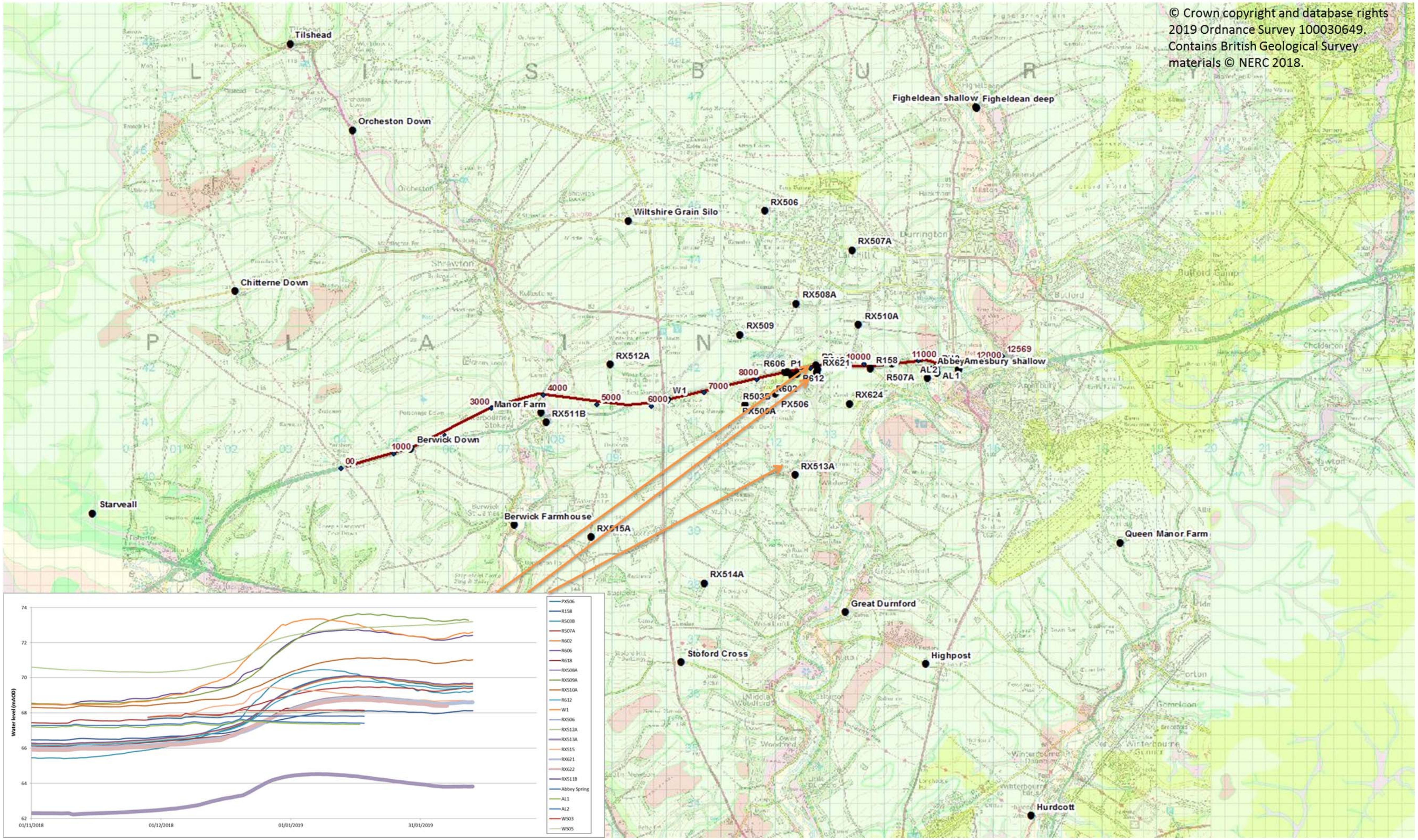

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Figure A2 Rapid groundwater level responses at Stonehenge Down

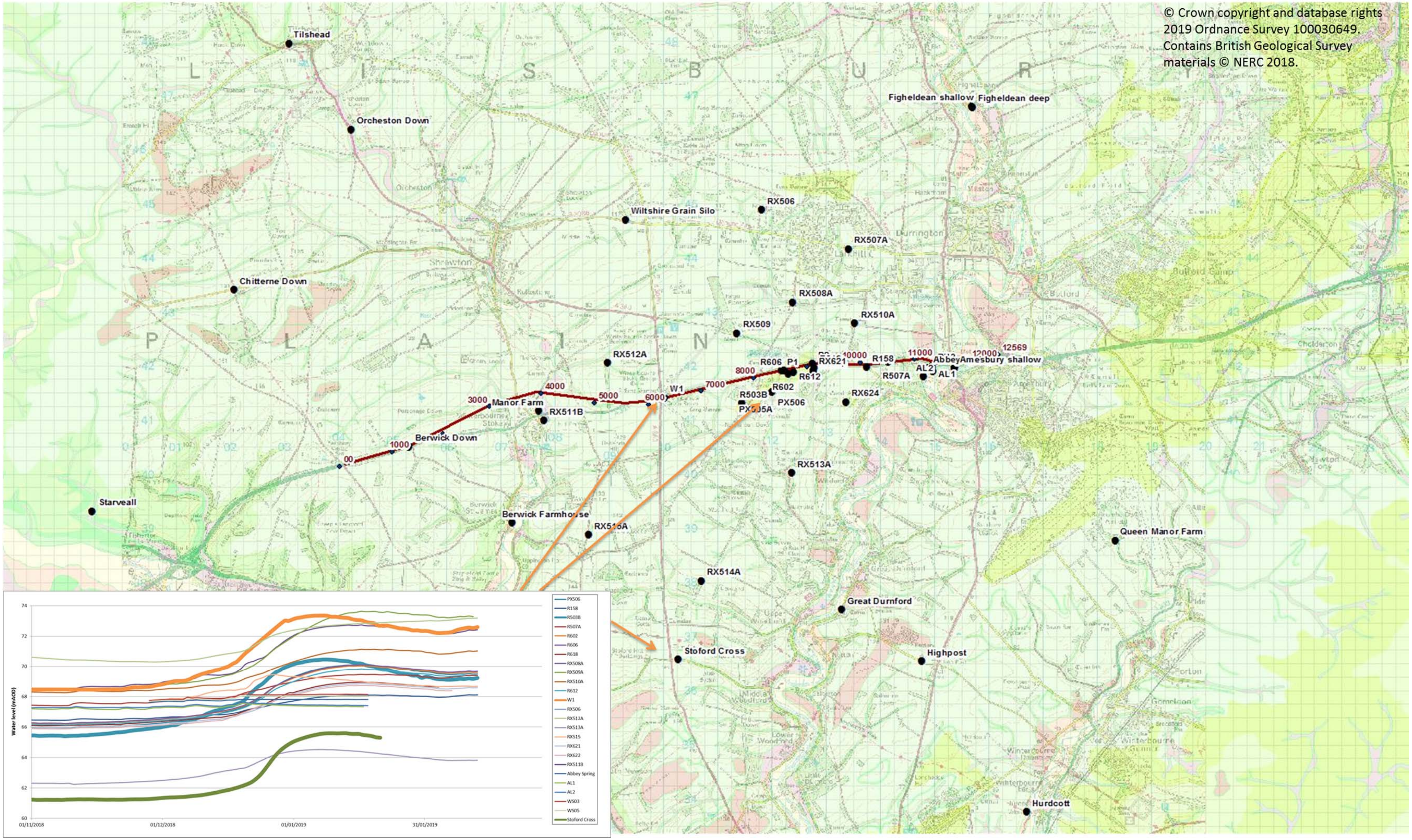


Figure A3 Gentle groundwater level responses east of Stonehenge Bottom valley and at River Till dry valley

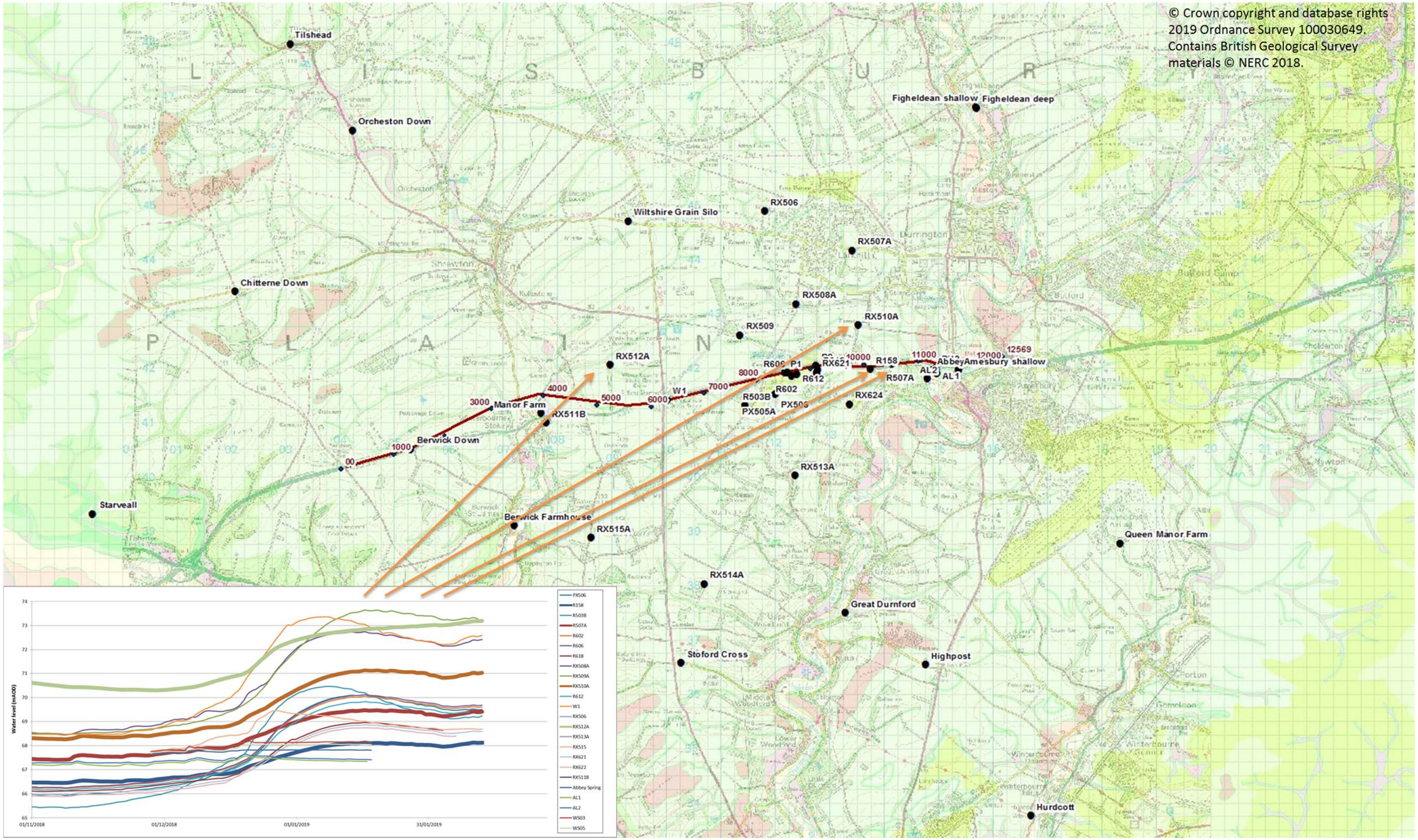


Figure A4 Rapid but delayed groundwater level responses in Stonehenge Down Chalk near Stonehenge Bottom valley

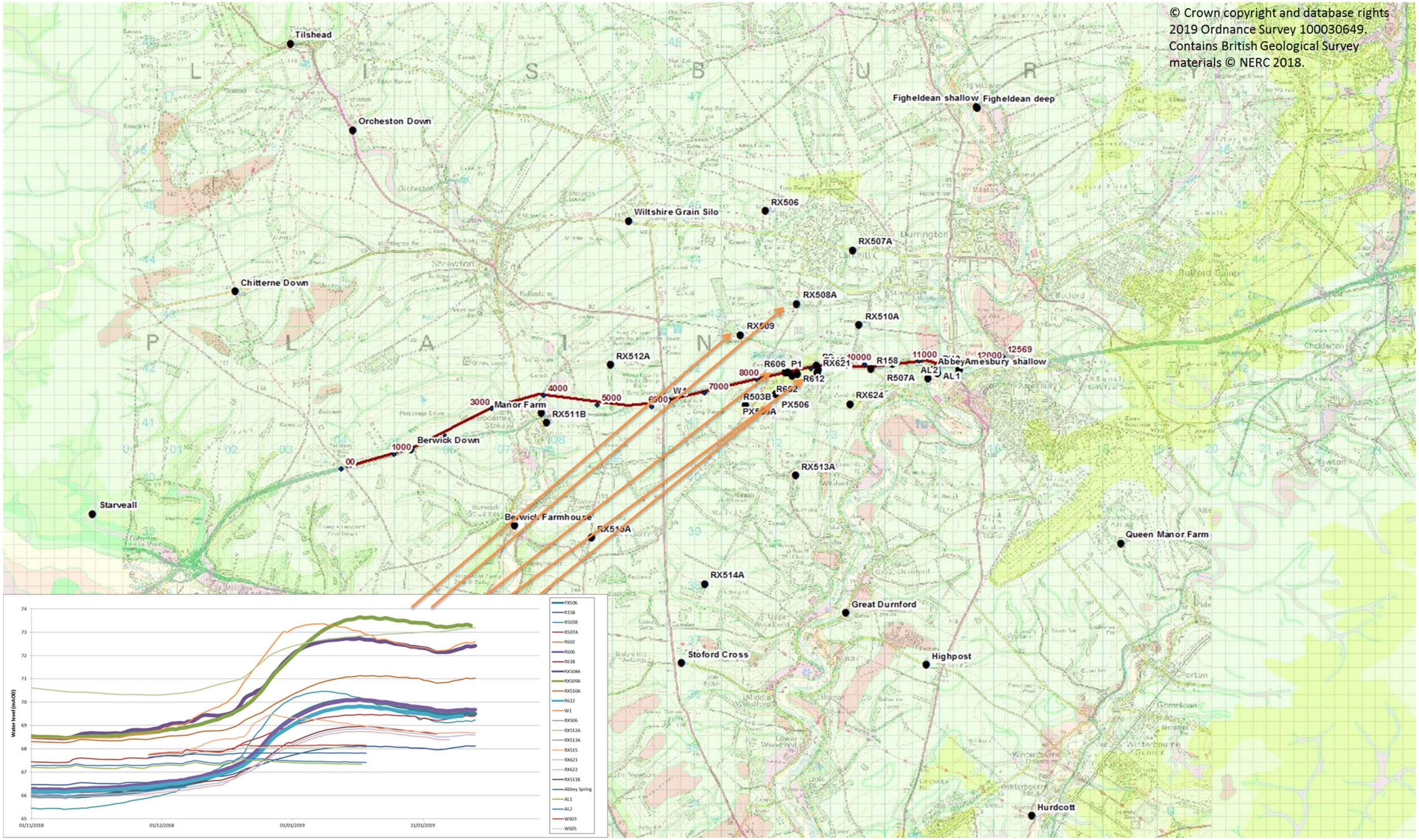
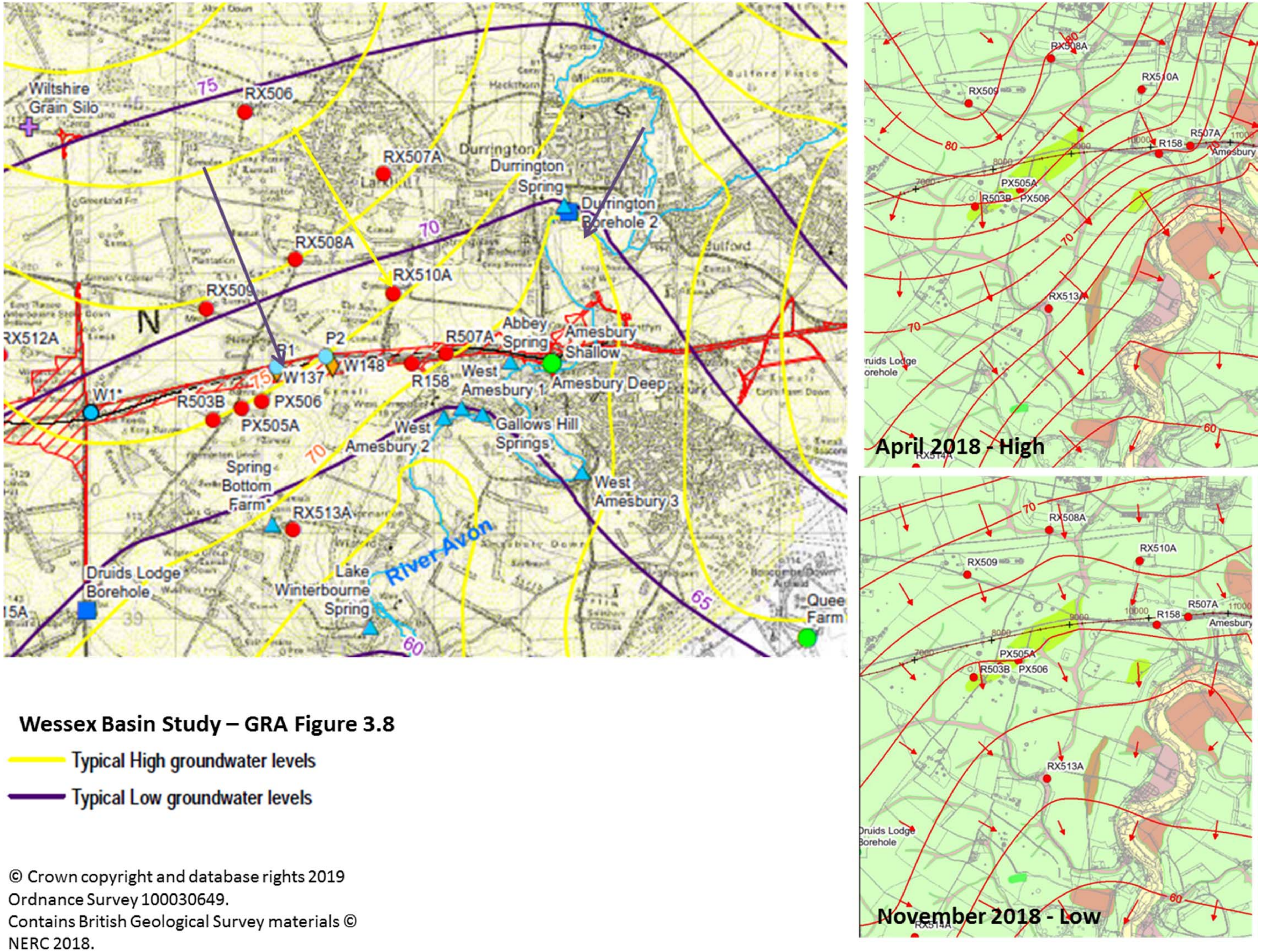


Figure A5 Comparison of groundwater flow directions from GRA and recent monitoring



Wessex Basin Study – GRA Figure 3.8

Appendix B New Groundwater Level Data and Model Calibration

Figure B1 Modelled and Observed Hydrographs from Annex 1 GRA model

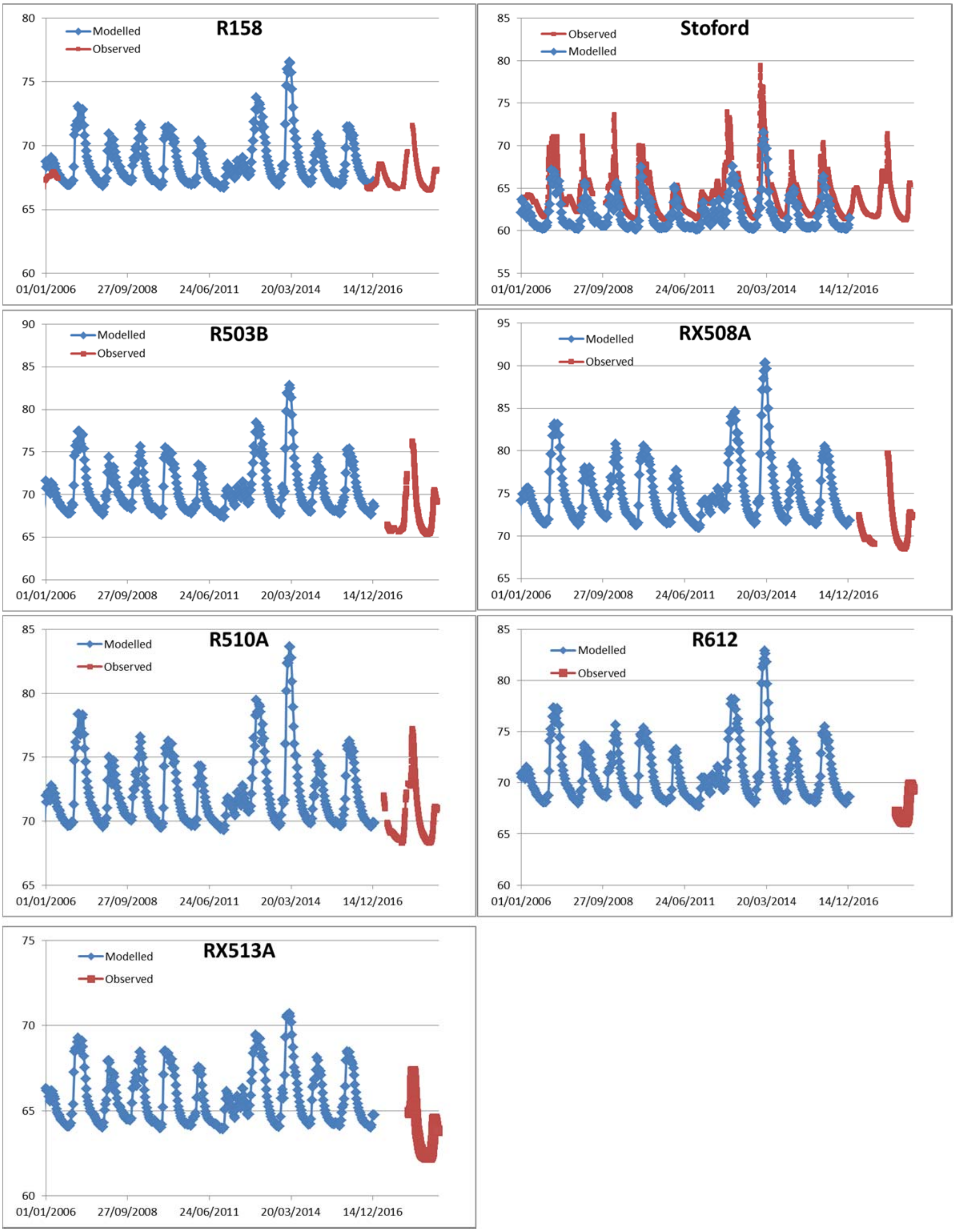


Figure B2 Modelled and Observed Hydrographs from VKD low end storage model

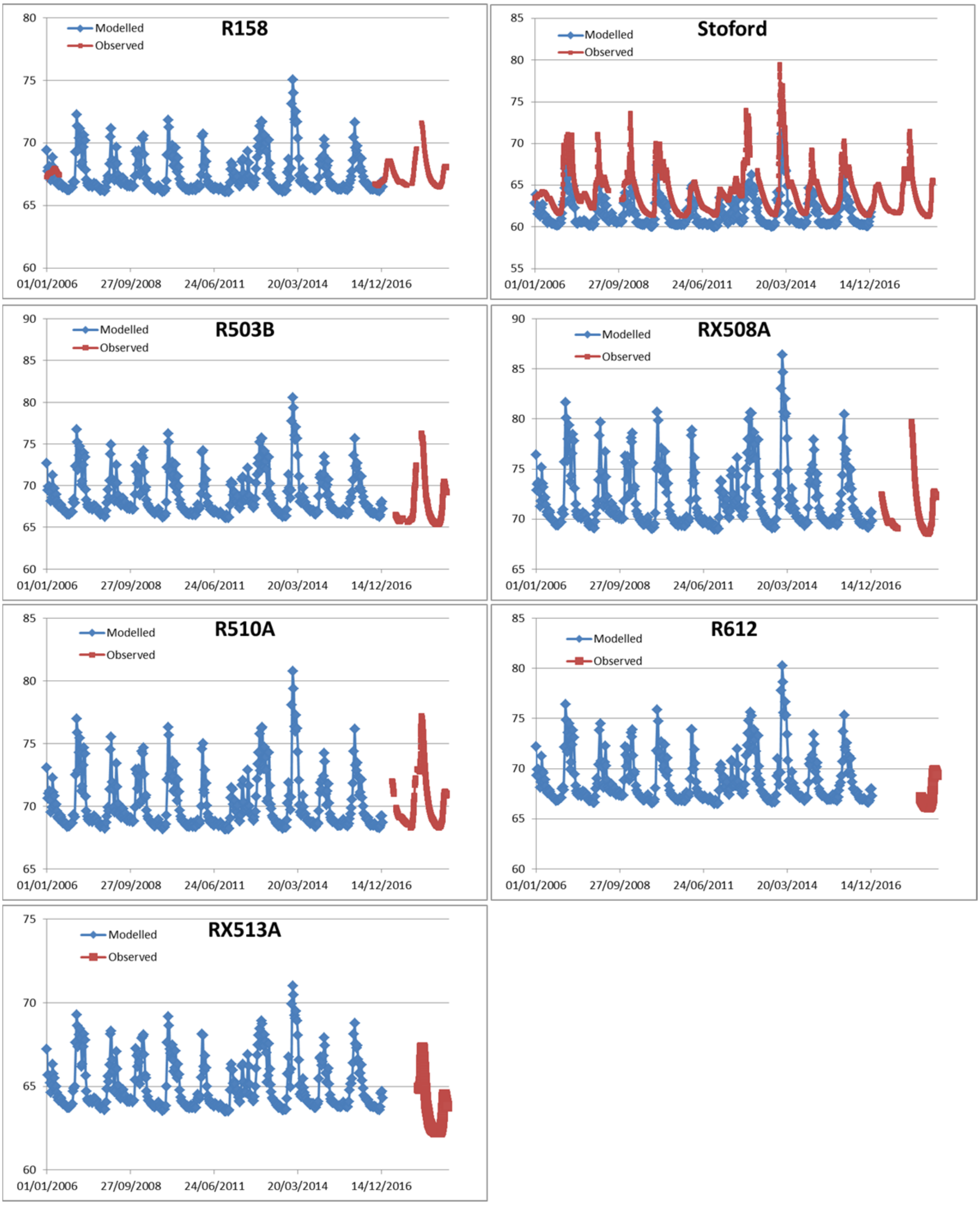


Figure B3 Modelled and Observed Hydrographs from Wessex Basin model

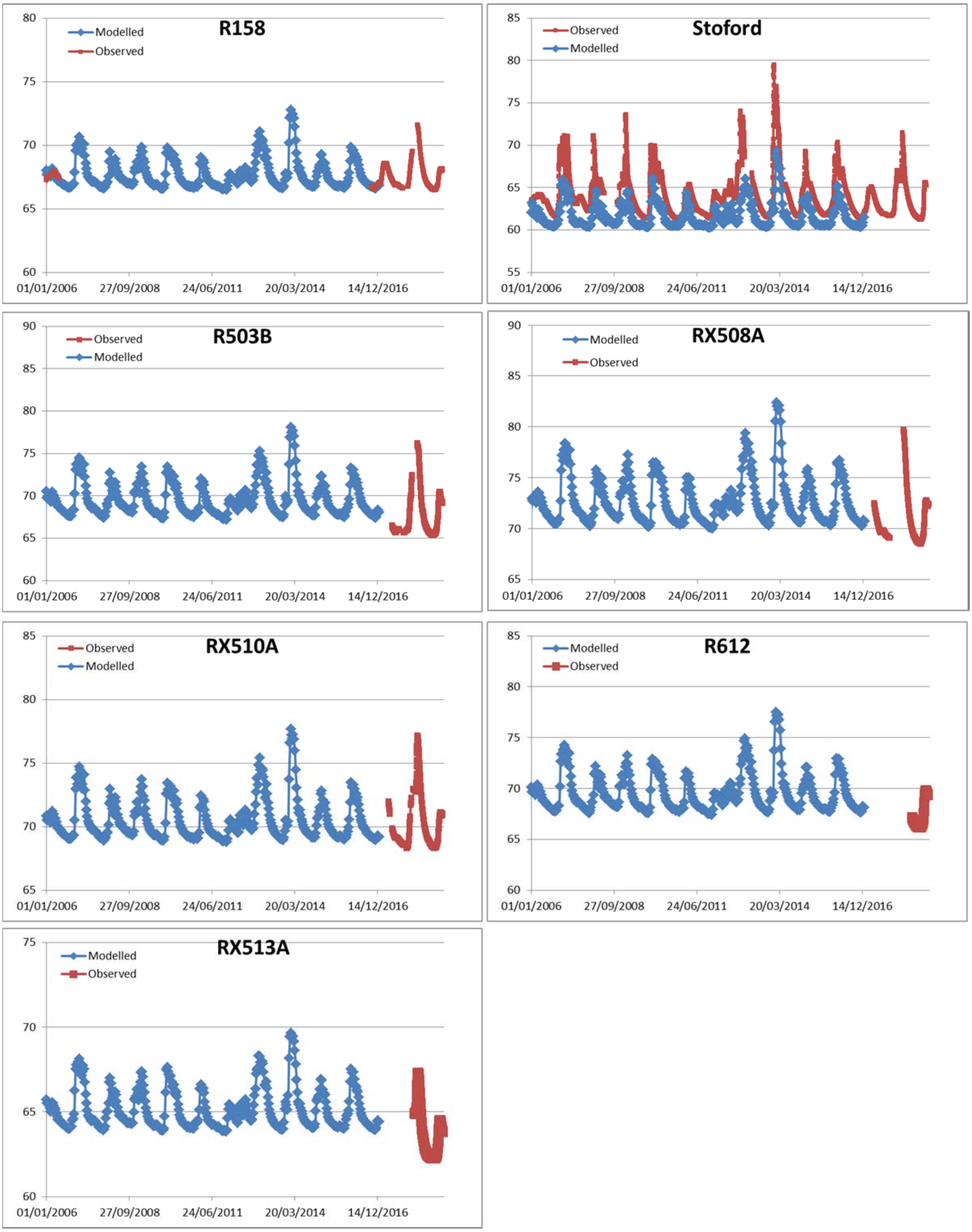


Figure B4 Combined Modelled and Observed Hydrographs from all models