3 June 2021 Reference No. 21455207-001-L-Rev0

Nicole Romanczuk
BHP Billiton Pty Ltd
Level 36, 125 St Georges Terrace
PERTH WA 6000

WESTERN RIDGE PER- AND POLYFLUOROALKYL SUBSTANCES MIXING ASSESSMENT

Dear Ms Romanczuk

1.0 INTRODUCTION

BHP Billiton Iron Ore (BHP) engaged Golder Associates Pty Ltd (Golder) to undertake a mixing assessment to evaluate potential risk of per- and polyfluoroalkyl substances (PFAS) identified at nearby Mount Whaleback mine of migrating towards the Western Ridge mine site, Western Australia (the site).

This letter outlines the findings from the modelling assessment which comprises a simple mass balance analysis to evaluate the potential concentrations of select PFAS compounds ((perfluorooctane sulfonic acid (PFOS) and the sum of PFOS and perfluorohexane sulfonic acid (PFOS+PFHxS)) in individual abstraction wells.

1.1 Site Setting

Western Ridge mine site is located near Newman, Western Australia, approximately 1,200 km northeast of Perth. The site is located west of the Mount Whaleback mine site where several areas have been identified as potentially contaminated with total recoverable hydrocarbons and PFAS. Recent groundwater sampling at Mount Whaleback (Golder, 2020b) has identified that PFOS and PFOS+PFHxS are present at concentrations above PFAS National Environmental Management Plan (NEMP) 2020 criteria (HEPA 2020).

A robust approach has been taken in an effort to evaluate the potential for dewatering at Western Ridge to cause exceedances of the ecological risk criteria. Furthermore, Western Ridge is located within a Priority 1 drinking water source area. The current mine site operational plan includes dewatering operation of the Mount Whaleback site until 2030 and that of Western Ridge until 2050.

This modelling presented in this letter focuses on PFAS impacts related to the following areas that have been delineated and characterised in accordance with the Contaminated Sites Guidelines (DWER, 2014) for detailed site investigations (Figure 1):

- WB24 and WB25 – Rail Loop Ponds (RLP)
- WB09 – Diesel pipeline leak
- WB18 – Historical Fuel Farm

- WB20 – Power Station
- WB26 – Fire Fighting Training Ground.

The Western Ridge area is located south-west of the OB35 pit and is composed of four main exploration areas: Eastern Syncline, Bill's Hill, Silver Knight and Mount Helen (Figure 1). The available information indicates that OB35 orebody and adjacent regional aquifers are connected, and that the high transmissivity of the regional aquifer likely extends west to the boundary with the Whaleback Fault (BHP, 2020). The geological conditions in the region have been described by BHP (2015, 2020) and Johnson & Wright (2001) but can be summarised as:

- The Silver Knight and Eastern Syncline are mainly hosted by the upper Marra Mamba members, however mineralisation of the overlying Wittenoom and underlying Jeerinah formations can also be seen in the orebodies.
- Bill's Hill and Mount Helen orebodies are hosted in the mineralised Brockman iron formation. The orebody aquifer is usually well delineated by the extent of the high-grade ore (assumed high permeability), with a halo of lower grade ore (assumed moderate permeability) around it.

1.2 Objective and Scope of Work

The key objectives of this stage of the modelling works are:

- Provide an assessment of the potential mixing of groundwater impacted by PFOS and PFHxS prior to abstraction (i.e., the potential mixing that will occur in situ as part of abstraction required for mining) for the following two scenarios:
  - **Scenario 1:** Assess the current proposed mine plan dewatering scenario which considers dewatering only in Western Ridge pit (Mount Helen, Eastern Syncline, Bill's Hill and Silver Knight) and OB35 pit as per the dewatering targets (i.e., OB35 ceases 2030).
  - **Scenario 2:** Assess the theoretical "worst-case" dewatering scenario, which considers dewatering only in Western Ridge pit (Mount Helen, Eastern Syncline, Bill's Hill and Silver Knight) with OB35 pit dewatering ceasing from March 2021.
- Estimate the potential volume of impacted water which may be captured by abstraction bores.
- Estimate the potential concentrations of PFOS as well PFOS+PFHxS in groundwater being abstracted from Western Ridge.

In evaluating the potential risk associated with PFAS in abstracted groundwater, the modelling results were compared to the following PFAS NEMP (2020) criteria:

- The 99% species protection for freshwater for PFOS which is 0.00023 µg/L.
- The drinking water criterion for PFOS+PFHxS which is 0.07 µg/L.

A summary of the workflow methodology developed to meet the objectives is provided below:

- **Section 2.0: Groundwater Modelling:** Review of BHP's Western Ridge groundwater model and updating the model to incorporate the hydrogeological modelling carried out for OB29, OB30, and OB35 pit operations (Golder, 2020a).

- **Section 3.0: 3-Dimensional (3-D) Contaminant Plume Development:** Development of a 3-D contaminant plume map using geostatistical kriging methodology to develop a plume distribution for PFOS and PFOS+PFHxS. The distribution is based on data collected by Golder between 2019 and 2020 (Golder, 2020b).
- **Section 4.0: Pumping Scenario Assessment**: As outlined above two pumping scenario assessments were completed. Future MODFLOW 2005 simulations were carried out to forecast groundwater flow in the region until 2050. The updated groundwater model from Section 2.0 has been used for the assessment.
- **Section 5.0: Sub-regional Water Budget Estimates**: Calculation of the volume of water arriving at abstraction bores from different regions of the groundwater model.
- **Section 6.0: Estimate of Mixing at Individual Abstraction Bores**: Calculation of the mixing factor for individual abstraction bores as a ratio of the volume of water entering the bores from contaminated zones to the total volume produced.

1.3 Modelling Assumptions

As part of these simulations the following assumptions have been made:

- The source areas concentrations are assumed to remain constant for the duration of the modelled simulation.
- The source areas identified in Section 6.1 are the only sources of PFAS considered as part of this modelling exercise. With respect to Western Ridge, this is considered to be a reasonable assumption as prior to exploration the site was undisturbed bushland.
- Other attenuation mechanisms such as degradation, sorption or diffusion have not been considered. The modelling presented herein is related solely to in-situ and ex-situ mixing affects.
- The 3-D contaminant plume has been assumed to be present within the top 10 m of the saturated zone. This assumption is discussed further in Section 3.0. Concentrations of contaminants of interest below this interval are assumed to be half the limit of reporting.
- Abstraction is distributed uniformly to the bores within each orebody throughout the dewatering schedule. No attempt to optimise the abstraction to minimise concentrations in abstracted groundwater has been made.
- Calculations completed using FlowSource assume steady state flow for each time step. To account for the transient conditions volumetric metrics have been calculated at each time-step and each stress periods as time-instant steady-state cases. Therefore, the accuracy of results during periods of changing abstraction rates may be affected and travel times to the bores are not considered.

2.0 GROUNDWATER MODELLING

2.1 BHP Model Overview

Modelling was undertaken updating and upgrading BHP's supplied regional groundwater model, which main characteristics are stated below (BHP, 2020):

- **TS_UNC_BASE:** history matching (January 2015 to March 2020) model described as the 'Base Case' model in BHP (2020), with 63 stress periods and head targets defined.
- **PR_UNC_BASE_V1:** predictive scenario (April 2020 to January 2050) for the Base Case model, with 121 stress periods and head targets defined (as analytic wells that monitor head with time).

BHP's model comprises six layers and finite difference grid, developed using the MODFLOW-Surfact code (Version 3.0), operating under the Groundwater Vistas (Version 6.96) graphical user interface. The model includes dewatering centres to create the drawdown in groundwater levels over time at various ore bodies. The groundwater model covers an active model area of 8 km (north-south) by 24 km (east-west) and has been rotated 26^{o} (clockwise).

The base of the model was set at a constant elevation of 150 m AHD, with boundary conditions assigned as follows:

- A General Head Boundary (GHB) along the eastern model boundary, set to equal the initial heads (522 m AHD). The conductance is set at a low value of 1 m^2/d.
- Drain boundary conditions are used to simulate dewatering. The drain conductance has been set to a very high value (1,000 m^2/d) to enable unlimited flow out of the model to reach target levels and unconstrained dewatering rates.
- The other model boundaries are designated as no flow.
- Initial heads are set at 522 m AHD at the start of the model (i.e., January 2015).
- Recharge is not applied to the model resulting in no hydraulic gradients present in the pre-mining scenario.

2.2 Updates to the Model

To provide consistency between this model and that used for the Whaleback modelling (Golder, 2020a), following updates have been made to the BHP model:

- A layer of low permeable clay has been added to the model in the northern part of the WB09 contaminated site (around MW107 and MW108). The feature has been extended to the east as far as WB20.
- A zone of shale has been added to the model to represent the shale and alluvium layers encountered in intrusive investigations above the dolomite near the contaminated sites WB09, WB18, and the RLP.

For the current assessment, the **PR_UNC_BASE_V1** BHP model has been used in MODFLOW 2005 using the Groundwater Vistas 8 interface. Figure A shows a plan view of Layer 1 of the groundwater model. It focuses on the area of OB29 and the RLP and shows cross-sectional view of the groundwater model in a northerly to southerly direction through the RLP and with OB29 toward the south. The different colours in the cross-section represent the different hydraulic conductivity applied to each geological unit. No changes have been made to the boundary conditions of the model.

As part of the model verification process, the updated model results have been compared to that of the same calibration targets as in the BHP model. The head predictions remain the same as that of the BHP model. The simple mass balance analysis shows that the model has an acceptable input to output discrepancy of approximately 0.005%. The vertical hydraulic gradients have also been represented well in the updated model. From now on, the modified BHP model has been referred to as the model in the report.

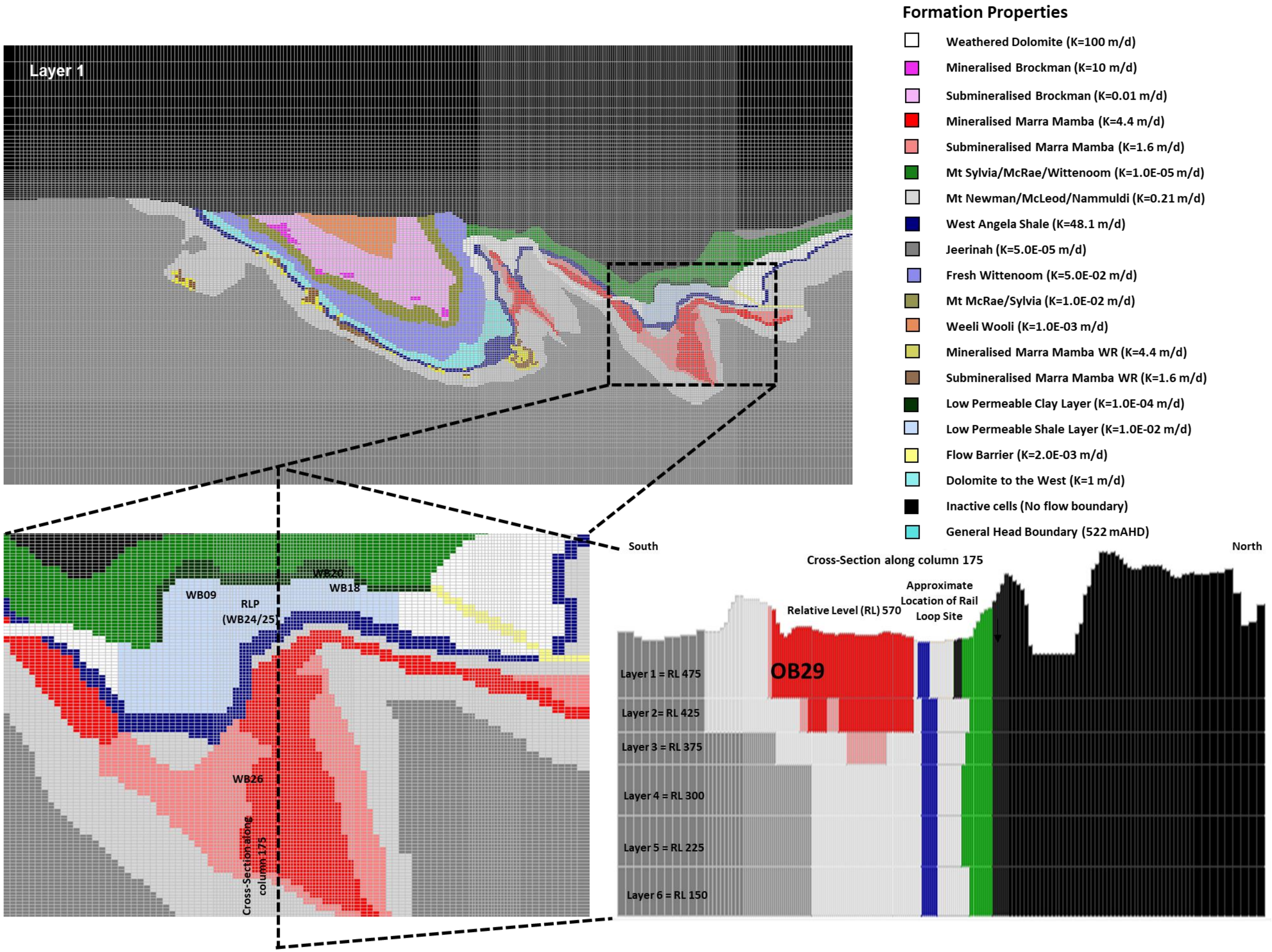


Figure A: Updated Groundwater Model

3.0 DEVELOPMENT OF 3-D CONTAMINANT PLUME

The mixing assessment requires using an interpretation of contaminant distribution in the groundwater system. The derived plume characterisation supports the calculation of concentrations at the abstraction bores as well as the calculation of mixing factors.

Data collected by Golder between 2019 and 2020 (Golder, 2020b) for PFOS and PFOS+PFHxS observed at monitoring bores at Mount Whaleback has been used to develop the 3-D contaminant plume or “map”. The available PFAS information outside of the main source areas at OB29 is limited. Recent limited baseline sampling at Western Ridge (Golder, 2021a, b and c) identified some PFAS detections, but concentrations of PFOS and PFHxS were below the LOR. It has been hypothesised that the PFAS detections are related to cross contamination due to groundwater well construction/activities and may not be representative of groundwater conditions in the wider area. Therefore, in this area and where no information is available, it has been assumed that concentrations of PFOS and PFHxS are half of the limit of reporting (LOR). If other sources do exist in the area, then the results from this assessment may underestimate the concentration at abstraction wells. The map overlying the model grid and the contaminant distribution in the well locations are shown in Figure 2.

Wells with PFOS and PFOS+PFHxS concentrations below the LOR of <0.0002 µg/L were assigned a concentration of 0.0001 µg/L, i.e., half the LOR in the respective 3-D plume map development. This approach assigns a minimum of half the LOR to ensure the calculations result in a conservative approach which likely overestimates the background contamination at the site.

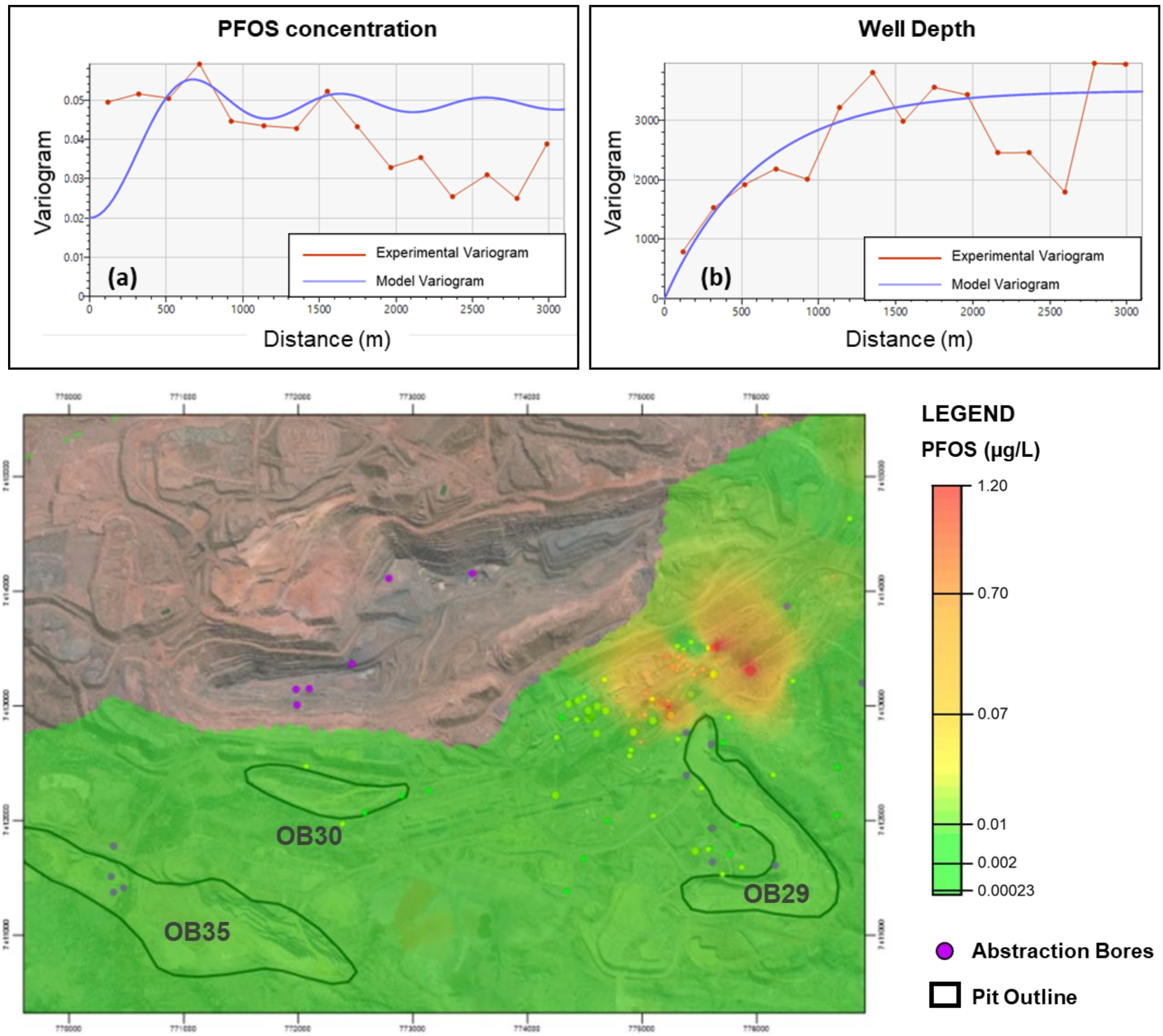
The statistical analyses of the PFOS and PFOS+PFHxS concentrations were performed using kriging and cokriging methods to determine the best fit contaminant distribution to the monitoring data. Using the kriging method, the full dataset was used to create interpolation maps describing the primary variables, PFOS and PFOS+PFHxS concentration. Cokriging was then used to evaluate the contribution of well depth as covariate when estimating the spatial distribution of both PFOS and PFOS+PFHxS concentrations. The experimental variograms were calculated for both the cokriging variables and then model variograms were inferred. Details on the fitted model variograms for PFOS, PFOS+PFHxS concentrations and well depths are listed in Table 1.

Figure B and Figure C illustrates experimental and model variograms for plume development with PFOS and well depths and PFOS+PFHxS and well depths, respectively. Cokriging model accuracy was determined by the mean standardised error (ME) and the root mean square error (RMSE). RMSE indicates how closely your model predicts the measured values. The smaller this error, the better. ME indicates the average of the standardised errors. This value should be close to 0. The model variogram using PFOS concentrations (Figure B) as primary variable produced a ME value centred around 0 (ME = 0.00024) and a low RMSE value (0.0014). The model variogram was then used to estimate PFOS concentrations (in µg/L) of the kriged surface (Figure B). The model variogram using PFOS+PFHxS concentrations illustrated in Figure C produced a ME value centred around 0 (ME = 0.00021) and a low RMSE value (0.0013). The model variogram was then used to estimate PFOS+PFHxS concentrations (in µg/L) of the kriged surface (Figure C). The PFOS and PFOS+PFHxS concentrations were allowed to vary between half of the LOR to the maximum observed PFOS and PFOS+PFHxS concentrations from the groundwater sampling.

The PFOS and PFOS+PFHxS plume maps were produced representing plume thicknesses of 10 m, which was verified as part of the Mt Whaleback Stage 5 modelling works (Golder, 2020c). The 3-D plume maps were developed on a grid with the lateral refinement (XY direction) same as that of the groundwater flow model and a vertical cross-section of 10 m thickness with a 5 m vertical grid refinement.

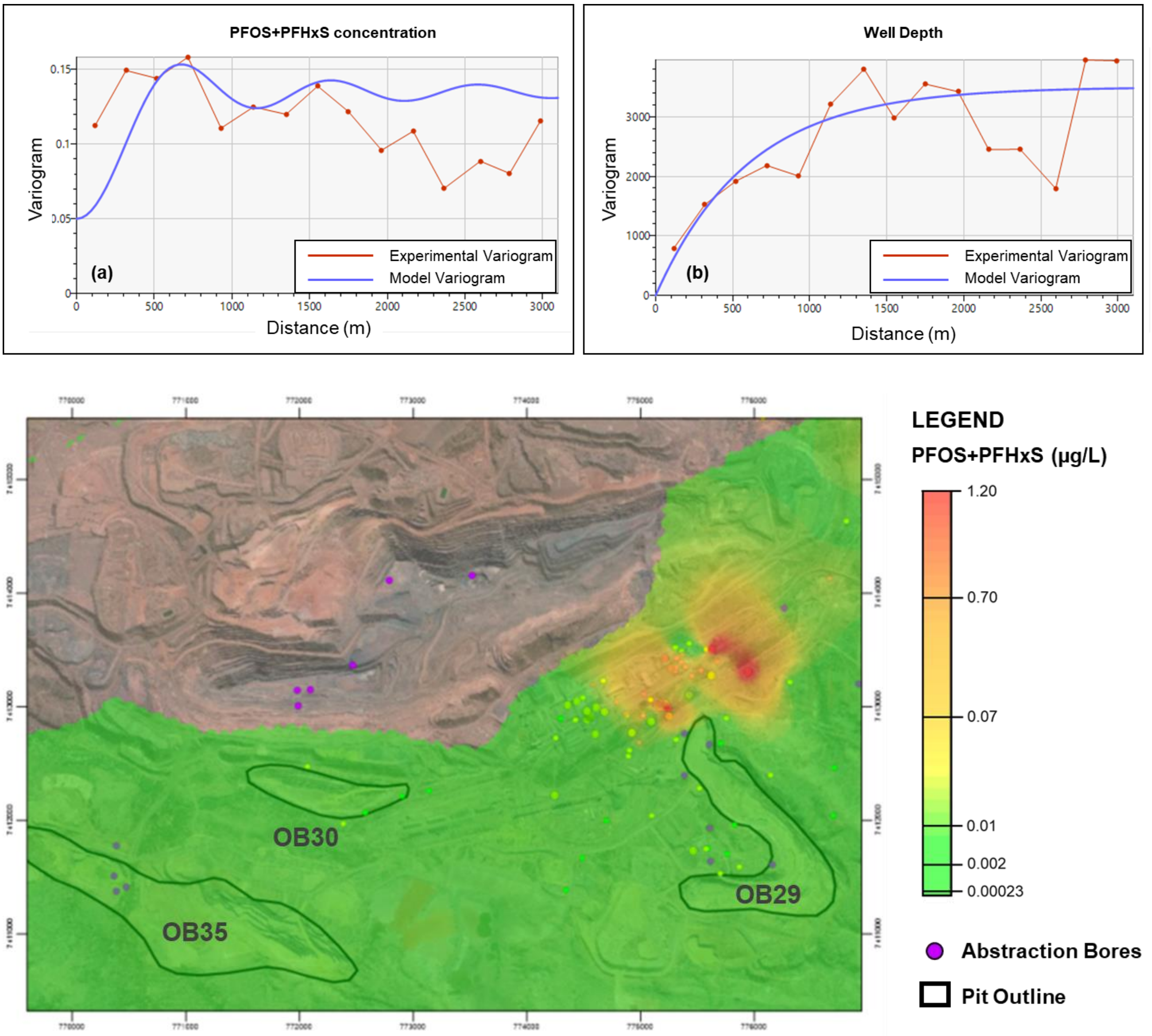
Table 1: Model variograms used for statistical distribution of variables PPFOS, FOS+PFHxS and well depth

Variable	Variogram Structure	Nugget	Sill	Correlation Length (m)
PFOS concentrations	Hole Effect	0.02	0.029	150
PFOS+PFHxS concentrations	Hole Effect	0.05	0.085	150
Well Depths	Exponential	0	3500	400



(c)

Figure B: Experimental and model variograms of (a) PFOS concentrations (µg/L) and (b) well depths and; (c) cokriging surface of PFOS concentration (µg/L)



(c)

Figure C: Experimental and model variograms of (a) PFOS+PFHxS concentrations (μg/L) and (b) well depths and; (c) cokriging surfaces of PFOS+PFHxS concentration (μg/L) and covariate well depths

4.0 ASSESSMENT OF PUMPING SCENARIOS

Two different proposed dewatering scenarios have been used for the predictive modelling in this report.

Scenario 1: Is based on the 2020 BHP hydrogeological model (BHP, 2020), which reflects BHP's planned dewatering strategy in 2020 for Western Ridge and OB35 pit until 2050. Dewatering has only been considered in Western Ridge pit (Mount Helen, Eastern Syncline, Bill's Hill and Silver Knight) and OB35 pit as per the dewatering targets (Figure D). As per the current plan, dewatering in OB35 ceases in 2030. No OB29 and OB30 dewatering has been considered. The cumulative abstraction volume for the Western Ridge and OB35 pits between 2020 and 2050 for Scenario 1 is presented in Figure E. It should be noted that OB35 reaches a maximum dewatering rate of 23 ML/d in 2023 and the rates have been calculated in such a way that the water level at OB35 gradually reaches 440 m RL at 2030 (i.e., the end of OB35 dewatering plan).

Scenario 2: Golder also assessed an alternative theoretical mining dewatering plan where the dewatering in OB35 pit ceases from March 2021 while that for the Western Ridge remains as per Scenario 1. This represents a “worst-case” scenario to account for possible future dewatering strategies which may have a higher influence on contaminant occurrence at the dewatering bores. The cumulative abstraction volume for the Western Ridge and OB35 pits between 2020 and 2050 is in Figure F.

Individual abstraction wells within each pit were assumed to abstract equal volumes throughout the dewatering schedule. The locations of the Western Ridge and OB35 abstraction wells are shown in Figure G. For OB35 pit, six existing abstraction wells (HEK0001P through HEK0006P) were used for the dewatering however for Western Ridge, hypothetical well locations have been used.

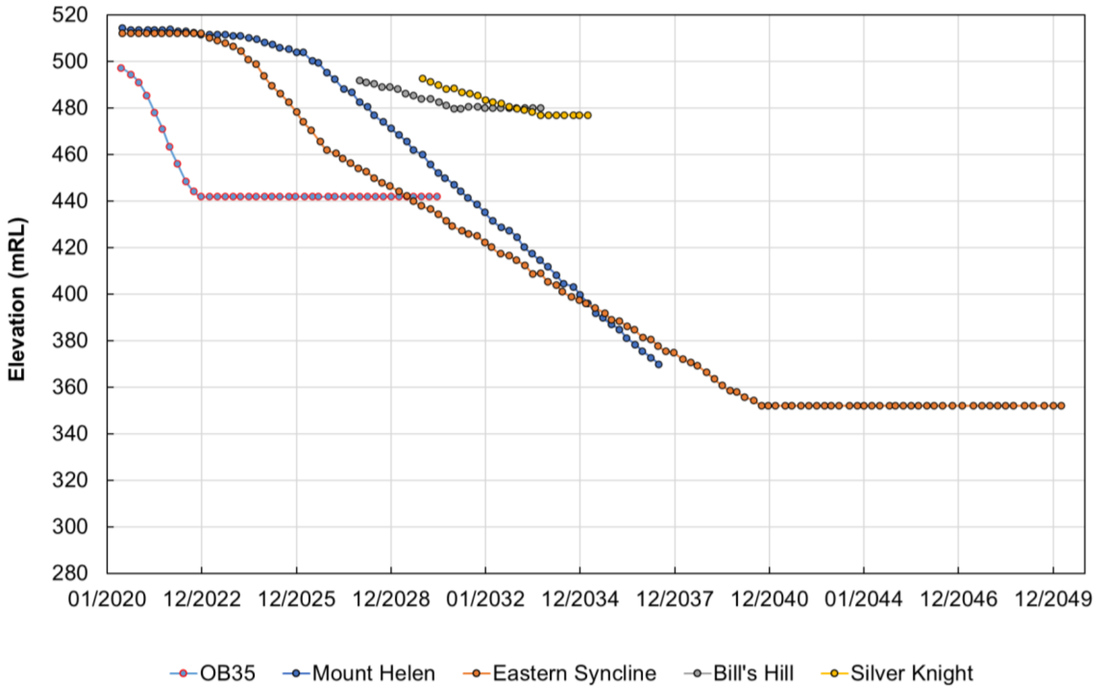


Figure D: BHP Dewatering Plan

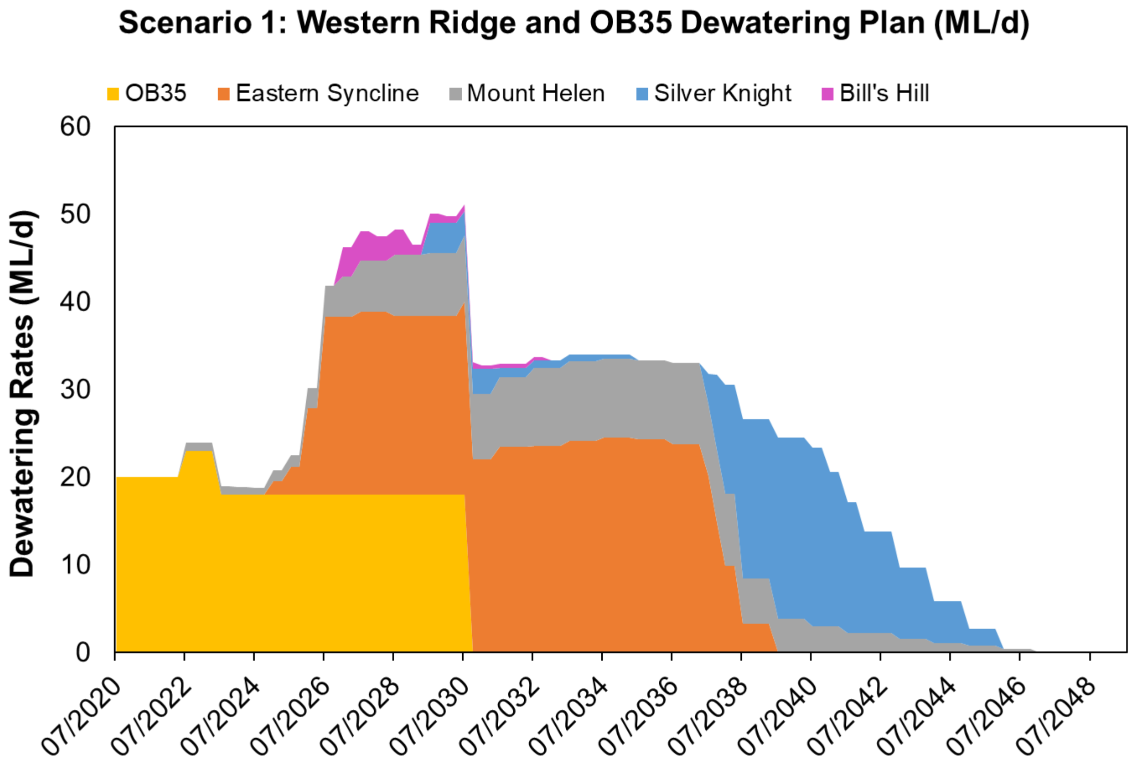


Figure E: Scenario 1 Mine Dewatering Rates

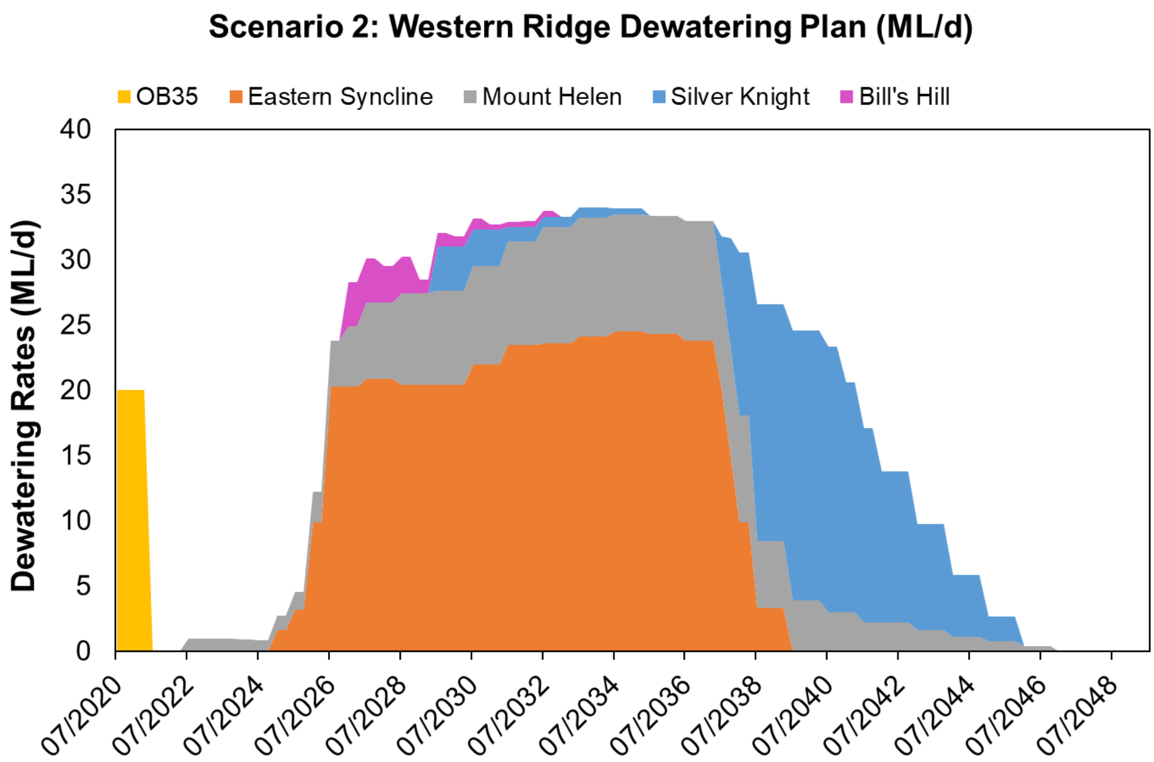


Figure F: Scenario 2 Mine Dewatering Rates

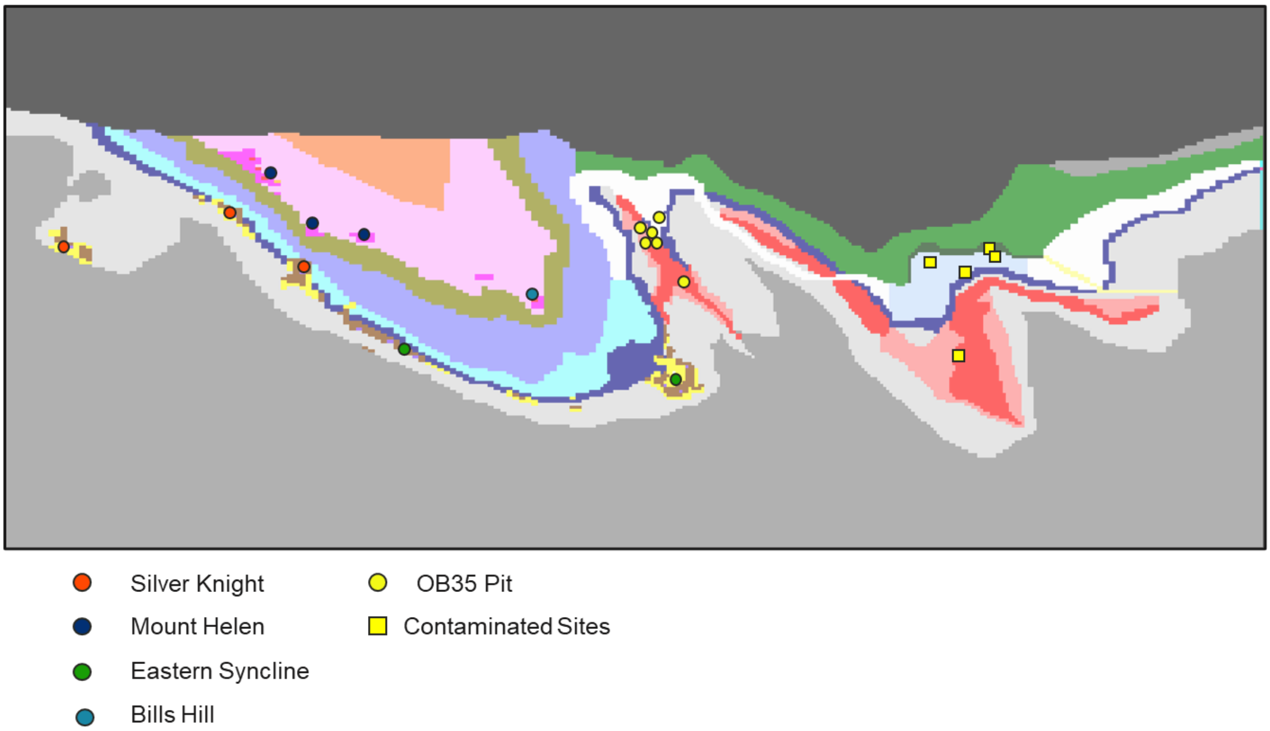


Figure G: Western Ridge and OB35 pit abstraction well locations in relation to contaminated sites

5.0 ESTIMATION OF SUB-REGIONAL WATER BUDGETS

5.1 FlowSource

FlowSource (Black and Foley, 2013) is a post-processing utility which analyses groundwater flow fields computed by MODFLOW groundwater models. FlowSource can volumetrically delineate steady-state and quasi-steady-state capture zones. FlowSource takes MODFLOW drawdown, discretisation and cell-by-cell files as inputs and then uses directed acyclic graphs (DAGs) to represent the groundwater flow path information but does not account for the travel time along the path. This enables estimation of the volume of groundwater that may ultimately reach a predefined 'destination' originating from each groundwater model cell. The 'destination' can be a single cell, or a group of cells and the cells need not be adjacent to one another.

For a specific "destination" model cell, FlowSource can be set up to calculate:

- Capture Fraction: The fraction of the flow through each model cell that will reach the destination cell.
- Volume From: The volume of water originating in each model cell that will reach the destination cell.

Numerous other metrics can be calculated, but the two described above are considered to be the most applicable in this assessment. FlowSource has been widely used globally by industry, consultants, and regulators for a variety of purposes such as well head protection, pump and treat optimisation and transient capture zone analysis (Black and Foley, 2013).

5.2 Analysis

FlowSource was applied to the cell-by-cell flows calculated by the groundwater model for both dewatering scenarios. The abstraction wells in the groundwater model were assigned pumping rates as described in Section 4.0. The dewatering rates applied to the model were checked against the water budget estimates from FlowSource analysis and the total water planned (as per Figure E and Figure F) is abstracted from the dewatering system. The abstraction wells were used as “destination” cells to calculate the Capture Fraction and Volume From parameters from the 2020 to 2050 model prediction period.

The Capture Fraction and Volume From estimates were calculated for the abstraction wells in Western Ridge and OB35 pit. For Scenario 1, four Western Ridge pit wells (Figure H and Figure I) and two OB35 pit wells HEK0002P and HEK0004P (Figure J) are shown as examples. For Scenario 2, only the Western Ridge pit wells are shown as examples (Figure K and Figure L) as OB35 is not operational.

FlowSource estimates the flow patterns for the entire groundwater model grid (including all layers). The example maps are shown for the top model layer. The “Volume From” maps for the top model layer indicate that for the given time instances, water reaching the abstraction wells from the model cells close to the wells are from deeper layers in the model indicating the successful dewatering operations near the well. Cells more distant from the pumping bores, but in the top model layer are not completely dewatered, but still contribute to the abstracted volume.

The FlowSource results indicate no flow to the HEK0002P (OB35) abstraction well from the north-east part of the model (near the contaminated sites) while HEK0004P (OB35) abstracts water from this region after a few years of pumping (Figure J). For Scenario 1, FlowSource results indicate that the Western Ridge wells do not capture water from the contaminated areas (Figure H and Figure I) while for Scenario 2, abstraction well at Eastern Syncline captures water from the contaminated region after few years of pumping (Figure K).

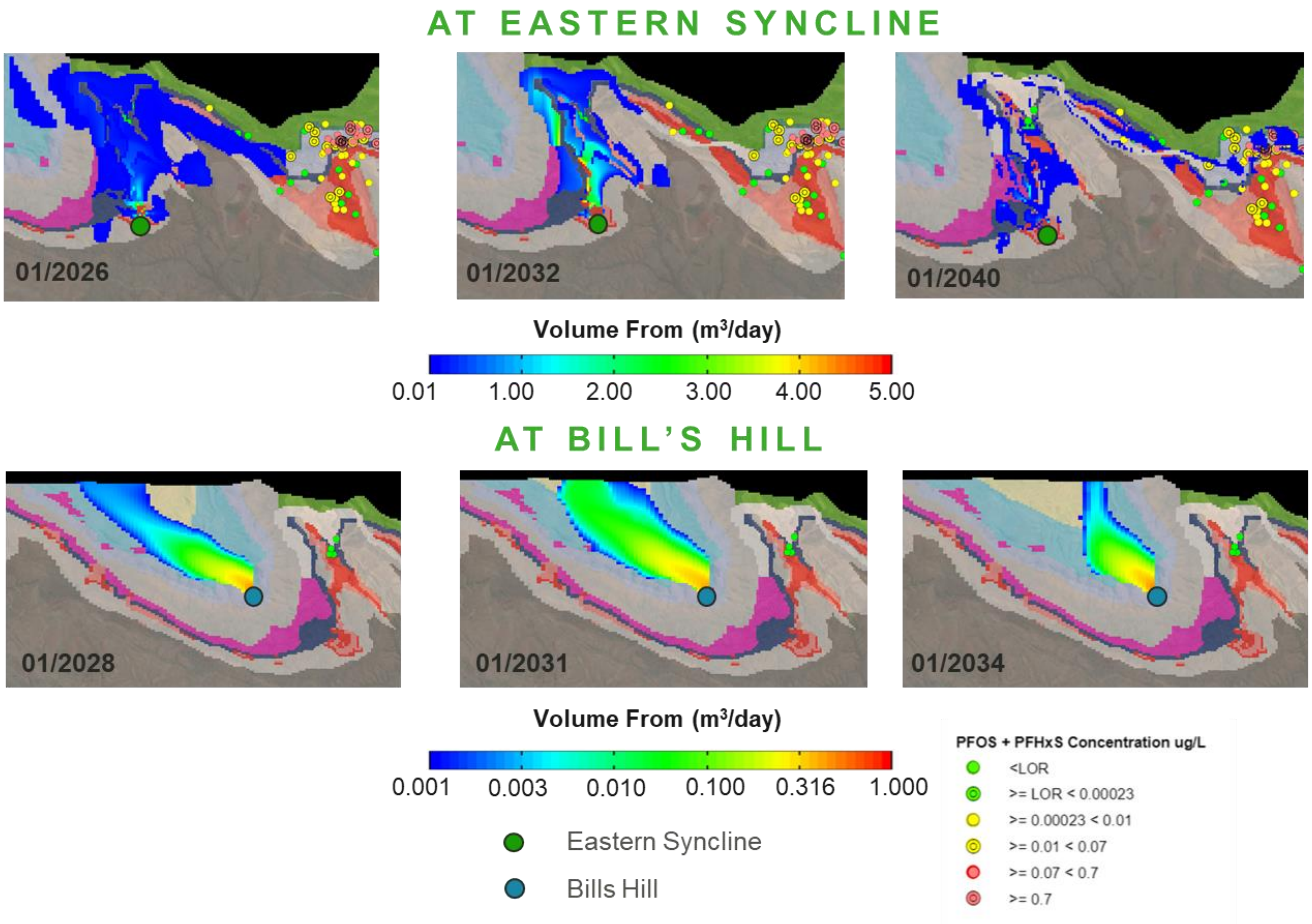


Figure H: Volume From estimates in layer 1 of the model with dewatering Scenario 1 for Western Ridge wells at Eastern Syncline (top) and Bill's Hill (bottom)

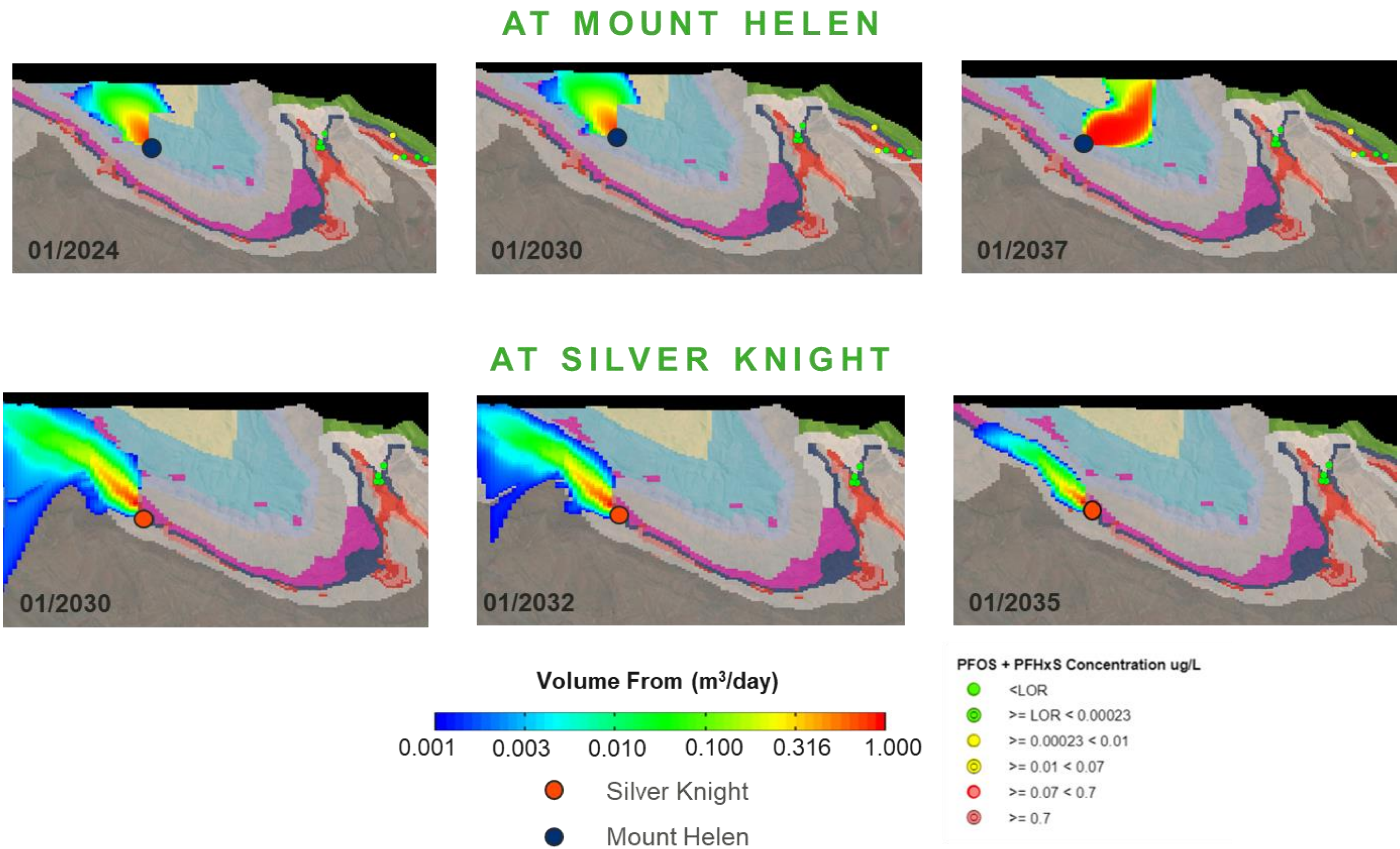


Figure I: Volume From estimates in layer 1 of the model with dewatering Scenario 1 for Western Ridge wells at Mount Helen (top) and Silver Knight (bottom)

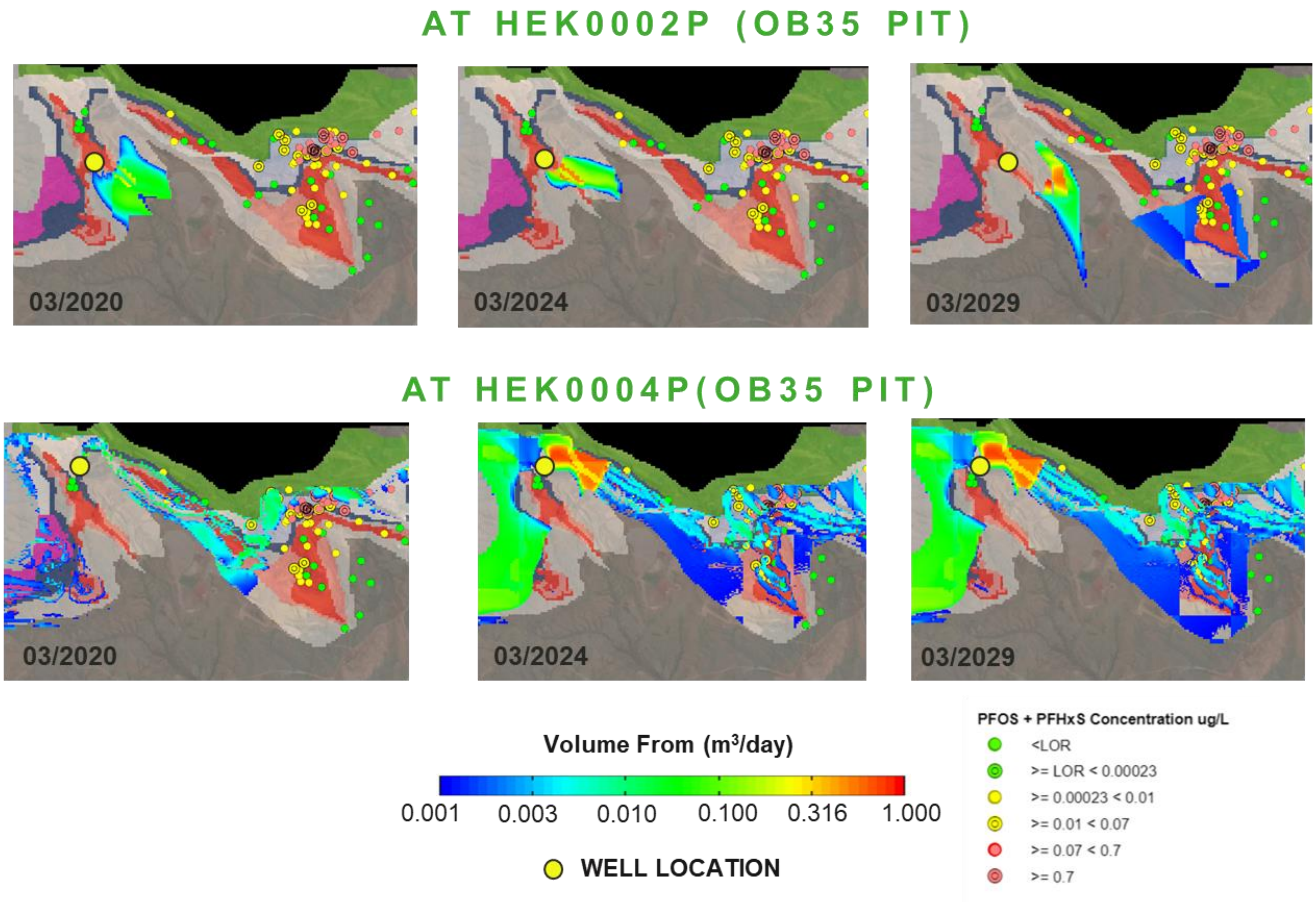


Figure J: Volume From estimates in layer 1 of the model with dewatering Scenario 1 for OB35 wells HEK0002P (top) and HEK0004P (bottom)

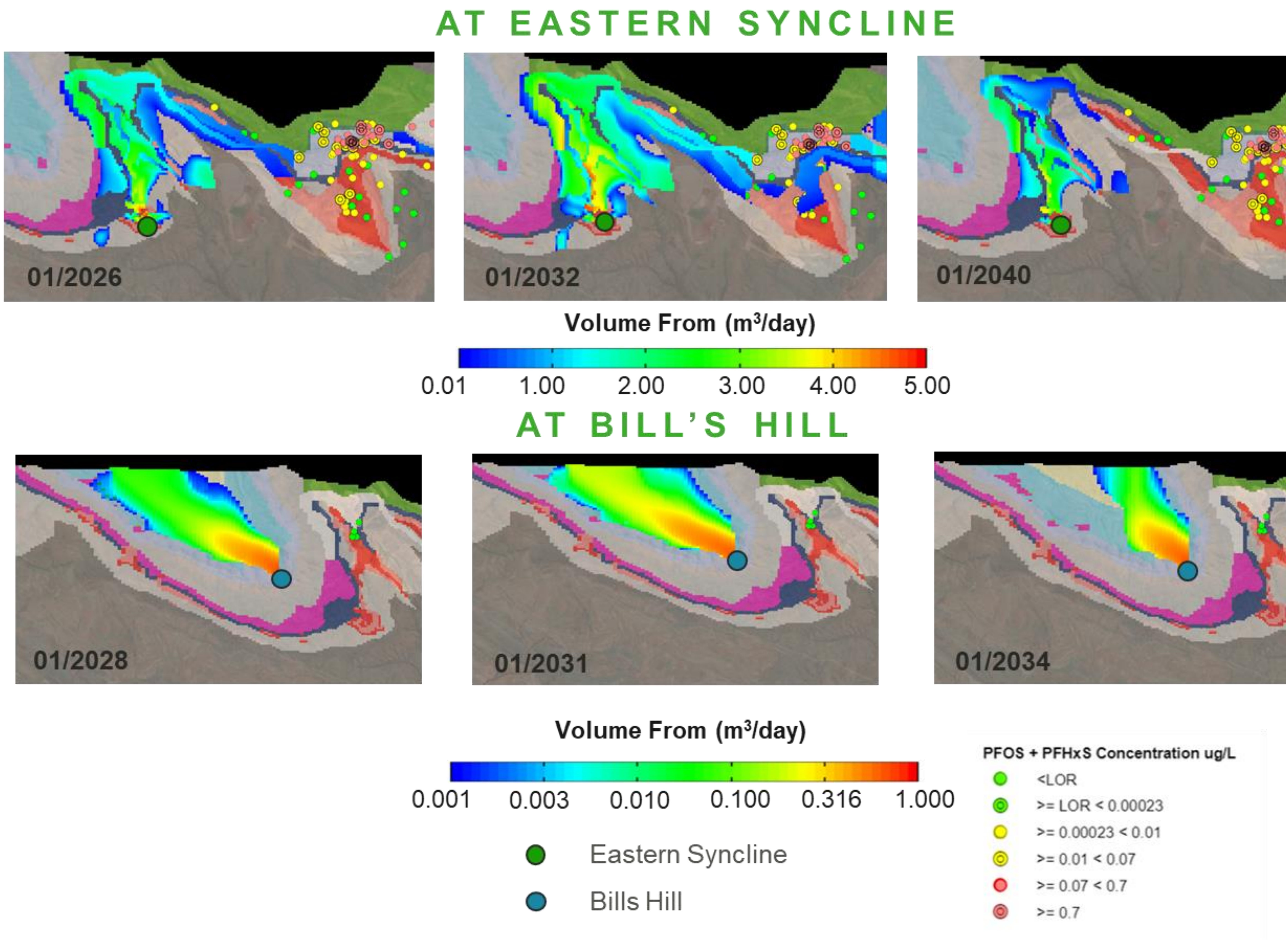


Figure K: Volume From estimates in layer 1 of the model with dewatering Scenario 2 for Western Ridge wells at Eastern Syncline (top) and Bill's Hill (bottom)

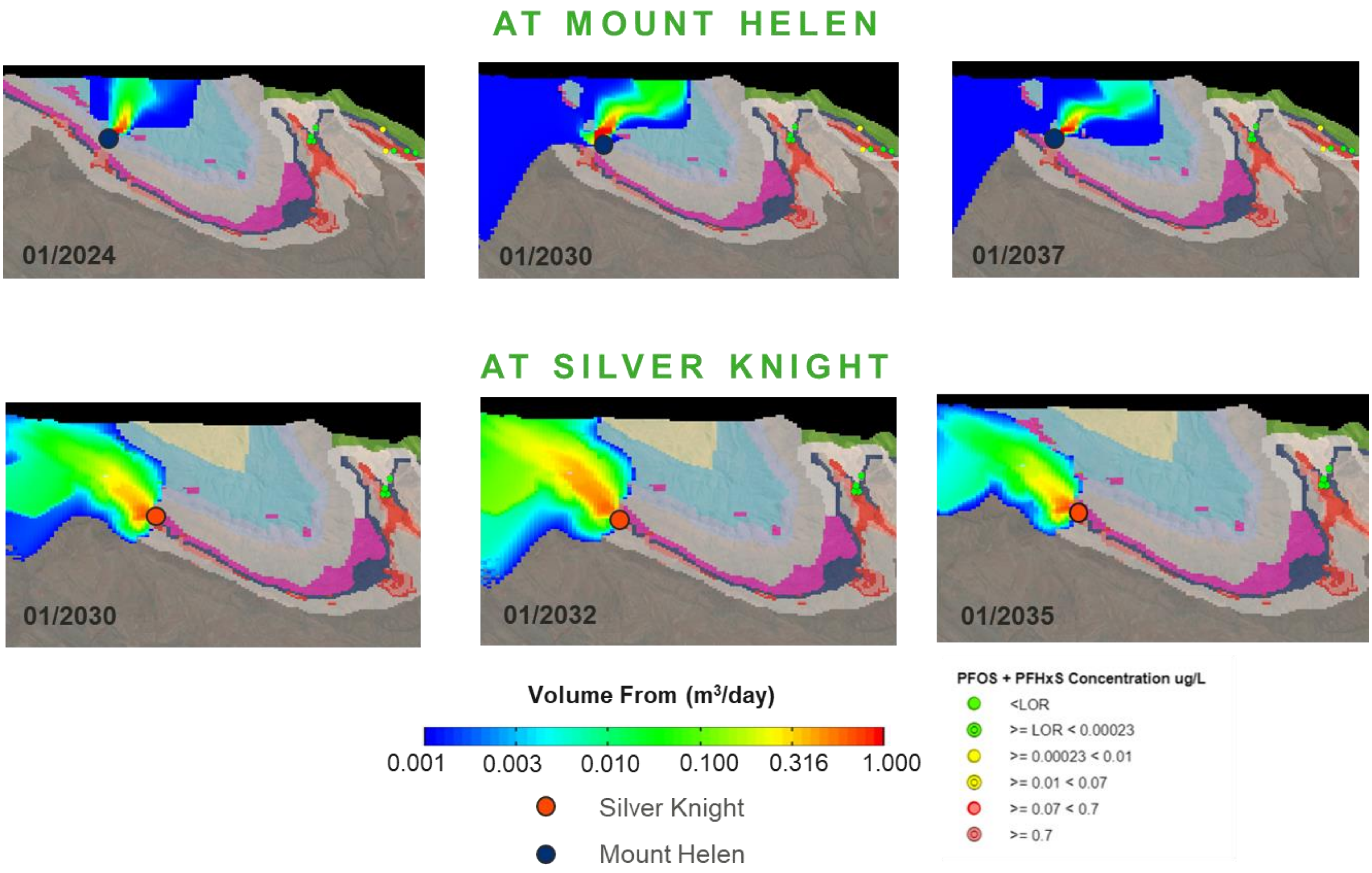


Figure L: Volume From estimates in layer 1 of the model with dewatering Scenario 2 for Western Ridge wells at Mount Helen (top) and Silver Knight (bottom)

6.0 MIXING ESTIMATION RESULTS

The results from the modelled dewatering scenarios are presented in the subsequent sections.

6.1 Estimated Concentration at Individual Abstraction Wells

A mixing factor which is defined as the ratio of the volume of water reaching the abstraction well from a contaminated region to that of the total volume of water being abstracted by the well (Figure M), was calculated for each individual abstraction well. It is important to estimate mixing because it provides critical information about the fluid dynamics within the groundwater system and shows how much the source has been mixed prior to reaching the abstraction well.

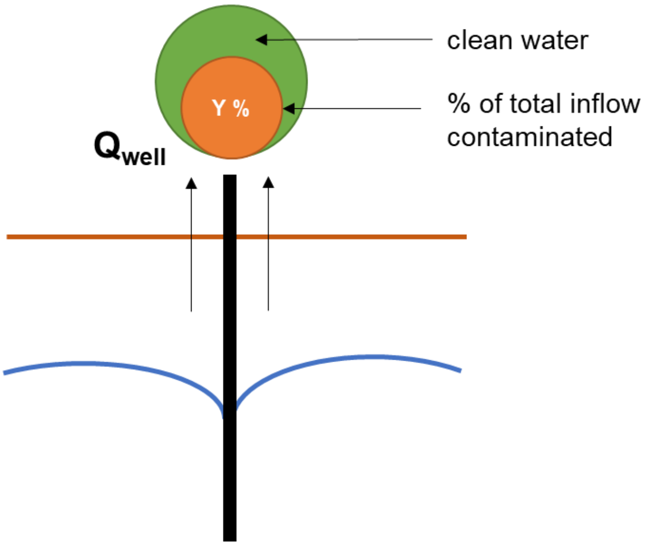


Figure M: Mixing Model

Assuming no mixing or degradation of contaminants, the concentration of contaminants at each abstraction well (C_{bore}) can be calculated as:

$$C_{bore} = \frac{Q_{well}\frac{Y}{100}C_{observed} + Q_{well}(1-\frac{Y}{100})C_{clean}}{Q_{well}}$$

where,

Q_{well} = Abstraction rate at well [L^3T^{-1}] (when there is no abstraction, Q_{well} assumes unit value)

Y = "Mixing Factor" which is the volumetric fraction of total inflow which is contaminated [-]

$C_{observed}$ = Observed or predicted concentration at the abstraction well [ML^{-3}]

C_{clean} = Lowest detection limit, in this instance half the LOR [ML^{-3}]

Using this concept, the individual abstraction well assessment was carried out using the following approach for both scenarios:

1) A representative concentration for each cell in the model was determined based on the 3-D kriged contamination plume map.

2) The volume of each model cell was determined from the grid.

3) For each model cell, the Volume From data from the FlowSource output was computed. A database was created for FlowSource outputs.

4) Mixing calculations were performed based on a source release mechanism that assumes the plume is depleted in areas away from known source areas. The areas of the model defined as source areas is presented in Figure N. The mixing calculations included the following:

   a) For plume areas not in the source zone, the cumulative Volume From, from step (3) was compared to the total volume of the cell from step (2) for each time step.

   b) For cumulative Volume From less than the total volume of the model cell, the mixing calculation was completed as in step 4a.

   c) For cumulative Volume From for a model cell greater than the total model cell volume, the concentration of contaminant in the model cell was assumed to be depleted and assigned a value of 0.0001 µg/L (half the LOR).

   d) For the plume areas designated as source zones (cells in known contaminated sites RLP, WB09, WB18, WB20 and WB26 where concentrations of PFOS and PFHxS have been observed in Golder's recent groundwater sampling), the concentrations were assumed to remain constant over time.

   e) The total of the mass of contamination from all cells was then calculated by multiplying the concentration with the Volume Flow derived from the FlowSource simulation.

   f) The total of the Volume From coming from model cells where the contaminant concentration is >0.0002 µg/L is considered to be the volume of water reaching the abstraction bores from contaminated region. This is then divided by the actual abstraction at the bores to calculate the mixing factor.

   g) The total the mass of contaminant from all cells is then divided by the actual abstraction at the bores to compute the concentration of the contaminant at the bore.

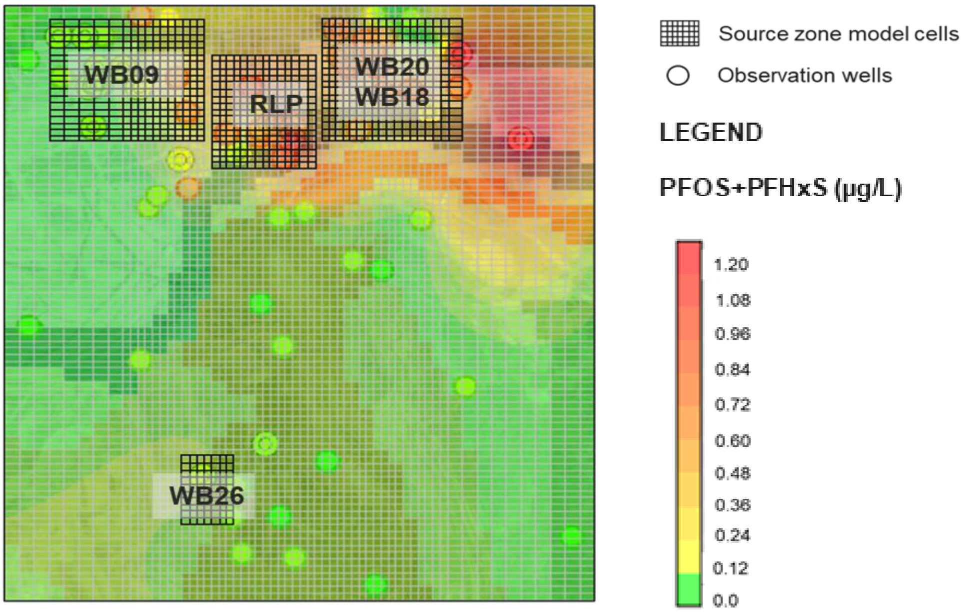


Figure N: Source Area Locations

6.2 Scenario 1

The mixing estimation was carried out using two plume maps: PFOS+PFHxS and PFOS. In the source release mechanism presented here, the initial plume observed in 2020 is assumed to deplete over time according to the mass removed during abstraction based on the mixing calculations. The source areas are assumed to remain constant for the duration of the modelled simulation. The mixing factor (Y) and the PFOS+PFHxS and PFOS concentrations at each Western Ridge and OB35 abstraction wells were calculated over the pumping period of 2020 to 2050 using the proposed dewatering plan (Scenario 1).

The time-series plots of the mixing factor and concentrations for Western Ridge wells and OB35 wells are presented in Figure O and Figure P, respectively. The initial plume is assigned to the model at the beginning of July 2020 and then the plume starts depleting. The observed PFOS+PFHxS and PFOS concentrations from the groundwater monitoring rounds at the abstraction bores HEK0003P, HEK0004P, HEK0005P, and HEK0006P were below the LOR (0.0002 µg/L) and are also shown on Figure P.

FlowSource estimates that the wells HEK0004P and HEK0006P capture a small fraction of water from the contaminant source areas. This leads to an increase in modelled concentration of PFOS+PFHxS and PFOS in these abstraction bores to approximately 0.0002 µg/L. As most of the volume of water abstracted from these wells is from the outside of the source area which results in the concentrations remaining below the 99% species protection criterion (0.00023 µg/L). This modelled value is equivalent to the LOR and therefore may not be detected in field samples.

The regulatory screening values for the 99% species protection criterion (0.00023 µg/L) and drinking water guideline (0.07 µg/L) (HEPA, 2020) are also presented in the plots. For the proposed dewatering plan, the concentrations in the Western Ridge as well as the OB35 wells remain below the 99% species protection criterion over the entire dewatering plan (Figure O and Figure P).

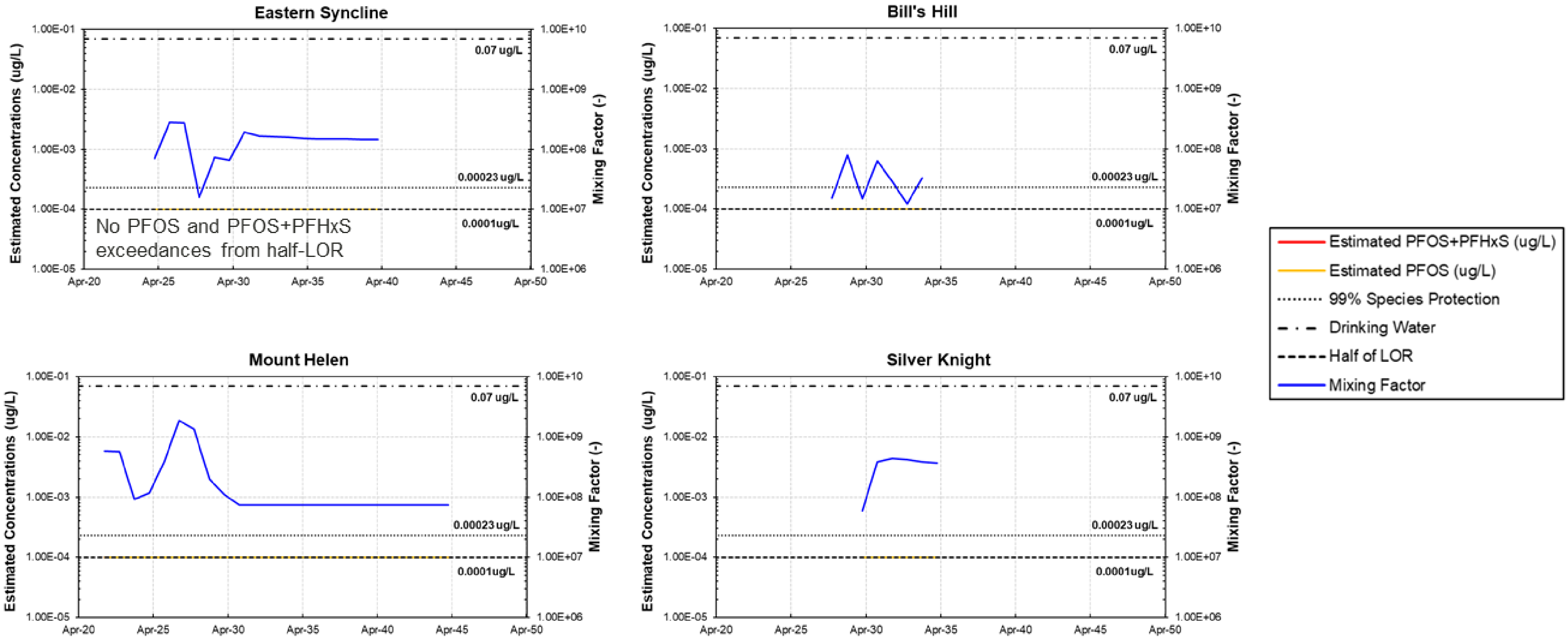


Figure O: Mixing factor, PFOS+PFHxS and PFOS concentration estimates at Western Ridge abstraction wells (at Eastern Syncline, Bill's Hill, Mount Helen and Silver Knight) from 2020 to 2050 for dewatering Scenario 1

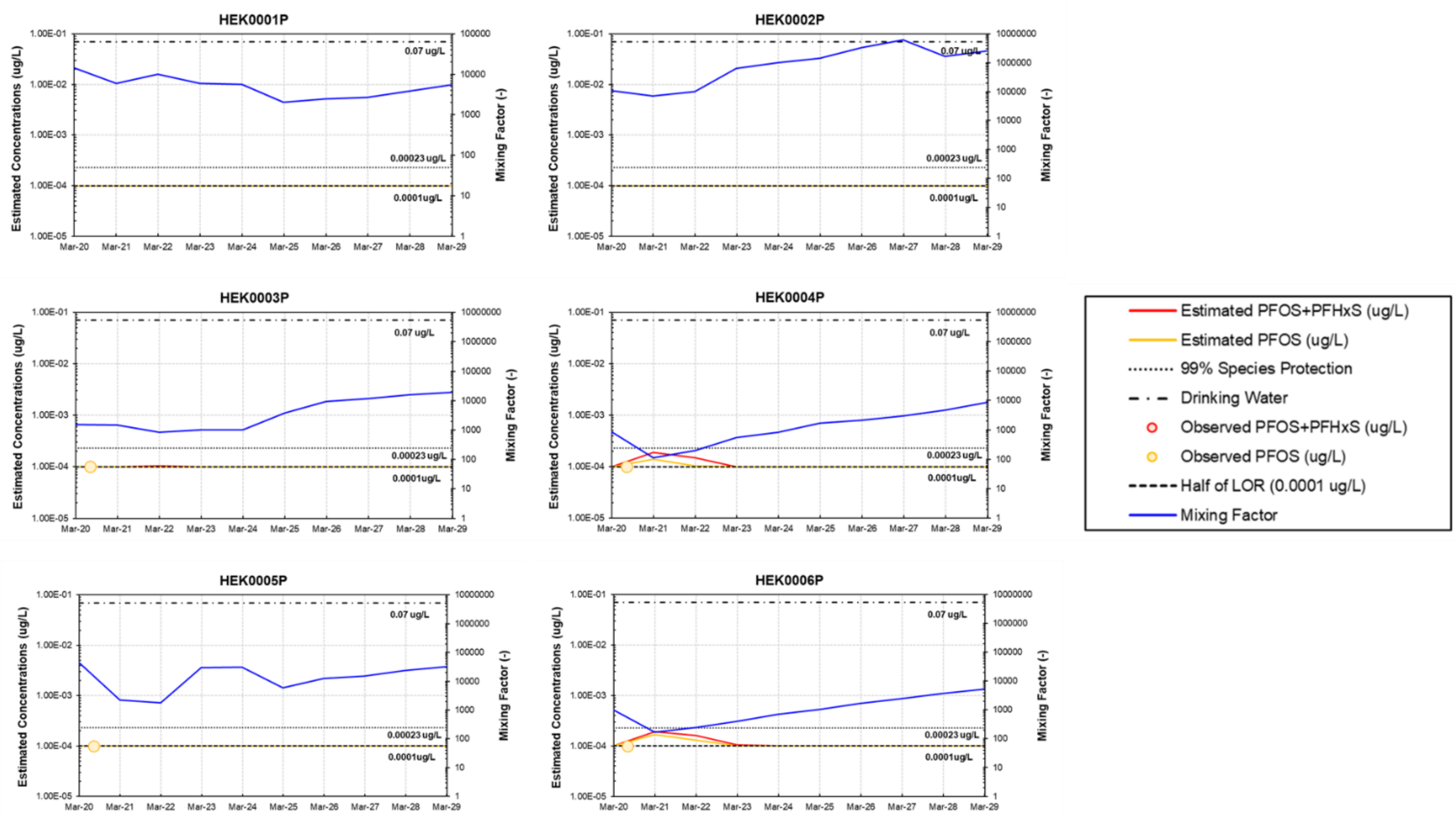


Figure P: Mixing factor, PFOS+PFHxS and PFOS concentration estimates at OB35 abstraction wells from 2020 to 2029

6.3 Scenario 2

The mixing factor (Y) and the PFOS+PFHxS and PFOS concentrations at the Western Ridge abstraction wells were calculated over the pumping period of 2020 to 2050 using the Scenario 2 dewatering plan.

The time-series plots of the mixing factor and concentrations are presented in Figure Q for the Western Ridge wells. The initial plume is assigned to the model at the beginning of July 2020 and then the plume starts depleting as described in Section 6.1. The regulatory screening values for the 99% species protection criterion (0.00023 µg/L) and drinking water guideline (0.07 µg/L) (HEPA, 2020) are also presented in the plots.

No PFOS and PFOS+PFHxS exceedances observed at Western Ridge for 99% species protection guideline of 0.00023 µg/L and drinking water guideline (0.07 µg/L). FlowSource estimates that Eastern Syncline captures a small fraction of water from the contaminant source areas when the abstraction rate reaches approximately 20 ML/d in 2025. This leads to an increase in modelled concentration of PFOS+PFHxS and PFOS in the abstraction bores to approximately 0.0002 µg/L. However, as most of the volume of water abstracted from Eastern Syncline is from the outside of the source area, it results in the concentrations remaining below the 99% species protection criterion (0.00023 µg/L).

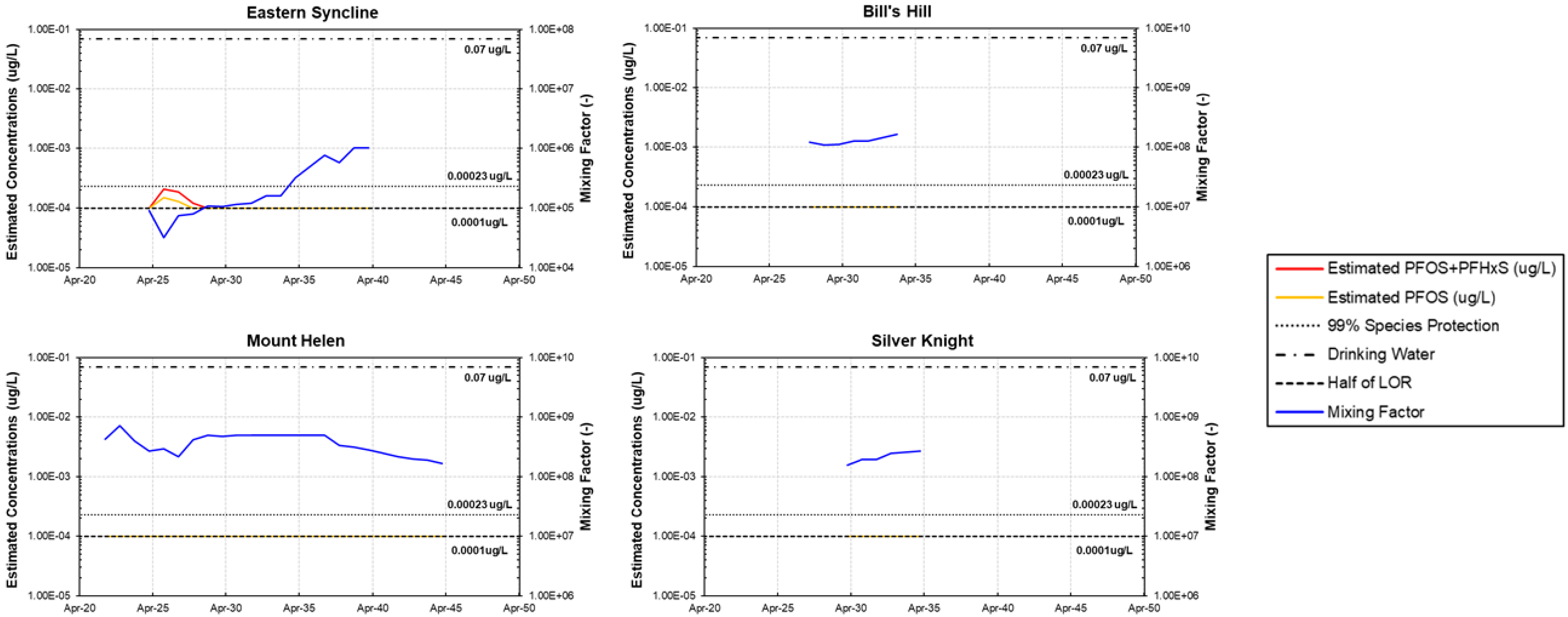


Figure Q: Mixing factor, PFOS+PFHxS and PFOS concentration estimates at Western Ridge abstraction wells (at Eastern Syncline, Bill's Hill, Mount Helen and Silver Knight) from 2020 to 2050 for dewatering Scenario 2

7.0 SUMMARY

BHP engaged Golder to undertake a hydrogeological modelling assessment to investigate the potential risk of per- and polyfluoroalkyl substances (PFAS) migrating towards Western Ridge dewatering bores and support future decisions related to dewatering and management of the excess water at the site. To achieve the objectives Golder undertook a mixing assessment for PFOS and PFOS+PFHxS which have been noted to exceed the relevant criteria (HEPA 2020) in groundwater at the adjacent Mount Whaleback site.

The modelling has been based on concentration data obtained from the recent groundwater sampling events (Golder, 2020b), which was used to develop a 3-D contaminant plume map for the adjacent Mount Whaleback site. Baseline information available for Western Ridge (Golder, 2021a, b, and c) indicates PFAS impacts are likely limited and therefore the background concentration in the area which has been used in the model is half the LOR (0.0001 µg/L).

The groundwater model for Western Ridge developed by BHP was modified to incorporate the hydrogeological modelling improvements completed for OB29, OB30, and OB35 pit operations (Golder, 2020a). The updated model was used to complete forward MODFLOW 2005 simulations to forecast groundwater flow in the region until 2050 for two pumping scenarios. FlowSource was then used to calculate the volume of water abstracted at Western Ridge and OB35 by individual bores from different regions of the groundwater model. The mixing assessments were carried out using the information from the 3-D plume map and the FlowSource estimates.

The plume scenario evaluated in this report assumes the plume depletes, and source areas provide a constant concentration. This is considered as a conservative assessment as source zone concentrations are likely to decrease overtime, especially at RLP, where the implementation of a low permeability cap over the PFAS-impacted soils is being constructed.

The results for the two dewatering scenarios were:

- No PFOS and PFOS+PFHxS exceedances of the 99% species protection guideline of 0.00023 µg/L and Australian drinking water guideline (0.07 µg/L) were noted in individual abstraction bores at OB35 during Scenario 1. However, HEK0004P and HEK0006P capture a small fraction of water from the contaminant source areas. This leads to an increase in modelled concentration above ½ LOR for PFOS+PFHxS and PFOS to approximately 0.0002 µg/L.
- No PFOS and PFOS+PFHxS exceedances observed at Western Ridge for 99% species protection guideline of 0.00023 µg/L and Australian drinking water guideline (0.07 µg/L) for either scenario.
- Under Scenario 1, the planned dewatering in accordance with the mine plan for Western Ridge, no PFOS and PFOS+PFHxS exceedances are observed above the half the LOR of 0.0001 µg/L.
- Under Scenario 2, Eastern Syncline pit captures a small fraction of water from the contaminant source areas when OB35 is not operational. This leads to an increase in modelled concentration above ½ LOR for PFOS+PFHxS and PFOS to approximately 0.0002 µg/L.

If other sources of PFAS are identified in the area, the findings in this letter should be reviewed as the PFAS concentrations may be underpredicted.

8.0 IMPORTANT INFORMATION

Your attention is drawn to the document titled – "Important Information Relating to this Report", which is included in Attachment B of this report. The statements presented in that document are intended to inform a reader of the report about its proper use. There are important limitations as to who can use the report and how it can be used. It is important that a reader of the report understands and has realistic expectations about those matters. It is important to understand that the results of this modelling have been based on certain assumptions. The reader should familiarise themselves of these assumptions and seek clarification if they are unclear. The Important Information document does not alter the obligations Golder has under the contract between it and its client.

Yours sincerely

GOLDER ASSOCIATES PTY LTD

Argha Namhata
Environmental Engineer

Keely Mundle
Associate, Principal Environmental Engineer

AN/KM,IYK/hn

Attachments: Figure 1 – Location Map
Figure 2 – Groundwater PFAS Results – Maximum Concentration
A – Important Information

https://golderassociates.sharepoint.com/sites/141991/project files/6 deliverables/21455207-001-l-rev0.docx

REFERENCES

BHP (2015). Ethel Gorge Ecohydrological Case Study. WAIO Pilbara Strategic Assessment, State Appendix 7, Appendix G.

BHP (2019), Whaleback Hydrogeological Assessment, Water Planning – Planning & Technical – Minerals Australia. March 2019.

BHP (2020). Western Ridge and OB29/30/35 Detailed Hydrogeological Assessment. Water Planning – Planning & Technical – Minerals Australia. March 2020.

Black, A., and Foley, C. (2013). FlowSource: A program to efficiently delineate volumetric capture areas pathways and source areas in groundwater models. In MODFLOW and More 2013: Translating Science into Practice.

Golder Associates (2020a) Whaleback Stage 4 Hydrogeological Assessment. September 2020. Report Reference 19118983-079-L-Rev1

Golder Associates (2020b) Mount Whaleback Additional PFAS Assessment. November 2020. Report Reference 19118983-085-R-RevA

Golder Associates (2020c) Whaleback Stage 5 Hydrogeological Assessment. December 2020. Report Reference 19118983-092-L-Rev0

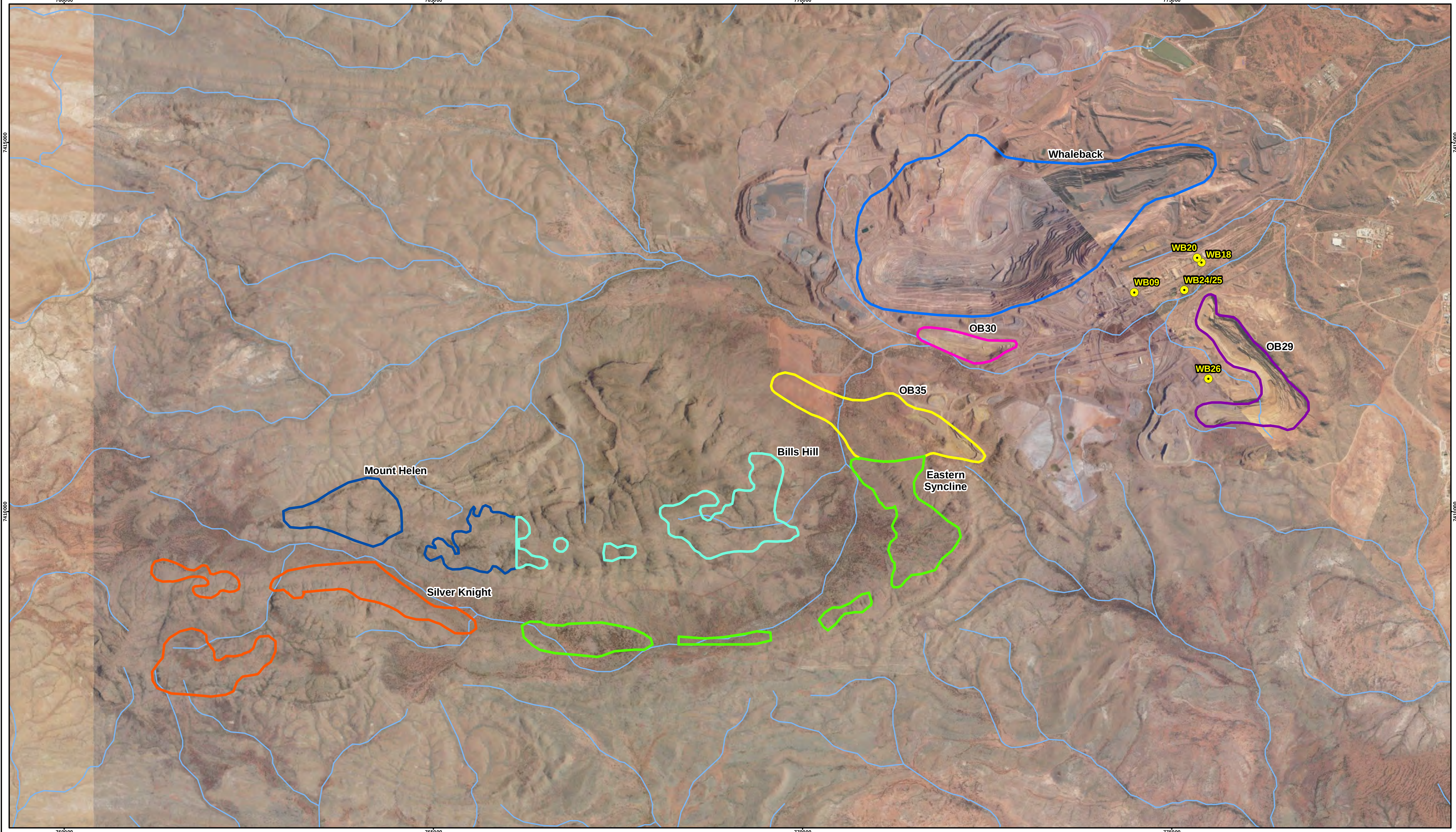
Golder Associates (2021a) Western Ridge – Afghan Springs Baseline Assessment, PFAS and TRH Groundwater baseline Assessment. Report Reference 21464272-003-R-Rev0

Golder Associates (2021b) Western Ridge – Eastern Syncline Baseline Assessment, PFAS and TRH Groundwater Baseline Assessment. Report Reference 21464272-004-R-Rev0

Golder Associates (2021c) Western Ridge – Crusher Study Area Baseline Assessment, PFAS and TRH Groundwater Baseline Assessment. Report Reference 21464272-005-R-Rev0

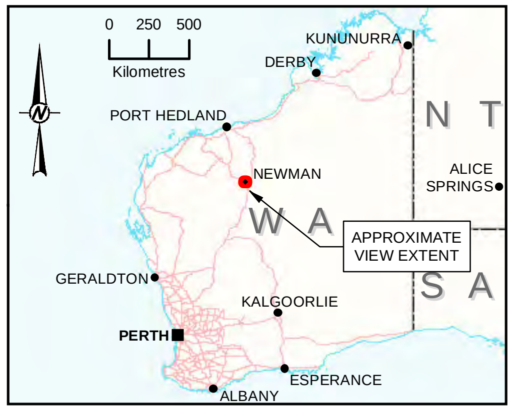
HEPA (2020), PFAS National Environmental Management Plan 2.0, 2020.

Johnson, S.L. & Wright, A.H. (2001). Central Pilbara Groundwater Study. Water and Rivers Commission, Hydrogeological Record Series, Report HG 8,102p. November 2001.



LEGEND

- CONTAMINATED SITE
- BILLS HILL
- EASTERN SYNCLINE
- MOUNT HELEN
- OB29
- OB30
- OB35
- SILVER KNIGHT
- WHALEBACK



NOT FOR CONSTRUCTION

DRAFT

0 1,000 2,000

1:50,000 METRES

CLIENT

BHP

CONSULTANT

GOLDER MEMBER OF WSP

YYYY-MM-DD	2021-04-20
DESIGNED	AN
PREPARED	AM
REVIEWED	
APPROVED	

NOTE(S)
1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50

REFERENCE(S)
1. OREBODY BOUNDARIES DIGITISED FROM BHP MAP "CM 1"
2. AERIAL IMAGERY FROM © WESTERN AUSTRALIAN LAND INFORMATION AUTHORITY TRADING AS LANDGATE (2018)

PROJECT

PFAS MIXING ASSESSMENT

TITLE

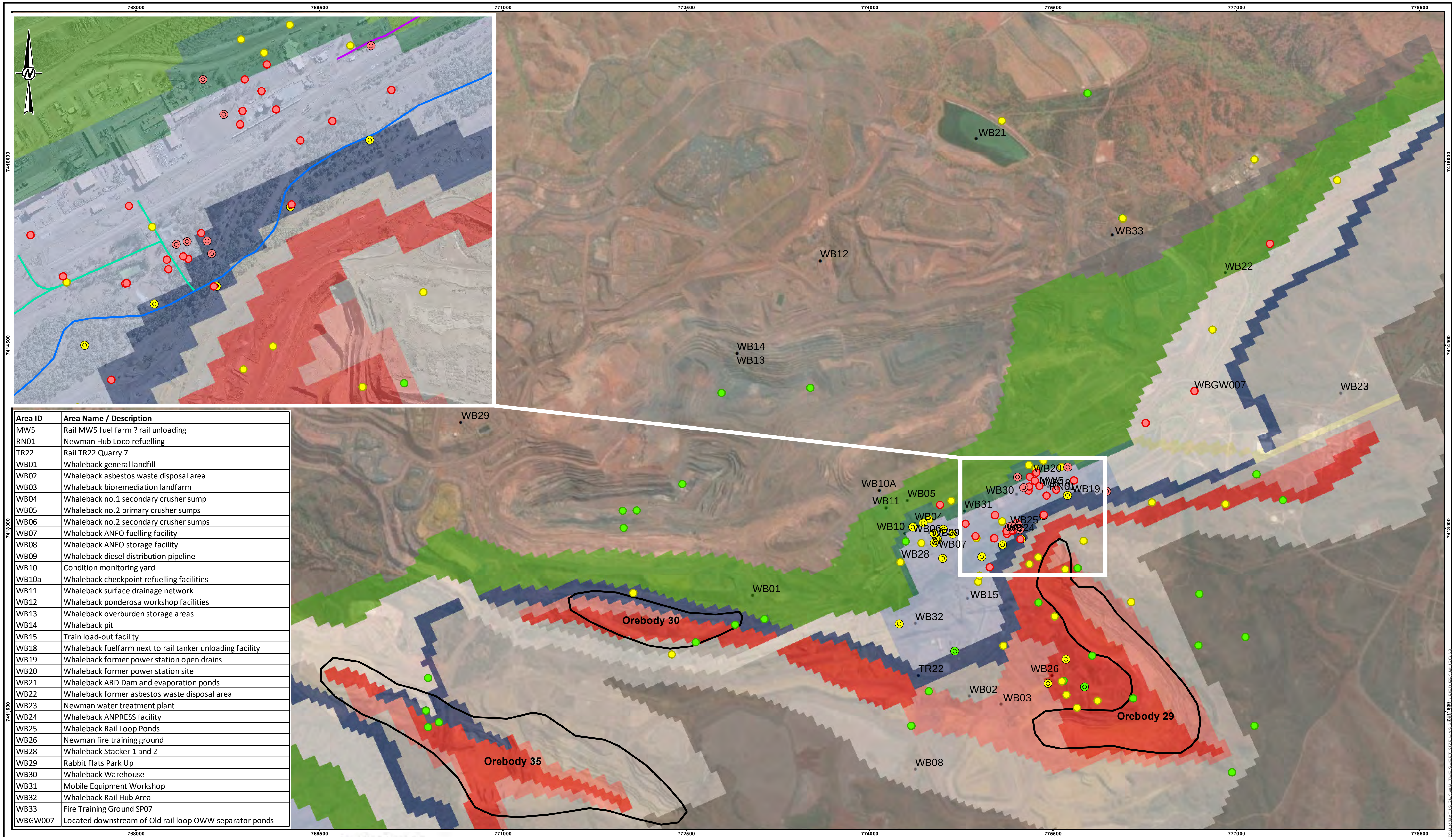
LOCATION MAP

PROJECT NO.	CONTROL	REV.	FIGURE
21455207	001 L	0	1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ISO A3

25mm

PATH: B:\BHP_Iron_Ore_Pty_Ltd\Western_ridge\99_PROJECTS\21455207_HydroSupport\02_PRODUCTION\MXD\001-L\21455207-001-L-F001-RevA.mxd PRINTED ON: 2021-04-20 AT: 9:12:16 AM



Area ID	Area Name / Description
MW5	Rail MW5 fuel farm ? rail unloading
RN01	Newman Hub Loco refuelling
TR22	Rail TR22 Quarry 7
WB01	Whaleback general landfill
WB02	Whaleback asbestos waste disposal area
WB03	Whaleback bioremediation landfarm
WB04	Whaleback no.1 secondary crusher sump
WB05	Whaleback no.2 primary crusher sumps
WB06	Whaleback no.2 secondary crusher sumps
WB07	Whaleback ANFO fuelling facility
WB08	Whaleback ANFO storage facility
WB09	Whaleback diesel distribution pipeline
WB10	Condition monitoring yard
WB10a	Whaleback checkpoint refuelling facilities
WB11	Whaleback surface drainage network
WB12	Whaleback ponderosa workshop facilities
WB13	Whaleback overburden storage areas
WB14	Whaleback pit
WB15	Train load-out facility
WB18	Whaleback fuelfarm next to rail tanker unloading facility
WB19	Whaleback former power station open drains
WB20	Whaleback former power station site
WB21	Whaleback ARD Dam and evaporation ponds
WB22	Whaleback former asbestos waste disposal area
WB23	Newman water treatment plant
WB24	Whaleback ANPRESS facility
WB25	Whaleback Rail Loop Ponds
WB26	Newman fire training ground
WB28	Whaleback Stacker 1 and 2
WB29	Rabbit Flats Park Up
WB30	Whaleback Warehouse
WB31	Mobile Equipment Workshop
WB32	Whaleback Rail Hub Area
WB33	Fire Training Ground SP07
WBGW007	Located downstream of Old rail loop OWW separator ponds

LEGEND

• CONTAMINATED SITE LOCATION

PFOS + PFHxS Concentration ug/L

- <LOR
- >= LOR < 0.00023
- >= 0.00023 < 0.01
- >= 0.01 < 0.07
- >= 0.07 < 0.7
- >= 0.7

Formation Properties

- Weathered Dolomite (K=100 m/d)
- Mineralised Brackman (K=10 m/d)
- Subminerailsed Brackman (K=0.01 m/d)
- Mineralised Marra Mamba (K=4.4 m/d)
- Submineralised Marra Mamba (K=1.6 m/d)
- Mt Sylvia/McRae/Wittenoom (K=1.0E-05 m/d)
- Mt Newman/McLeod/Nammuldi (K=0.21 m/d)
- West Angela Shale (K=48.1 m/d)
- Jeerinah (K=5.0E-05 m/d)
- Low Permeable Clay Layer (K=1.0E-04 m/d)
- Low Permeable Shale Layer (K=1.0E-02 m/d)
- Flow Barrier (K=2.0E-03 m/d)
- Dolomite to the West (K=1 m/d)
- Inactive cells (No flow boundary)
- General Head Boundary (522 mAHD)

NOT FOR CONSTRUCTION
DRAFT

0 500 1,000
1:30,000 METRES

NOTE(S)
1. COORDINATE SYSTEM: GDA 1994 MGA ZONE 50
2. AERIAL PHOTOGRAPH SOURCED FROM SOURCE: ESRI, MAXAR, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER

CLIENT
BHP

PROJECT
PFAS MIXING ASSESSMENT

CONSULTANT
GOLDER
MEMBER OF WSP

YYYY-MM-DD	2021-04-20
DESIGNED	AN
PREPARED	AM
REVIEWED	
APPROVED	

TITLE
GROUNDWATER PFAS RESULTS – MAXIMUM CONCENTRATIONS

PROJECT NO.	CONTROL	REV.	FIGURE
21455207	001 L	0	2

ATTACHMENT A

Important Information

The document ("Report") to which this page is attached and of which this page forms a part has been issued by Golder Associates Pty Ltd ("Golder") subject to the important limitations and other qualifications set out below.

This Report constitutes or is part of services ("Services") provided by Golder to its client ("Client") under and subject to a contract between Golder and its Client ("Contract"). The contents of this page are not intended to and do not alter Golder's obligations (including any limits on those obligations) to its Client under the Contract.

This Report is provided for use solely by Golder's Client and persons acting on the Client's behalf, such as its professional advisers. Golder is responsible only to its Client for this Report. Golder has no responsibility to any other person who relies or makes decisions based upon this Report or who makes any other use of this Report. Golder accepts no responsibility for any loss or damage suffered by any person other than its Client as a result of any reliance upon any part of this Report, decisions made based upon this Report or any other use of it.

This Report has been prepared in the context of the circumstances and purposes referred to in, or derived from, the Contract and Golder accepts no responsibility for use of the Report, in whole or in part, in any other context or circumstance or for any other purpose.

The scope of Golder's Services and the period of time they relate to are determined by the Contract and are subject to restrictions and limitations set out in the Contract. If a service or other work is not expressly referred to in this Report, do not assume that it has been provided or performed. If a matter is not addressed in this Report, do not assume that any determination has been made by Golder in regards to it.

At any location relevant to the Services conditions may exist which were not detected by Golder, in particular due to the specific scope of the investigation Golder has been engaged to undertake. Conditions can only be verified at the exact location of any tests undertaken. Variations in conditions may occur between tested locations and there may be conditions which have not been revealed by the investigation and which have not therefore been taken into account in this Report.

Golder accepts no responsibility for and makes no representation as to the accuracy or completeness of the information provided to it by or on behalf of the Client or sourced from any third party. Golder has assumed that such information is correct unless otherwise stated and no responsibility is accepted by Golder for incomplete or inaccurate data supplied by its Client or any other person for whom Golder is not responsible. Golder has not taken account of matters that may have existed when the Report was prepared but which were only later disclosed to Golder.

Having regard to the matters referred to in the previous paragraphs on this page in particular, carrying out the Services has allowed Golder to form no more than an opinion as to the actual conditions at any relevant location. That opinion is necessarily constrained by the extent of the information collected by Golder or otherwise made available to Golder. Further, the passage of time may affect the accuracy, applicability or usefulness of the opinions, assessments or other information in this Report. This Report is based upon the information and other circumstances that existed and were known to Golder when the Services were performed and this Report was prepared. Golder has not considered the effect of any possible future developments including physical changes to any relevant location or changes to any laws or regulations relevant to such location.

Where permitted by the Contract, Golder may have retained subconsultants affiliated with Golder to provide some or all of the Services. However, it is Golder which remains solely responsible for the Services and there is no legal recourse against any of Golder's affiliated companies or the employees, officers or directors of any of them.

By date, or revision, the Report supersedes any prior report or other document issued by Golder dealing with any matter that is addressed in the Report.

Any uncertainty as to the extent to which this Report can be used or relied upon in any respect should be referred to Golder for clarification.