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Updated Groundwater Modelling for Bendigo Ophir Gold Deposit

14/08/2026

Prepared by Kōmanawa Solutions Ltd. for Matakanui Gold Ltd.



Kōmanawa:

1. (verb) to spring, well up (of water)
2. (verb) to spring, well up (of thoughts, ideas)

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Key Outcomes

Key Outcomes

- We developed a high resolution 3D groundwater model of the near surface environment and coupled it with an optimised deep groundwater model of the schist system.
- The deep groundwater model was able to replicate the observed heads and upper catchment fluxes, but tended to over-predict the lower catchment (SCO1) fluxes. The deep model provides an acceptable representation of the schist system and a strong basis for assessing the impacts of the deeper system on the potential for lost seepage.
- The coupled model was run for a large stochastic suite of parameter combinations to explore the potential for lost seepage from the TSF (Tailings Storage Facility), SHELF (Shepherds Creek Engineered Landform), and SHFILL (Shepherds Creek Valley Fill). The full stochastic suite included many parameter combinations that are not realistic, so further analysis was undertaken to reject unrealistic parameter combinations (e.g., those yielding heads far above the land surface) and to further refine the predictions of likely lost seepage.
- The full stochastic suite of coupled models suggests that the dominant risk for lost seepage is to the shallow groundwater system and surface water system in the Shepherds Creek catchment. This includes the SiltPond (Shepherds Creek Silt Pond). After discounting those results from the full stochastic suite which produce indefensibly high estimates of lost seepage, the modelling broadly rejects the hypothesis that substantial seepage may be lost to the deep schist system without being detected by the proposed monitoring network. This provides substantial confidence that even a very unlikely scenario of lost seepage would be detected by the monitoring network.
- The modelling suggests that adequate underdrainage of the SHFILL is essential to manage the potential for lost seepage from the TSF, SHELF, and SHFILL. The deep model inversion suggests that the area of the SHFILL is likely to be a substantial discharge zone for the deeper schist system. Without adequate underdrainage, the model predicts high heads in the SHFILL which includes potential for upward seepage. Whilst underdrains were explicitly included in the coupled model, effective drainage could also be implemented as a more conductive base layer in the SHFILL to achieve a similar outcome. Further design work beyond the scope of this study is required to determine the most appropriate underdrainage design.
- Based on the revised stochastic suite, we suggest that a very conservative upper limit for likely lost seepage from the TSF is less than 8%, but more than 4%. Most model realisations suggest that the likely lost seepage is < 3%. These figures assume that the SHFILL is adequately underdrained.
- The deep model inversion suggests that the area upstream of the currently planned TSF underdrainage is likely to be a substantial discharge zone for the deeper schist system. The modelling did not suggest that including an extended underdrainage system would substantially affect the likely lost seepage from the TSF, but an underdrainage system may warrant further investigation nonetheless to ensure that heads in the TSF are primarily due to infiltration rather than deep groundwater discharge.
- The deep model inversion developed realisations that had a very high conductivity weathered schist in the area of the SUMP (Shepherds Creek Engineered Landform Seepage Collection Sump). The posterior conductivity of the weathered schist in this area was found to be very poorly constrained, but it is a key parameter in determining the potential for lost seepage from the SHELF. We understand that the proposed mine design includes removal of much of the weathered schist under the SUMP. If the geometric mean of the modified schist can ensure a transmissivity of less than $2 \times 10^{-5} \text{ m}^2/\text{s}$, then the lost seepage from the SHELF is likely to be less than 9% (95th percentile). Note that most models at this limit suggest lost seepage from the SHELF is < 5%. This is equivalent to a geometric mean conductivity of less than $1 \times 10^{-6} \text{ m/s}$ for the modelled 20 m thick layer of weathered schist. Further reduction in conductivity yields further reductions in lost seepage. This assessment assumes that the SHFILL is adequately underdrained.
- Without underdrainage there is a substantial risk of lost seepage from the SHFILL, but if under-

drainage is implemented, the likely upper limit of lost seepage from the SHFILL is < 10% (95th percentile), with most models suggesting < 5%.

- Based on these findings, we suggest the following design criteria to minimise the potential seepage from the TSF, SHELF, and SHFILL:
 1. Ensure that the SHFILL is adequately underdrained to prevent upward seepage from the deeper schist system. This has the additional benefit of creating a second capture zone for any lost seepage from the TSF and SHELF.
 2. Ensure that the area of weathered schist under the SUMP is modified to ensure a conductivity of less than 10^{-6} m/s (geometric mean), ideally less than 10^{-7} . This is consistent with the existing plans to remove much of the weathered schist, but the modelling results presented here highlight the importance of this design criterion.
 3. Ensure that the monitoring network is implemented as planned, with particular attention to the monitoring of surface water at SCO1, groundwater near SCO1, and the silt pond.
 4. Consider the extension of the underdrainage system in the TSF to the upper TSF deep discharge zone to ensure that heads in the TSF are primarily due to infiltration rather than deep groundwater discharge.

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List of Breakaway Boxes

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Definitions and Abbreviations

CHB Constant-Head Boundary

CIT Come In Time deposit

DRN Drain Boundary Condition

IQR Inter Quartile Range

OFFSHORE “Offshore” boundary to allow for seepage to flow out of the model domain

PROCESS Mine process infrastructure including landforms, ponds, and associated infrastructure

QALCL Quaternary Alluvium and Colluvium

RAS Rise and Shine deposit

RCH Recharge Boundary Condition

SHELF Shepherds Creek Engineered Landform

SHFILL Shepherds Creek Valley Fill

SiltDam Silt Pond Dam

SiltPond Shepherds Creek Silt Pond

SREX Srex deposit

SUMP Shepherds Creek Engineered Landform Seepage Collection Sump

TGF Thompson’s Gorge Fault

TSF Tailings Storage Facility

TSF-D Tailings Storage Facility - Dam

TZ-3 Textural Zone 3

TZ-4 Textural Zone 4

VWP Vibrating Wire Piezometer

1 Report Purpose and Structure

This report and work is undertaken to support the request for information from Matakanui Gold Limited in relation to the Bendigo-Ophir Gold Project application under the Fast-track Approvals Act 2024. Specifically, this work is undertaken to address:

- *Please provide additional information to better understand the hydrogeological characterisation of the site and wider receiving environment in terms of groundwater and contaminant movement from the site and the ultimate effects on the surface and groundwater receiving environment. This requires additional baseline data collection and modelling, including but not necessarily limited to:*
 - *Three-dimensional groundwater contamination modelling.*
 - *Quantification and demonstration of uncaptured seepage, including details of the seepage scenarios through the site and wider receiving environment.*
- *We expect all models to be appropriately calibrated against existing conditions with consideration of:*
 - *A range of potential geological scenarios that may realistically be foreseen; and*
 - *Variable environmental conditions which demonstrate the range of effects possible.*

The main body of this report provides a high-level overview of the assessment and modelling work undertaken and the key findings, with details on the model build; optimisation methods, results, sensitivity analysis and forward model predictions provided in the appendices. These appendices are referenced when needed in the main body of the report.

2 Introduction and Background

This assessment is part of a much larger body of work supporting the application for the Bendigo Ophir Gold Project. Rather than reiterating the detailed geological, hydrogeological, site design, and other information that has been provided in previous reports, we provide a very high-level summary of the geological and hydrogeological context of the site with references to the relevant reports and information sources.

Key sources of information used for this assessment include:

- **Hope and Torvelainen (2025)** - Design and details of the Shepherds Creek TSF (Tailings Storage Facility) and associated infrastructure.
- **Carter and Torvelainen (2025)** - Design and details of the Bendigo Ophir Gold Project process plant and associated infrastructure including SHFILL (Shepherds Creek Valley Fill).
- **Carter et al. (2025)** - Design and details of the Shepherds Creek silt pond and associated infrastructure.
- **Hope and Torvelainen (2025)** - Design and details of the Shepherds Creek TSF (Tailings Storage Facility) and TSF-D (Tailings Storage Facility - Dam).
- **Zou and Carter (2025)** - Design and details of the Bendigo Ophir Gold Project SHELF (Shepherds Creek Engineered Landform) and SUMP (Shepherds Creek Engineered Landform Seepage Collection Sump).
- **Zou and Torvelainen (2026)** - Design and details of the Bendigo Ophir Gold Project stream diversion and associated infrastructure.
- **Bryce et al. (2025)** - Post mining closure plan
- **weber (2025)** and appendices - Mine impacted water overview report. Key appendices include Net percolation assessment, Source term definition, water quality forecast, water load balance model
- **Rekker (2025)** - Surface water assessment and characterisation report.
- **Torvelainen (2026)** - Update on the SHFILL (Shepherds Creek Valley Fill) design and associated seepage collection systems.
- **Reid and Weber (2026)** - Water Management plan.
- Other sources provided in the fast track application and supporting documents.

2.1 Site Characteristics

The project area is located broadly within the Shepherds Creek and Rise and Shine Creek valleys on the western flank of the Dunstan Mountains (Figure 2.1). The site ranges in elevation from approximately 400 m to 900 m above sea level. The area is classified as temperate, with a mean annual air temperature of approximately 8 °C and mean annual rainfall of approximately 500mm. Some of the site receives snowfall in the winter months, while the lower elevations generally remain snow free. The Shepherds Creek and Rise and Shine Creek catchments are steep catchments with narrow valley floors and steep side slopes. Shepherds Creek discharges to the Lindis River, via the Ardgour Aquifer. Shepherds Creek is often dry after it exits the steep topography of the Dunstan Mountains. Rise and Shine Creek becomes a tributary of Bendigo Creek, which eventually discharges to the Clutha River.

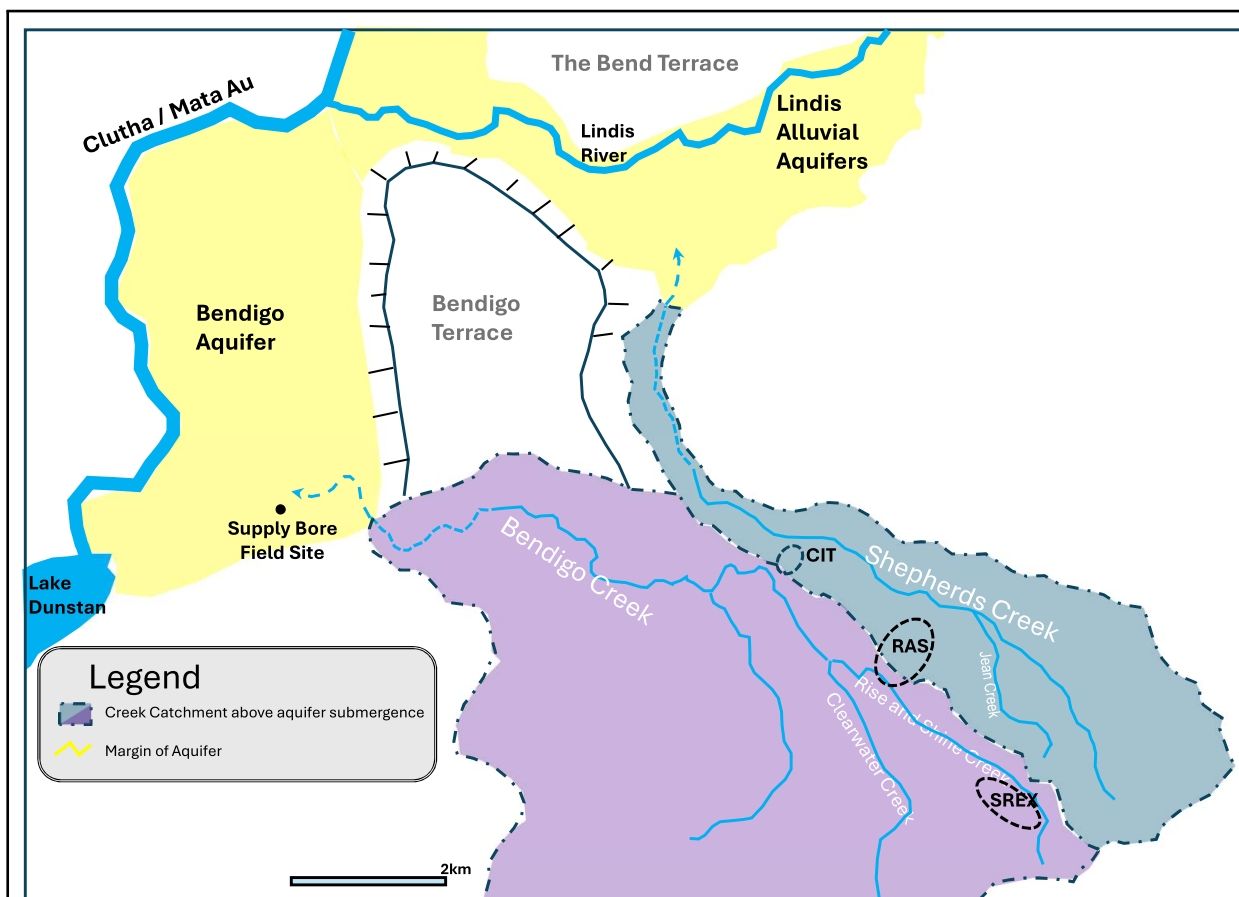


Figure 2.1: Map of the general site hydrology

The geology of the area has been extensively described in other reports for the project, but in summary the area is dominated by basement rock comprised of the Rakaia Terrain schist covered in places by thin veneers of quaternary alluvium and colluvium. For the purposes of the groundwater modelling we simplified the geological environment into five distinct groups which are (in stratigraphic order):

- Surficial veneers of colluvium and alluvium (in the valley bottoms)
- Weathered basement rock (i.e., schist) and/or local mass wasting features.
- TZ-3 (Textural Zone 3) Schist: Rakaia Terrain Quartzofeldspathic schist and greyschist (Turnbull et al., 2001).
- Rise and Shine Shear Zone: The shear zone and associated fault gouges were created by both brittle and ductile deformation associated with multiple activations of the TGF (Thompson's Gorge Fault). This zone is the target of the proposed mining activities.

- TZ-4 (Textural Zone 4) Schist: Rakaia Terrain Quartzofeldspathic schist, greyschist, and gneiss (Turnbull et al., 2001).

2.2 Water quality monitoring

It is beyond the scope of this report to assess or review the water quality monitoring program for the Bendigo Ophir Gold Project. Our assumptions for the purposes of the discussion within this report are that the water quality monitoring program will include:

- Monitoring of Shepherds Creek at the lower end of the steep catchment before it enters the Quaternary sediments Northwest of the range front (i.e., at the SCO1 site).
- Monitoring of groundwater in the alluvial sediments within the final gorge of Shepherds Creek (i.e., near the SCO1 site) to assess the groundwater quality of any groundwater flow below Shepherds Creek.
- Monitoring of the SiltPond (Shepherds Creek Silt Pond) to assess any potential seepage from the TSF and SHELF (Shepherds Creek Engineered Landform) into the SiltPond.

These monitoring sites are reasonably assumed to ensure that the only pathway for lost seepage from the TSF, SHELF, and SHFILL (Shepherds Creek Valley Fill) to the wider environment that is not monitored is through the deep schist system discharging more generally to the Ardgour Aquifer and Lindis River. To our knowledge, these monitoring sites are already planned and/or implemented.

3 Predictions of Interest

The work undertaken for this project and described in this report focuses on assessing three key predictions of interest for the Bendigo Ophir Gold deposit. These predictions are:

1. The likelihood and magnitude of contaminated seepage from the mine site that may be lost to the shallow and the deep groundwater systems (see below).
2. The potential drivers for the loss of contaminated seepage to the shallow and deep groundwater systems and the sensitivity of lost seepage to model parameters.
3. The impacts of mining related dewatering to affect the likelihood and magnitude of lost contaminated seepage.

The potential for lost seepage from the mine features to the shallow and deep groundwater system is a potential pathway for contaminants to enter the wider environment. In addition, collected seepage and other mine impacted water will be treated prior to discharge to ensure that the water quality is suitable to prevent adverse effects on the receiving environment. The treatment system must be designed to accommodate any lost seepage from the mine site so that the receiving environment water quality is not adversely affected.

4 Model Conceptualisation

Groundwater in the Shepherds Creek catchment can be conceptualised as two interacting systems: a shallow groundwater system and a deep groundwater system. For the purposes of this project we define the shallow groundwater systems to encompass the QALCL (Quaternary Alluvium and Colluvium) and weathered TZ-3 and TZ-4 units within the Shepherds Creek catchment. Based on the previous site investigation, this shallow groundwater system is expected to occur within the upper 25 m of subsurface. The deep groundwater system is defined to encompass the unweathered TZ-3 and TZ-4 units, as well as the TGF and associated faulted and fractured zones that are expected to occur below the shallow groundwater system. This includes the host rock of the deposit, the Rise and Shine Shear Zone. The shallow system is expected to provide recharge to the deep system, particularly in the upper portions of the catchment, and the deep system is likely to discharge to the shallow system either in the lower portions of Shepherds Creek valley or further downstream in the Ardgour Aquifer. For the modelling undertaken here, we have divided the two systems into two semi-distinct models – one for the shallow system and one for the deep system. The models are explicitly coupled, which means that

MODFLOW 6 iteratively solves both models concurrently and hence simulates head changes in one simulation. Hence, water and contaminant mass fluxes from the seepage model affect the deep groundwater model and vice versa. The main reason for separating the groundwater system into two submodels is the large difference in a spatial scale between the deep and shallow groundwater systems. The shallow model has a fine discretization to ensure processes associated with fine scale features are accurately captured. The coarser model has a coarser discretization to reduce the computational cost of simulating a large domain, which in turn makes it possible to optimize the model.

The model domains are shown in [Figure 4.1](#). The deep model boundaries are defined to encompass the full catchment of Shepherds Creek, Rise and Shine Creek, and some of the adjacent catchment. The seepage (shallow) model boundaries are defined to capture the key mining activities (e.g., SHELF).

The direct coupling of the two models ensures that impacts of mining-related drawdown in the deep groundwater system on the shallow groundwater system will be captured in the shallow (seepage) model. Similarly, losses of contaminated seepage from the shallow groundwater system to the deep groundwater system will be captured in the deep groundwater model.

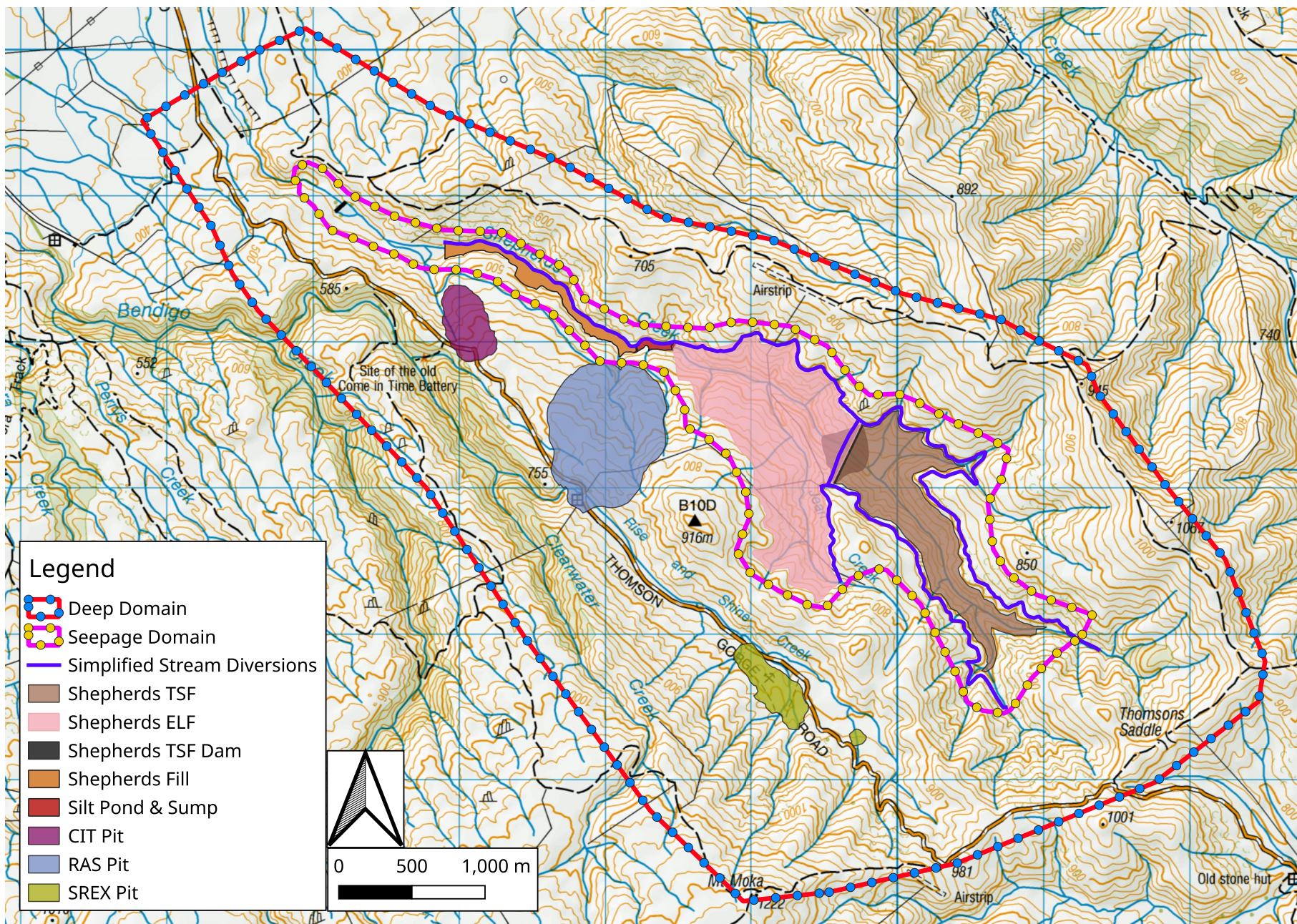


Figure 4.1: Overview map
 The boundaries of the seepage and deep model are pictured as well as key PROCESS features for the seepage model.

4.1 Potential Contaminated Seepage Sources, Sinks and Pathways

We define the potential contaminant sources as below. Other potential sources of contaminated seepage exist, but these have been excluded from the assessment. [Section 5](#) provides a non-exhaustive list of the components that have been excluded from the assessment, and the rationale for their exclusion.

- **TSF:** The tailings storage facility is expected to be a major source of contaminated seepage due to the nature of the materials stored within it.
- **SHELF:** The Shepherds Creek Engineered Landform is expected to be a source of contaminated seepage due to the nature of the materials stored within it.
- **SiltPond:** The Shepherds Creek Silt Pond is a possible source of contaminated seepage. For the most part, the silt pond is expected to be a source of clean water, with its primary purpose being to capture and treat sediment-laden water running off the Shepherds Creek Engineered Landform and other mine infrastructure. We include it as a potential source of contaminated seepage as part of a conservative assessment and to allow for the possibility of upgradient contaminant discharge to the silt pond.
- **SHFILL:** The Shepherds Creek Valley Fill is developed from lower sulphur-bearing waste rock, but is included as a potential source of seepage.
- **RAS (Rise and Shine deposit) pit and underground workings:** The Rise and Shine pit and underground workings are expected to be a sink for mining impacted groundwater. However, in the post closure scenario, the underground workings and pit are expected to flood to 490 m elevation, which could potentially become a source of mining impacted groundwater. Therefore, we include it as a potential source of contaminated seepage in the post closure scenario.

Each source of seepage requires a unique transport model, which adds to the computational cost of each model. After reviewing a suite of initial model simulations, we found that the RAS pit and underground workings were exclusively a sink for contaminated seepage. Therefore, to reduce the computational demands of the model, we have excluded the RAS pit and underground workings as a potential source of contaminated seepage. We will still track the total flux of water from the RAS pit and underground workings, but we do not capture the transport and fate of contaminants in this water (should any be lost). Additionally, initial runs showed very little loss of water from the SiltPond. This is expected to be a relatively clean water source, so we have also excluded it as a potential source of contaminated seepage. This tradeoff allows us to better explore the plausible range of key model input parameters in the seepage model while still capturing the most probable sources of contaminated seepage.

We define the potential sinks for contaminated seepage as:

- **Captured seepage:** This is defined as any seepage that is discharged to the seepage collection systems.
- **SiltPond:** “Lost” contaminated seepage from the TSF or SHELF that discharges to the SiltPond.
- **Shepherds Creek:** Contaminated seepage that discharges to Shepherds Creek downstream of SHFILL.
- **Shallow groundwater system:** Contaminated seepage that flows parallel to Shepherds Creek and eventually discharges to either Shepherds Creek or the Ardour Aquifer. This seepage could exist in either the QALCL or weathered TZ-3 and TZ-4 units.
- **Deep groundwater system:** Contaminated seepage that flows downwards through the unweathered schist units and enters the deep groundwater system in the unweathered TZ-3 and TZ-4 schist. It is expected that the deep groundwater system will eventually discharge to the shallow groundwater system, Ardour Aquifer, Shepherds Creek, and/or the Lindis River. The deep transport pathways are not well-constrained and are likely to occur on much longer timescales than the shallow groundwater system, given the relatively low permeability of the unweathered schist units.

The potential flow pathways are shown in [Figure 4.2](#). Starting from the TSF, contaminated water not captured by the TSF drainage system could flow downwards through the TSF material into the QALCL and weathered schist units, and then ultimately into the deep groundwater system. Alternatively, contaminated water could flow laterally through the QALCL and weathered schist units downgradient to the TSF-D (Tailings Storage Facility - Dam). During construction, the area adjacent to and underlying the TSF-D will be stripped of the QALCL and most of the weathered schist units. This will act as a barrier to direct lateral flow, but some seepage could still

flow laterally through the remaining weathered schist units and/or adjacent to the TSF-D. The seepage would then enter the sub-SHELF area where it would be mixed with any seepage from the SHELF. This water could discharge to the SHELF drainage system, to the deeper groundwater system, or flow laterally through the QALCL and weathered schist units to the SUMP (Shepherds Creek Engineered Landform Seepage Collection Sump). The sump is also built on stripped ground, but there is the potential for seepage to flow laterally through the remaining weathered schist units and/or adjacent to the SUMP. This process repeats for the SiltPond and the SHFILL as potential seepage intersects the SiltDam (Silt Pond Dam) and Shepherds Creek Valley Fill - Seepage Dam, respectively. It should be noted that the SiltPond is expected to be a source of clean(er) water, and is therefore more likely to be relevant as a potential sink than a potential source.

4.2 Deep Groundwater Conceptualisation

The model has been broken into 34 layers, which are parallel to the present surface elevation and represent:

- **Layer 1:** A simplified representation of the QALCL units. This unit is undifferentiated and is expected to be a mixture of alluvium and colluvium.
- **Layer 2:** A single layer representing the weathered TZ-3 and TZ-4 schist.
- **Layers >2:** The unweathered TZ-3 and TZ-4 schist, as well as the TGF and associated faulted and fractured zones that are expected to occur below the shallow groundwater system. These layers do not represent geological units but instead provide consistent discretisation in the vertical direction. Geological units are superimposed on these layers through the parameterisation of the hydraulic properties.

The deep model also contains an OFFSHORE ("Offshore" boundary to allow for seepage to flow out of the model domain) area (i.e., out of the domain) beyond the Northwestern end of the model domain. This area is west of the front of the Dunstan Range and is included in the model to allow for flow out of the Shepherds Creek catchment towards the Lindis River and the Ardour Aquifer.

There is significant available data to inform the parameterisation of the deep groundwater model, particularly in the unweathered TZ-3 and TZ-4 schist. We therefore undertook an inversion (optimisation) of the deep groundwater model using the available data.

4.3 Seepage Conceptualisation

A conceptual model of the seepage system is provided in [Figure 4.2](#). The model is simplified into 5 distinct layers which represent:

1. **Layer 1:** The PROCESS sites, i.e., TSF, TSF-D, SHELF, SUMP, SiltPond, SiltDam, and SHFILL, which, for the most part sit above the current land surface.
2. **Layer 2:** QALCL (Quaternary Alluvium and Colluvium). Areas of alluvium are expected to occur in the valleys and adjacent to Shepherds Creek, while colluvium is expected to occur on the hillslopes.
3. **Layer 3:** Weathered TZ-3 and TZ-4 schist. Weathered schist is expected to occur within the first 10-25 m of the landscape under the QALCL. Weathered schist is expected to have higher hydraulic conductivity than unweathered schist due to higher fracture density and weathering of the rock matrix.
4. **Layer 4, 5:** Unweathered TZ-3 and TZ-4 schist. These layers represent the interface between the shallow and deep groundwater systems.

The seepage model is directly coupled to the deep groundwater model, with vertical coupling between the bottom of the seepage model and the top of the deep groundwater model in the relevant portions of the model domain. Horizontal coupling is also present between the two models for each layer of the seepage model excluding layer 1 (i.e., the process sites).

There is minimal data to inform an inversion (optimisation) of the seepage model. Instead, we undertook a prior parameter stochastic suite and sensitivity analysis to assess the potential for contaminated seepage loss to the shallow and deep groundwater systems. Essentially we defined a conservative range of potential parameter values for the seepage model, and ran a suite of models across the parameter space to assess the

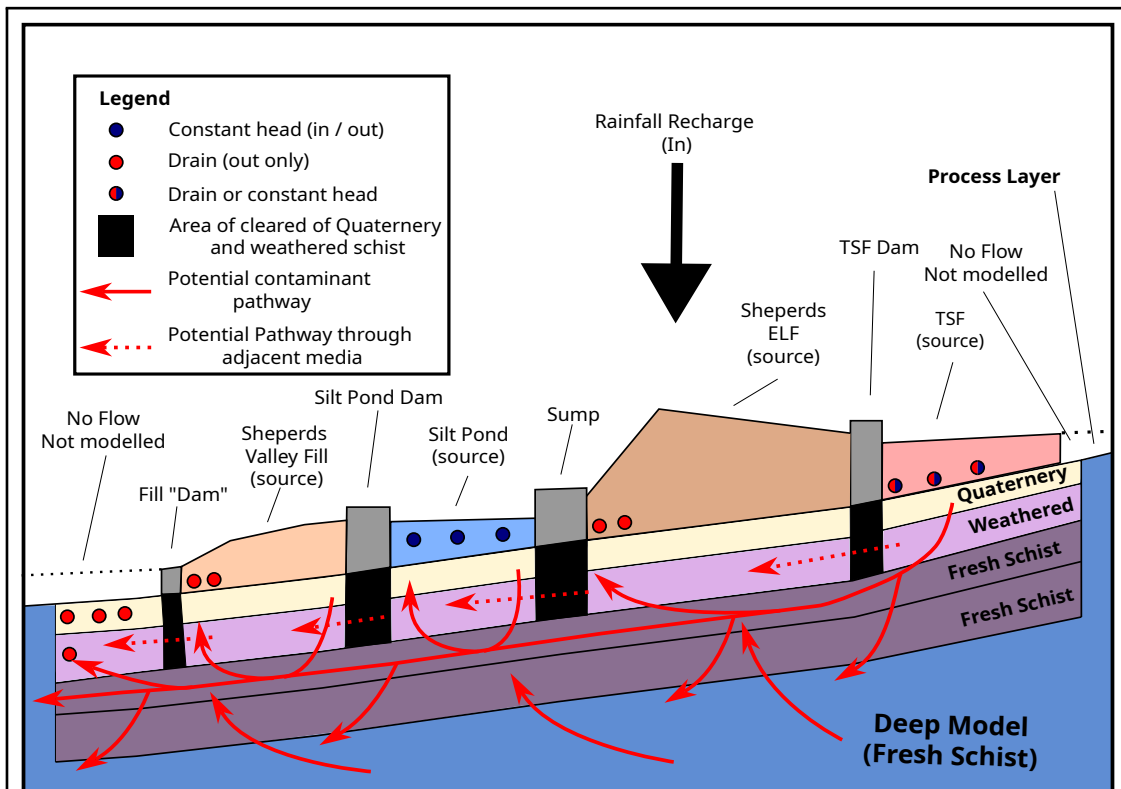


Figure 4.2: A conceptual model of the seepage model

This is a conceptual cross-section of the seepage model running parallel to Sheperds Creek (not to scale).

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Project: Bendigo Ophir Gold
Client: Matakanui Gold Ltd.
Date: 14/08/2026

potential for contaminated seepage loss to the shallow and deep groundwater systems and the drivers of this loss.

5 Model Scoping Decisions

The process of creating a groundwater model requires a number of decisions to be made regarding the processes and features to include in the model, as well as the level of detail to include for each process and feature. The following list of components were excluded from the model scope, and we have provided a rationale for the decision to exclude each component.

- **Inversion of the seepage model:** The seepage model was not inverted to the parameterisation of the hydraulic properties or other model parameters, instead it was run as a prior stochastic suite of models to assess the potential for contaminated seepage loss to the shallow and deep groundwater systems. We chose not to invert the seepage model for several reasons. First, there is relatively little data available to constrain the seepage model. Although there are some head measurements in the QALCL and weathered schist units and a parameter inversion to replicate these heads could potentially provide a slightly constrained parameter range, the outcome would likely be non-unique and compromised by uncertainty in model structure. For example, we assume a uniform thickness of 5 m for the QALCL and 20 m for the weathered schist, but these thicknesses are likely to vary across the site. Transmissivity (hydraulic conductivity multiplied by thickness) will be hard to constrain without a better knowledge of the thickness of these units and the exact spatial location of the alluvium versus colluvium. The response of Shepherds Creek to rainfall events would also provide some constraint, but this would require a carefully conducted gain/loss assessments across the length of Shepherds Creek, which is not currently available and would likely not achieve a significant reduction in uncertainty overall. Finally, much of the system is going to be significantly affected by mining activities. The process of adding large masses of material on these sediments will change the hydraulic properties of the system, and therefore any inversion of the model may not be applicable to the post-mining scenario. We instead limited our validation of the seepage model to a high level “reasonableness” check of the heads and fluxes in the model.
- **Transient hydraulic conditions:** The modelling undertaken here was steady state, which means “average” conditions at equilibrium. We did not model transient hydraulic conditions, for several reasons. First, there is minimal data available to constrain the transient hydraulic conditions. Second, the sources of contaminated seepage are expected to be capped and/or constrained by down gradient bunds and/or seepage collection systems, which will reduce any transient effects. This assessment is focused on the long term risk of contaminated seepage loss through the shallow and deep groundwater systems, which is expected to occur on longer timescales.
- **Modelling of the internal structure of the PROCESS sites:** PROCESS sites, i.e., TSF, TSF-D, SHELF, SUMP, SiltPond, SiltDam, SHFILL, and Shepherds Creek Valley Fill - Seepage Dam were modelled as bulk units rather than explicitly replicating their complex structure. We used a range of hydraulic properties to assess the sensitivity of the seepage model to the internal structure of these PROCESS sites.
- **Chemical reactions and sorption:** These were excluded from scope of the modelling due to the added complexity required to model these processes. We instead focused on the physical transport of contaminants, and conservatively assumed that all contaminants are stable (i.e., no chemical mass is lost during the transport process).
- **Western Engineered Landform and SREX (Srex deposit) Engineered Landform:** Due to time constraints, we have focused on the TSF and SHELF as the primary sources of contaminated seepage. Additional engineered landforms for the CIT (Come In Time deposit) and SREX are likely to discharge to the Bendigo Creek catchment, and modelling of these engineered landforms is out of scope for this project.
- **Topsoil stacks and other minor mine infrastructure:** Other minor mine infrastructure, including topsoil stacks, are not expected to be significant sources of contaminated seepage (Bryce et al., 2025) and were therefore not modelled.
- **Explicit representation of mass wasting areas:** Potential mass wasting features (e.g., landslides) have been identified in the Shepherds Creek catchment (e.g., Zou and Carter, 2025). Investigation of these features in the area of the TSF suggests that they are not currently active, and are generally quite shallow

(<25 m deep) (Hope and Torvelainen, 2025). Therefore, we consider that the range of hydraulic properties used to represent the QALCL and weathered TZ-3 and TZ-4 units in the seepage model capture the potential for these features to affect the loss of contaminated seepage to the shallow and deep groundwater systems.

- **Explicit representation of losses from the Shepherds Creek diversion and other clean/dirty water diversions:** We did not explicitly include the potential for losses from the Shepherds Creek diversion and other clean/dirty water diversions in the seepage model. These diversions will be underlain by low conductivity (<10⁻⁷ m/s) materials so leakage should be minimal (Zou and Torvelainen, 2026). Additionally, the focus of this modelling is on the potential loss of contaminated seepage from the mine site, not the water and mass balance of the seepage collection system. Therefore, differences in fluxes to the seepage collection system due to losses from the diversions is less relevant than the potential for these fluxes to cause driving heads in the shallow and deep groundwater systems. We explored various heads in the PROCESS units based on parameterisation of the drain invert elevations and land surface recharge. This range of heads adequately covers the potential effects of the diversions on the seepage model.
- **Seepage from the SUMP:** The seepage of contaminated water from the SUMP is another potential source of contaminated seepage to the shallow and deep groundwater systems. However, we excluded it from our assessment because it has been explicitly designed to prevent leakage, and has been previously engineered and assessed in Zou and Carter (2025). The spatial precision of the modelling required to assess potential seepage from the SUMP is also inconsistent with the landscape scale of the seepage model.
- **Surface water modelling:** Detailed surface water modelling, including the impacts of captured seepage has been undertaken by other members of the project team, and is out of scope for this project.
- **Modelling of the Ardgour Aquifer:** We did not model the impacts of lost seepage to the Ardgour Aquifer for two reasons. First, the main pathway for lost seepage to the Ardgour Aquifer is expected to be through Shepherds Creek, and/or the near creek shallow groundwater system, so we can conservatively assume that all lost seepage will ultimately enter the Ardgour Aquifer. Second, previous modelling of the Ardgour Aquifer has been undertaken in Dumont and Rekker (2025), which could not reject the null hypothesis that mine-derived containment in the Ardgour Aquifer will not receive significant dilution from other water sources. Without additional data, this modelling cannot be improved.

6 High-level Methodology

The approach taken for this assessment was as follows:

1. **Data review and compilation:** All relevant geological, hydrogeological, and geotechnical data were reviewed and compiled to inform the model development. This included historical reports, site investigations, and monitoring data.
2. **Model conceptualisation and build:** The model conceptualisation separated the site into two coupled components: a deep model focused on the larger scale schist hydrological system, and a high-resolution seepage model focused on the near-surface and PROCESS components. The deep model build is described in Section A. The model includes land surface recharge, simplified surface water features through surface drains, and an OFFSHORE boundary condition to allow for the potential of deep groundwater flow beyond the mouth of the Shepherds Creek valley. The seepage model build is described in Section C. The seepage model focuses on the top 45 m of the system and includes the relevant PROCESS features such as the TSF, SHELF, and SHFILL. These two models are coupled to allow for mass and water transfers between the two models.
3. **Model parametrisation:** The deep model was highly parameterised with spatially variable hydraulic conductivity and recharge (Section A.4). The parameter ranges were informed by the available data and literature values. The parameter ranges were typically wide to avoid biasing the inversion process. The seepage model inherited the hydraulic conductivity and recharge from the deep model, with additional parameters for the PROCESS features such as the TSF and SHELF (Section C.4). These parameters were informed by the design specifications, but were also allowed to vary significantly to support uncertainty and sensitivity analysis.
4. **Stochastic inversion of the deep model:** The inversion of the deep model is the process of predicting the

likely parameter values for the model based on the observed data (i.e., an optimisation) (Section B). The inversion process was stochastic, meaning that a range of possible parameter values were considered, rather than a single deterministic solution. This ensures that the forward prediction include the uncertainty in the parameter values, and allows for a more robust assessment of the likely seepage behaviour.

5. **Stochastic suite of coupled model:** Modelling the forward predictions (i.e., lost seepage) was done using a stochastic suite of coupled models (Section E). This includes a range of optimised realisations of the deep model, as well as the seepage model with varying parameters for the PROCESS features. The stochastic suite includes random sampling of the parameter space, targeted reduction of uncertainty, and targeted optimisation of the best and worst case scenarios. We discuss this further below.
6. **Coupled model sensitivity analysis and drivers:** We use two methods to assess the sensitivity of the coupled model to the various parameters. First is a simple Spearman rank correlation analysis to assess the correlation between the parameters and the model outputs. Second is a random forest machine learning model parameter importance analysis to assess the non-linear relationships between the parameters and the model outputs.
7. **Model predictions and forward seepage likelihood analysis:** The raw results of the forward stochastic suite of coupled models were not purely random: we guided the selection of parameters to identify those that are more/less likely to cause lost seepage, and those that were more uncertain based on the previously evaluated parameter sets. Additionally, some parameter sets may produce unrealistic results in situations where two parameters have been selected that are contradictory to each other. As an example, the coincidence of high recharge with very low hydraulic conductivity would be contradictory because recharge is directly correlated with hydraulic conductivity. This coupling would provide unrealistically high heads (e.g., significant artesian pressures) in the model. Therefore, we reviewed and revised the parameter sets to exclude unrealistic combinations and refined our understanding of the parameter space. Although we could have limited parameter space to avoid these unrealistic combinations, this would have risked *a. priori*. biasing the results. We therefore felt that it was more robust to undertake a posterior filtering rather than assuming a given combination is unrealistic.

7 Deep Model Inversion Overview

The results of the deep model inversion are described in detail in Section B.2. The following is a high-level overview of the key points and findings that are relevant to the assessment of seepage and the potential for lost seepage from the Bendigo Ophir Gold Project.

1. The deep model inversion was able to provide a reasonable fit to the observed open hole water level surveys. The model generally under-predicts the heads on the ridgelines and over-predicts the heads in the valley bottoms. There is some prior-data conflict between the observed water level survey heads (e.g., one measurement suggests high heads, while an adjacent measurement suggests low heads).
2. The deep model inversion performs very well against the more robust VWP (Vibrating Wire Piezometer) observations, noting that there are some conflicts between the observed VWP heads and the observed open hole water level survey heads as above. Importantly, the model replicates the observed upward head gradients in the schist.
3. An initial inversion was able to replicate the observed heads equally well under very high levels of Land Surface Recharge (200+ mm/yr) and at much lower levels of Land Surface Recharge (20-70 mm/yr). This is a common challenge where recharge and hydraulic conductivity are non-unique parameters and multiple combinations of these parameters can provide similar fits to the observed heads.
4. The deep model inversion was able to replicate the observed fluxes in upper Shepherds Creek and Rise and Shine Creek, but only under the lower recharge range. This suggests that the lower recharge and associated lower hydraulic conductivity is more likely to be representative of the site conditions.
5. The model inversion struggled to replicate the observed fluxes in the lower Shepherds Creek catchment (SCO1). Some of this may be due to model simplification (e.g., no losing reaches), but it is likely that the model overpredicts surface water discharge, particularly in the lower reaches of Shepherds Creek. Importantly the assessment of lost seepage is done on proportional contaminant mass flux (e.g., the proportion of contaminant mass lost to the environment rather than the PROCESS drains). This relies on

the total mass, not the concentrations of contaminants, therefore the excess fluxes will not “dilute” the lost seepage assessment.

6. The model inversion suggests lower conductivity in the weathered schist, TZ-3 schist, and TZ-4 schist than the prior parameterisation, which was based on observed aquifer testing.
7. The model inversion suggests that the TGF is a higher conductivity feature than the surrounding schist.
8. The model sensitivity analysis highlights a conflict between replicating head observations and surface water flux observations. Higher recharge yields a better fit to the observed heads, while lower recharge yields a better fit to the observed surface water fluxes. This conflict suggests that there is a model structural error which prevents the model from replicating both the observed heads and surface water fluxes. Based on the sensitivity analysis, we suggest that more information and complexity in the near surface system including the recharge and QALCL is the most likely mechanisms to resolve this conflict. The predictions of interest do not rely on the concentration of contaminants, but the total mass flux. Therefore, we suggest that this near-surface model structural error is unlikely to have a significant effect on the assessment of lost seepage from the Bendigo Ophir Gold Project.
9. Overall model heads follow the topography and the topographic effects become more muted with depth.
10. The model predicts two primary discharge areas for the deep schist system to Shepherds Creek: (Figure 7.1). One in the upper catchment upstream of Jean Creek (“Drained TSF/SHELF”), and a second in the lower catchment below point 795 (“Main Discharge”). The upper discharge area falls within the proposed TSF and SHELF, while the lower discharge area falls within the proposed SHFILL. There is substantial uncertainty over the precise location and magnitude of these discharge areas, and the model does over-predict the fluxes in the lower catchment, but the general location of these discharge areas is likely to be correct. Note there is a discharge area (“Undrained TSF”) in the upper catchment of the proposed TSF, which does not fall within the proposed TSF underdrainage area.
11. We developed a posterior suite of deep model realisations to use in the coupled seepage model. This suite of models was selected based on both goodness of fit (objective function minimisation) and coverage of likely values for the model parameters. The suite provides good coverage of the potential impacts of the deep schist system on the likelihood and magnitude of lost seepage from the Bendigo Ophir Gold Project.

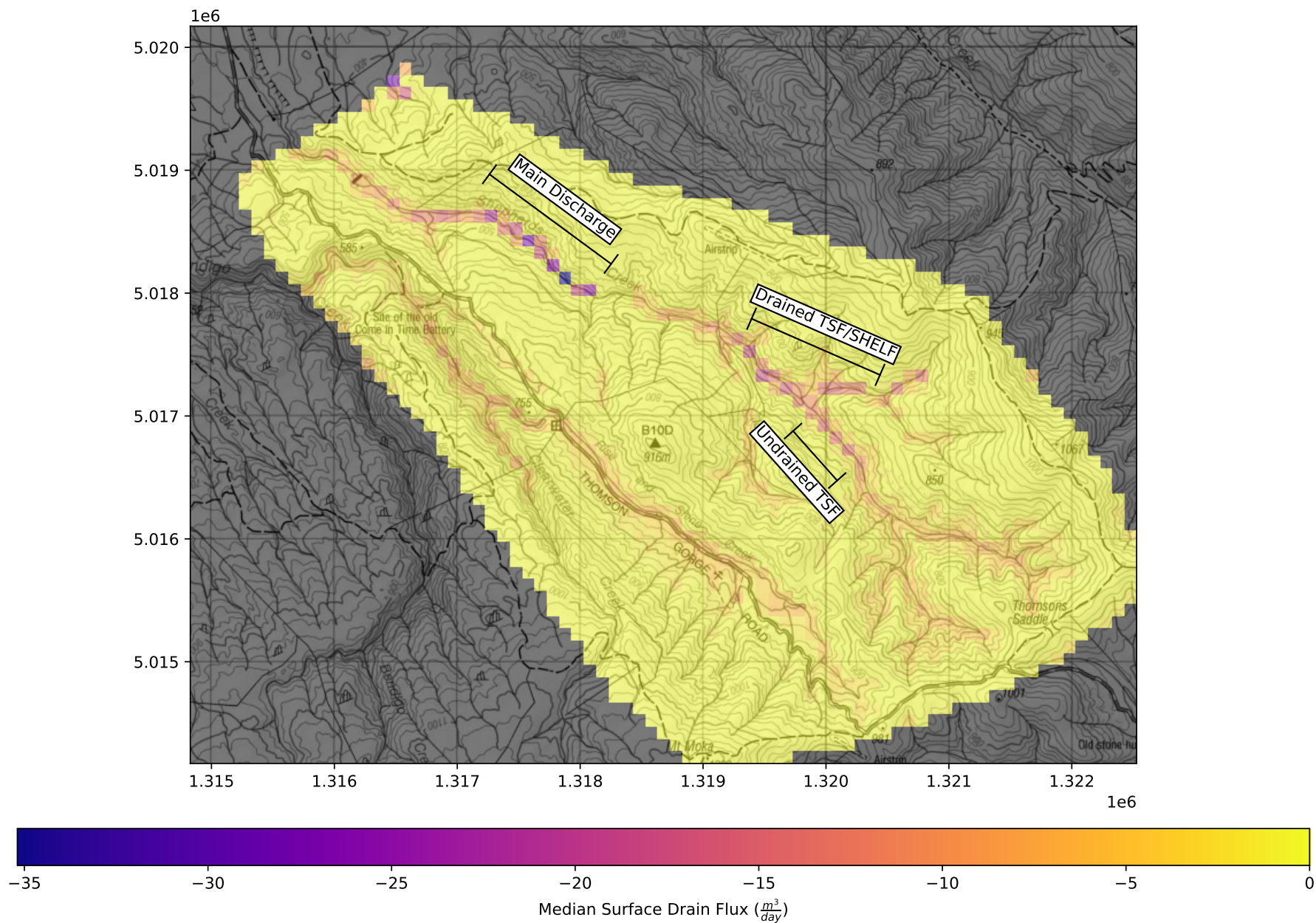


Figure 7.1: Predicted deep system discharge areas
 Negative flux values indicate discharge from the deep schist system to the shallow system / surface water.

8 Assessments of Prediction of Interest

8.1 Seepage Sensitivity Analysis

The first prediction of interest is to understand the drivers and sensitivity of seepage from the TSF, SHELF, and SHFILL lost to the environment. By understanding these drivers, we can ensure that the design of the TSF, SHELF, and SHFILL accommodates the potential for lost seepage.

Section F.2 provides a detailed description of the sensitivity analysis undertaken on the coupled model suite to assess the sensitivity and drivers of potential lost seepage from the TSF, SHELF, and SHFILL. The key drivers of lost seepage from the TSF are the TSF underdrainage, the conductivity of the TSF material and QALCL and the recharge to the TSF. This suggests that the dominant driver of TSF lost seepage is the head in the TSF, which is predominantly driven by the recharge to the TSF. The key drivers of lost seepage from the SHELF are the presence or absence of SHFILL underdrainage, the effectiveness of the SHELF drains (as defined by the SHELF drain elevation invert), and the conductivity of the weathered schist in the area of the SUMP. The key drivers of lost seepage from the SHFILL are the presence or absence of SHFILL underdrainage and to a lesser extent the conductivity of the SHFILL material and QALCL.

These results highlight the importance of the SHFILL underdrainage in reducing the potential for lost seepage from the SHFILL. The SHFILL area also acts as a discharge point for the deeper schist system. The combination of discharge from the deeper system and underdrainage of the SHFILL effectively forces much of the seepage lost from the primary TSF and SHELF systems to be effectively captured by the SHFILL underdrainage system. Additionally, the results highlight the need to ensure that the weathered schist in the area of the SUMP is sufficiently low conductivity to reduce the potential for lost seepage from the SHELF. Removal of much of the weathered schist is already planned under the SUMP (Zou and Carter, 2025), which will likely reduce the potential for lost seepage from the SHELF. Development and implementation of a robust construction and field-testing/QA procedures will provide confidence that this is achieved.

8.2 Potential for Contaminated Seepage

The assessment of the potential for the loss of contaminated seepage from the TSF, SHELF, and SHFILL is described in detail in Section F.1 and Section F.3.1. This assessment includes a large raw stochastic suite of model realisations that preferentially attempts to either minimise or maximise the potential for lost seepage from the TSF, SHELF, and SHFILL. The purpose of this work was to understand the likely drivers of seepage loss rather than providing predictions of the likelihood of losses. This raw assessment is likely to yield unrealistically high estimates of lost seepage, including unrealistic parameter combinations. Therefore, we have further refined the assessment by filtering the raw stochastic suite to remove unrealistic parameter combinations and/or place additional design constraints on the TSF, SHELF, and SHFILL to reduce the potential for lost seepage. The result is a robust assessment of the likely lost seepage from the TSF, SHELF, and SHFILL with a high level of confidence that mis-parametrisation of the model is unlikely to underestimate the potential for lost seepage.

The model is a very conservative assessment of the potential for lost seepage from the TSF, SHELF, and SHFILL for several reasons. The model is undertaken as a pseudo-steady-state contaminant transport model. This means that the sources are assumed to produce constant leaching loads over a nearly indefinite period of time. It also means that there is no consideration of the respective flow paths and the relative travel times. Seepage leached through the shallow system (e.g., QALCL and weathered schist) will likely have travel times on the order of years to 10s of years (Burgess, 2026). Seepage travelling through the deeper schist system will likely have travel times on the order of upper 10s of years to 100s of years. For reference the time period used in the modelling to achieve steady state is approximately 1000 years. Note that the contaminant velocity also depends on the porosity, which, because the assessment is based on pseudo-steady-state, was defined to ensure numerical stability rather than representing the best estimate of the porosity. Additionally, the model assumes conservative transport of contaminants. In reality there is potential for attenuation, sorption, and other transformations that may reduce the true contaminant load. Finally, the model is undertaken on a gross contaminant mass load basis, which prevents any dilution effects from mitigating the potential consequences

of lost seepage.

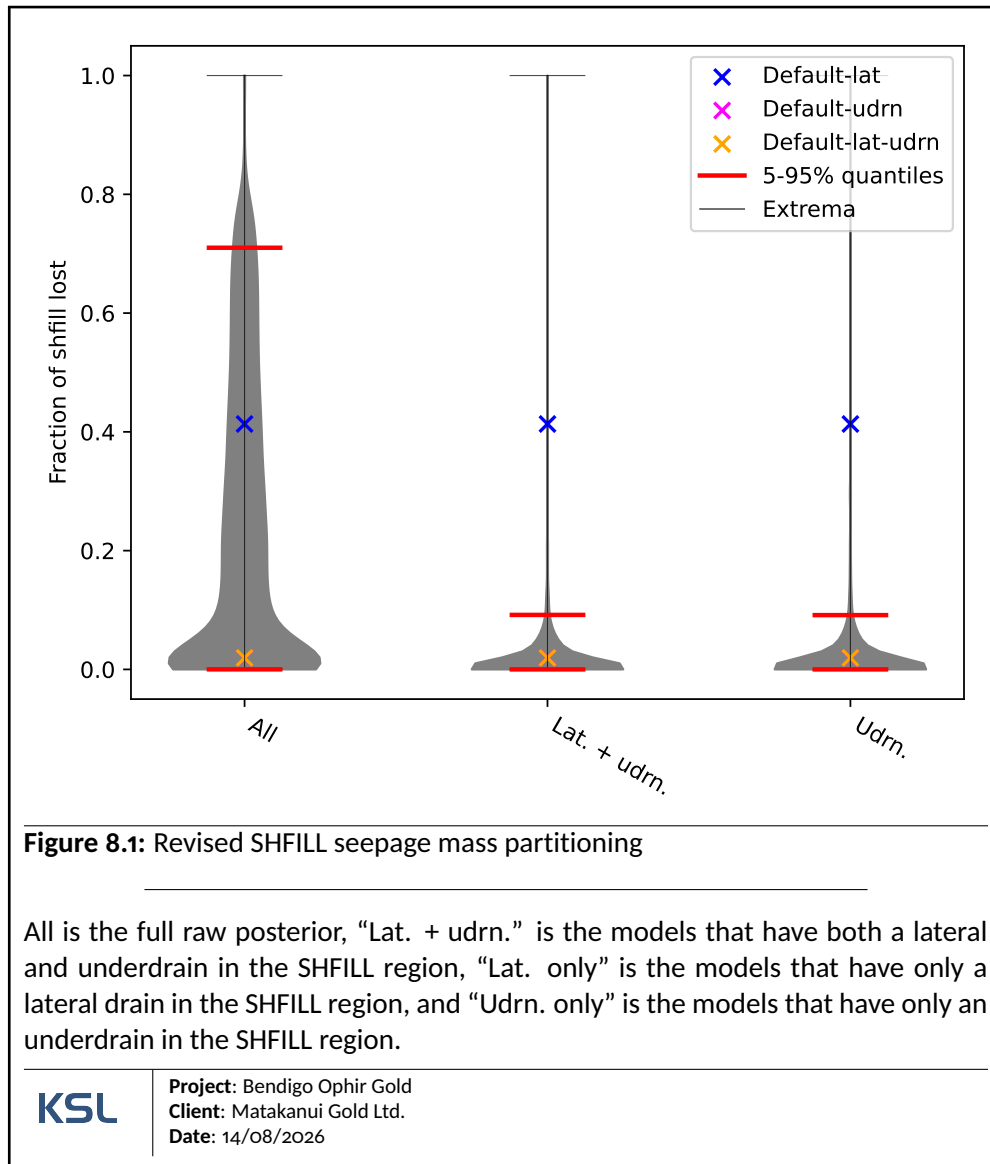
The raw stochastic suite of coupled models was able to find parametrisations with significant lost seepage from each source. To reiterate, these results are likely to be unrealistic and significantly overestimate the potential for lost seepage. Importantly, the raw results suggest that the dominant receiving environment for lost seepage is the shallow system within Dunstan Mountains in the Shepherds Creek catchment. There are minimal realisations that yield significant lost seepage to the deep schist system. Therefore, assuming an adequate monitoring regime, we can conclude that even if the very unlikely scenario which yields significant lost seepage were to arise, it will almost certainly be detected in the shallow system and/or surface water system in the Shepherds Creek catchment. We suggest that the risk of undetected lost seepage entering the Ardour Aquifer and Lindis River at meaningful levels is very low.

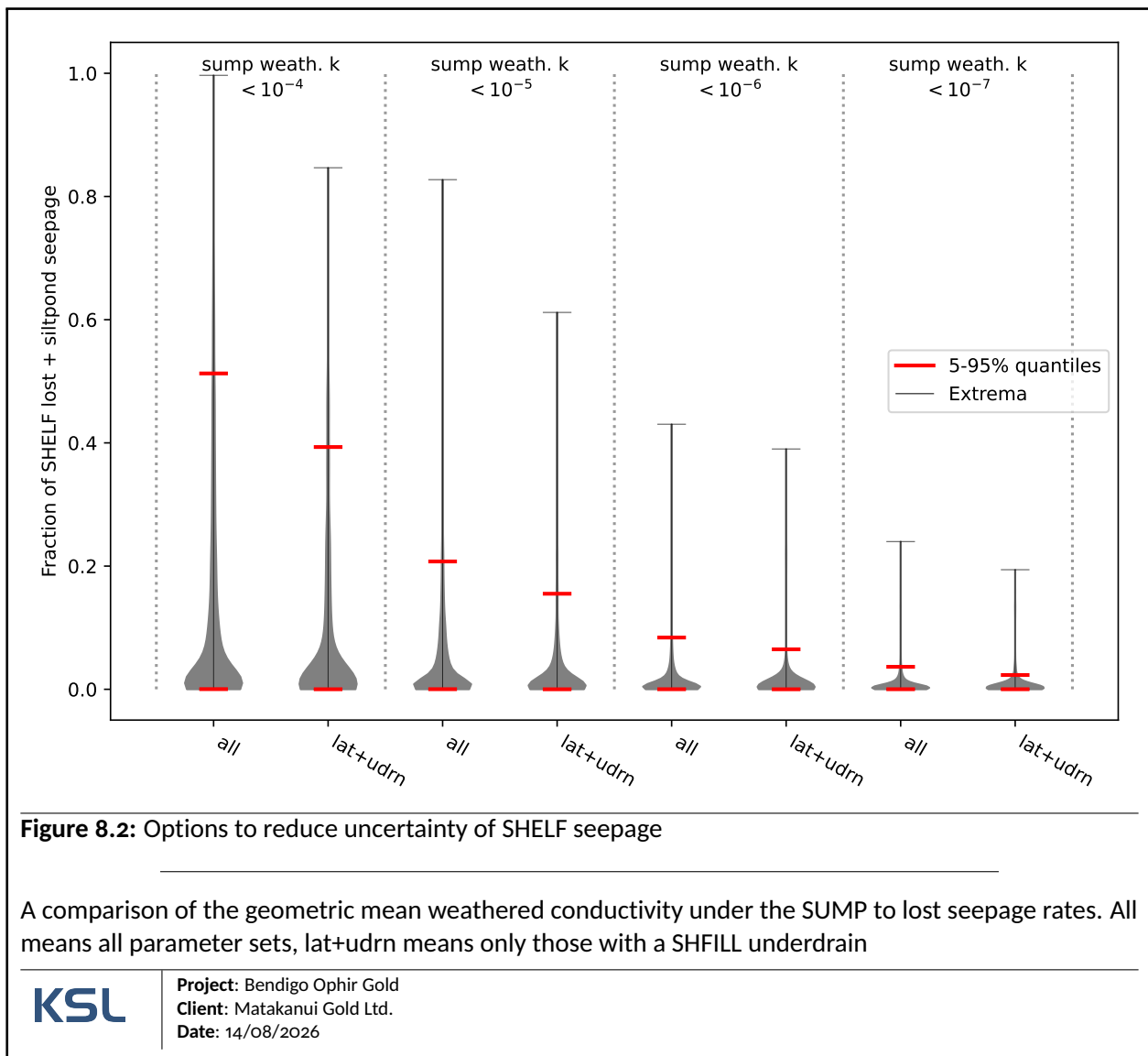
We then undertook subsequent analysis to refine the raw stochastic suite of predictions into a more realistic assessment of the likely lost seepage from the SHFILL, SHELF, and TSF. This assessment ensures that the predictions of likely lost seepage is robust, defensible, and not subject to contradictory parameter combinations. For example very high recharge in combination with very low conductivity is a contradictory parameter combination. If low conductivity exists, then excess recharge is likely to be refused and not infiltrate into the system.

For the SHFILL, the model predicts significant seepage if the SHFILL is not adequately underdrained (Figure 8.1). Where adequate underdrainage is implemented, the model predicts that the likely lost seepage from the SHFILL is < 10% (95th percentile), with most models suggesting < 5%. This highlights the importance of the SHFILL underdrainage in reducing the potential for lost seepage from the SHFILL. The underdrainage was implemented as explicit DRN (Drain Boundary Condition) features in the model, but a similar effect may also be achieved with a more conductive base layer in the SHFILL. Design of the underdrainage system is beyond the scope of this study, but it is clear that adequate underdrainage is essential to reduce the potential for lost seepage from the SHFILL.

Seepage from the SHELF was significant in the raw stochastic suite (Figure 8.2). This was primarily driven by the presence of high conductivity weathered schist in the area of the SUMP in some of the deep model realisations. This area was poorly constrained in the deep model inversion, but yielded significant effects. During the construction of the SUMP much of the weathered schist will be removed, which will significantly reduce the conductivity of the weathered schist in this area. If values are less than 10^{-6} m/s, which is more consistent with the existing testing in the area, then the likely lost seepage from the SHELF is < 9% (95th percentile), with most models suggesting < 5%. Inclusion of the SHFILL underdrainage also provides an additional mechanism to capture seepage from the SHELF (reducing the 95th percentile to 7%). Further reductions in the conductivity of the weathered schist further reduces the potential for lost seepage from the SHELF to 95th percentile values as low as 3%. Care should be taken during the construction of the SUMP to ensure that the bulk conductivity of the weathered schist is reduced to less than 10^{-6} m/s.

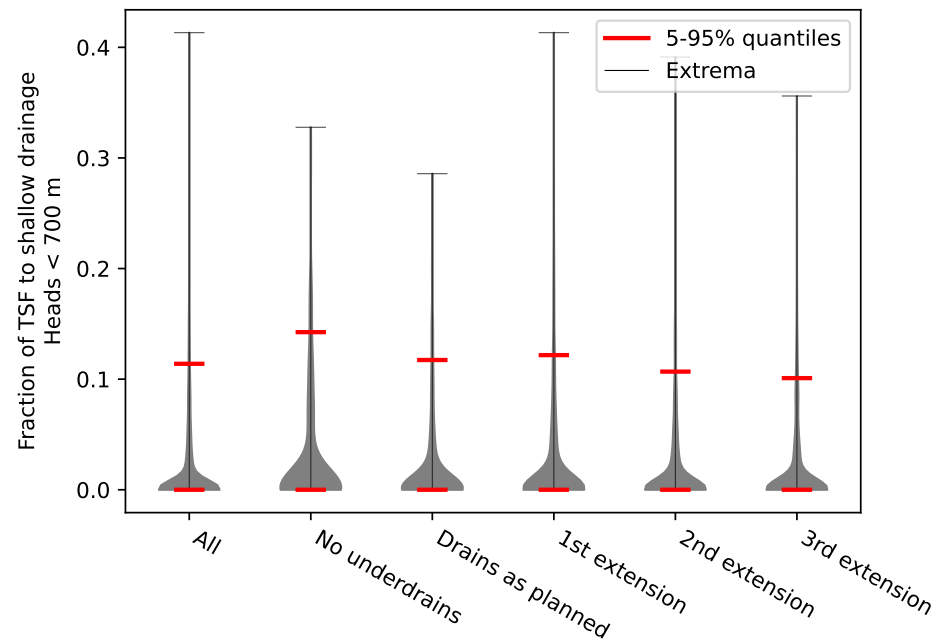
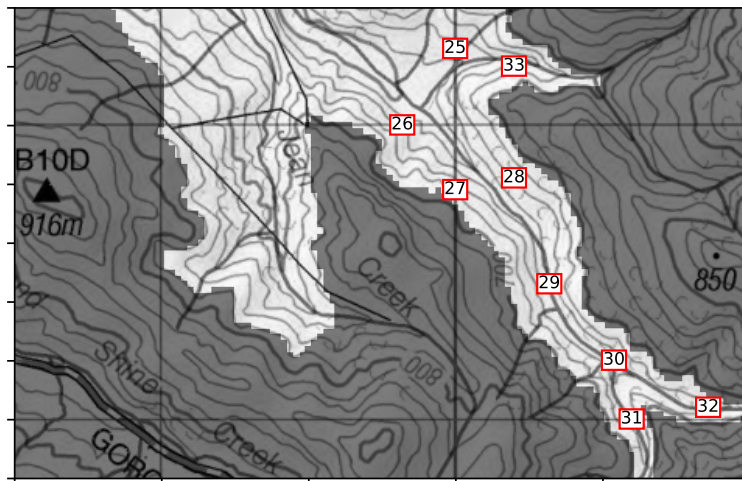
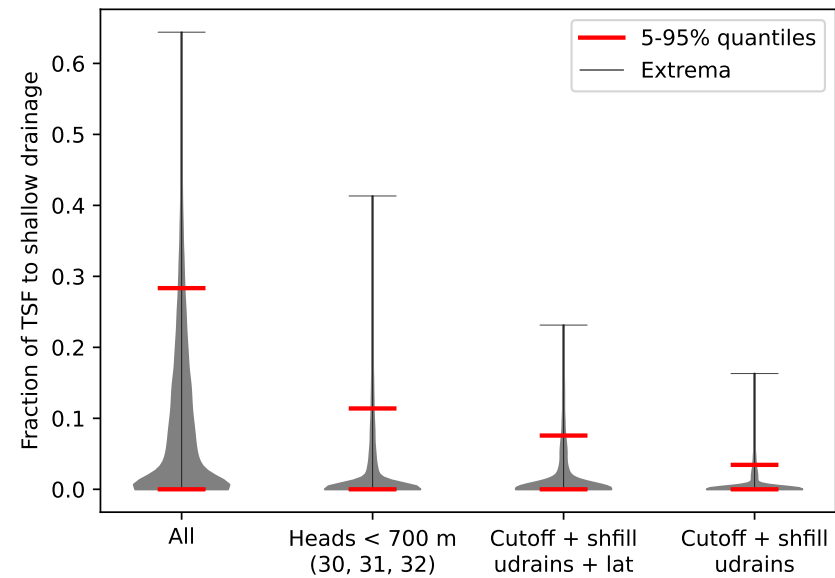
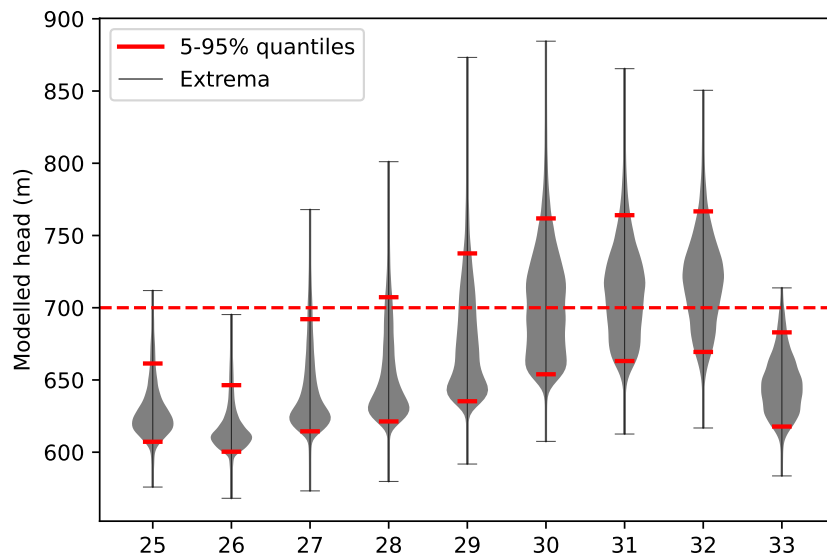
Finally, the TSF showed significant lost seepage in the raw stochastic suite. This was primarily driven by high recharge to the TSF in combination with low conductivity of the TSF material and QALCL. This yielded unreasonably high heads in the TSF and therefore significant lost seepage. The sensitivity analysis provides confidence that the driver of these high heads is the recharge and conductivity interaction rather than larger scale discharge from the deeper schist system. We undertook a filtering assessment to remove model realisations with the unreasonably high heads (Figure 8.3). Filtering the raw stochastic suite to remove any model the predicted heads in the upper TSF above 700 m (10 m above the top of the TSF) significantly reduced the potential for lost seepage with a 95th percentile of 12%. After the filtering, the effects of expanded underdrainage in the TSF were assessed (Figure 8.3 bottom right). The expanded underdrainage was not found to affect the TSF seepage in the filtered suite, however the expanded underdrainage did provide another mechanism to reduce the heads in the upper TSF. The deep model predicts a major discharge area in the upper TSF area. Expanding the underdrainage in this area to ensure that heads are only driven by infiltration rather than deep schist discharge may be beneficial. Including the SHFILL underdrainage provided a further mechanism to capture “lost” seepage from the TSF, which reduced the 95th percentile to 8%. Approximately half of the seepage lost in the underdrained SHFILL was captured by the lateral SHFILL drains. The lateral drains are a numerical representa-





tion of discharge from the steep slopes adjacent to the SHFILL and are not a physical feature of the design. It is likely that some of this seepage would infiltrate into the SHFILL and be captured by the underdrainage system. Where discharge in the SHFILL area is only allowed into the underdrains (i.e., no lateral drains), the 95th percentile lost seepage from the TSF is 4%. Given these simplifying assumptions, we suggest that a reasonable upper limit for the likely lost seepage from the TSF is less than 8%, but greater than 4%. This estimate assumes that the SHFILL is adequately underdrained. Note that most model realisations suggest lost seepage from the TSF is < 3%.

An overview of the revised distributions of lost seepage from the TSF, SHELF, and SHFILL is provided in [Figure 8.4](#). Note that there are still some model realisations that yield lost seepage beyond the 95th percentile figures discussed above. We suggest that these represent very unlikely combinations of parameters and/or unrealistic parameter combinations and are exceptionally unlikely to occur in reality. Further investigation of these parameter combinations could be undertaken as part of the final implementation and build of the TSF, SHELF, and SHFILL, but we suggest that the current assessment provides a robust and conservative assessment of the likely lost seepage from the Bendigo Ophir Gold Project.



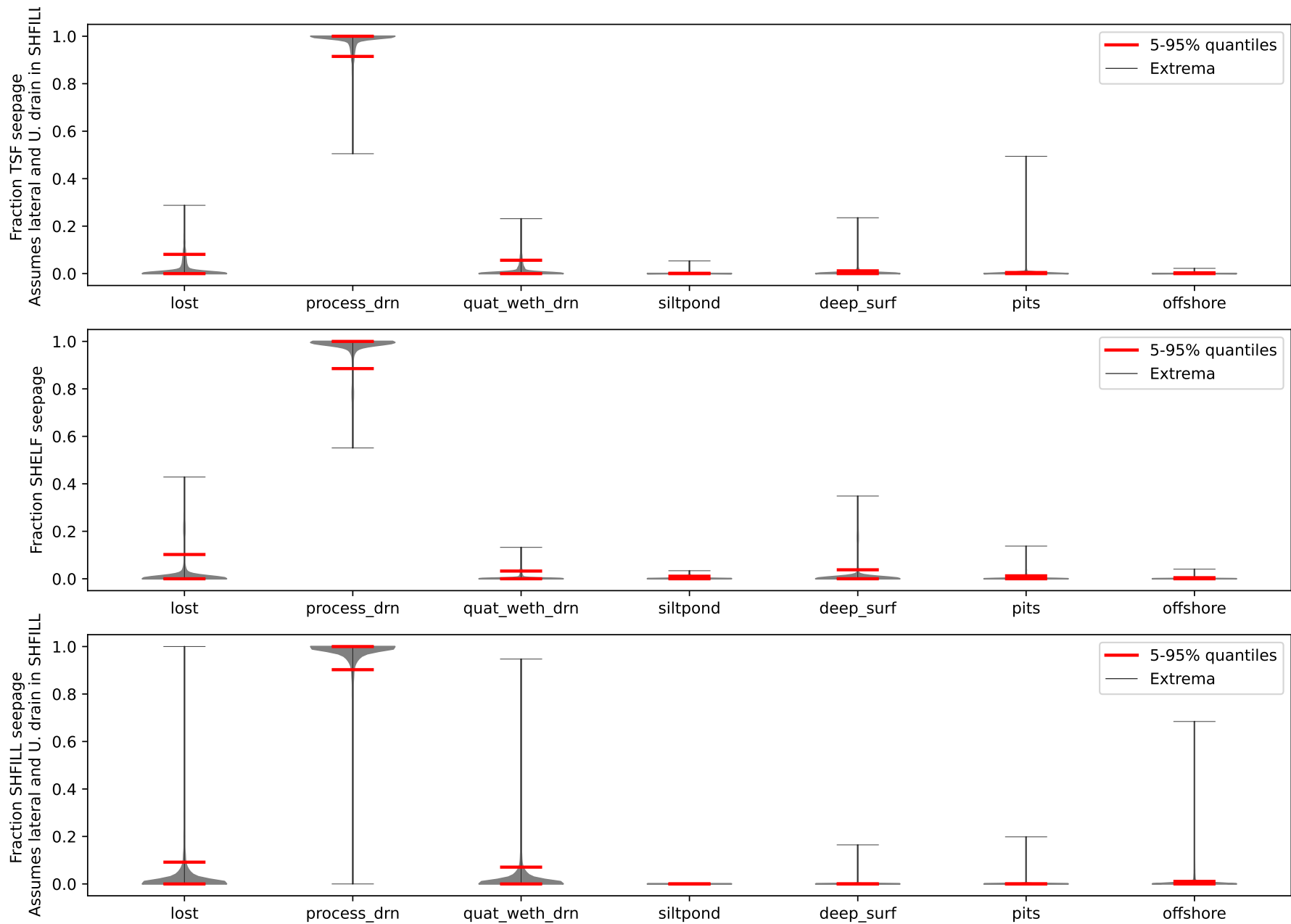


Figure 8.4: Overall revised seepage estimates
 The distributions shown assume both lateral and underdrain seepage in the SHFILL and that the weathered rock conductivity in under and adjacent to the Sump is $< 10^{-6}$ m/s

8.3 RAS Pit and Underground Dewatering Effects

The final prediction of interest is to assess the potential effects of the RAS pit and underground dewatering on the potential for lost seepage from the TSF, SHELF, and SHFILL. The concern is that dewatering in the RAS pit and underground workings may reduce the heads in the deep schist system, which in turn could induce a greater proportion of seepage to be lost to the deep schist system or to underflow the seepage capture systems. Figure 8.5 shows the sensitivity of lost seepage to the `deep_sim_type` parameter, which controls the dewatering of the deep schist system. Sensitivity is measured here both with a Spearman rank correlation coefficient and a random forest importance metric. Note that the random forest importance metric is a non-linear measure of sensitivity and the sensitivity of all parameters sums to one. For more information on the sensitivity analysis methods see Section E.1. Dewatering of the RAS pit and underground workings has minimal sensitivity to the lost seepage discharging to most receptors. Exceptions include discharge to the RAS pit/underground and the “offshore” system for all sources, and the discharge to the deep model surface drains for the SHFILL source. Here the `deep_sim_type` parameter has a maximum importance of 0.05, which is still relatively low.

There are positive correlations between the `deep_sim_type` and the sensitive receptors. This makes sense as the `deep_sim_type`=1 is flooded to 490, while `deep_sim_type`=2 is fully dewatered. From this we can conclude that dewatering of the RAS pit and underground workings is likely to have an effect on the quantity of lost seepage to the RAS pit, and OFFSHORE system, but these receptors represent a very small proportion of the total lost seepage (see Figure 8.4). Therefore, we suggest that dewatering of the RAS pit and underground workings is unlikely to have a significant effect on the potential for lost seepage from the Bendigo Ophir Gold Project.

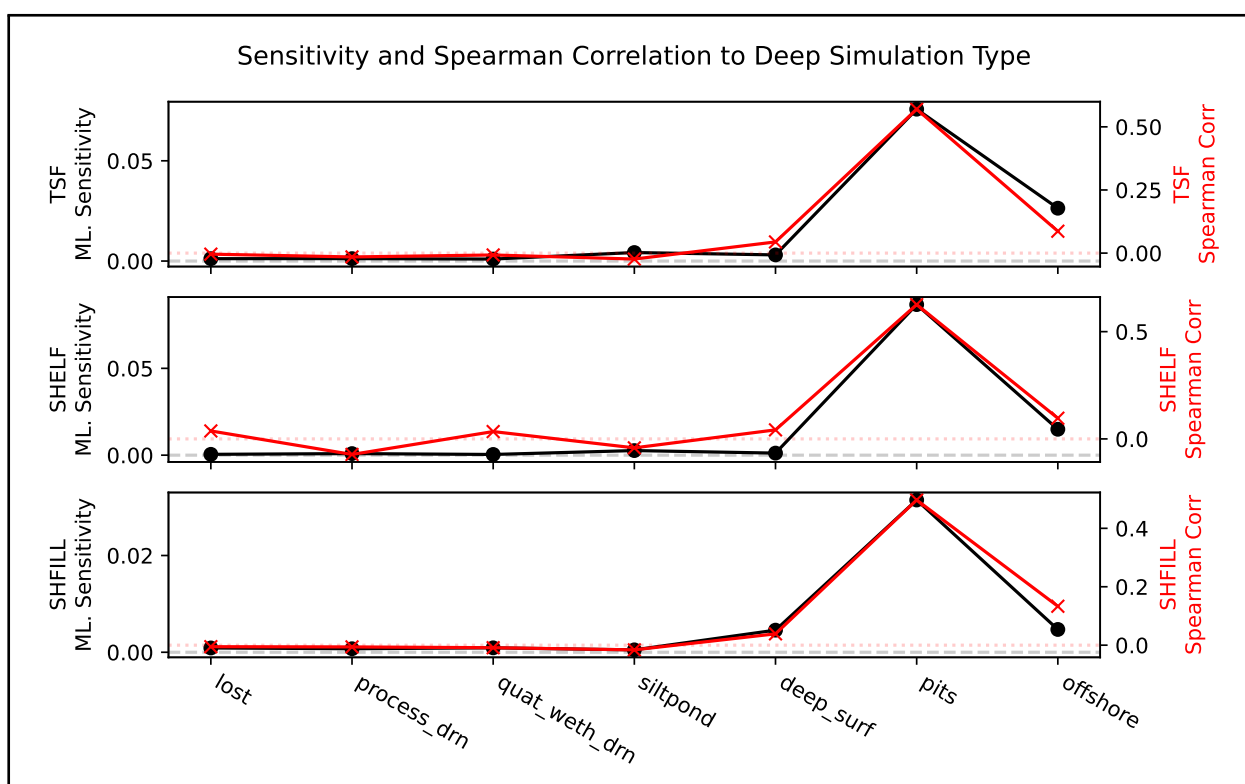


Figure 8.5: Sensitivity of seepage loss to `deep_sim_type`

Red lines show the Spearman Correlation, while black lines show the random forest importance. `deep_sim_type`=1 is flooded to 490, while `deep_sim_type`=2 is fully dewatered.

9 Conclusions and Recommendations

We have undertaken a detailed hydrogeological assessment of the Bendigo Ophir Gold Project site, focusing on the potential for lost seepage from the TSF, SHELF, and SHFILL features. The assessment included a high-resolution 3D groundwater model of the near-surface environment coupled to an optimised deep groundwater model of the schist system. The model inversion of the deep model was able to replicate the observed heads and upper catchment fluxes, but tended to over-predict the lower catchment (SCO1) fluxes. Further refinement of the near-surface system may allow for better replication of the lower catchment fluxes, but the deep model provides a sufficient representation of the schist system to assess the potential for lost seepage. The over-prediction of the lower catchment fluxes is unlikely to substantially affect the mass partitioning between the shallow and deep systems, and the excess water is not material as our assessment of lost seepage is based on a contaminant mass balance rather than predicted concentrations.

We assessed the mass partitioning of lost seepage from the TSF, SHELF, and SHFILL features between the shallow receiving environment, the deep schist system, and the PROCESS water management system. The modelling approach pared a large stochastic suite of coupled models with further subsequent refinement of the stochastic suite. The refinement was required to remove unrealistic parameter combinations and/or to reduce uncertainty by including additional design criteria. The modelling suggests that the dominant receiving environment for seepage not captured by the PROCESS water management system is the shallow groundwater system and surface water system in the Shepherds Creek catchment. This ensures that any lost seepage is very likely to be detected by the planned monitoring network, and that the potential for lost seepage to the deep schist system is low.

The revised stochastic suite suggests several key design criteria to minimise the potential for lost seepage from the TSF, SHELF, and SHFILL features:

1. Ensure that the SHFILL is adequately underdrained to prevent upward seepage from the deeper schist system. This has the additional benefit of creating a second capture zone for any lost seepage from the TSF and SHELF.
2. Ensure that the area of weathered schist under the SUMP is modified to ensure a conductivity of less than 10^{-6} m/s (geometric mean), ideally less than 10^{-7} . This is consistent with the existing plans to remove much of the weathered schist, but this work highlights the importance of this design criterion.
3. Consider the extension of the underdrainage system in the TSF to the upper TSF deep discharge zone. This intervention did not substantially affect the likely lost seepage from the TSF in the modelled results, but it may be prudent to ensure that heads in the TSF are primarily due to infiltration rather than deep groundwater discharge.

If these design criteria (excepting extension of the underdrainage system in the TSF) are implemented, the modelling suggests that the likely upper limit for lost seepage is between 4% and 8% for the TSF, less than 9% for the SHELF, and less than 10% for the SHFILL (95th percentile). Most model realisations suggest lower values of lost seepage; less than 3% for the TSF, less than 5% for the SHELF, and less than 5% for the SHFILL. There are some model realisations with higher lost seepage in the stochastic suite. Not all of these realisations have been evaluated for realism, but they are considered to be very unlikely. Although further investigation of these outliers could be undertaken as part of the design criteria refinement, we suggest that their likelihood is very low and that they are not considered to be a material risk to the project. Overall the modelling suggests that the potential for lost seepage is low, and that should it occur in excess of the likely limits presented above, it is very likely to be detected by the planned monitoring network.

10 Limitations

There are a number of limitations to the modelling and assessment undertaken in this report; they include:

- The model scope components detailed in [Section 5](#). As discussed in that section, we do not believe that these limitations should materially affect the conclusions of this report.

- The model assumes that the groundwater system is bounded by the model domain. Particularly it assumes that groundwater flow does not occur North into Dry Creek, or East into Thomsons Creek. This is a reasonable assumption given the steep topography, the low hydraulic conductivity of the schist, and the observed heads in the area which are consistently higher at ridgelines and lower in the Shepherds Creek valley.
- The model is a simplified representation of the groundwater system, in particular the model cannot replicate the explicit effects of fine scale heterogeneity and/or fracturing within the schist. This is a typical limitation of groundwater models, and the model is considered to be a reasonable representation of the system at the scale of interest.
- The SiltPond is represented as a constant head boundary in the model, this allows for an infinite source of water to the system. This is unlikely to be material as excess flux from the SiltPond in the model is likely to be captured by the PROCESS water management system in the SHFILL. However, this model should not be used to assess water mass balances in the SiltPond.
- The deep model inversion over-predicts the groundwater discharge to the lower catchment (SCO1) by up to 50%. This is likely due to the simplified representation of the surface water system and near-surface sediments (QALCL) in the model. The model should not be used to assess water mass balances in the lower catchment, but this should not affect the conclusions of this report as the assessment of lost seepage is based on a contaminant mass balance rather than predicted concentrations.
- Both models were developed to specifically assess the relative mass partitioning of seepage from the TSF, SHELF, and SHFILL features between the shallow receiving environment, the deep schist system, and the PROCESS water management system. The model has not been developed for other purposes. Any use of the model outside of this scope should be undertaken with caution and with appropriate expert review.

References

- Bryce, L., Hillman, C., Dodge, C., and Wilson, J. (2025). BENDIGO-OPHIR GOLD PROJECT MINE CLOSURE PLAN. Technical Report J-NZO454-002-R-Rev2, Mine Closure Management Pty Ltd. [2](#), [5](#)
- Burgess, R. (2026). BOGP MWSF Seepage Risk Assessment. Technical Report J-H-NZO238-003-M-Revo, Hydro Geochem Group. [8.2](#), [A.4](#)
- Carter, P., Qiu, P., and Torvelainen, E. (2025). SHEPHERDS SILT POND TECHNICAL REPORT. Technical Report EGL Ref: 9702, Engineering Geology Ltd. [2](#), [C.4](#)
- Carter, P. and Torvelainen, E. (2025). PROCESS PLANT, INFRASTRUCTURE, AND ADMINISTRATION AREAS GEOTECHNICAL REPORT. Technical Report EGL Ref: 9702, Engineering Geology Ltd. [2](#)
- Dumont, M. H. (2025). Estimating Land Surface Recharge for Otago. Technical Report Z25001.1, Komanawa Solutions Ltd Science. [A.4](#), [A.4](#)
- Dumont, M. H. and Rekker, J. (2025). Post closure impacts of bendigo ophir gold deposit on the ardour aquifer. Report Z24002.m2, Kōmanawa Solutions Ltd. [5](#)
- Freeze, R. A. and Cherry, J. A. (1979). *Groundwater*. Prentice-Hall, Englewood Cliffs, N.J. [A.4](#), [C.4](#)
- Hope, A. and Torvelainen, E. (2025). SHEPHERDS TAILINGS STORAGE FACILITY TECHNICAL REPORT. Technical Report EGL Ref: 9702, Engineering Geology Ltd. [2](#), [5](#), [C.3](#), [C.4](#), [F.3.1](#)
- Pedregosa, F., Varoquaux, G., Gramfort, A., Michel, V., Thirion, B., Grisel, O., Blondel, M., Prettenhofer, P., Weiss, R., Dubourg, V., Vanderplas, J., Passos, A., Cournapeau, D., Brucher, M., Perrot, M., and Duchesnay, E. (2011). Scikit-learn: Machine learning in Python. *Journal of Machine Learning Research*, 12:2825–2830. [B.1](#)
- Reid, S. and Weber, P. (2026). Water Management Plan - 2026. Technical report, Matakanui Gold Ltd. [2](#)
- Rekker, J. (2025). Bendigo - Ophir Gold Mine Project – Surface Water & Catchment Existing Environment & Effects Assessment. Technical Report Z24002BOG-2, Kōmanawa Solutions Ltd. [2](#), [A.3](#), [2](#), [B.5](#)
- Torvelainen, E. (2026). Statement of Evidence of Eric Torvelainen on behalf of Matakanui Gold Limited in response to Request for Information. [2](#), [C.4](#)
- Turnbull, I., Mortimer, N., and Craw, D. (2001). Textural zones in the haast schist—a reappraisal. *New Zealand Journal of Geology and Geophysics*, 44(1):171–183. [2.1](#)
- Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., Burovski, E., Peterson, P., Weckesser, W., Bright, J., Van Der Walt, S. J., Brett, M., Wilson, J., Millman, K. J., Mayorov, N., Nelson, A. R. J., Jones, E., Kern, R., Larson, E., Carey, C. J., Polat, İ., Feng, Y., Moore, E. W., VanderPlas, J., Laxalde, D., Perktold, J., Cimrman, R., Henriksen, I., Quintero, E. A., Harris, C. R., Archibald, A. M., Ribeiro, A. H., Pedregosa, F., Van Mulbregt, P., SciPy 1.0 Contributors, Vijaykumar, A., Bardelli, A. P., Rothberg, A., Hilboll, A., Kloeckner, A., Scopatz, A., Lee, A., Rokem, A., Woods, C. N., Fulton, C., Masson, C., Häggström, C., Fitzgerald, C., Nicholson, D. A., Hagen, D. R., Pasechnik, D. V., Olivetti, E., Martin, E., Wieser, E., Silva, F., Lenders, F., Wilhelm, F., Young, G., Price, G. A., Ingold, G.-L., Allen, G. E., Lee, G. R., Audren, H., Probst, I., Dietrich, J. P., Silterra, J., Webber, J. T., Slavič, J., Nothman, J., Buchner, J., Kulick, J., Schönberger, J. L., De Miranda Cardoso, J. V., Reimer, J., Harrington, J., Rodríguez, J. L. C., Nunez-Iglesias, J., Kuczynski, J., Tritz, K., Thoma, M., Newville, M., Kümmerer, M., Bolingbroke, M., Tartre, M., Pak, M., Smith, N. J., Nowaczyk, N., Shebanov, N., Pavlyk, O., Brodtkorb, P. A., Lee, P., McGibbon, R. T., Feldbauer, R., Lewis, S., Tygier, S., Sievert, S., Vigna, S., Peterson, S., More, S., Pudlik, T., Oshima, T., Pingel, T. J., Robitaille, T. P., Spura, T., Jones, T. R., Cera, T., Leslie, T., Zito, T., Krauss, T., Upadhyay, U., Halchenko, Y. O., and Vázquez-Baeza, Y. (2020). SciPy 1.0: Fundamental algorithms for scientific computing in Python. *Nature Methods*, 17(3):261–272. [A.4](#), [B.1](#)
- weber, P. (2025). Mine Impacted Water Overview Report. Technical Report J-NZO488-001-R-Revo, Mine Waste Management. [2](#), [C.4](#)

- Zou, J. and Carter, P. (2025). SHEPHERDS, WESTERN, AND SREX ENGINEERED LANDFORMS, AND, COME IN TIME PIT BACKFILL. Technical Report EGL Ref: 9702, Engineering Geology Ltd. [2](#), [5](#), [8.1](#), [C.3](#), [C.4](#)
- Zou, J. and Torvelainen, E. (2026). STREAM AND SURFACE WATER DIVERSIONS LETTER. Technical Report EGL Ref: 9702, Engineering Geology Ltd. [2](#), [5](#)

A Deep Model Build

A.1 Software and Implementation

The deep model is built as a MODFLOW 6 groundwater flow and transport simulation using FloPy.

A.2 Structure and Geometry

The deep domain is represented on a regular 100 m grid with 34 vertical layers. This yields a final model shape of 34 layers by 60 rows by 77 columns.

The layering is a mixture of conceptual unit-based layering (QALCL and weathered schist) and numeric layering. The layers are defined as follows:

- **Layer 1: QALCL:** a consistent 5 m thick layer representing the undifferentiated quaternary cover.
- **Layer 2: Weathered Schist:** a consistent 20 m thick layer representing the weathered schist.
- **Layer >2: TZ-3, TGF, TZ-4 schist:** the remaining layers are broken into arbitrary thickness layers representing fine discretisation of the TGF, TZ-3, and TZ-4 schist. The thickness of the layers is progressive with a minimum thickness of 10 m, and the thickness increasing with depth based on: 10 for total depth > 0 m, 25 for total depth > 100 m, 50 for total depth > 350 m. The layering continues until 200 m elevation is reached. Cells below 200 m elevation are inactive and act as a no-flow boundary condition.

The model domain is shown in [Figure 4.1](#) and [Figure A.1](#). In addition to the Shepherds Creek catchment, the model domain also includes an OFFSHORE area to the Northwest of the catchment. The OFFSHORE area is included to allow for the potential for groundwater to flow out of the catchment and discharge directly to the Ardgour Aquifer and/or Lindis River. A plan view of this area is shown in [Figure A.1](#). The OFFSHORE is not intended to properly represent this portion of the groundwater system. It is a numerical simplification that allows for some seepage to extend beyond the catchment boundary rather than forcing a no-flow boundary and thus forcing all discharge to occur at the surface of the model and in the Shepherds Creek catchment. We have explicitly set the top two layers of the OFFSHORE area to be inactive, which means that no recharge is applied to this area. This was done to ensure that the area can act as only a sink of water and to further highlight that it is a conceptual simplification of the system in this area.

A.3 Boundary Conditions

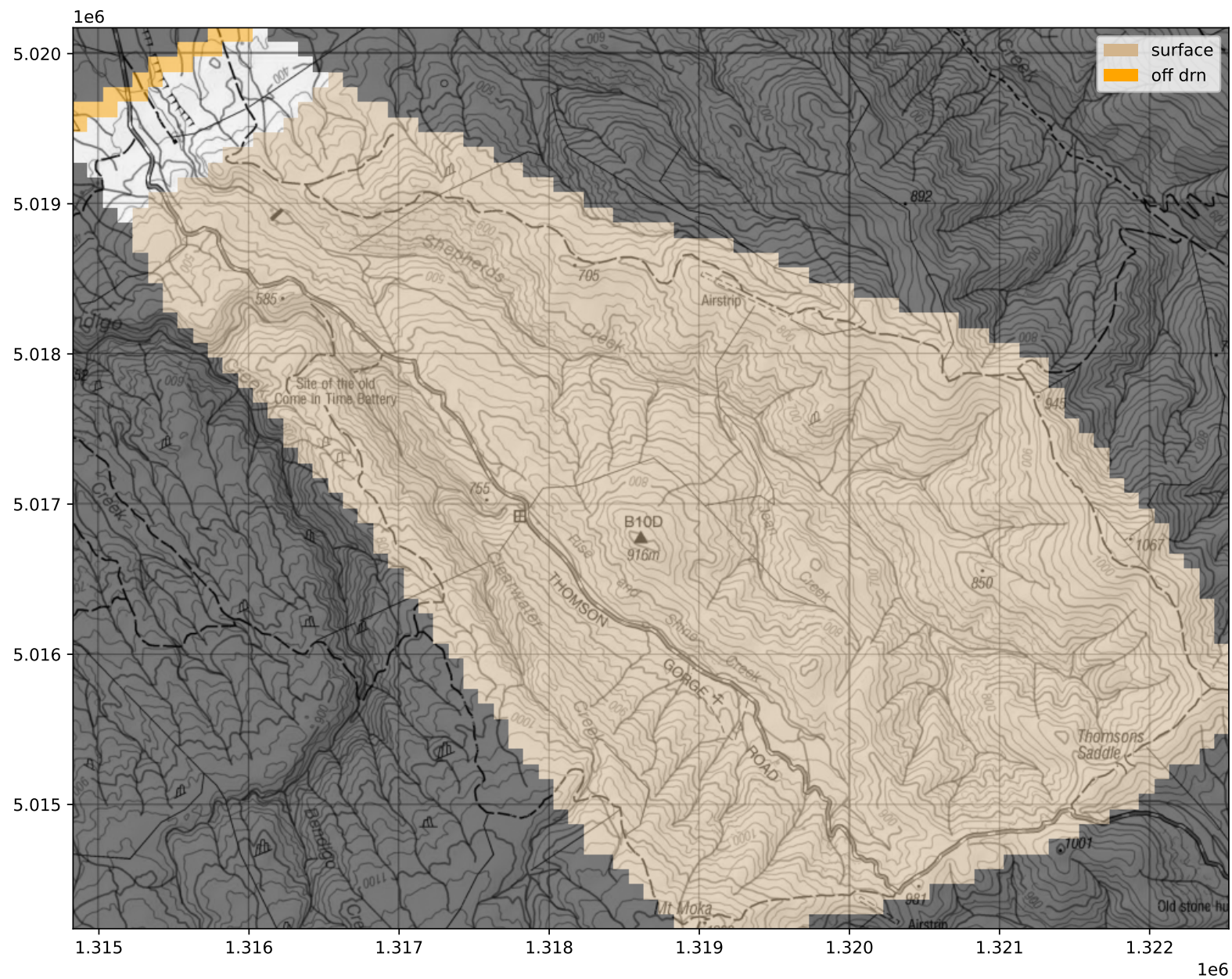
Boundary conditions represent potential inflows and outflows of water from the groundwater system. The deep model uses, at most, three types of boundary conditions: CHB (Constant-Head Boundary), DRN, and RCH (Recharge Boundary Condition). A CHB boundary applies a specified head to the model cell and acts as both a potential source and sink of water. A DRN boundary applies a head-dependent outflow to the model cell and acts as a potential sink of water. Finally, a RCH boundary applies a specified flux of water to the model cell and acts as the dominant source of water to the model domain.

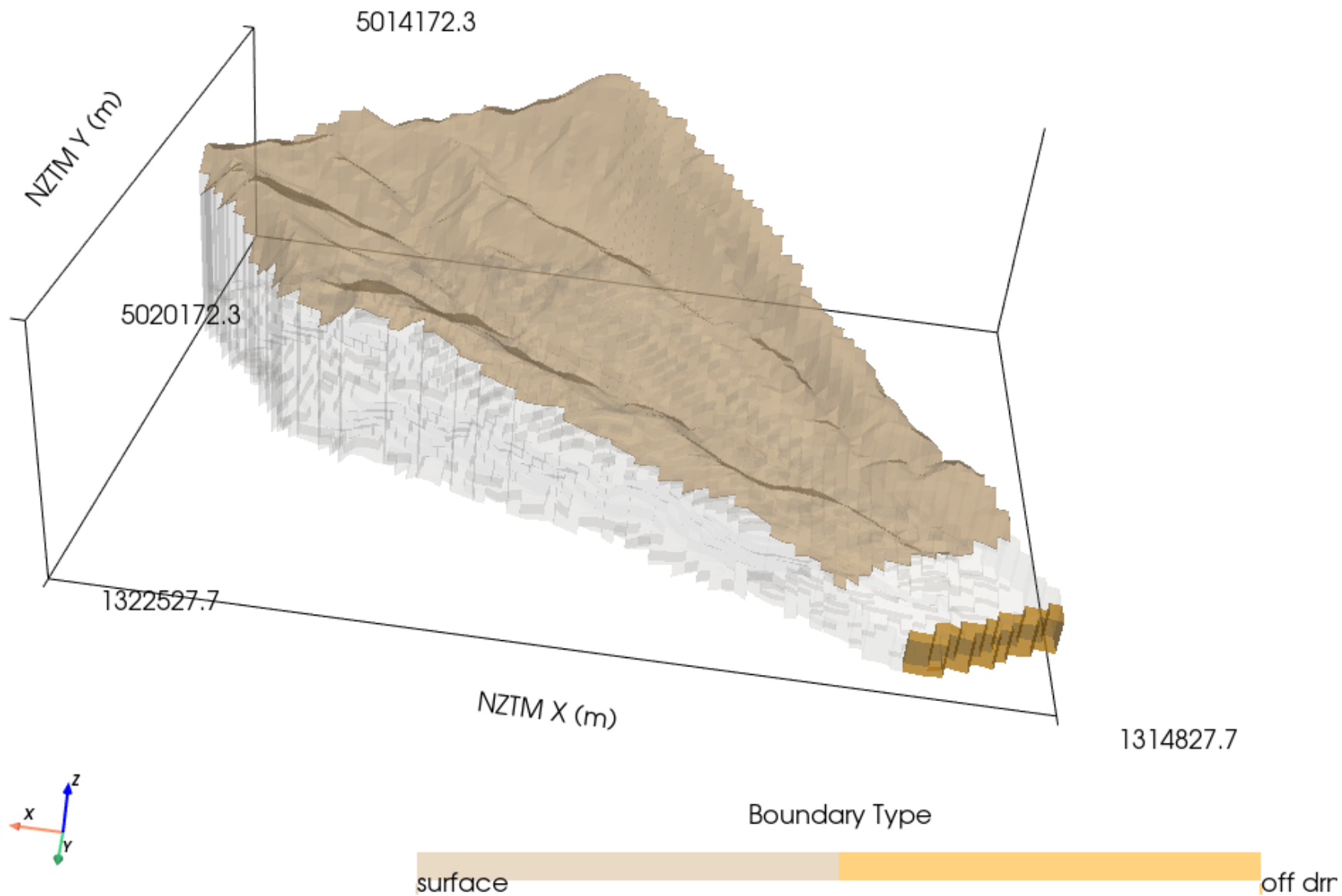
The boundary conditions are applied to the model domain as follows:

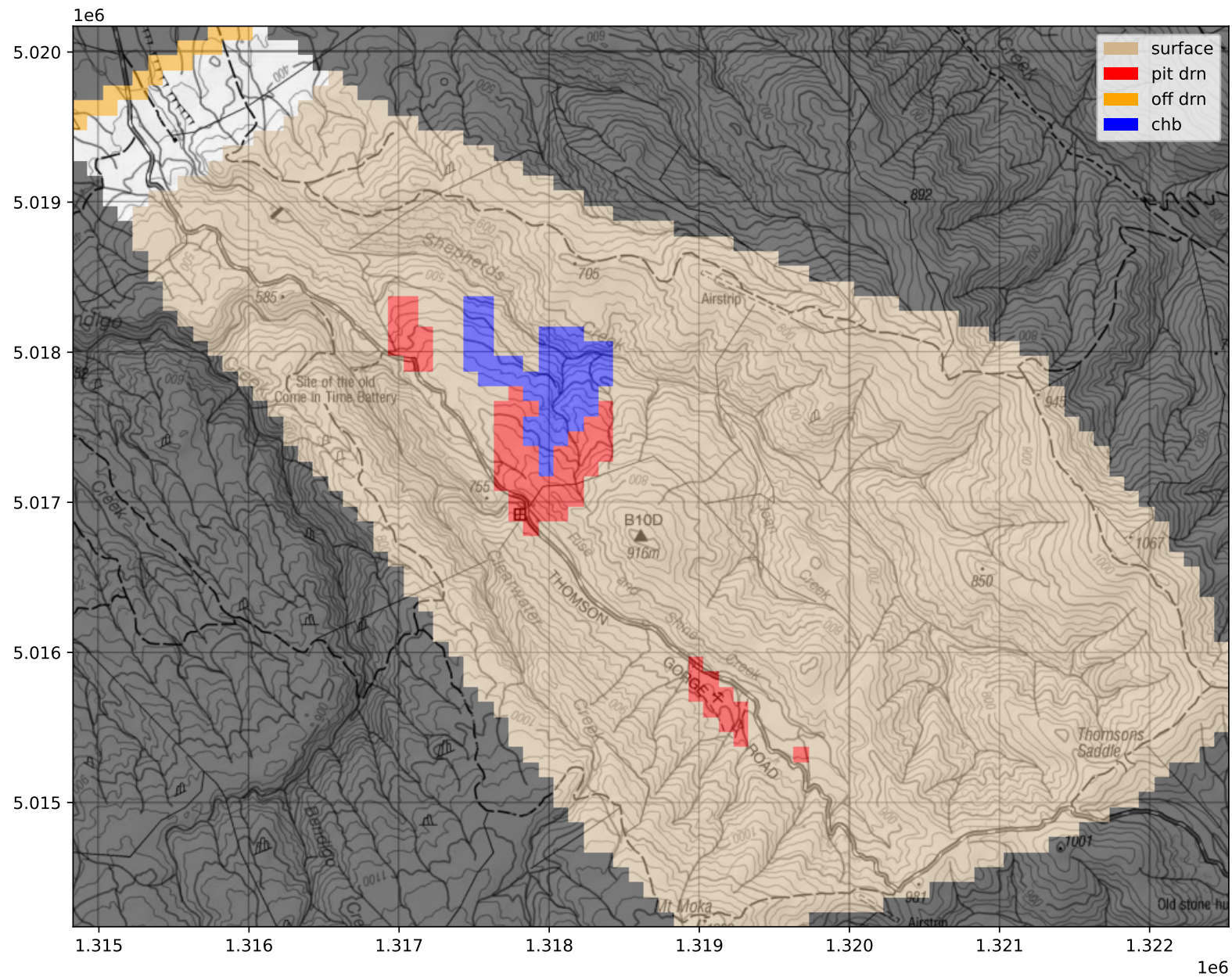
- **Land surface recharge (RCH):** A uniform recharge rate is applied to the top active layer in the model domain (except that of the OFFSHORE area, where no recharge is applied).
- **Surface drainage (DRN):** A head-dependent drainage boundary condition is applied to all active cells in the top layer of the model domain (this excludes the OFFSHORE area). Conceptually, this represents the potential for discharge to surface water features (e.g., Shepherds Creek and its tributaries) and/or the potential for refused recharge leading to runoff, which eventually discharges to surface water features.
- **RAS pit and underground workings (CHB|DRN):** The RAS pit and underground workings (when present) depend on the simulation type. In the pre-mining simulation, no boundary condition is applied to the RAS pit and underground workings. In the during-mining simulation, DRN boundary conditions are applied to all active cells intersected by the RAS pit and underground workings with an invert elevation set at the bottom of the model cell two cells below the boundary cell or the minimum of the excavation in that vertical column. This allows for significant dewatering at each cell, while ensuring the model is numerically stable. In the post-mining simulation, DRN boundary conditions are applied to all active cells intersected by the RAS pit and underground workings with a cell bottom greater than the static water level of the pit and underground workings (490). All other active cells intersected by the RAS pit and underground workings are assigned a CHB boundary condition with a head equal to the static water level of the pit and underground workings (490).
- **CIT and SREX pits (DRN):** Potential discharge and dewatering of the CIT and SREX pits is represented by a head-dependent drainage boundary condition applied at the bottom of the cell 2 layers below or the minimum elevation of the pit in that spatial cell, whichever is higher.
- **OFFSHORE discharge area (DRN):** At the far Northwest end of the “offshore” area, a head-dependent drainage boundary condition is applied to all active cells of the model domain. The invert elevation and conductance of these cells are parameterised relative to the cell top.

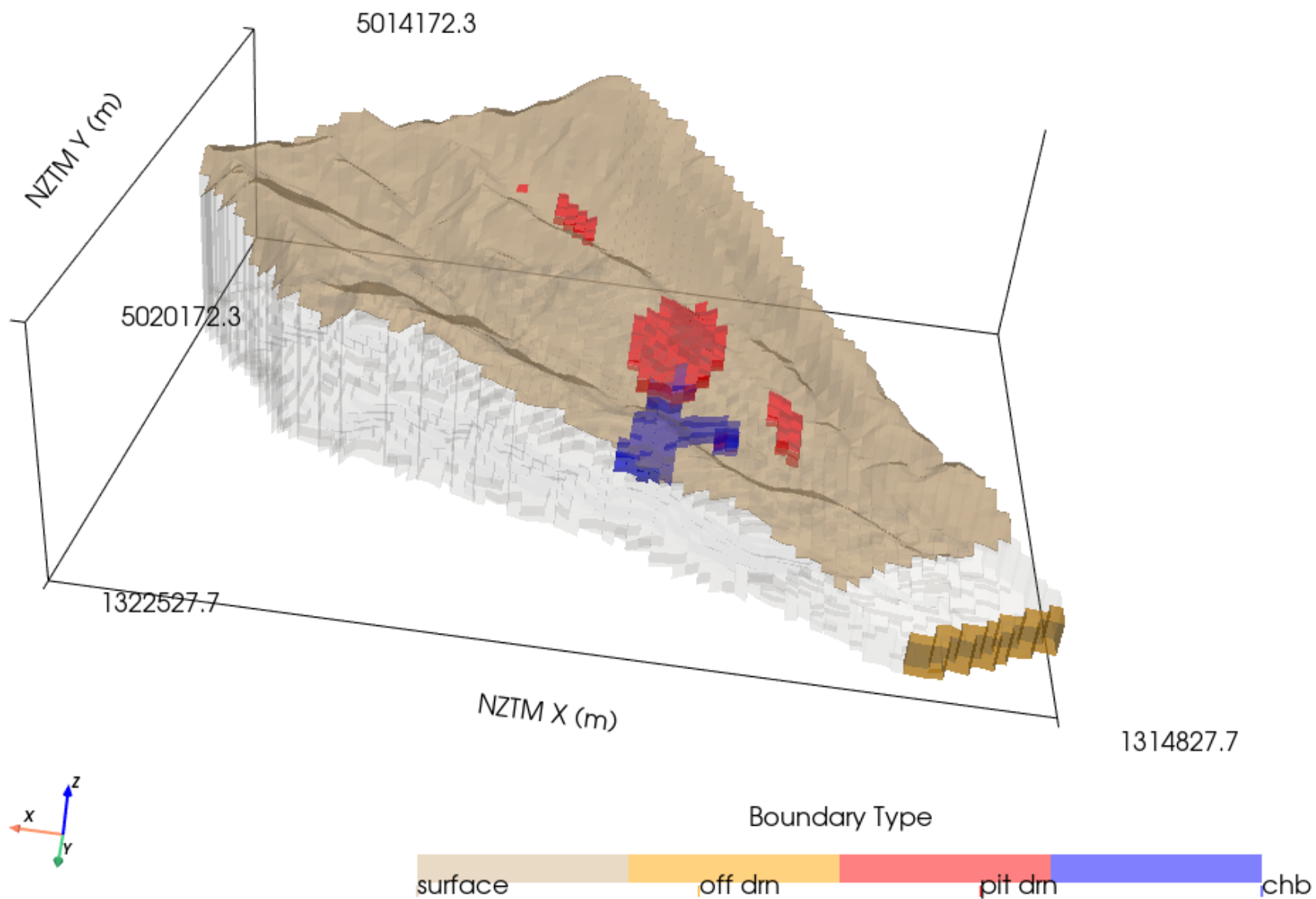
Rekker (2025) found much lower flows in the Jean Creek tributary of Shepherds Creek compared to the flow in the main stem of Shepherds Creek upstream of the Jean Creek confluence. Additionally, far fewer springs were observed on the southern side of Shepherds Creek. This relative difference was attributed to soil, subsoil permeability and moisture retention dynamics, and topographic effects on net rain falling in each part of the catchment (Rekker, 2025). To allow the model to better capture these effects, we have included a spatially parameterised recharge multiplier ($rch = rch_0 \times rch_{spatial}$). The spatial recharge multiplier is defined by 31 pilot points, which are interpolated across the model domain using a radial basis function (RBF) interpolation with a linear kernel. Figure A.8 shows the location of the recharge multiplier pilot points and an example interpolation.

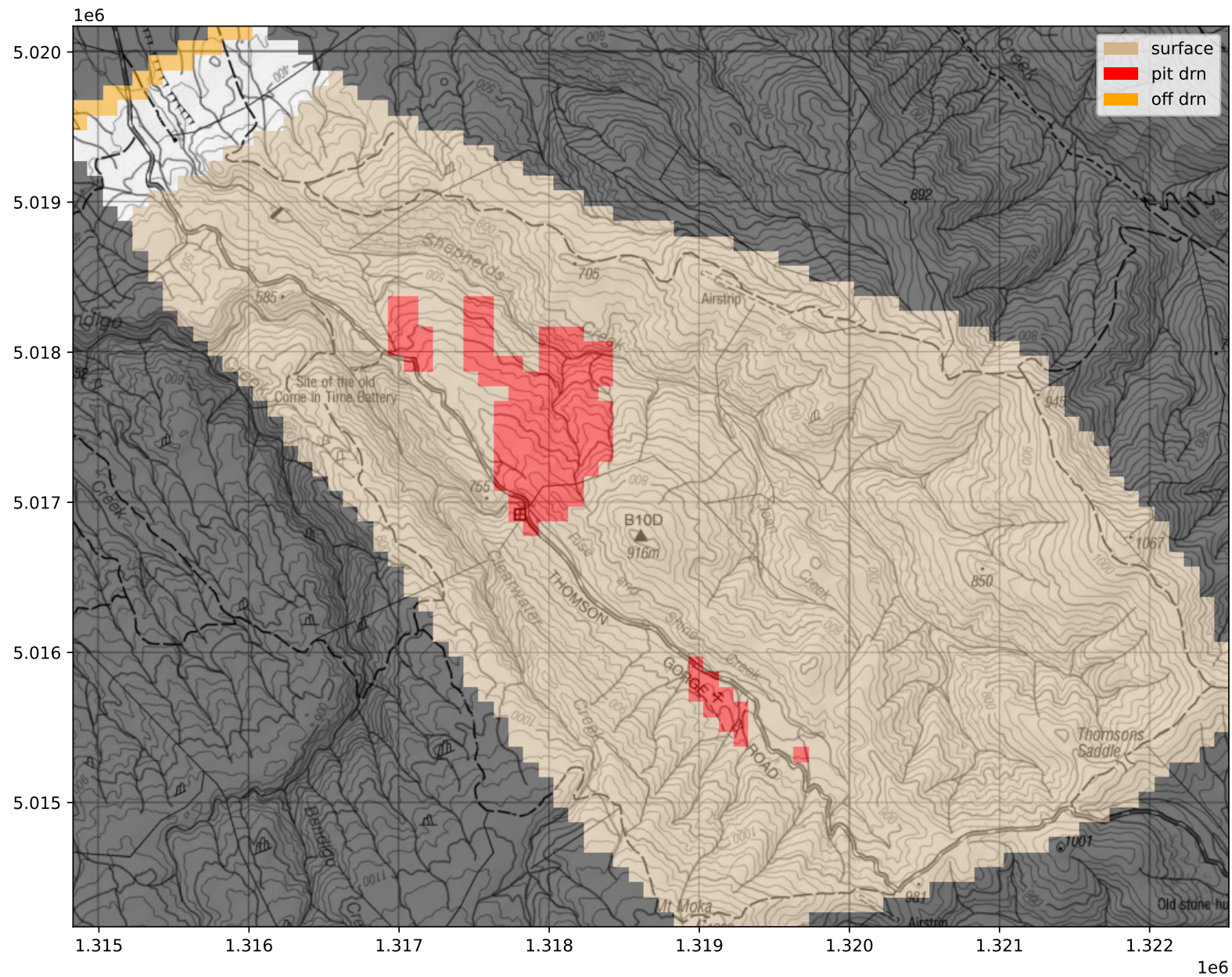
Figure A.2 to Figure A.7 show the 2D and 3D visualisations of the boundary conditions for the pre-mining, post-mining, and during mining simulations.

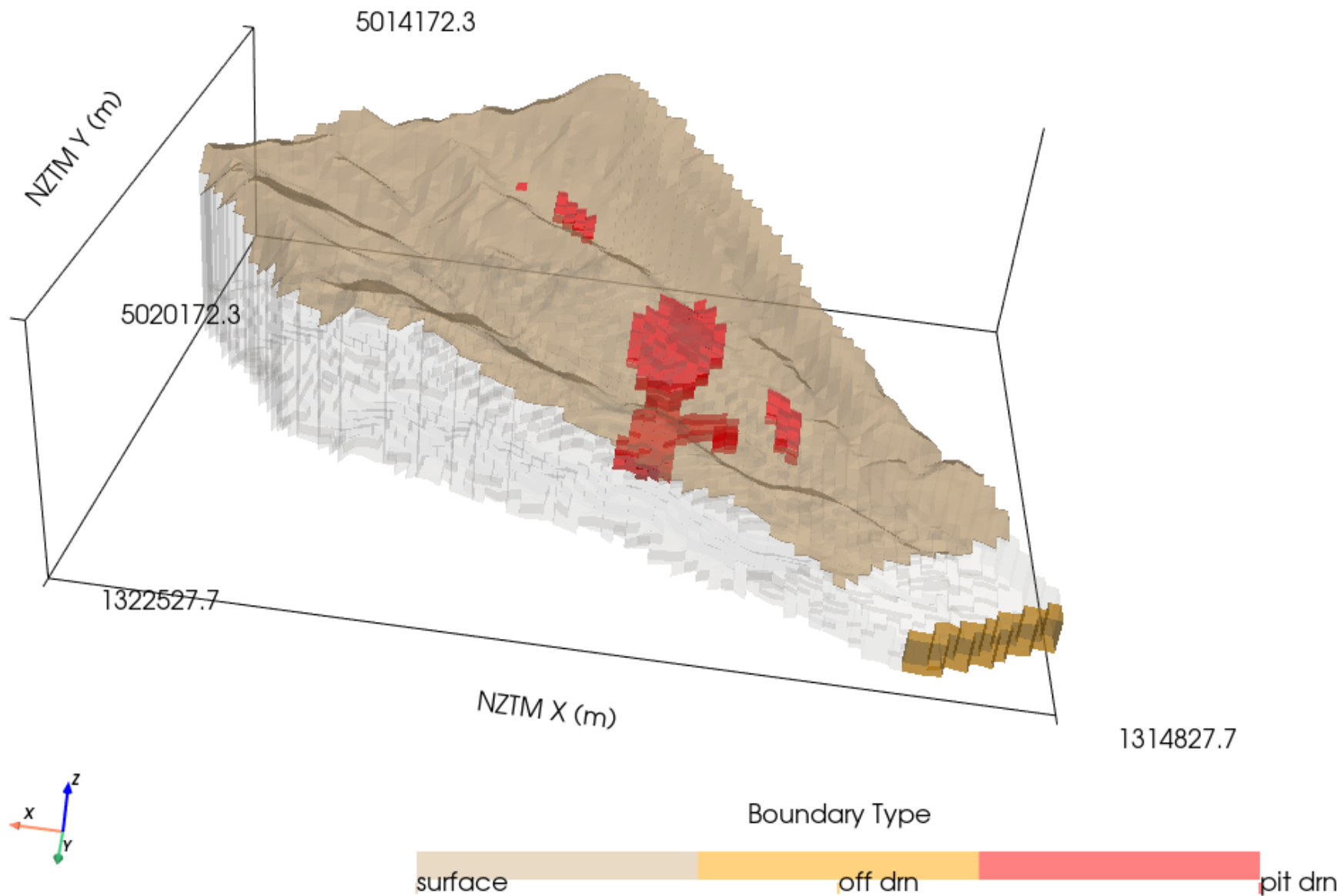












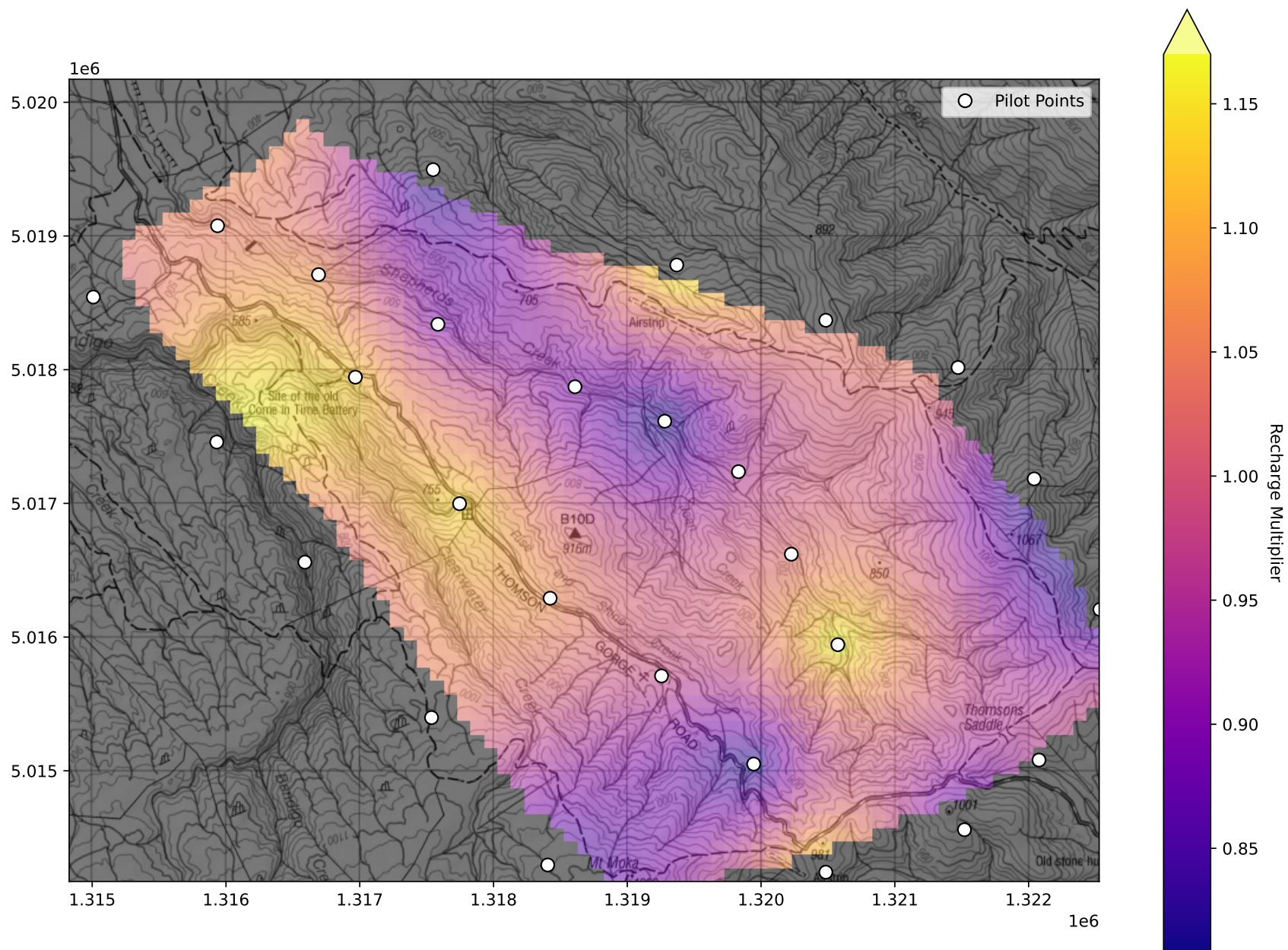


Figure A.8: Recharge multiplier pilot points and example interpolation
 Note the values for the interpolation are randomly selected between 0.8 and 1.2 for the purpose of this example.

A.4 Parameterisation

There are broadly four groups of parameters in the deep model:

- **Boundary Condition Parameters (bnd):** These parameters define the characteristics of the boundary conditions applied to the model, such as conductance and elevation offsets for drains, recharge rates, and heads in constant head boundaries (when present).
- **Hydraulic Conductivity Parameters (kst):** These parameters define the hydraulic conductivity values for different geological units in the model, including the undifferentiated quaternary cover, weathered schist, TGF zone, tz3 schist, and tz4 schist. This group also includes the thickness of the TGF “layer”, which is also parameterised.
- **Anisotropy parameters (vka):** These parameters control the ratio of horizontal to vertical hydraulic conductivity in the model layers ($k_v = k_h/vka$, where k_v is the vertical hydraulic conductivity, k_h is the horizontal hydraulic conductivity, and vka is the anisotropy parameter).
- **Simulation control parameters (sc):** These parameters control simulation settings, currently only `sim_type` exists to control whether the simulation is pre-mining, during mining (full dewatering of the pits and underground workings), or post-mining (where the RAS pit and underground workings are partially flooded (head=490)).

These parameters can either be varied in the optimisation process or frozen to a default value, meaning that their value does not change. A full list of parameters, their ranges, and whether they are frozen or not is provided in [Table A.1](#). The hydraulic conductivity parameters for the TGF, TZ-3, TZ-4, and weathered schist are spatially variable and are interpolated from a set of pilot points using a radial basis function (RBF) interpolation method ([Virtanen et al., 2020](#)) with a linear. The pilot points are distributed spatially in the x and y directions across the model domain ([Figure A.10](#)). For the TGF and weathered schist, the pilot point interpolation occurs in two dimensions; i.e. hydraulic conductivity does not change with depth (see [Figure A.13](#)). For the TZ-3 and TZ-4 schist, the pilot point interpolation occurs in three dimensions, with the pilot points repeated in the vertical direction every 100 and 100meters, respectively. This means that hydraulic conductivity varies spatially in three directions. All interpolation is performed in $\log_{10}$ space, and the interpolated values are exponentiated to return to linear space prior to being applied to the model.

The deeper schist layers (>2) are divided into three zones: TGF, TZ-3, and TZ-4. The definition of these zones is defined relative to the TGF location, which was defined interpolating and extrapolating observed contacts in boreholes.

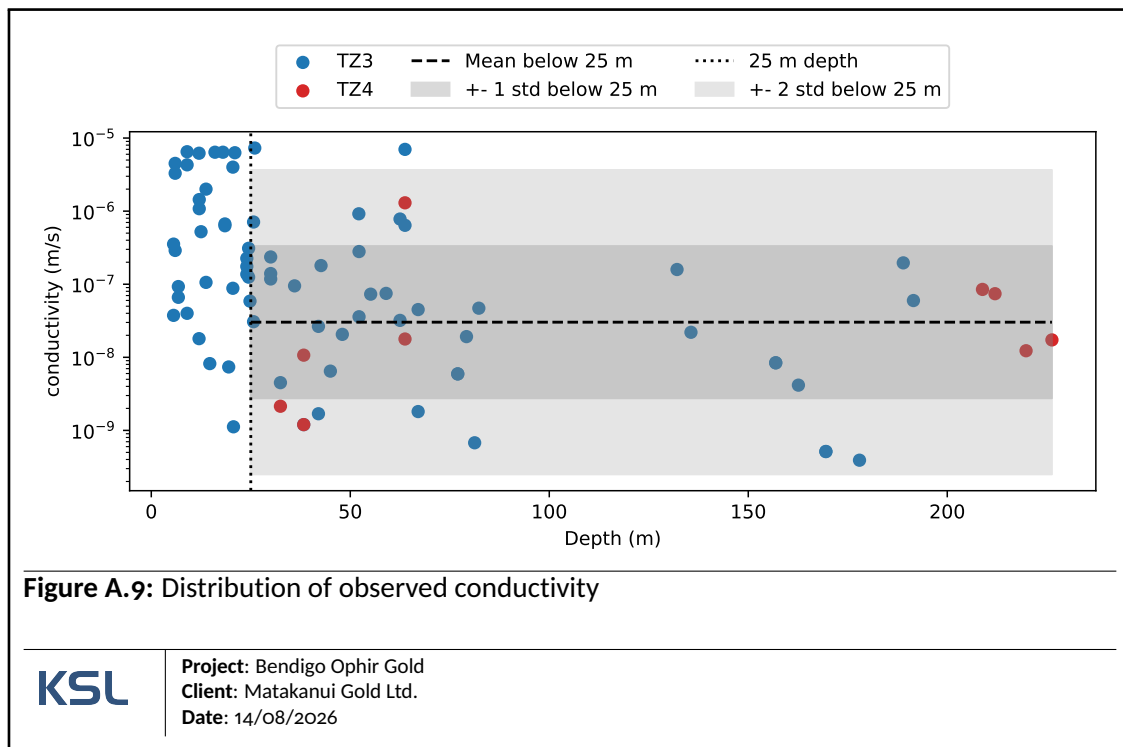
The layer is defined as follows:

$$\begin{cases} TZ3, & \text{if } z > z_{TGF} + \frac{thick_{TGFZ}}{2} \\ TGF, & \text{if } z_{TGF} - \frac{thick_{TGFZ}}{2} \leq z \leq z_{TGF} + \frac{thick_{TGFZ}}{2} \\ TZ4, & \text{if } z < z_{TGF} - \frac{thick_{TGFZ}}{2} \end{cases} \quad (A.1)$$

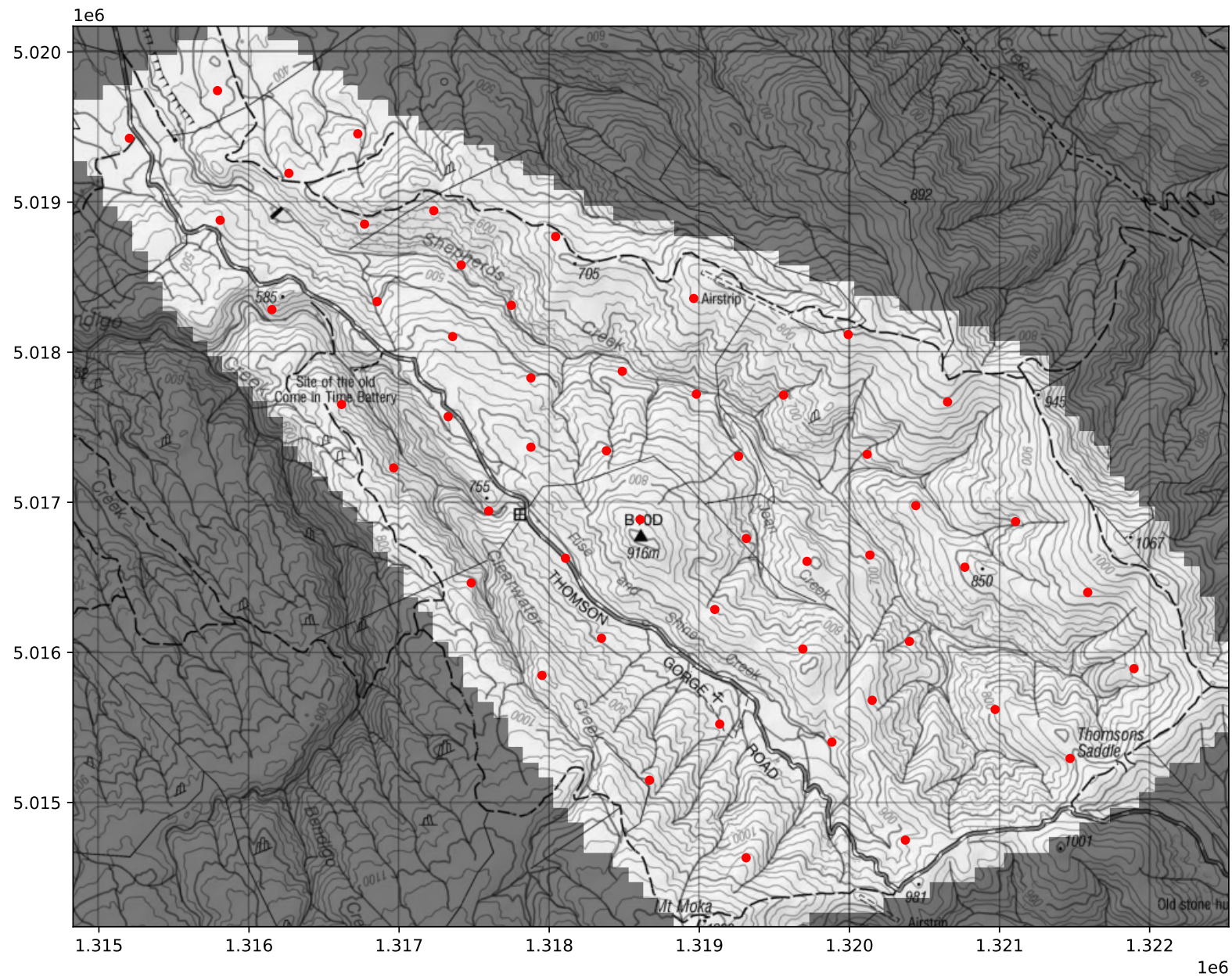
Where z is the cell center elevation, z_{TGF} is the TGF contact elevation for the row and column of the cell, and $thick_{TGFZ}$ is the thickness of the TGF zone (which is a parameter of the model).

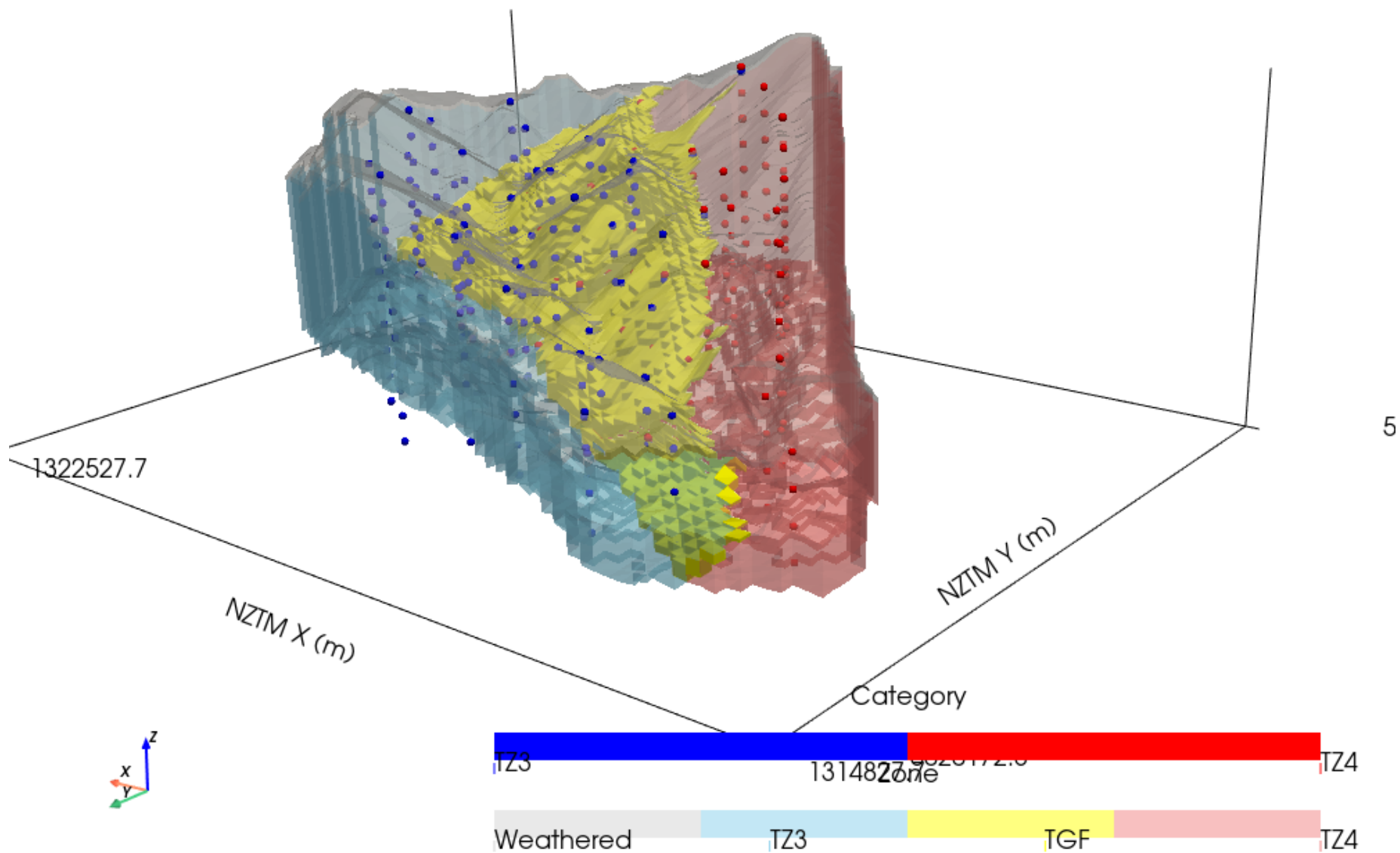
The parameter values of the weathered schist and TZ-3 and TZ-4 are based on the observed distributions of hydraulic conductivity from testing in the catchment ([Figure A.9](#)). We have expanded the parameterisation range beyond those values observed in the catchment to account for the large area of the model domain relative to the area sampled and to allow for compensatory parameterisation where the model contains structural errors and simplifications. As an example of a compensatory parameter for a structural error, if a unit, say QALCL is modelled to be 5 m thick, but in reality it is 10 m thick, then the conductivity of the unit may be optimised to half the “true” value to account for the structural error in the model (i.e., wrong thickness). This is a very simple example, but more complex structural errors and simplifications are likely to exist in the model.

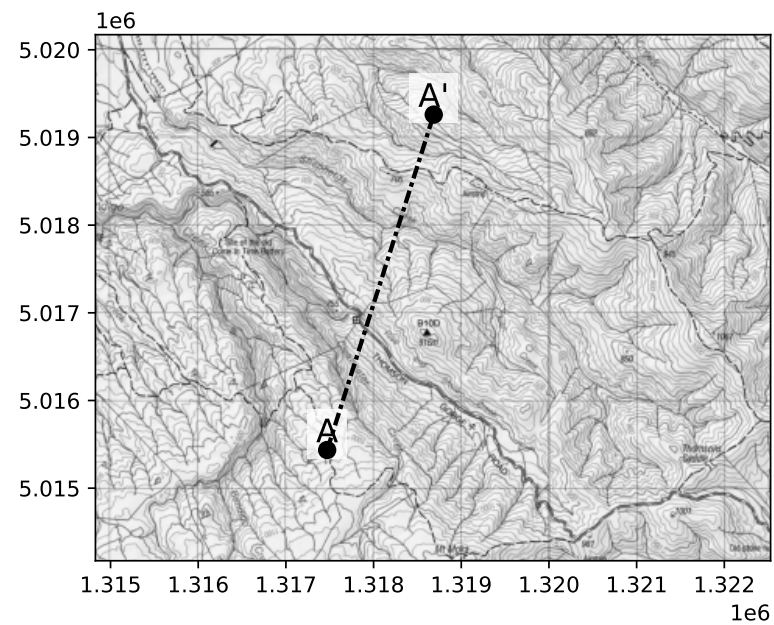
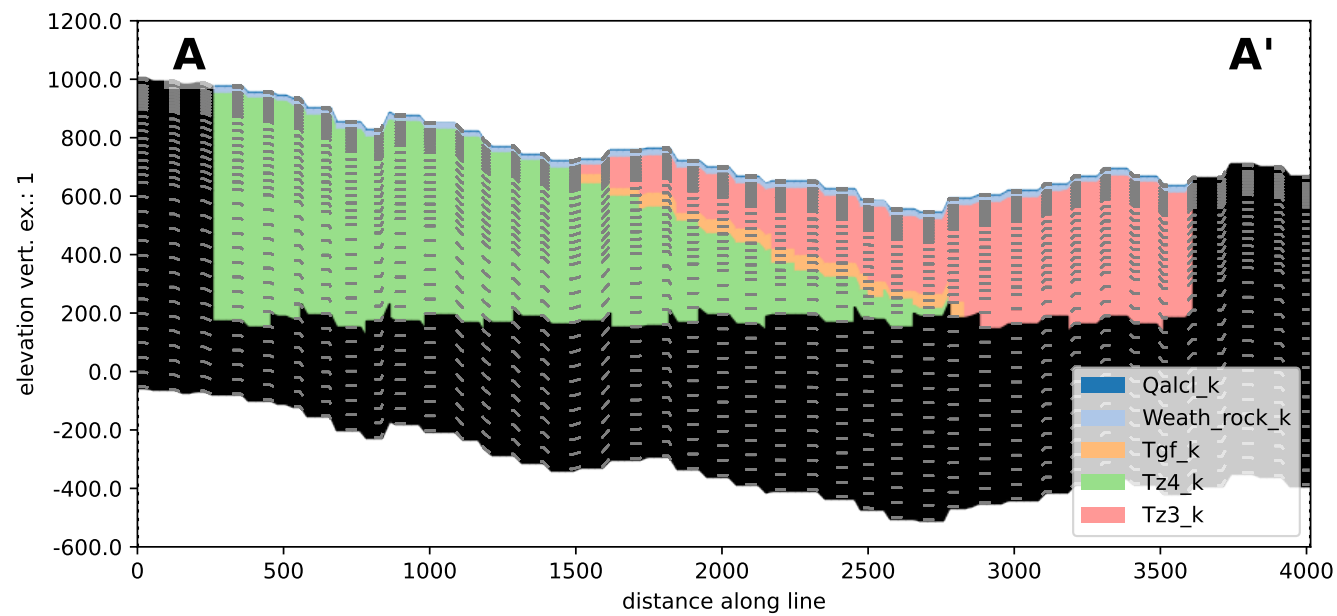
An initial optimisation was undertaken with a much larger range of land surface recharge (54-285 mm/year),



which was based on regional scale recharge estimates for Otago (Dumont, 2025). Initial results showed that the model could replicate the observed groundwater levels with a very high recharge rate (>200 mm/year); however, the model was unable to replicate the observed flows in Shepherds Creek and Rise and Shine Creek with this high recharge rate. Where the optimisation was forced to fit the observed flows at the expense of the observed groundwater levels, the optimisation preferred much lower recharge rates near the lower bound of the recharge parameter. Therefore, the recharge rate was then significantly reduced to its current range (10-70 mm/year) to force the optimisation to find a solution that was more consistent with the observed flows in Shepherds Creek and Rise and Shine Creek. Using a lower range of recharge than that estimated by Dumont (2025) is justified for two key reasons. First, the modelling of Dumont (2025) assumes that near surface soil dynamics are the dominant control on recharge. In this catchment very shallow soils and relatively impermeable weathered schist are likely to create a significant barrier to recharge. Second, the modelling of Dumont (2025) is based on regional to national scale data inputs, which are likely to have inaccuracies at the local scale. We could have increased the weighting of the flow observations in the optimisation process to account for this, but setting the recharge parameterisation to a lower range is a more direct way to ensure that the optimisation process finds a solution that is consistent with the observed flows in Shepherds Creek and Rise and Shine Creek and the observed groundwater levels in the model domain.







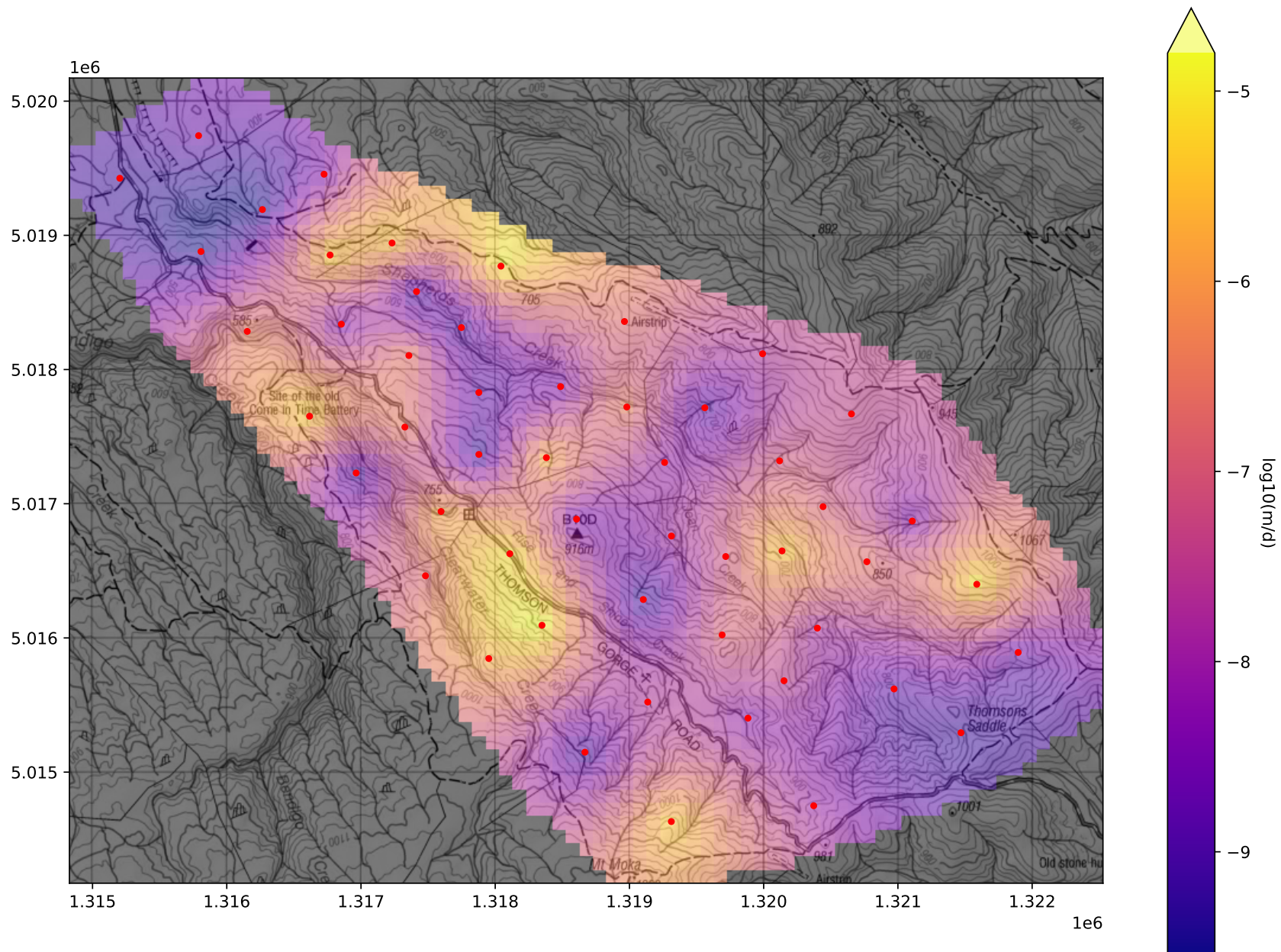


Table A.1: Overview of parameters for the deep model. Frozen values are fixed to the default value.

Parameter	Group	Min	Max	Default	Unit	Distribution	Frozen	Description	Source
off_drn_cond	bnd	-2.0	4.0	3.0	log10(m2/day)	uniform(-2.0 - 4.0)	False	Conductance for OFFSHORE drains, -2 no drns	Set arbitrarily high
off_drn_elev	bnd	-15.0	15.0	0.0	m elv offset from cell top	uniform(-15.0 - 15.0)	False	Invert elev for OFFSHORE drains	Sensitivity parameter
pit_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Conductance for pit drains	Set arbitrarily high
rch	bnd	10.0	70.0	50.0	mm/year	uniform(10.0 - 70.0)	False	Recharge applied to model top	Initially from Dumont (2025) but reduced after partial optimisation
rch_spat(n=31)	bnd	0.8	1.2			uniform	False	Spatial recharge multiplier	Set to allow variation based on slope, aspect, and land cover
surf_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Conductance for surface drains	Set arbitrarily high
qalcl_k	kst	-7.5	-4.0	-5.0	log10(m/s)	uniform(-7.5 - -4.0)	False	K for the undifferentiated quaternary cover	Freeze and Cherry (1979)
tgf_k(n=52)	kst	-8.5	-4.5		log10(m/s)	uniform	False	K values for tgf zone	Range from wreathed schist to tz3/tz4
tgf_thickness	kst	10.0	40.0	15.0	m	uniform(10.0 - 40.0)	False	Thickness of the tgf layer	Informed from bore logs
tz3_k(n=178)	kst	-9.5	-6.0		log10(m/s)	normal(-7.5, 1.0)	False	K values for tz3 schist	Burgess (2026)
tz4_k(n=166)	kst	-9.5	-6.0		log10(m/s)	normal(-7.5, 1.0)	False	K values for tz4 schist	Burgess (2026)
weath_rock_k(n=52)	kst	-9.5	-4.5		log10(m/s)	normal(-5.3, 0.5)	False	Spatially distributed k value for the bulk weathered rock	Burgess (2026)
sim_type	sc	0.0	2.0	0.0		uniform(0 - 2)	True	Identifier for the simulation type: 0=pre mining; 1=post mining - pit/lake hds = 490; 2=during mining - pit/underground fully dewatered	
qalcl_vka	vka	1.0	50.0	10.0		uniform(1.0 - 50.0)	False	Single kv multiplier for quaternary layer(s) $kv = \frac{k}{vka}$	Sensitivity range of 1-50
tgf_vka	vka	1.0	100.0	1.0		uniform(1.0 - 100.0)	False	Single kv multiplier for tgf layer(s) $kv = \frac{k}{vka}$	Sensitivity range of 1-100
tz3_vka	vka	1.0	100.0	1.0		uniform(1.0 - 100.0)	False	Single kv multiplier for tz3 schist layer(s) $kv = \frac{k}{vka}$	Sensitivity range of 1-100
tz4_vka	vka	1.0	100.0	1.0		uniform(1.0 - 100.0)	False	Single kv multiplier for tz4 schist layer(s) $kv = \frac{k}{vka}$	Sensitivity range of 1-100
weath_vka	vka	1.0	100.0	50.5		uniform(1.0 - 100.0)	False	Single kv multiplier for weathered layer(s) $kv = \frac{k}{vka}$	Sensitivity range of 1-100

A.5 Observations / Targets

There are three observation groups in the deep model:

1. **High-frequency groundwater level observations:** There are 53 VWP installed in the model domain. These VWP records provide very high-frequency groundwater level observations at multiple depths within one borehole. The VWP records provide a high confidence observation of the mean groundwater levels and mean groundwater head gradients in the model domain. Two anomalous VWP records were excluded from the optimisation. The anomalous records and their reasons for exclusion are as follows:
 - (a) **GWo4 - S20393:** A transcription error yielded unrealistic readings, but this was only corrected after the optimisation process was completed, so this VWP was excluded from the optimisation process. Note that the values are very close to the other VWP in GWO4 and GWO5, so this is unlikely to significantly affect the optimisation process.
 - (b) **MDD365 - S12843:** This VWP shows a very strong downward gradient, which is inconsistent with other nearby head records, including the very close records of at bore MDD499 and MDD511. All other adjacent VWP records show an upward gradient. Given this dissimilarity with nearby records, we suggest that this VWP record is erroneous.

The record associated with the highest piezometer (S20393) in GWO4 is likely erroneous. This piezometer was installed very recently, so may be a result of installation issues that will resolve over time. As such, we have excluded this piezometer from the optimisation process.

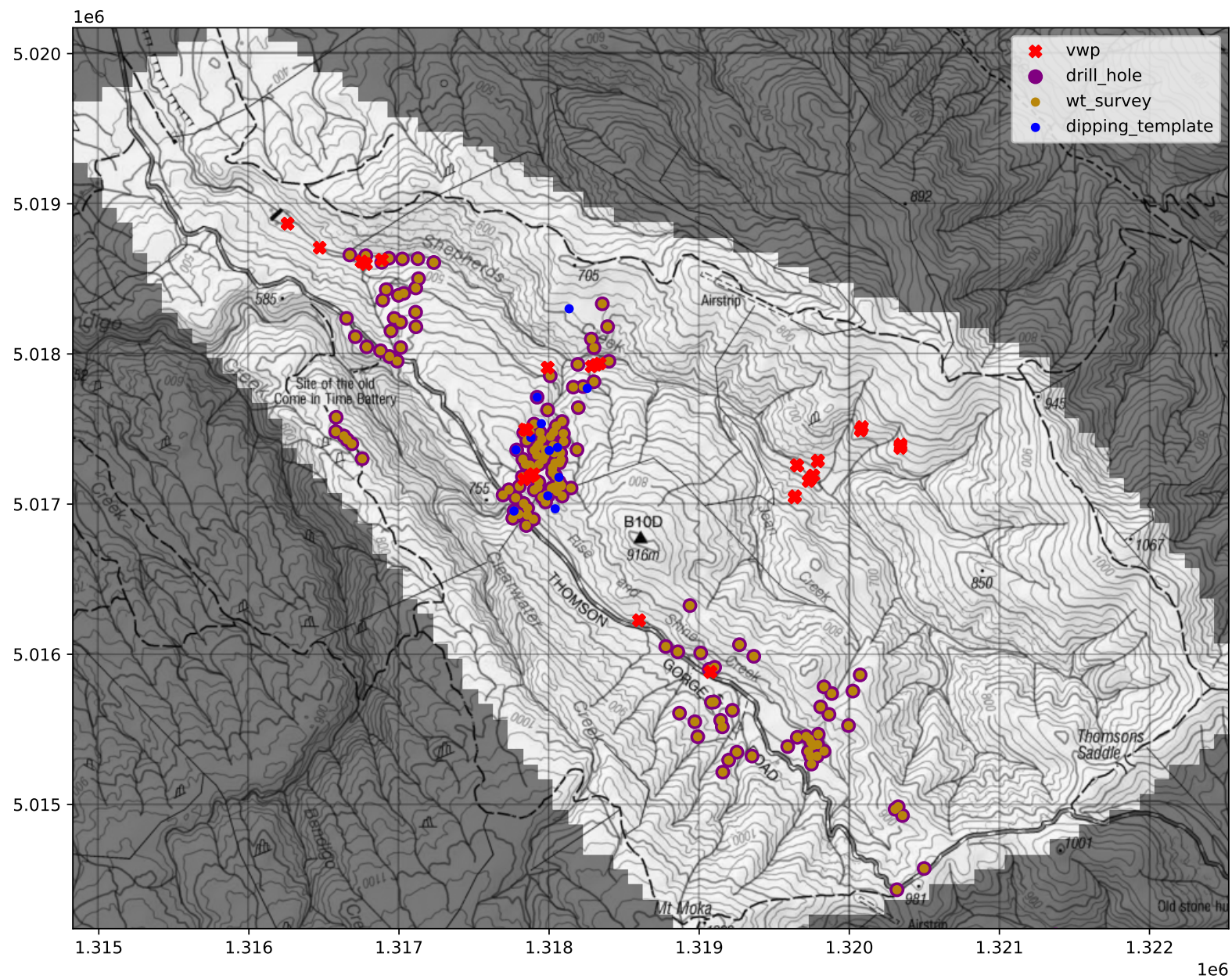
2. **Surface water flow observations:** The surface water flow observations in Shepherds Creek, its tributaries, and Rise and Shine Creek provide the only volumetric flow constraint on the model. As such, these observations are critical to the model optimisation process. Identifying the component of the flow duration curve that represents the steady state groundwater contribution to the flow is challenging. In thick alluvial aquifers, the groundwater contribution to flow is typically represented by the low-flow component of the flow duration curve. However, Shepherds Creek and Rise and Shine Creek are dominated by shallow Quaternary and weathered schist groundwater, which will not provide the same buffering effect as a thick alluvial aquifer. Therefore, we will use the median flow of the flow duration curve as a proxy for the steady state groundwater contribution to flow. The location and assumed catchments for the flow observations are shown in [Figure A.23](#). It is observed that the flows in RSO1 are typically lower than the flows in the upstream RSO2 site, which has been attributed to either measurement error, localised abstraction, or losing water to the alluvial fill of Rise and Shine Creek ([Rekker, 2025](#)). None of the aforementioned processes are simulated in the model, so we have excluded RSO1 from the optimisation process.
3. **Instantaneous groundwater level observations:** There are one or more manually taken water level observations at 176 bores. These observations provide a snapshot of the groundwater levels at a specific time and location. These dipping observations are less reliable than the VWP records, both because of the infrequency of the observations and because the dipping observations typically occur in open boreholes. Therefore, it is difficult to determine the exact depth of the observation as multiple depth zones may contribute to the observed water level. Nevertheless, the large spatial distribution of the dipping observations provides a useful constraint on the model, particularly in areas where there are no VWP records. Several of the dipping observations were noted as either dry (no water level observed) or artesian (water level above ground surface). [Figure A.17](#) shows the locations of the dry and artesian observations. The dry observations are typically adjacent to multiple other dipping observations. These observations may be due to the bore being dry at the time of the observation, a lack of connection between the borehole and fractures, or represent very localised water levels. Therefore, we have excluded the dry observations from the optimisation process. All but one of the artesian observations are located in the quaternary alluvium associated with Rise and Shine Creek. These artesian observations likely represent localised structures within the quaternary alluvium that are not captured in the model, and therefore we have also excluded these observations from the optimisation process. The remaining dipping observations are being broken into 3 classes:
 - **Water level surveys - absolute values:** There were 4 surveys (2023-01-01, 2023-08-01, 2023-11-28, 2024-01-20) conducted across the model domain, which will be used to assess the average groundwater levels in an absolute sense.
 - **Water level surveys - relative values:** The water level surveys will also be imposed as relative values

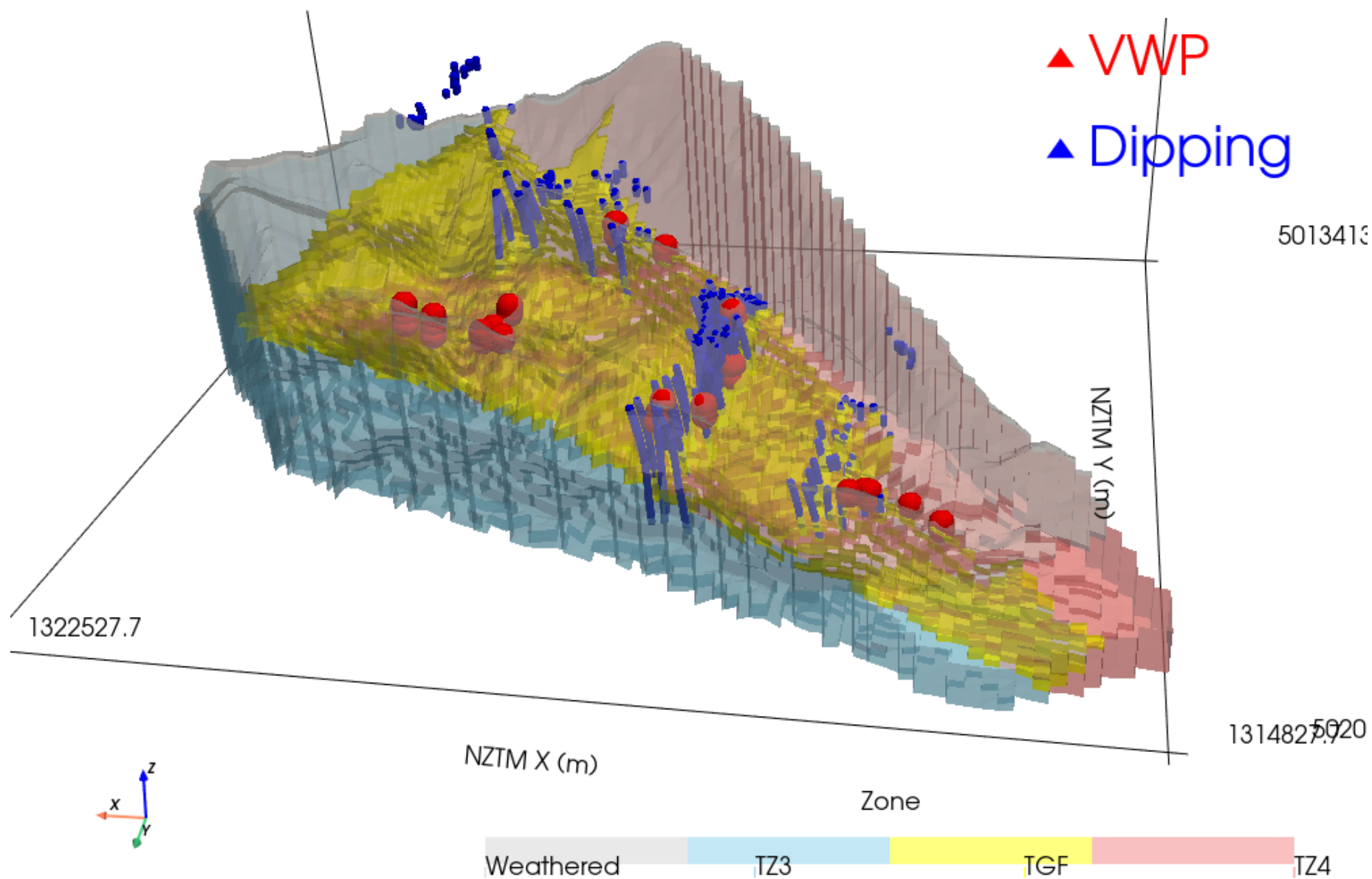
to ensure that the model is able to capture the relative groundwater gradients across the observations. The relative values will be calculated as the min-max normalised (e.g., scaled to a 0-1 range) values of the water level surveys.

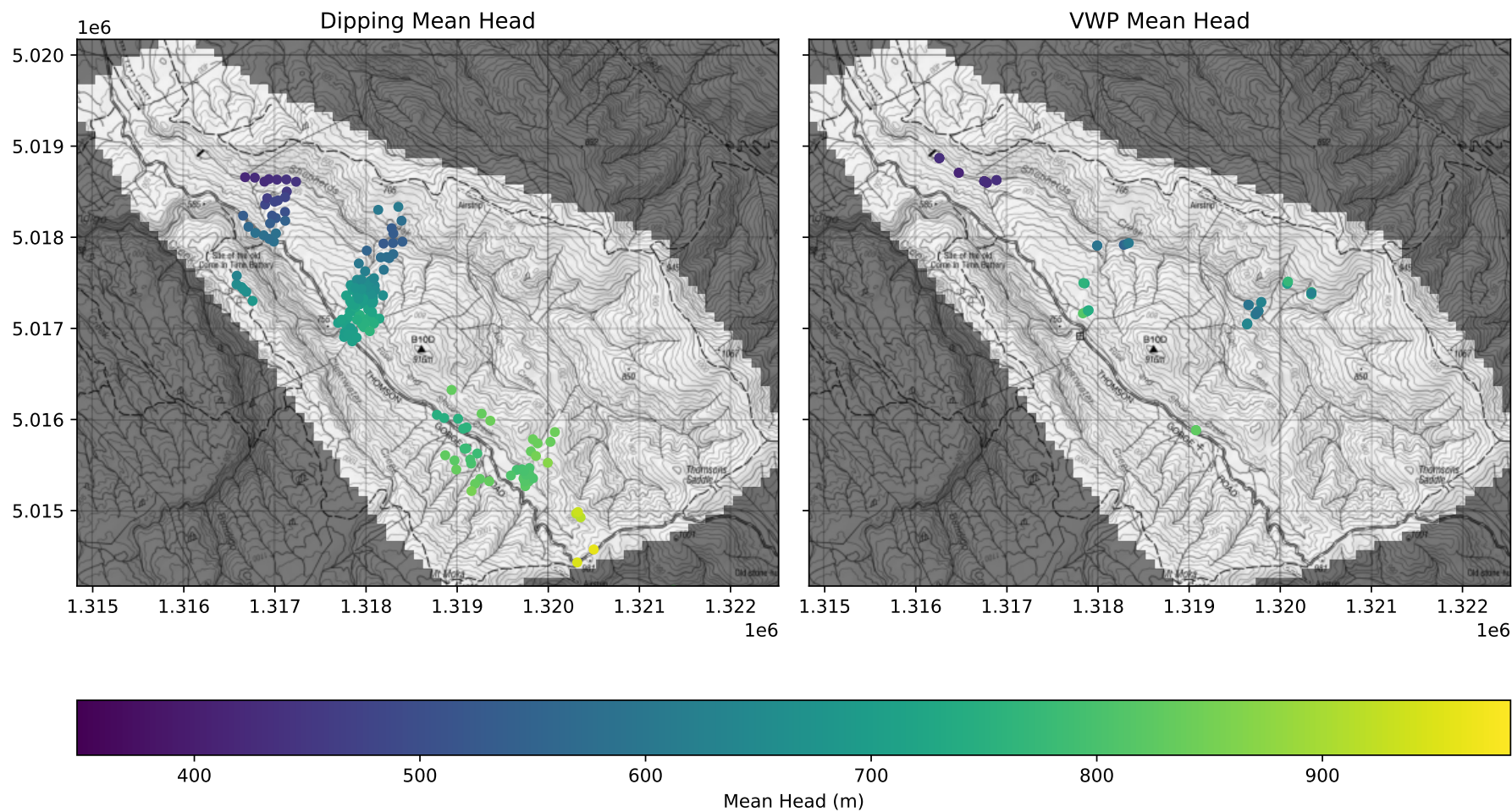
- **Other dipping observations:** Additional dipping observations will be used in only an absolute sense.

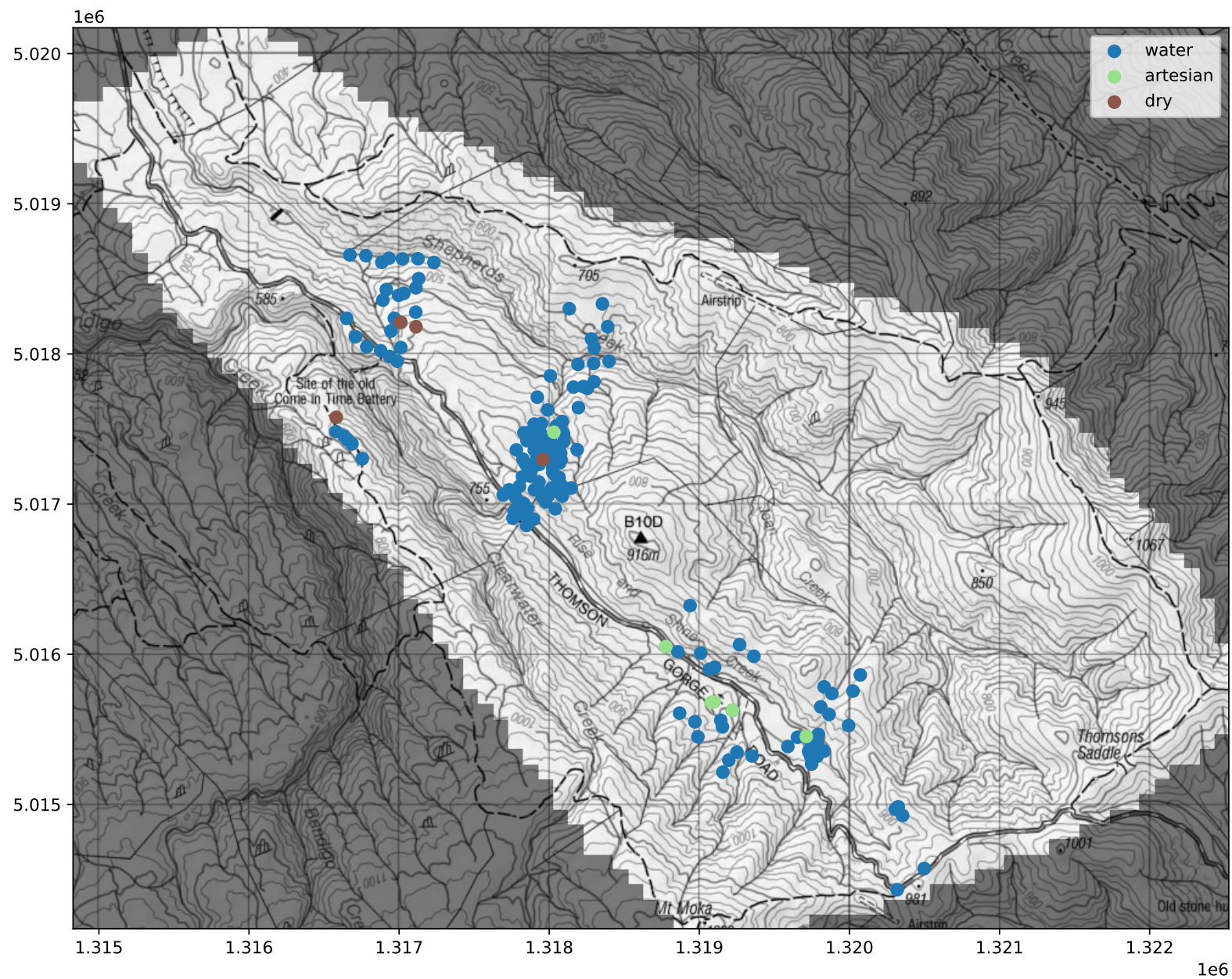
The locations of the groundwater level observations are shown in [Figure A.14](#) and [Figure A.15](#). The mean groundwater level observations are shown in [Figure A.16](#). [Figure A.18](#) shows the locations of the VWP with the bore labeled. The vertical gradients and lithology for each group of VWP are shown in the figures starting with [Figure A.19](#)

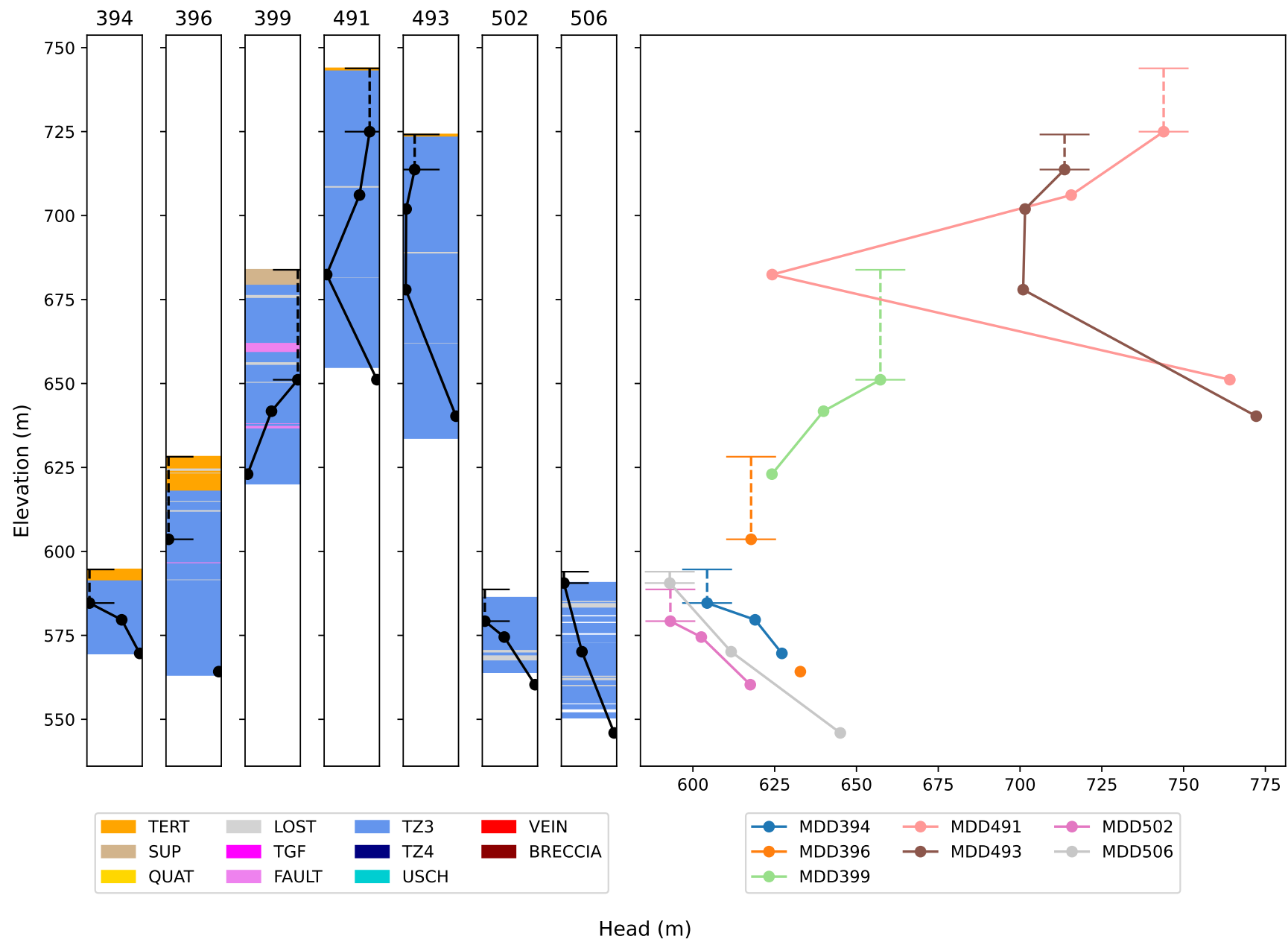
Extracting an equivalent value from the model for the dipping observations is challenging. The dipping observations are typically taken in open boreholes, which may or may not intersect the representative fracturing in the rock mass that makes up the conductivity of the model cell. Additionally, multiple depths (e.g. model cells) may contribute to the observed water level. The borehole scale interaction between different depths is not possible to capture in the model as it relies on very fine scale heterogeneity that is not captured in the model. Instead, we will assess the modelled value for comparison to the dipping observation as the head in all the model cells which are intersected by the open hole that is closest to the observed groundwater level. The top layers of the model are more likely to suffer from structural errors associated with the simplification of the top layers. Therefore, the top 3 layers will be removed from the possible observation points of the open hole bores. If the open hole bores only extend to within the top 3 layers, then the bottom most layer of the borehole will be used. This approach reduces the potential for the small scale borehole heterogeneity to bias the model but does decrease the information content of the observation.

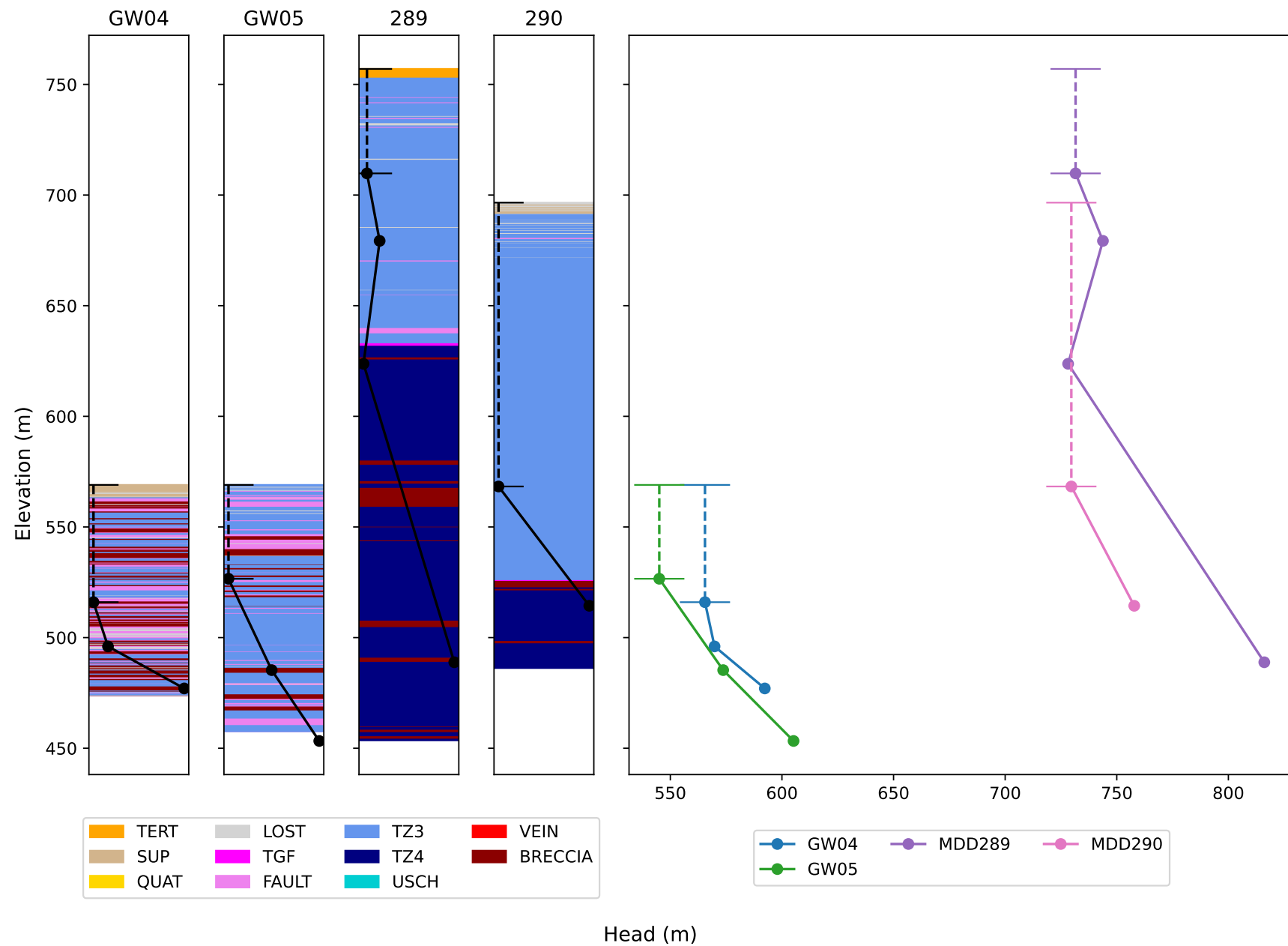


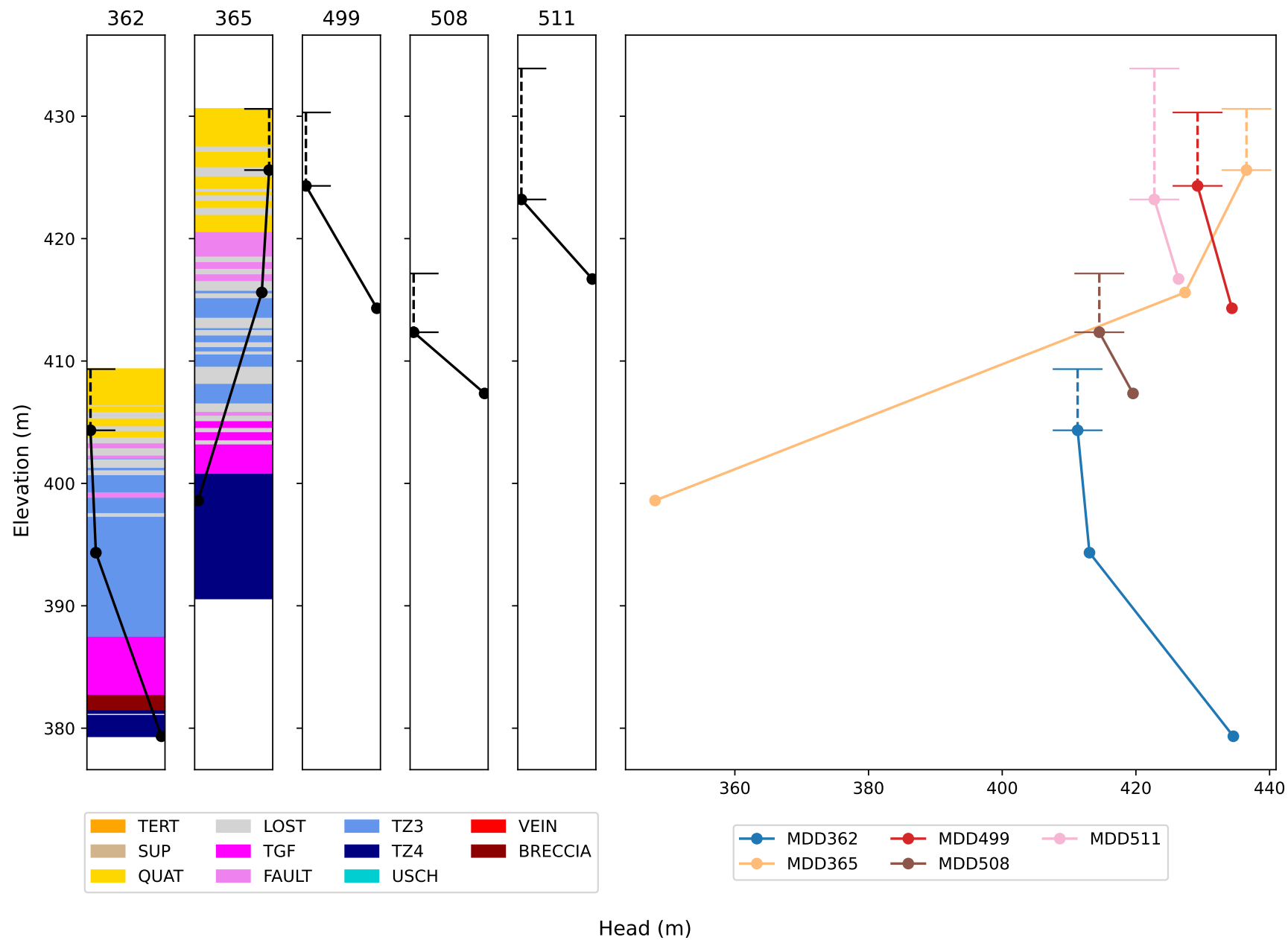


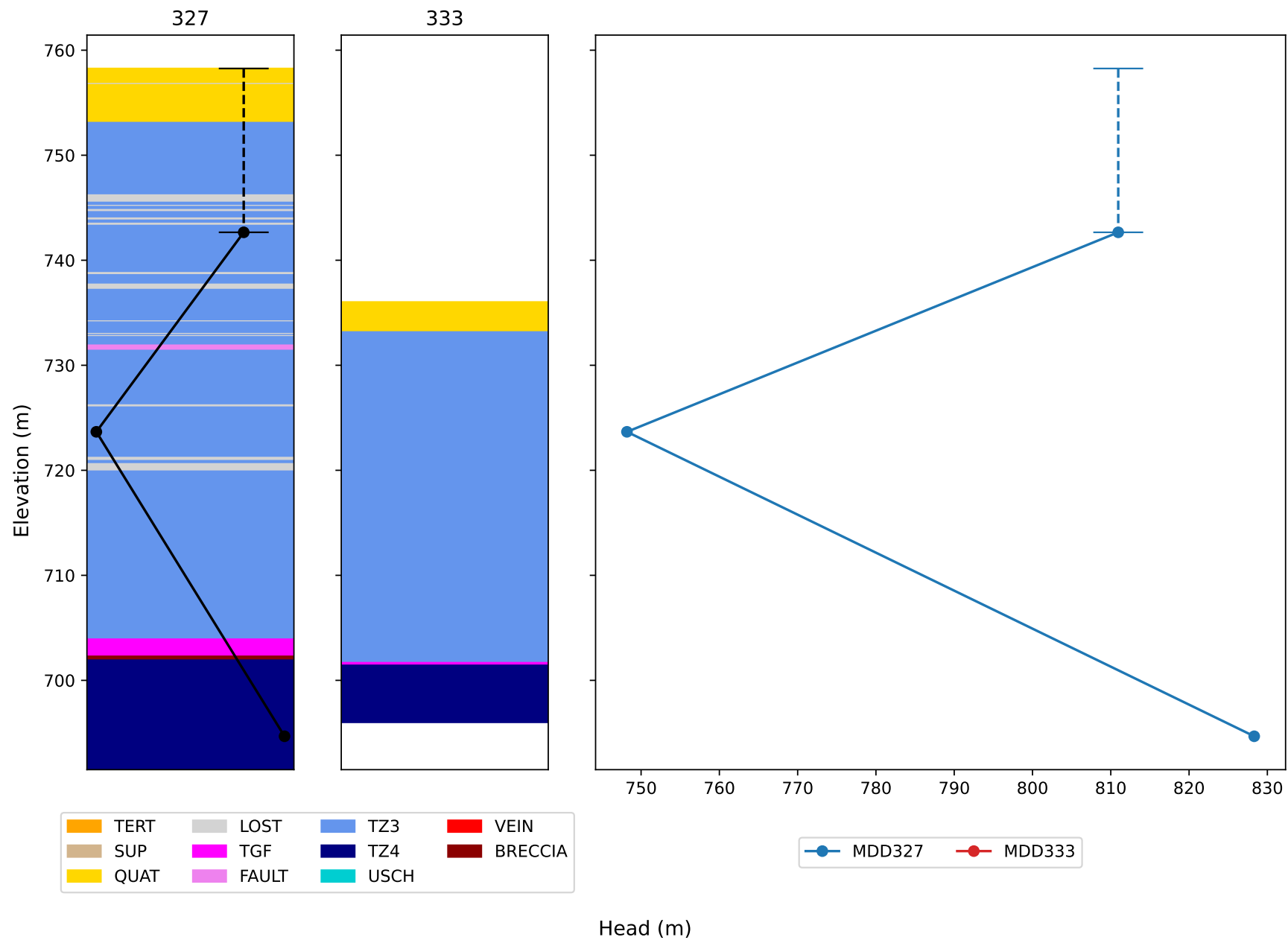












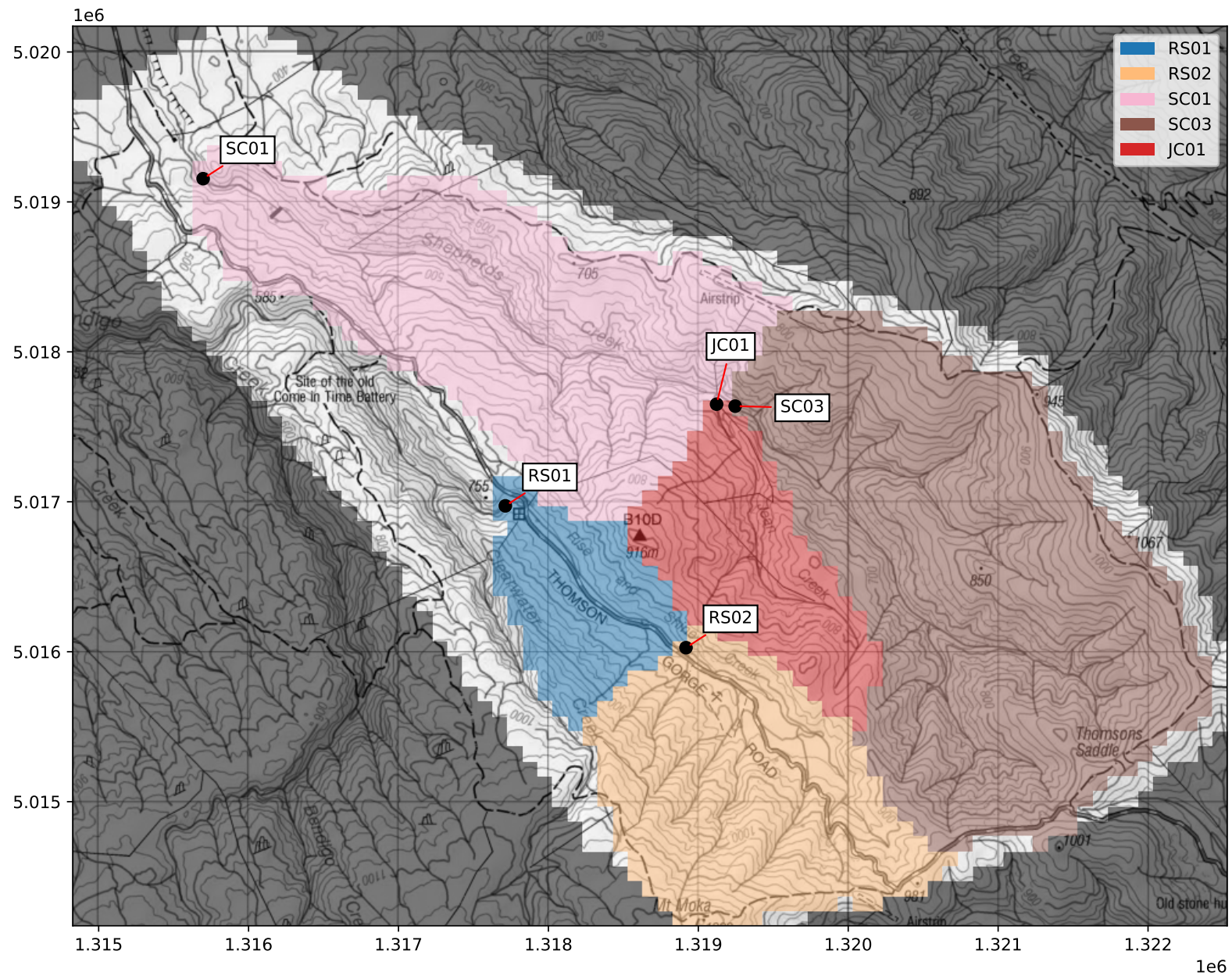


Table A.2: True observations for the deep model (head obs. in m, flux obs in m3/day).

name	type	value	name	type	value	name	type	value
MDDo03-abs_wls	abs_wls	798.52	MDDo05-abs_wls	abs_wls	781.25	MDDo06-abs_wls	abs_wls	755.93
MDDo07-abs_wls	abs_wls	697.98	MDDo09-abs_wls	abs_wls	723.92	MDDo10-abs_wls	abs_wls	717.16
MDDo11-abs_wls	abs_wls	712.7	MDDo12-abs_wls	abs_wls	718.05	MDDo13-abs_wls	abs_wls	689.24
MDDo14-abs_wls	abs_wls	673.76	MDDo16-abs_wls	abs_wls	659.82	MDDo18-abs_wls	abs_wls	619.95
MDDo19-abs_wls	abs_wls	660.36	MDDo20-abs_wls	abs_wls	642.88	MDDo24-abs_wls	abs_wls	720.54
MDDo29-abs_wls	abs_wls	537.69	MDDo35-abs_wls	abs_wls	456.35	MDDo37-abs_wls	abs_wls	571.09
MDDo38-abs_wls	abs_wls	477.86	MDDo39-abs_wls	abs_wls	600.57	MDDo41-abs_wls	abs_wls	525.02
MDDo42-abs_wls	abs_wls	551.84	MDDo43-abs_wls	abs_wls	505.83	MDDo44-abs_wls	abs_wls	530.07
MDDo45-abs_wls	abs_wls	680.9	MDDo48R-abs_wls	abs_wls	685.28	MDDo49-abs_wls	abs_wls	439.89
MDDo52-abs_wls	abs_wls	444.2	MDDo54-abs_wls	abs_wls	707.25	MDDo55-abs_wls	abs_wls	531.93
MDDo59-abs_wls	abs_wls	832.37	MDDo61-abs_wls	abs_wls	744.9	MDDo64-abs_wls	abs_wls	747.71
MDDo68-abs_wls	abs_wls	829.7	MDDo69-abs_wls	abs_wls	611.06	MDDo71-abs_wls	abs_wls	833.93
MDDo73-abs_wls	abs_wls	851.26	MDDo76-abs_wls	abs_wls	726.74	MDDo77-abs_wls	abs_wls	840.35
MDDo78-abs_wls	abs_wls	577.37	MDDo79-abs_wls	abs_wls	719.03	MDDo84-abs_wls	abs_wls	666.6
MDDo87-abs_wls	abs_wls	694.31	MDDo88-abs_wls	abs_wls	867.8	MDDo89-abs_wls	abs_wls	838.41
MDDo90-abs_wls	abs_wls	716.34	MDDo92-abs_wls	abs_wls	837.65	MDDo96-abs_wls	abs_wls	734.7
MDDo98-abs_wls	abs_wls	747.23	MDDo99-abs_wls	abs_wls	835.33	MDD102-abs_wls	abs_wls	919.46
MDD105-abs_wls	abs_wls	655.43	MDD106-abs_wls	abs_wls	914.47	MDD107-abs_wls	abs_wls	840.87
MDD109-abs_wls	abs_wls	655.47	MDD110-abs_wls	abs_wls	714.87	MDD114-abs_wls	abs_wls	696.49
MDD115-abs_wls	abs_wls	576.32	MDD125-abs_wls	abs_wls	752.1	MDD127-abs_wls	abs_wls	649.99
MDD128-abs_wls	abs_wls	579.43	MDD131-abs_wls	abs_wls	677.71	MDD134-abs_wls	abs_wls	595.32
MDD136-abs_wls	abs_wls	675.56	MDD144-abs_wls	abs_wls	726.59	MDD145-abs_wls	abs_wls	676.94
MDD150-abs_wls	abs_wls	687.48	MDD151-abs_wls	abs_wls	752.87	MDD155-abs_wls	abs_wls	677.11
MDD157-abs_wls	abs_wls	727.2	MDD159-abs_wls	abs_wls	692.87	MDD161-abs_wls	abs_wls	747.33
MDD163-abs_wls	abs_wls	745.75	MDD165-abs_wls	abs_wls	712.59	MDD166-abs_wls	abs_wls	751.42
MDD168-abs_wls	abs_wls	669.05	MDD169-abs_wls	abs_wls	656.25	MDD176-abs_wls	abs_wls	700.2
MDD177-abs_wls	abs_wls	684.26	MDD177R-abs_wls	abs_wls	684.3	MDD178-abs_wls	abs_wls	750.81
MDD180-abs_wls	abs_wls	710.08	MDD181-abs_wls	abs_wls	685.53	MDD182-abs_wls	abs_wls	751.06
MDD194-abs_wls	abs_wls	638.58	MDD207-abs_wls	abs_wls	675.32	MDD257-abs_wls	abs_wls	701.61

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Table A.2: True observations for the deep model (head obs. in m, flux obs in m3/day). (Continued)

name	type	value	name	type	value	name	type	value
MRC001-abs_wls	abs_wls	745.47	MRC002-abs_wls	abs_wls	746.94	MRC007-abs_wls	abs_wls	826.89
MRC008-abs_wls	abs_wls	834.24	MRC009-abs_wls	abs_wls	852.86	MRC015-abs_wls	abs_wls	800.24
MRC017-abs_wls	abs_wls	833.84	MRC021-abs_wls	abs_wls	820.61	MRC022-abs_wls	abs_wls	827.97
MRC026-abs_wls	abs_wls	705.02	MRC027-abs_wls	abs_wls	583.3	MRC028-abs_wls	abs_wls	579.59
MRC029-abs_wls	abs_wls	584.32	MRC030-abs_wls	abs_wls	562.74	MRC031-abs_wls	abs_wls	533.8
MRC033-abs_wls	abs_wls	577.21	MRC035-abs_wls	abs_wls	581.69	MRC038-abs_wls	abs_wls	814.21
MRC039-abs_wls	abs_wls	801.18	MRC040-abs_wls	abs_wls	794.12	MRC041-abs_wls	abs_wls	805.89
MRC043-abs_wls	abs_wls	717.58	MRC044-abs_wls	abs_wls	694.7	MRC045-abs_wls	abs_wls	700.73
MRC047-abs_wls	abs_wls	708.37	MRC060-abs_wls	abs_wls	426.96	MRC061-abs_wls	abs_wls	482.12
MRC062-abs_wls	abs_wls	464.52	MRC066-abs_wls	abs_wls	526.9	MRC069-abs_wls	abs_wls	483.77
MRC070-abs_wls	abs_wls	479.94	MRC072R-abs_wls	abs_wls	433.22	MRC073-abs_wls	abs_wls	428.26
MRC077-abs_wls	abs_wls	425.13	MRC078-abs_wls	abs_wls	419.43	MRC079-abs_wls	abs_wls	741.91
MRC081-abs_wls	abs_wls	697.57	MRC082-abs_wls	abs_wls	701.65	MRC083-abs_wls	abs_wls	702.87
MRC084-abs_wls	abs_wls	704.68	MRC085-abs_wls	abs_wls	793.02	MRC086-abs_wls	abs_wls	802.36
MRC087-abs_wls	abs_wls	812.95	MRC088-abs_wls	abs_wls	803.62	MRC089-abs_wls	abs_wls	820.85
MRC090-abs_wls	abs_wls	833.71	MRC093-abs_wls	abs_wls	750.69	MRC094-abs_wls	abs_wls	756.48
MRC096-abs_wls	abs_wls	946.83	MRC097-abs_wls	abs_wls	959.62	MRC100DT-abs_wls	abs_wls	931.52
MRC124-abs_wls	abs_wls	685.88	MRC125-abs_wls	abs_wls	660.8	MRC126-abs_wls	abs_wls	663.81
MRC127-abs_wls	abs_wls	664.85	MRC128-abs_wls	abs_wls	655.77	MRC142-abs_wls	abs_wls	795.61
MRC147-abs_wls	abs_wls	814.19	MRC153-abs_wls	abs_wls	804.11	MRC158-abs_wls	abs_wls	797.33
MRC163-abs_wls	abs_wls	516.51	MRC166-abs_wls	abs_wls	538.08	cit_drn-budget	budget	
offshore_drn-budget	budget		raspit_chb-budget	budget		raspit_drn-budget	budget	
srex_drn-budget	budget		underground_chb-budget	budget		underground_drn-budget	budget	
MDD003-rel_wls	rel_wls	0.7	MDD005-rel_wls	rel_wls	0.67	MDD006-rel_wls	rel_wls	0.62
MDD007-rel_wls	rel_wls	0.52	MDD009-rel_wls	rel_wls	0.56	MDD010-rel_wls	rel_wls	0.55
MDD011-rel_wls	rel_wls	0.54	MDD012-rel_wls	rel_wls	0.55	MDD013-rel_wls	rel_wls	0.5
MDD014-rel_wls	rel_wls	0.47	MDD016-rel_wls	rel_wls	0.45	MDD018-rel_wls	rel_wls	0.37
MDD019-rel_wls	rel_wls	0.45	MDD020-rel_wls	rel_wls	0.41	MDD024-rel_wls	rel_wls	0.56
MDD029-rel_wls	rel_wls	0.22	MDD035-rel_wls	rel_wls	0.07	MDD037-rel_wls	rel_wls	0.28

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Table A.2: True observations for the deep model (head obs. in m, flux obs in m3/day). (Continued)

name	type	value	name	type	value	name	type	value
MDDo38-rel_wls	rel_wls	0.11	MDDo39-rel_wls	rel_wls	0.34	MDDo41-rel_wls	rel_wls	0.2
MDDo42-rel_wls	rel_wls	0.25	MDDo43-rel_wls	rel_wls	0.16	MDDo44-rel_wls	rel_wls	0.2
MDDo45-rel_wls	rel_wls	0.48	MDDo48R-rel_wls	rel_wls	0.49	MDDo49-rel_wls	rel_wls	0.04
MDDo52-rel_wls	rel_wls	0.05	MDDo54-rel_wls	rel_wls	0.53	MDDo55-rel_wls	rel_wls	0.21
MDDo59-rel_wls	rel_wls	0.76	MDDo61-rel_wls	rel_wls	0.6	MDDo64-rel_wls	rel_wls	0.61
MDDo68-rel_wls	rel_wls	0.76	MDDo69-rel_wls	rel_wls	0.35	MDDo71-rel_wls	rel_wls	0.77
MDDo73-rel_wls	rel_wls	0.8	MDDo76-rel_wls	rel_wls	0.57	MDDo77-rel_wls	rel_wls	0.78
MDDo78-rel_wls	rel_wls	0.29	MDDo79-rel_wls	rel_wls	0.55	MDDo84-rel_wls	rel_wls	0.46
MDDo87-rel_wls	rel_wls	0.51	MDDo88-rel_wls	rel_wls	0.83	MDDo89-rel_wls	rel_wls	0.78
MDDo90-rel_wls	rel_wls	0.55	MDDo92-rel_wls	rel_wls	0.77	MDDo96-rel_wls	rel_wls	0.58
MDDo98-rel_wls	rel_wls	0.61	MDDo99-rel_wls	rel_wls	0.77	MDD102-rel_wls	rel_wls	0.93
MDD105-rel_wls	rel_wls	0.44	MDD106-rel_wls	rel_wls	0.92	MDD107-rel_wls	rel_wls	0.78
MDD109-rel_wls	rel_wls	0.44	MDD110-rel_wls	rel_wls	0.55	MDD114-rel_wls	rel_wls	0.51
MDD115-rel_wls	rel_wls	0.29	MDD125-rel_wls	rel_wls	0.62	MDD127-rel_wls	rel_wls	0.43
MDD128-rel_wls	rel_wls	0.3	MDD131-rel_wls	rel_wls	0.48	MDD134-rel_wls	rel_wls	0.33
MDD136-rel_wls	rel_wls	0.47	MDD144-rel_wls	rel_wls	0.57	MDD145-rel_wls	rel_wls	0.48
MDD150-rel_wls	rel_wls	0.5	MDD151-rel_wls	rel_wls	0.62	MDD155-rel_wls	rel_wls	0.48
MDD157-rel_wls	rel_wls	0.57	MDD159-rel_wls	rel_wls	0.51	MDD161-rel_wls	rel_wls	0.61
MDD163-rel_wls	rel_wls	0.6	MDD165-rel_wls	rel_wls	0.54	MDD166-rel_wls	rel_wls	0.61
MDD168-rel_wls	rel_wls	0.46	MDD169-rel_wls	rel_wls	0.44	MDD176-rel_wls	rel_wls	0.52
MDD177-rel_wls	rel_wls	0.49	MDD177R-rel_wls	rel_wls	0.49	MDD178-rel_wls	rel_wls	0.61
MDD180-rel_wls	rel_wls	0.54	MDD181-rel_wls	rel_wls	0.49	MDD182-rel_wls	rel_wls	0.61
MDD194-rel_wls	rel_wls	0.41	MDD207-rel_wls	rel_wls	0.47	MDD257-rel_wls	rel_wls	0.52
MRCoo1-rel_wls	rel_wls	0.6	MRCoo2-rel_wls	rel_wls	0.61	MRCoo7-rel_wls	rel_wls	0.75
MRCoo8-rel_wls	rel_wls	0.77	MRCoo9-rel_wls	rel_wls	0.8	MRCo15-rel_wls	rel_wls	0.7
MRCo17-rel_wls	rel_wls	0.77	MRCo21-rel_wls	rel_wls	0.74	MRCo22-rel_wls	rel_wls	0.76
MRCo26-rel_wls	rel_wls	0.53	MRCo27-rel_wls	rel_wls	0.3	MRCo28-rel_wls	rel_wls	0.3
MRCo29-rel_wls	rel_wls	0.31	MRCo30-rel_wls	rel_wls	0.27	MRCo31-rel_wls	rel_wls	0.21
MRCo33-rel_wls	rel_wls	0.29	MRCo35-rel_wls	rel_wls	0.3	MRCo38-rel_wls	rel_wls	0.73

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Table A.2: True observations for the deep model (head obs. in m, flux obs in m3/day). (Continued)

name	type	value	name	type	value	name	type	value
MRC039-rel_wls	rel_wls	0.71	MRC040-rel_wls	rel_wls	0.69	MRC041-rel_wls	rel_wls	0.72
MRC043-rel_wls	rel_wls	0.55	MRC044-rel_wls	rel_wls	0.51	MRC045-rel_wls	rel_wls	0.52
MRC047-rel_wls	rel_wls	0.53	MRC060-rel_wls	rel_wls	0.01	MRC061-rel_wls	rel_wls	0.12
MRC062-rel_wls	rel_wls	0.08	MRC066-rel_wls	rel_wls	0.2	MRC069-rel_wls	rel_wls	0.12
MRC070-rel_wls	rel_wls	0.11	MRC072R-rel_wls	rel_wls	0.03	MRC073-rel_wls	rel_wls	0.02
MRC077-rel_wls	rel_wls	0.01	MRC078-rel_wls	rel_wls	0.0	MRC079-rel_wls	rel_wls	0.6
MRC081-rel_wls	rel_wls	0.51	MRC082-rel_wls	rel_wls	0.52	MRC083-rel_wls	rel_wls	0.52
MRC084-rel_wls	rel_wls	0.53	MRC085-rel_wls	rel_wls	0.69	MRC086-rel_wls	rel_wls	0.71
MRC087-rel_wls	rel_wls	0.73	MRC088-rel_wls	rel_wls	0.71	MRC089-rel_wls	rel_wls	0.74
MRC090-rel_wls	rel_wls	0.77	MRC093-rel_wls	rel_wls	0.61	MRC094-rel_wls	rel_wls	0.62
MRC096-rel_wls	rel_wls	0.98	MRC097-rel_wls	rel_wls	1.0	MRC100DT-rel_wls	rel_wls	0.95
MRC124-rel_wls	rel_wls	0.49	MRC125-rel_wls	rel_wls	0.45	MRC126-rel_wls	rel_wls	0.45
MRC127-rel_wls	rel_wls	0.45	MRC128-rel_wls	rel_wls	0.44	MRC142-rel_wls	rel_wls	0.7
MRC147-rel_wls	rel_wls	0.73	MRC153-rel_wls	rel_wls	0.71	MRC158-rel_wls	rel_wls	0.7
MRC163-rel_wls	rel_wls	0.18	MRC166-rel_wls	rel_wls	0.22	MDD012-spot	spot	702.65
MDD014-spot	spot	674.63	MDD039-spot	spot	602.36	MDD063-spot	spot	605.37
MDD117-spot	spot	533.73	MDD147-spot	spot	641.94	MDD166-spot	spot	747.42
MDD168-spot	spot	656.1	MDD210-spot	spot	677.42	MDD219-spot	spot	576.09
MDD383-spot	spot	719.56	MDD425-spot	spot	761.49	MRC081-spot	spot	695.77
jc01-sw	sw	-0.0	rs02-sw	sw	-414.72	sco1-sw	sw	-838.08
sco3-sw	sw	-682.56	GWo4_S20457-vwp	vwp	569.81	GWo4_S20458-vwp	vwp	592.32
GWo5_S20061-vwp	vwp	545.05	GWo5_S2230879-vwp	vwp	573.68	GWo5_S2628896-vwp	vwp	605.2
MDD289_S12419-vwp	vwp	731.55	MDD289_S14463-vwp	vwp	728.2	MDD289_S14515-vwp	vwp	816.09
MDD289_S4053-vwp	vwp	743.8	MDD290_S14445-vwp	vwp	729.65	MDD290_S14446-vwp	vwp	757.82
MDD327_S12538-vwp	vwp	748.19	MDD327_S14293-vwp	vwp	810.95	MDD327_S9727-vwp	vwp	828.32
MDD333_S12842-vwp	vwp		MDD333_S5412-vwp	vwp		MDD333_S6774-vwp	vwp	
MDD362_S12290-vwp	vwp	411.28	MDD362_S12844-vwp	vwp	413.05	MDD362_S12845-vwp	vwp	434.58
MDD365_S12841-vwp	vwp	427.36	MDD365_S12843-vwp	vwp		MDD365_S12846-vwp	vwp	436.54
MDD394_S12851-vwp	vwp	627.21	MDD394_S12852-vwp	vwp	619.02	MDD394_S16800-vwp	vwp	604.34

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Table A.2: True observations for the deep model (head obs. in m, flux obs in m3/day). (Continued)

name	type	value	name	type	value	name	type	value
MDD396_S16801-vwp	vwp	617.79	MDD396_s1800486-vwp	vwp		MDD396_sn15933-vwp	vwp	632.85
MDD399_S14294-vwp	vwp	657.31	MDD399_S15932-vwp	vwp	624.16	MDD399_S17575-vwp	vwp	639.94
MDD491_S14447-vwp	vwp	764.14	MDD491_S19902-vwp	vwp	743.9	MDD491_S19912-vwp	vwp	715.65
MDD491_S2226728-vwp	vwp	624.23	MDD493_S16935-vwp	vwp	700.96	MDD493_S19892-vwp	vwp	713.62
MDD493_S19903-vwp	vwp	701.54	MDD493_S20459-vwp	vwp	772.21	MDD499_S19893-vwp	vwp	429.23
MDD499_S19904-vwp	vwp	434.37	MDD502_S16902-vwp	vwp	602.57	MDD502_S16904-vwp	vwp	617.54
MDD502_S19894-vwp	vwp	593.11	MDD506_S16934-vwp	vwp	645.07	MDD506_S20404-vwp	vwp	611.69
MDD506_S20429-vwp	vwp	592.92	MDD508_S19896-vwp	vwp	419.57	MDD508_S20430-vwp	vwp	414.53
MDD511_S20656-vwp	vwp	422.76	MDD511_S20662-vwp	vwp	426.38			

A.6 Simulation Characteristics

The deep model is a steady-state flow simulation. The flow model is run using a fully confined solution (e.g., cells are always fully saturated and cannot go dry). A fully confined solution provides a more numerically stable solution, but because no cells can become inactive (go dry), some flow paths may be overestimated. Additionally, the saturated thickness used for the calculation of transmissivity is the full cell thickness, which may also lead to higher than realistic flow rates in some areas. This is most relevant for the QALCL and weathered schist layers, where in reality dry cells are likely to occur. This is unlikely to affect the flow in the TGF, TZ-3, and TZ-4 schist, where the model is expected to be fully saturated. Most of the model observations are located in the TGF, TZ-3, and TZ-4 schist, so the effect of the fully confined solution is expected to be minimal on the model optimisation.

B Deep Model Optimisation

B.1 Methodology

The model inversion was preformed using a machine learning proxy inversion method. Here the model is run for an initial suite of parameter sets and the model outputs are used to train a machine learning model. The machine learning model is then used to minimize an objective function (goodness of fit) and suggests parameter set updates. These parameter sets are then used to run the full model and the outputs are used to update the machine learning model. This process is repeated until an acceptable fit to the observed data is achieved.

The objective function used for this inversion was a sum weighted log-likelihood function for grouped observations (VWP records, absolute water level surveys, relative water level surveys, and surface water flows). The log-likelihood function for each group of observations was calculated as follows:

$$\log \mathcal{L} = -\frac{n}{2} \log \left(\sum_{i=0}^n (y_i - \hat{y}_i)^2 - \frac{1}{2} \sum_{i=0}^n \left(\frac{y_i - \hat{y}_i}{\sigma_i} \right)^2 \right) \quad (\text{B.1})$$

Where n is the number of observations, y_i is the observed value (measured), $\hat{y}_i$ is the modelled value, and σ_i is error term for each observation. We do not have formal error estimates for each observation, so we assumed a constant error of 0.5 m for the VWP, 1.0 m for the absolute water level surveys and spot dipping measurements, 0.005 (0.5%) for the relative water level surveys, and 20 m³/day for the surface water flows. Note that the absolute value of the log-likelihood function is not typically a meaningful quantity as it depends on the number of observations used. Also, we are using an optimisation approach that aims to minimize the objective function, so we have flipped the sign of the log-likelihood function to make it a minimization problem ($\log \mathcal{L} \times -1$).

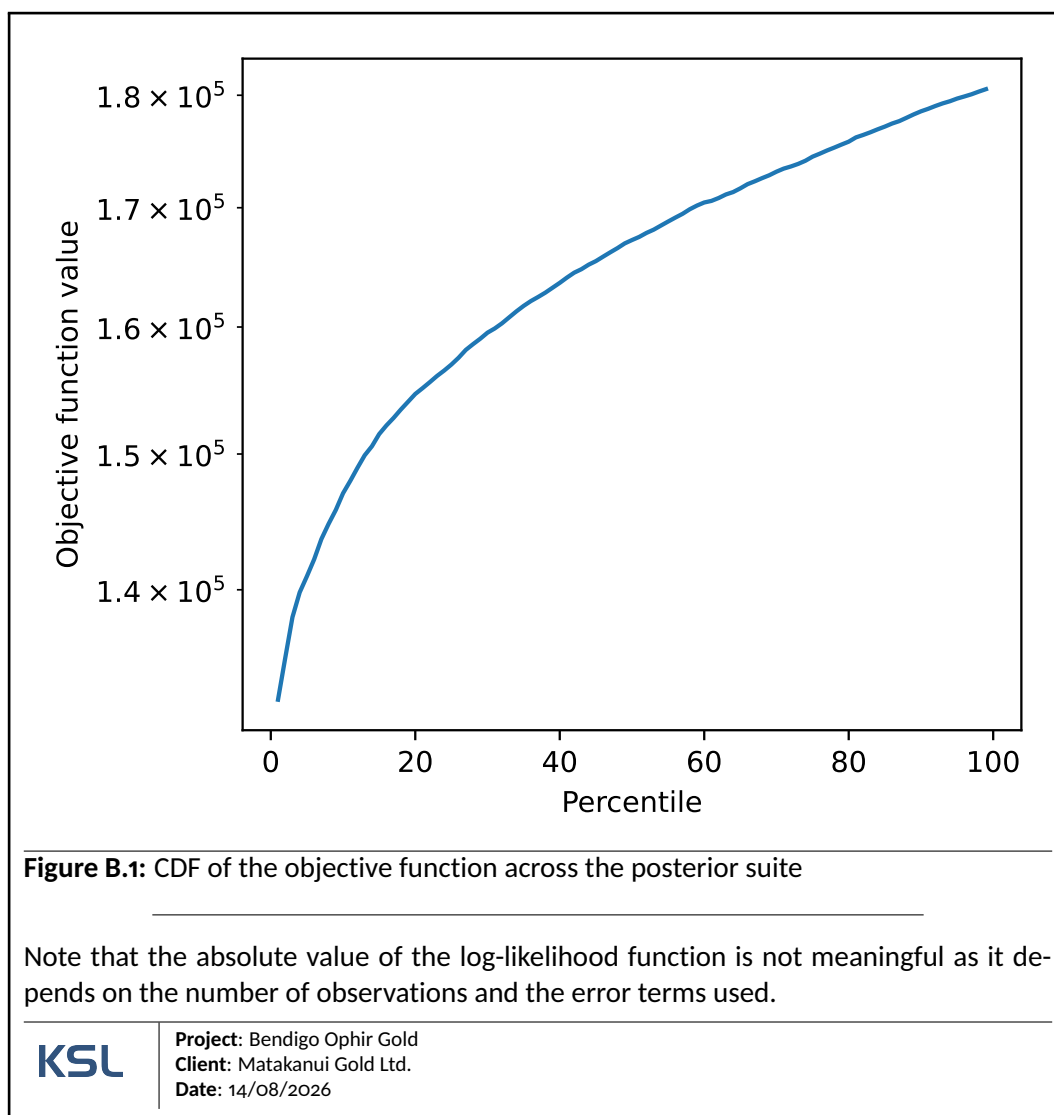
We evaluated the log-likelihood function with two different component weighting schemes. The first was the raw log-likelihood function and the second was a weighted log-likelihood function where the surface water flow component was weighted 10 times higher than the other components. This surface water weighted objective function provided more emphasis on fitting the surface water flows, which suffered under the raw log-likelihood function due to the relatively small number of surface water observations relative to groundwater observations.

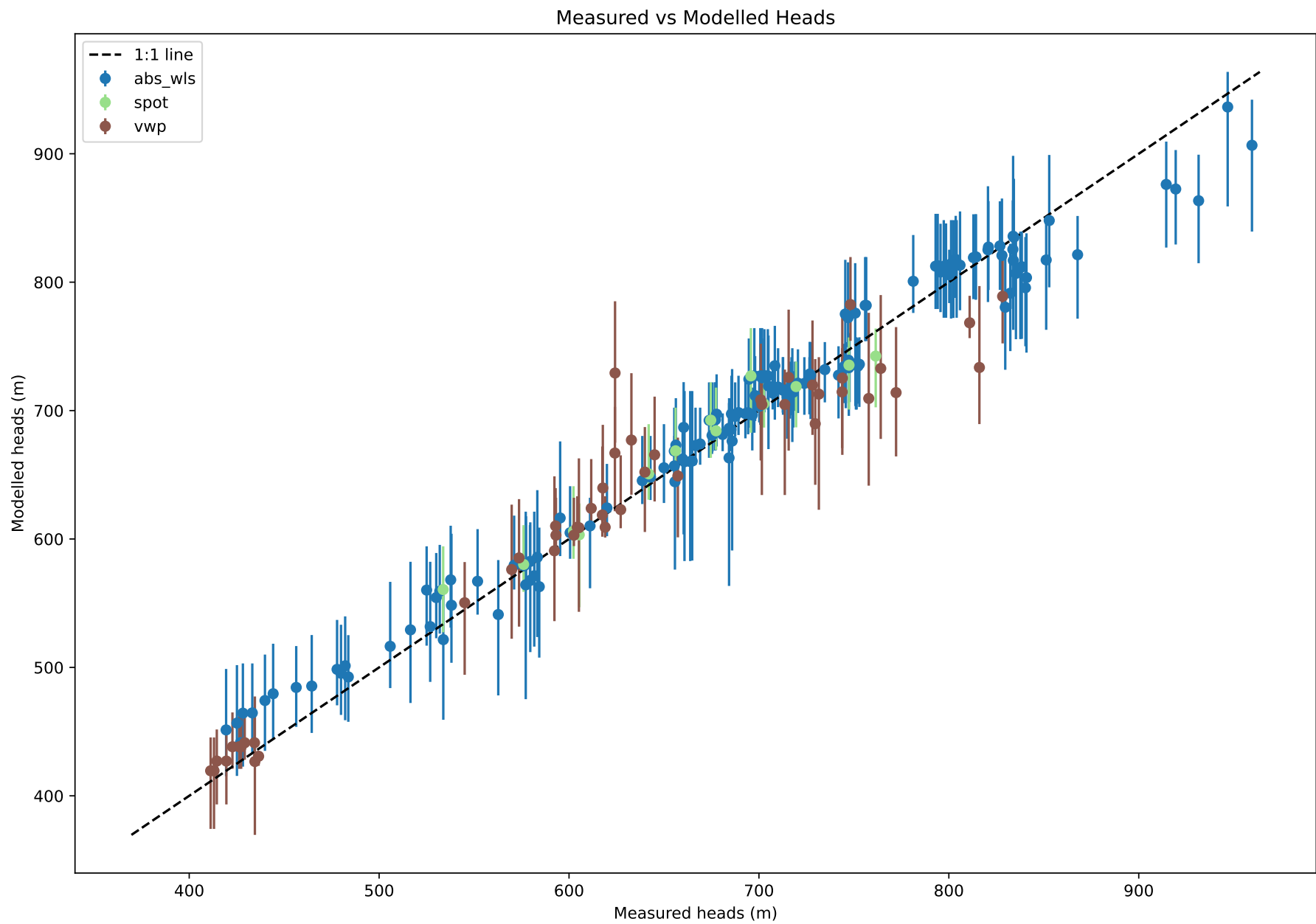
The optimisation was run by initially sampling approximately 10,000 randomly selected parameter sets from the prior distributions. Each following iteration trained a random forest regressor (predicting the objective function) and a random forest classifier (predicting whether the parameter set would converge) on all previously run parameter sets (Pedregosa et al., 2011). Then a dual annealing (Virtanen et al., 2020) optimisation algorithm was used to identify potential minima in the objective function space (using the random forest regressor as a proxy for the full model). The algorithm was run with different random starting points to ensure at least 1,000 potential parameter sets were identified. This suite was then filtered to 500 parameter sets to evaluate with the full model. The filtering was based on a weighted combination of the predicted objective

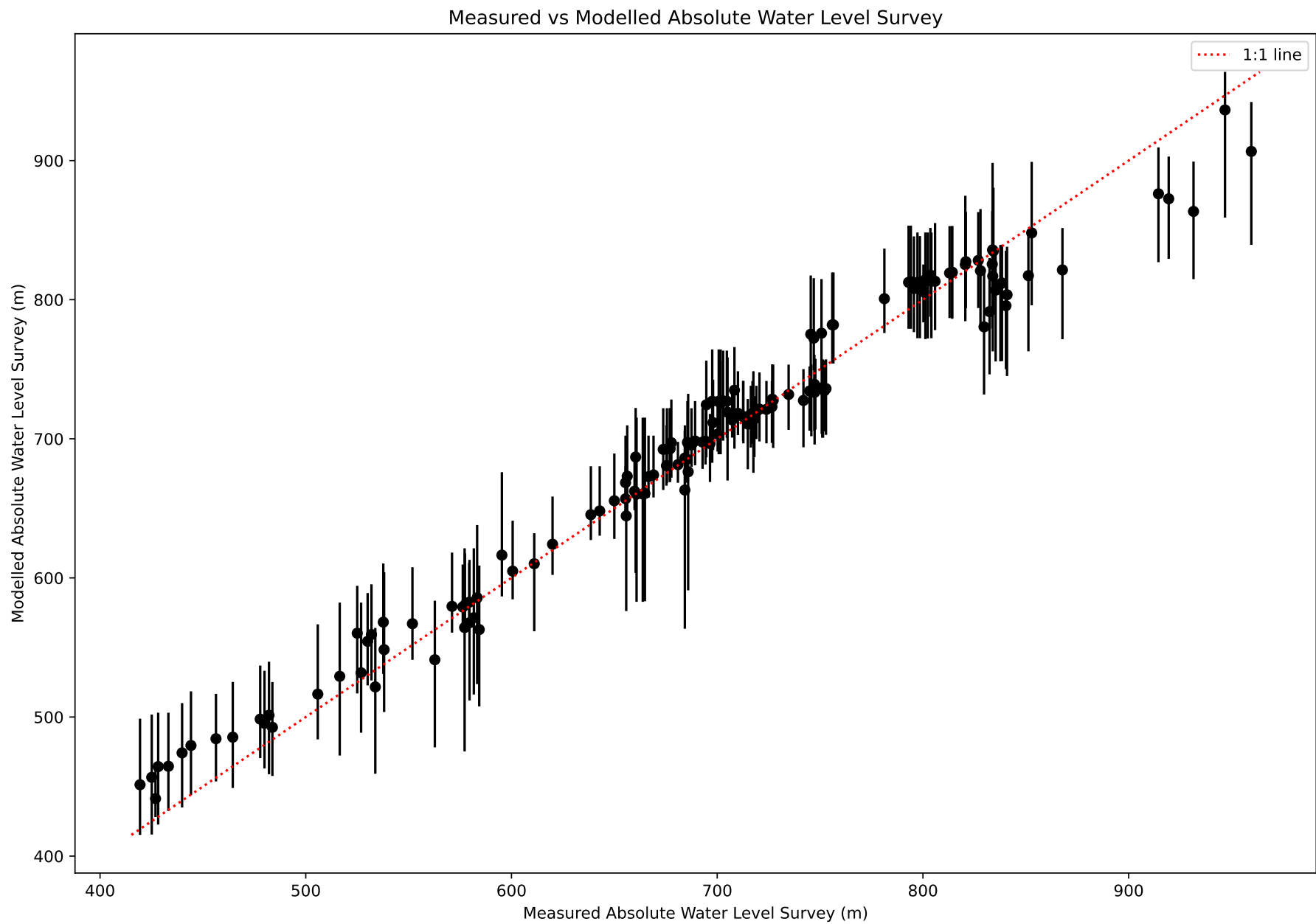
function, maximizing the likelihood of convergence, and maximizing the normalised distance from previously run parameter sets (to ensure exploration of the parameter space). The relative weightings were minimization:2, convergence:1, distance:1. The optimisation was run for 141 iterations with a total of 80836 model runs, though some iterations were focused on exploring specific components of the objective function (e.g., surface water flows) and ignored other components (e.g. VWP and water level surveys). The results of the optimisation were manually assessed and the optimisation was stopped when the objective function was no longer improving and the modelled outputs provided a reasonable fit to the observed data.

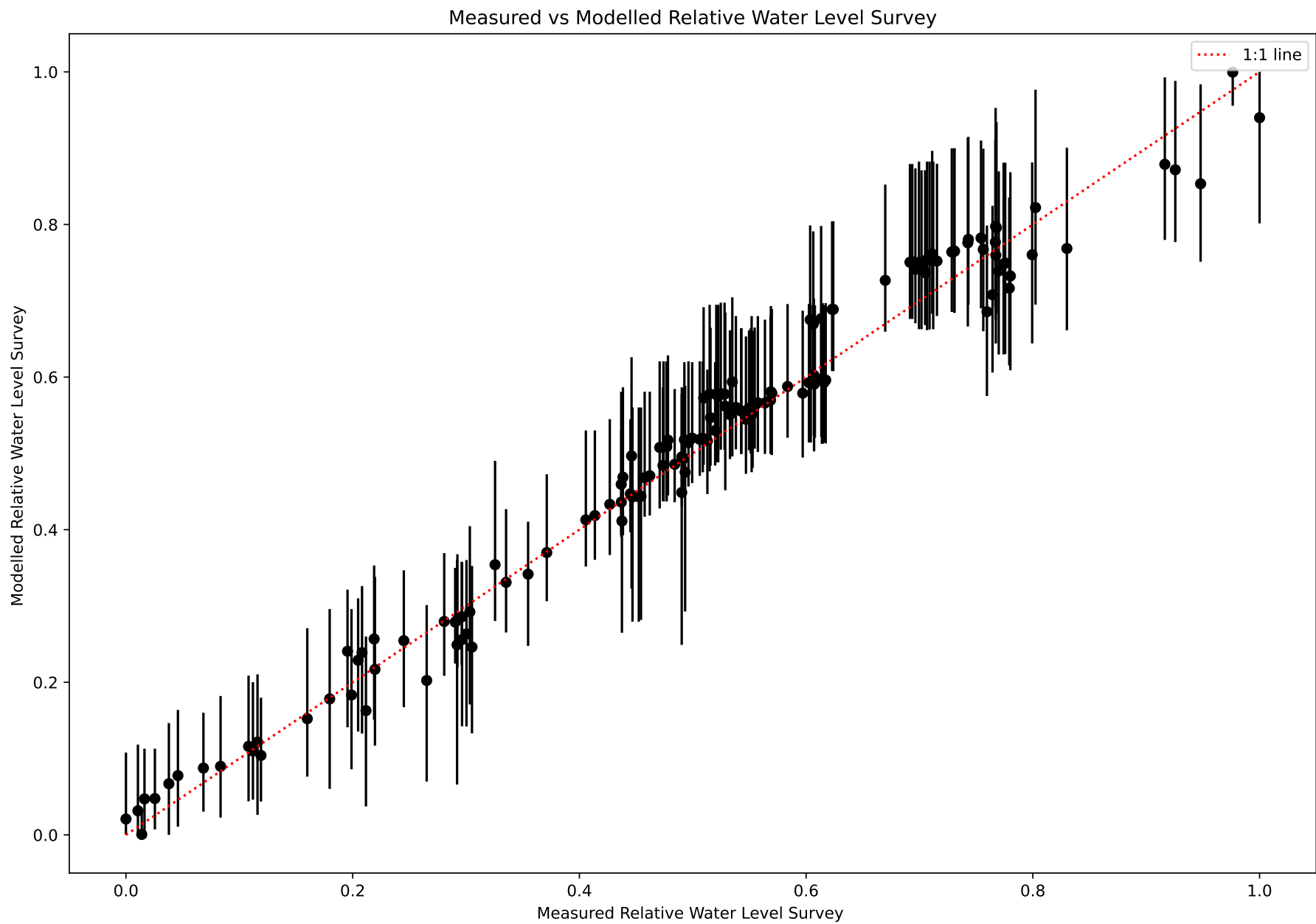
B.2 Optimisation Results

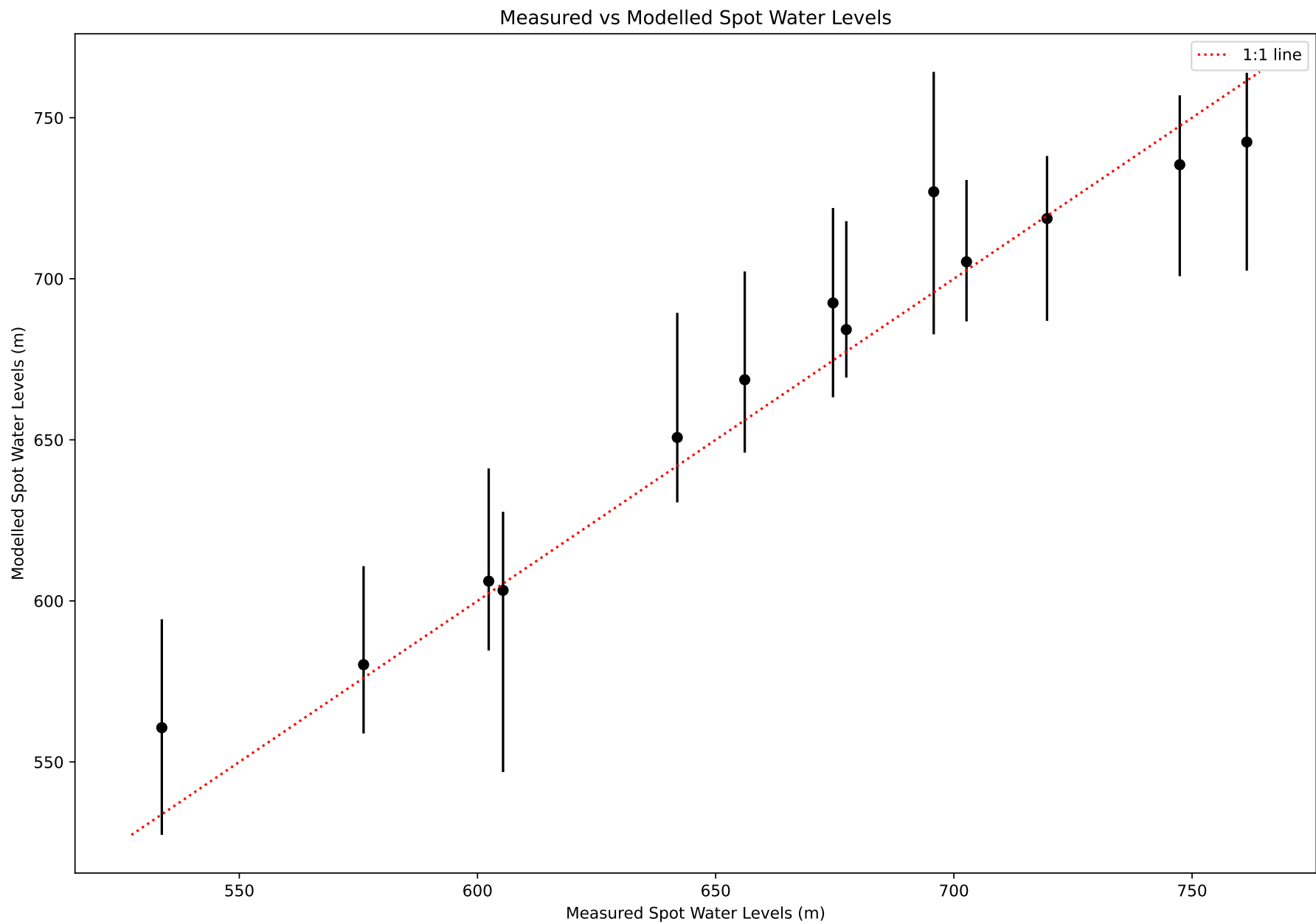
To assess the results of the optimisation, we developed a posterior distribution of the model parameters, here based on the best 10% of the parameter sets from the optimisation. The choice of 10% is somewhat arbitrary, but it provides a reasonable balance between exploring parameter space and focusing on the best fitting parameter sets. Only parameter sets that fell within the revised recharge limits (10-70 mm/year) were considered for the posterior distribution. Additionally, any parameter set that did not converge was excluded from the posterior distribution. A cumulative density function of the objective function is shown in [Figure B.1](#). To assess the fit of the model to the observed data, we have produced a number of figures showing the modelled outputs compared to the observed data. These results are presented here, but discussed more fully in [Section B.6](#).

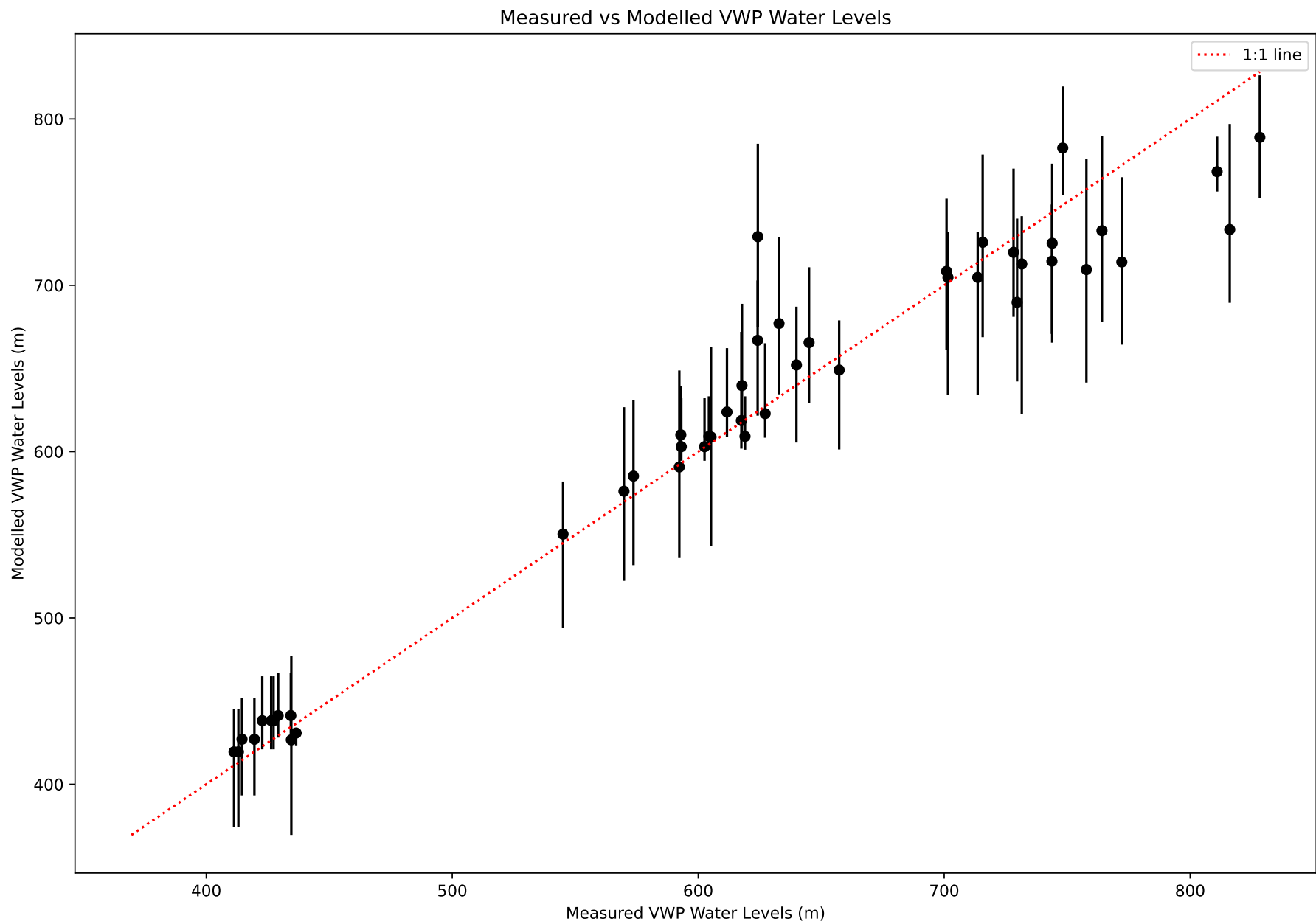


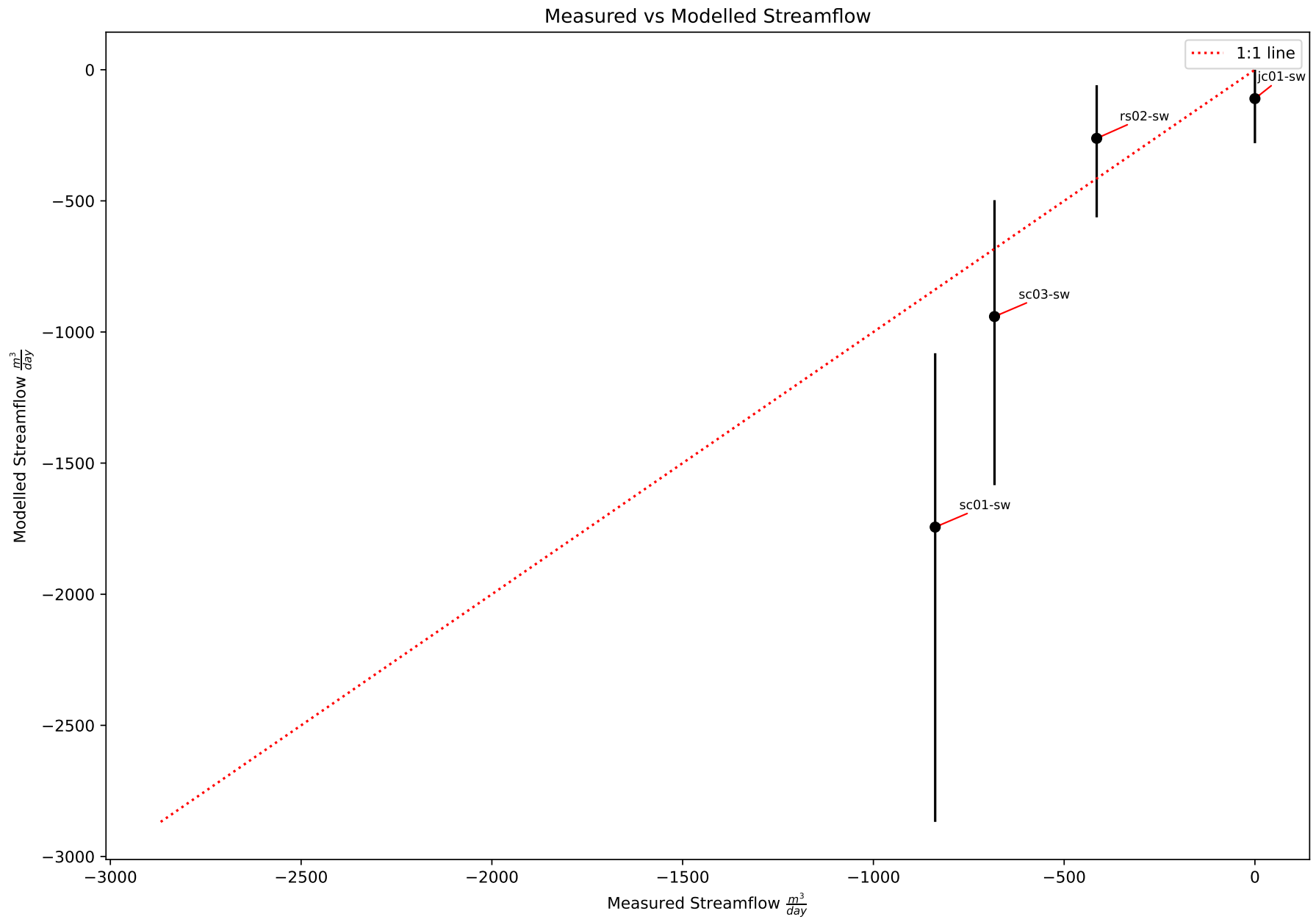


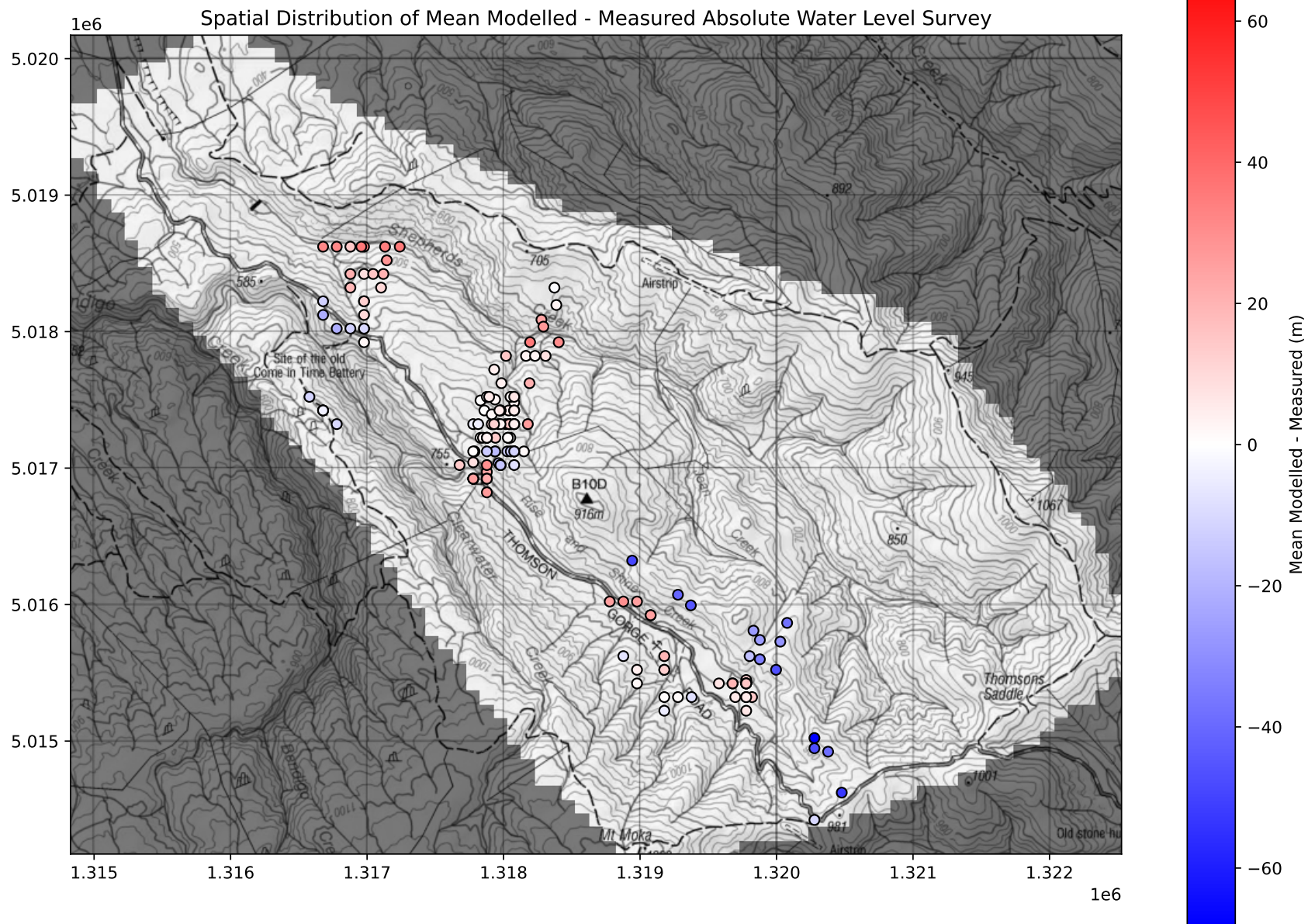


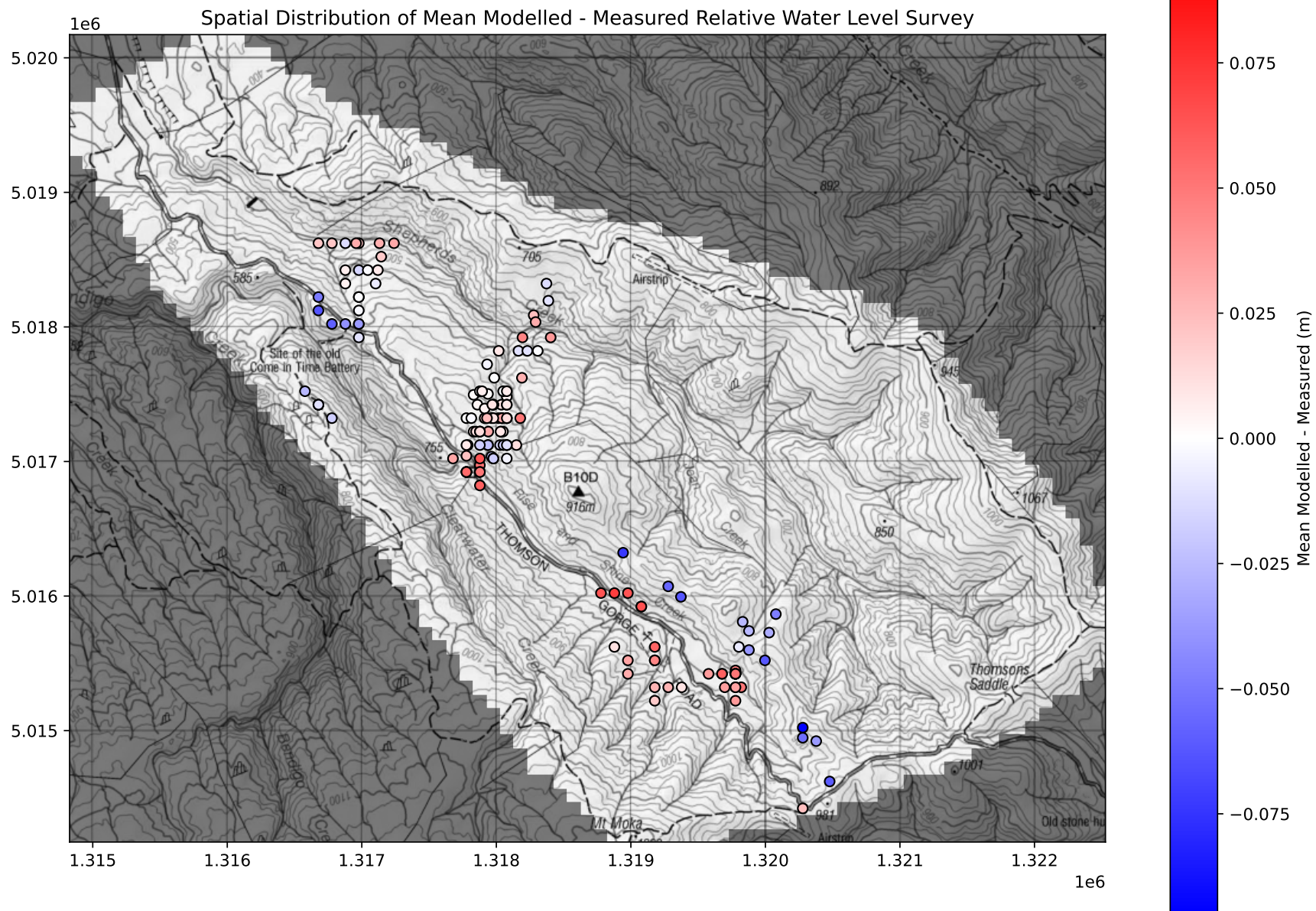


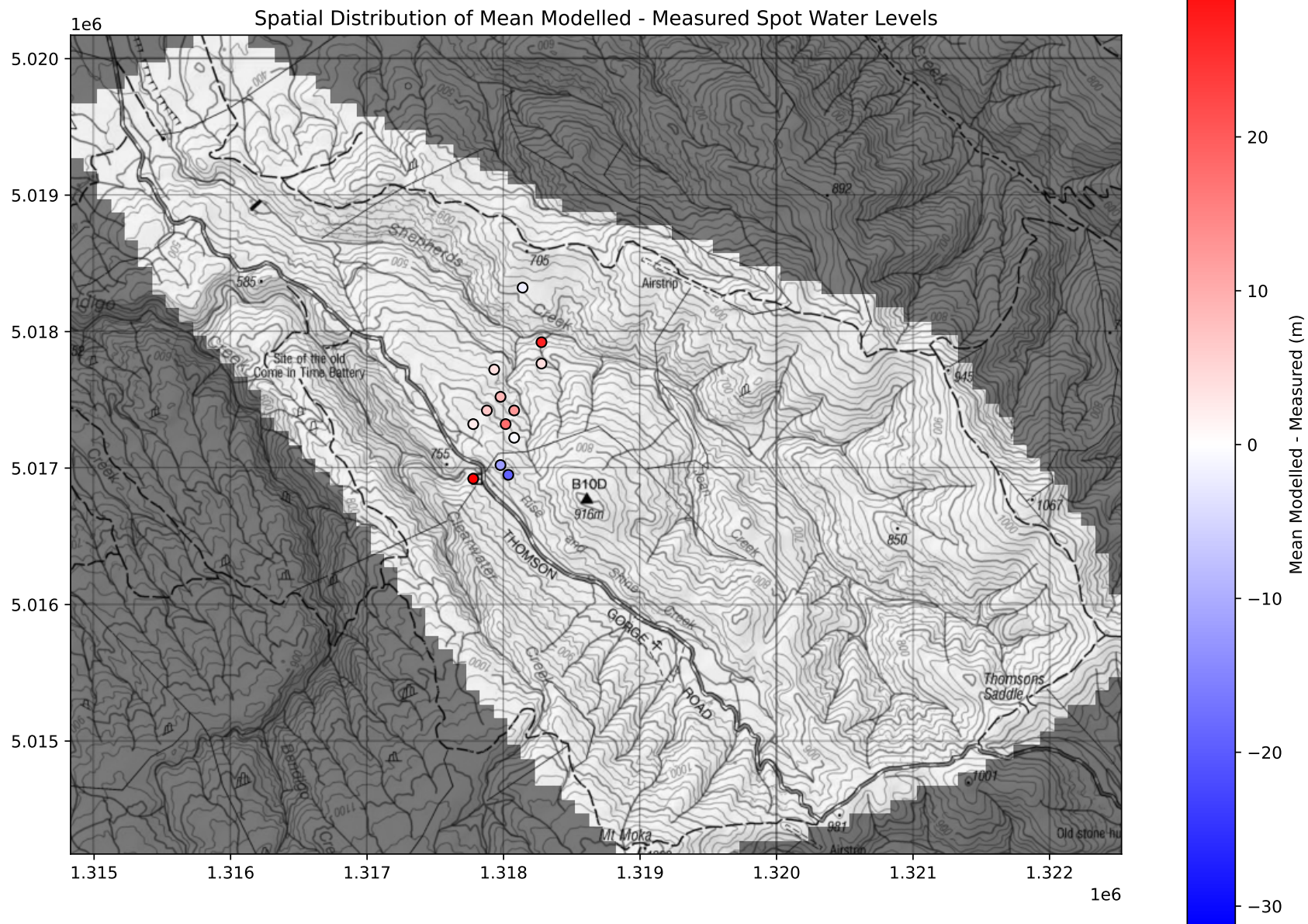


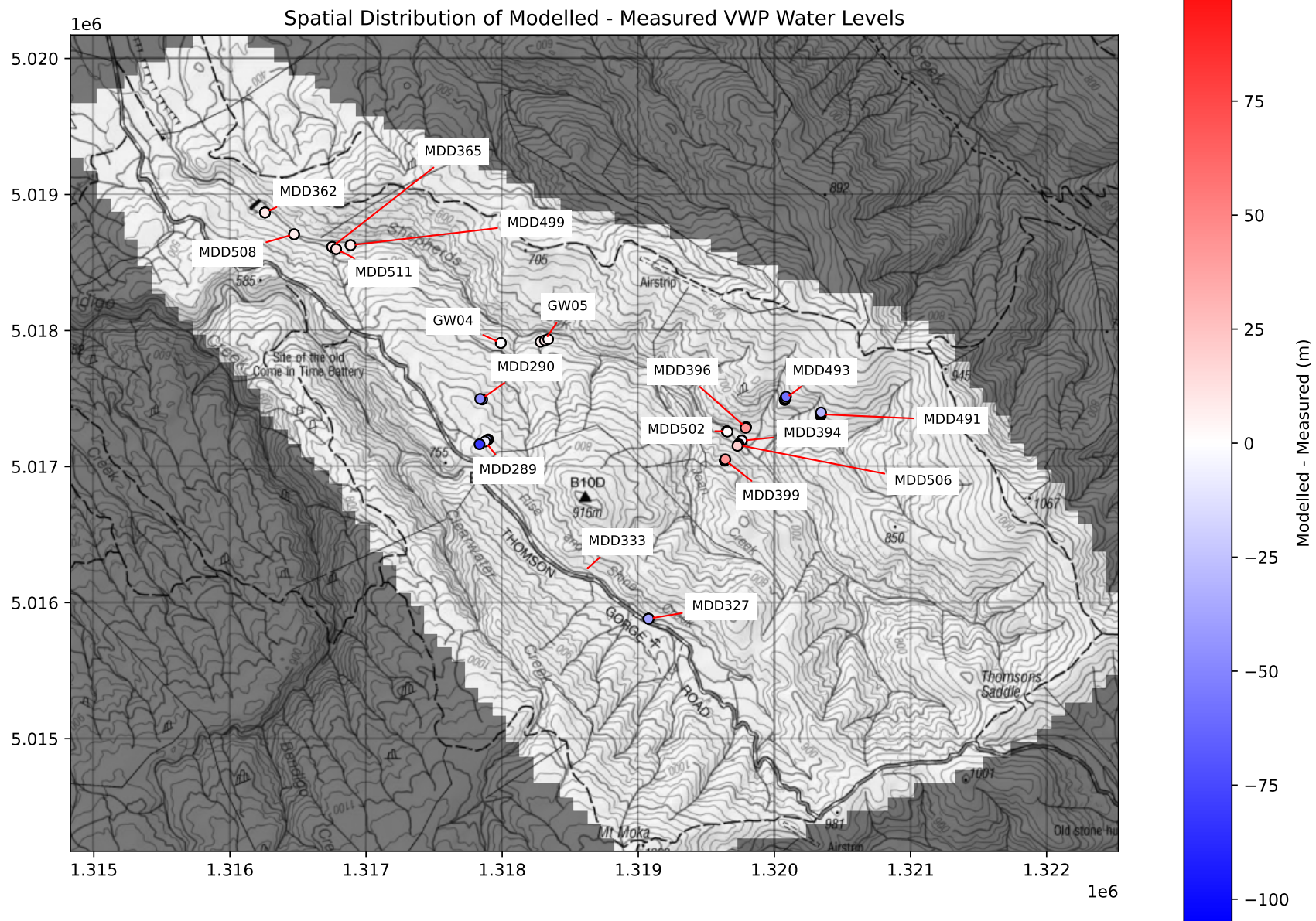


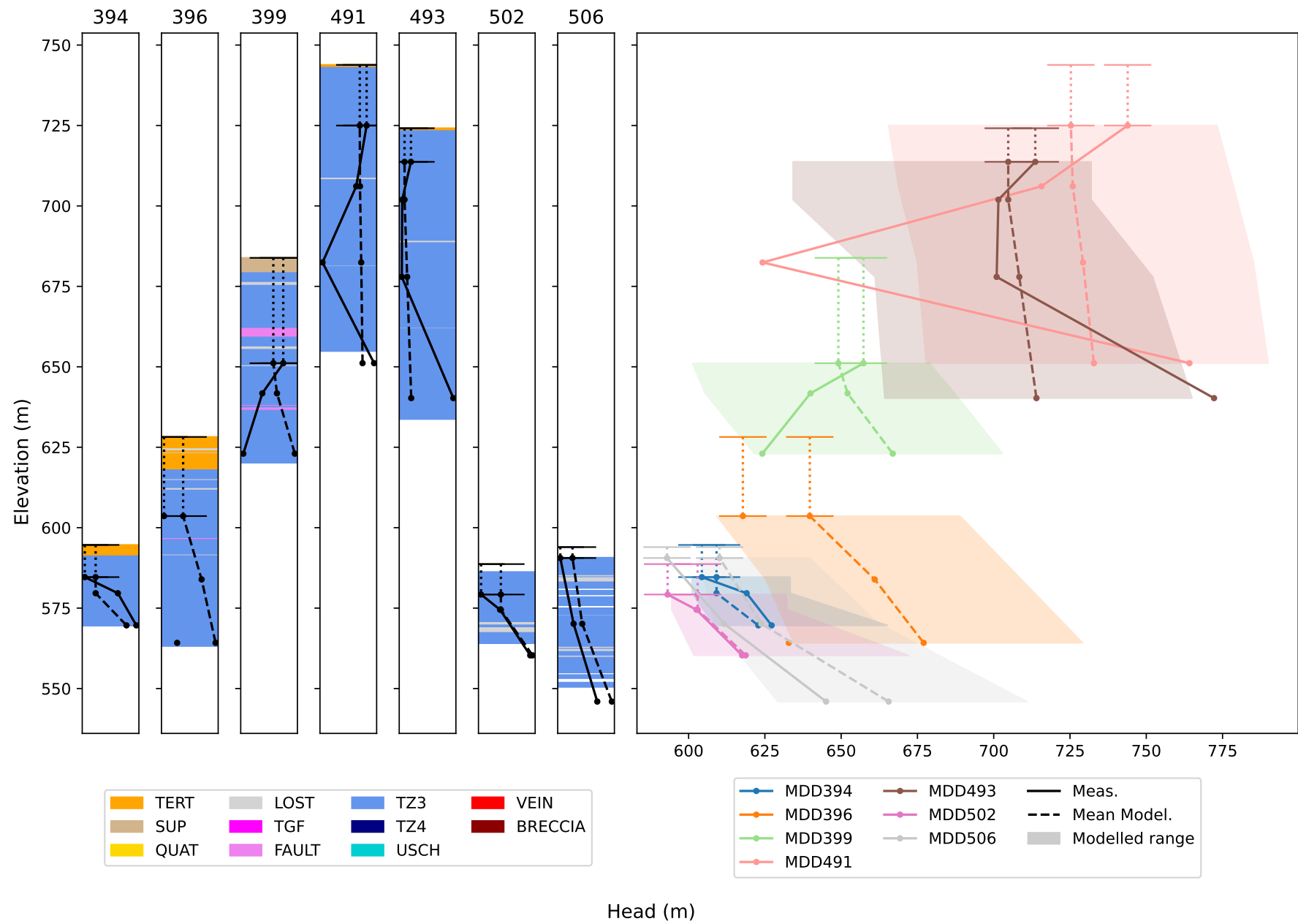


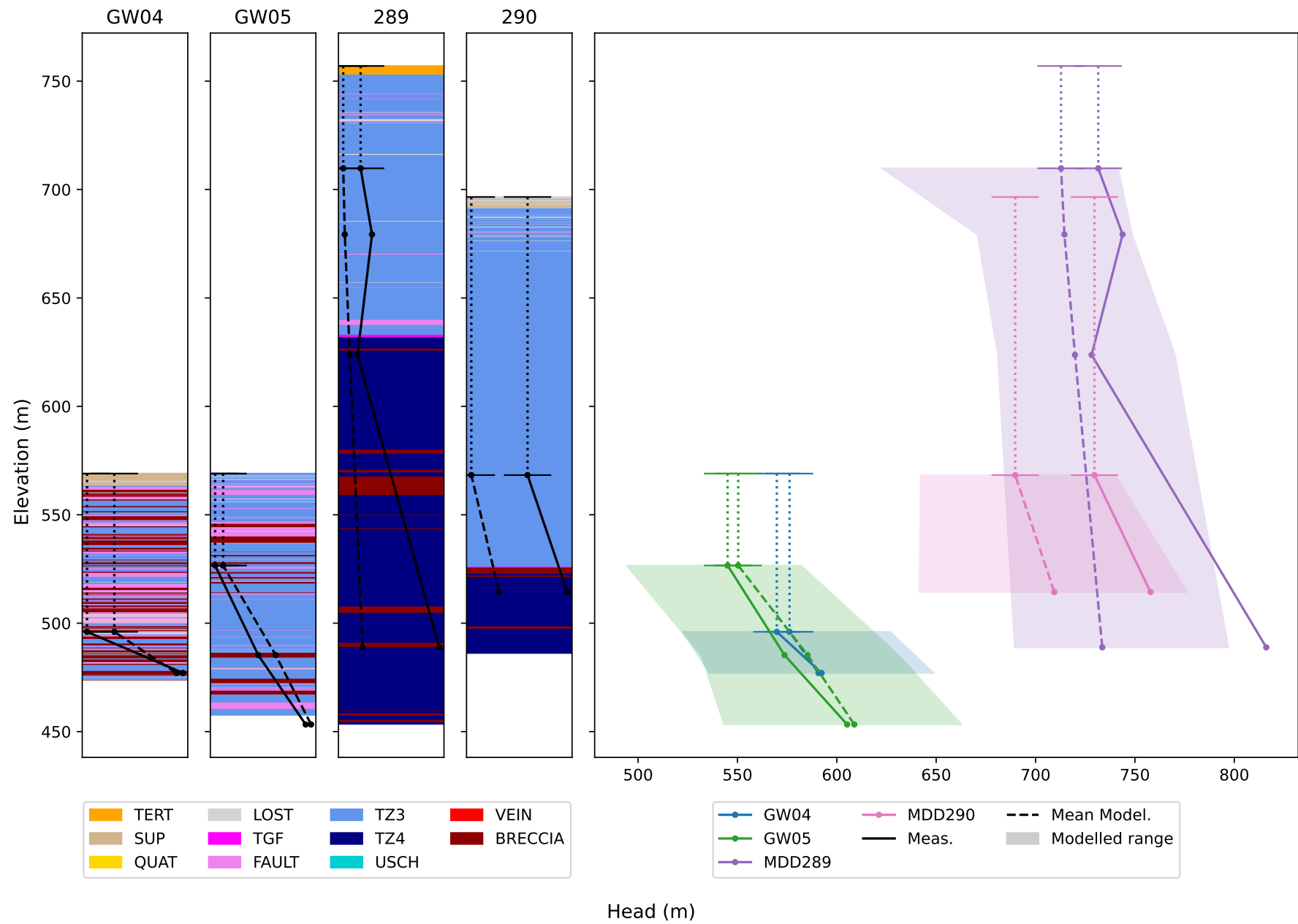


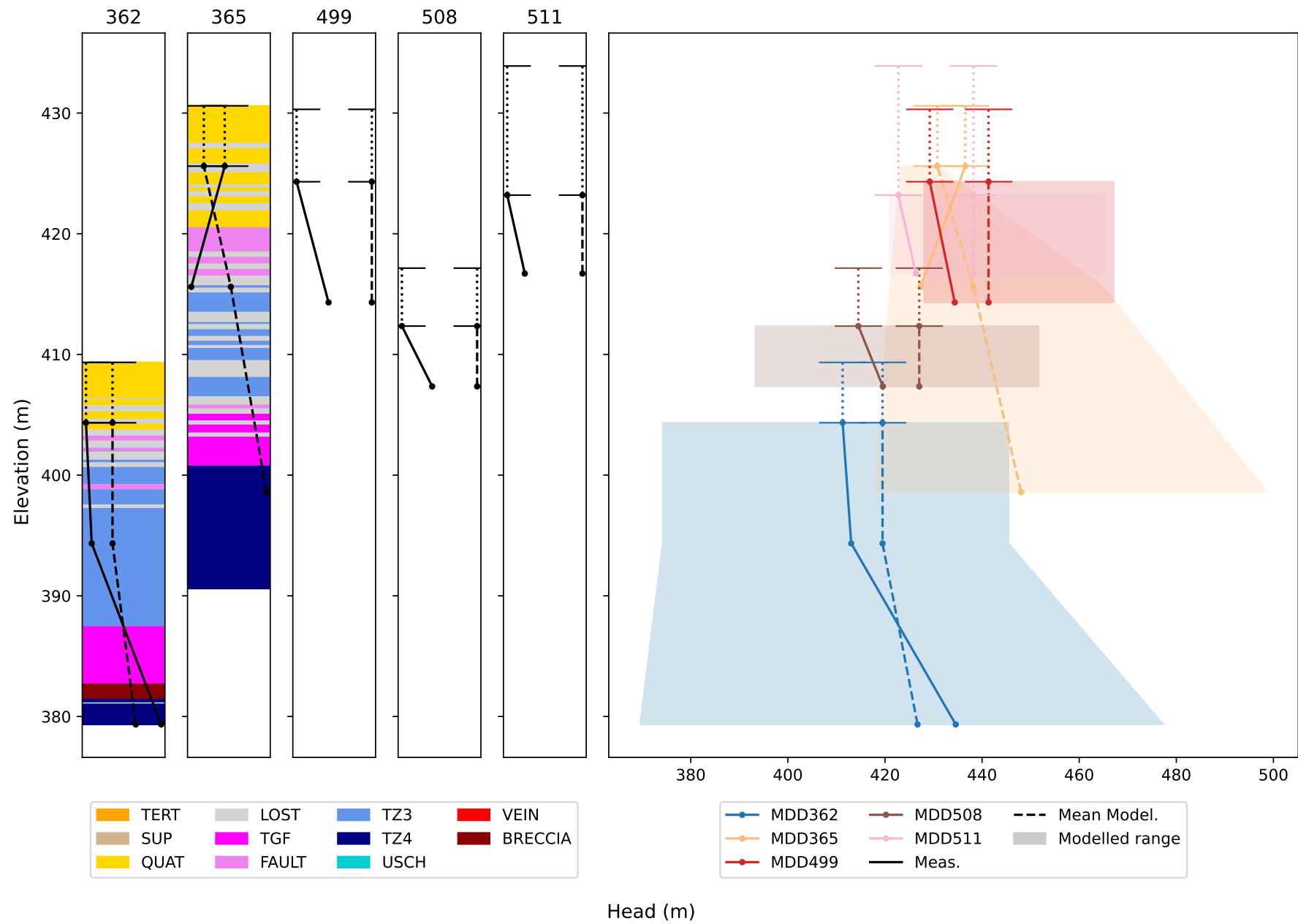


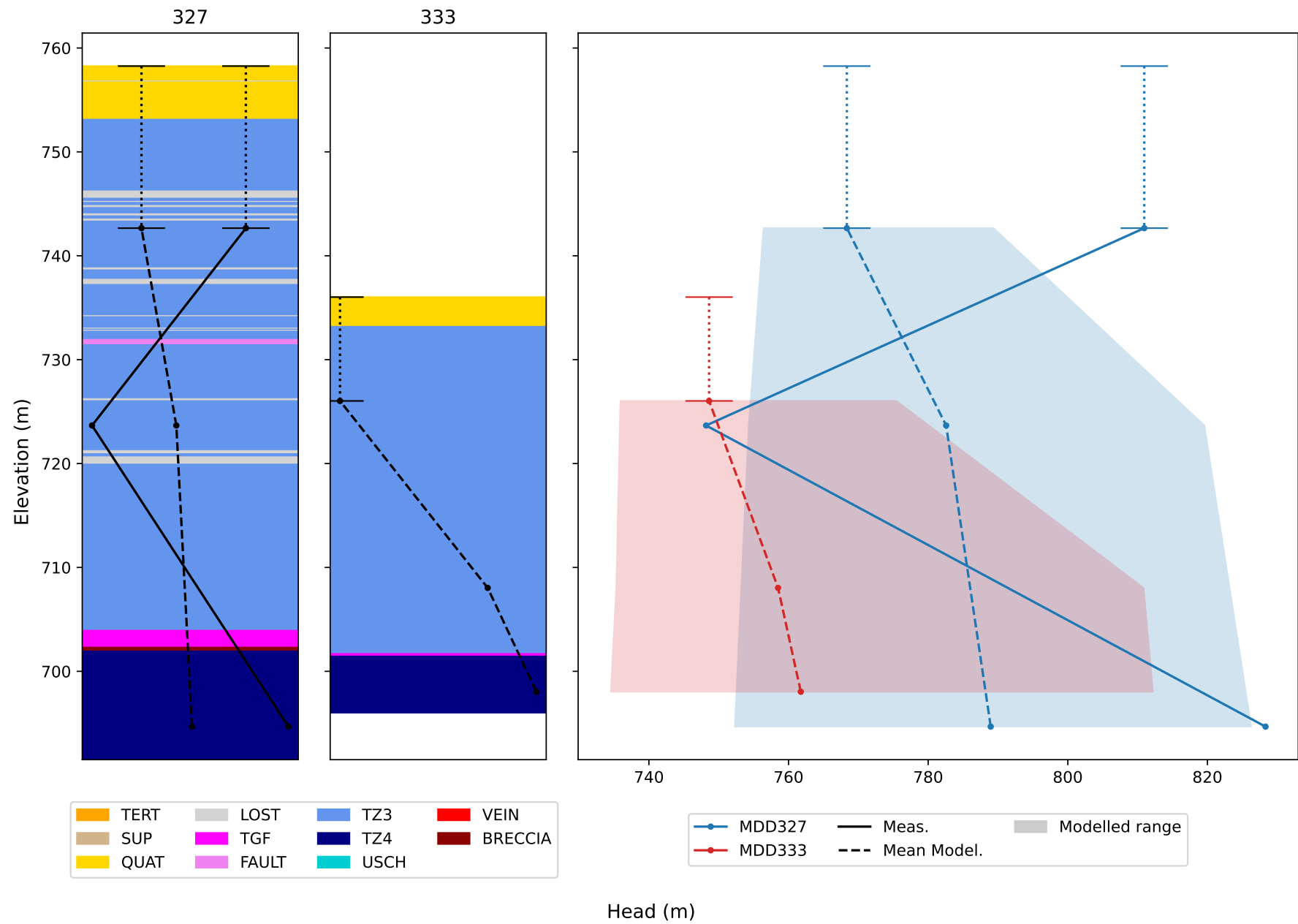












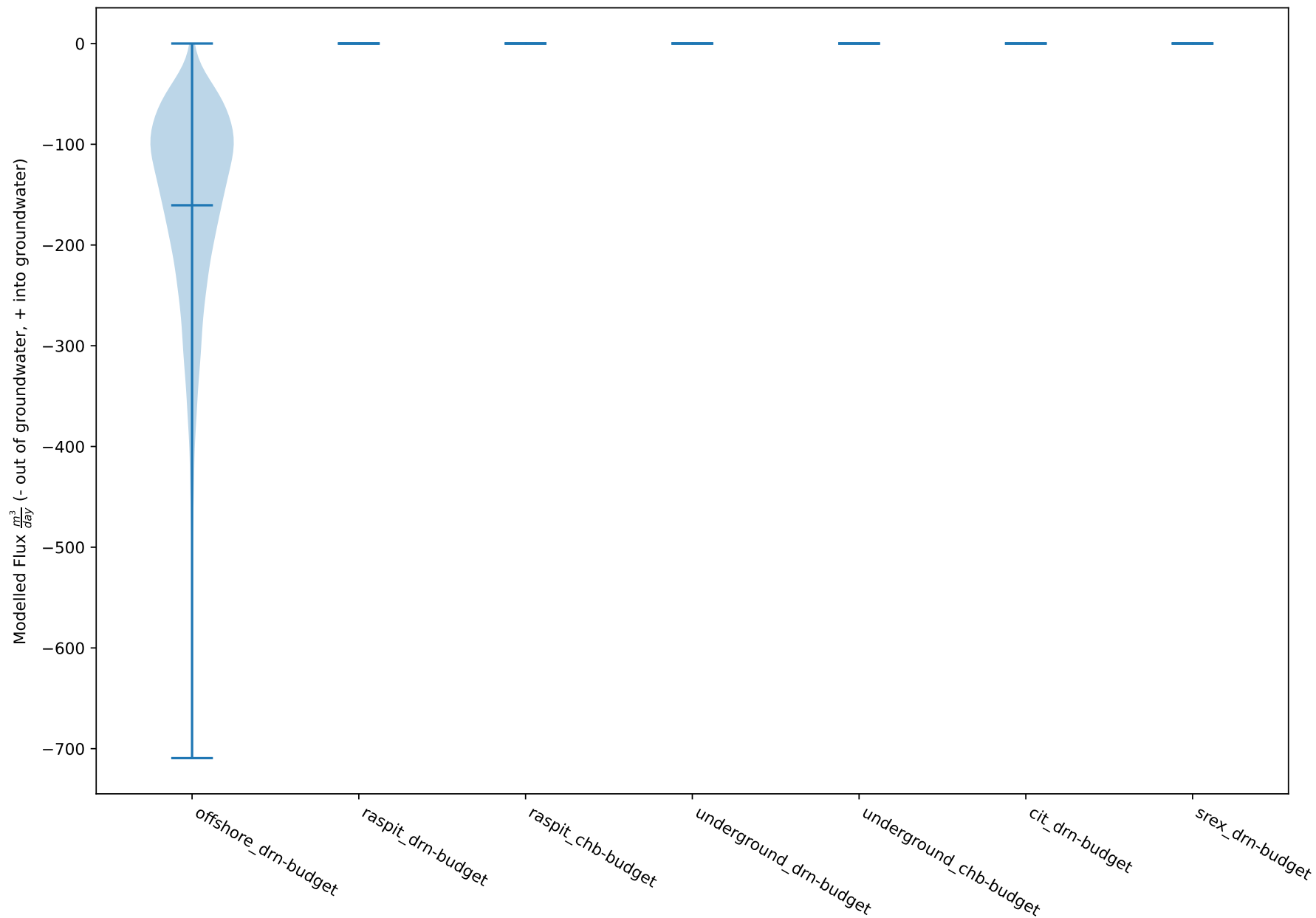


Figure B.16: Distribution of fluxes

Note that no mining features are included in this model, so the budget values are all zeros. Fluxes out of the groundwater model are negative, while fluxes into the groundwater model are positive.

B.3 Sensitivity Analysis

Figure B.17 shows tradeoff between the different components of the objective function. Generally, the groundwater level surveys, VWP data, and spot measurements are well aligned, with a largely linear direct correlation between the components. The relative water level surveys show some additional scatter, but are still broadly aligned with the other components. The surface water flow components show a much less defined relationship with the other components. This reflects the fact that fluxes and heads are not directly related and that there are multiple ways to fit the groundwater levels without fitting the surface water flows.

We conducted a sensitivity analysis of the model parameters against the objective function and various components of the objective function. This was done for the full suite, the full suite within the revised recharge limits, and the posterior distribution. Note that a positive correlation here means an increase of the objective function and thus a worse fit to the observed data, while a negative correlation means a decrease of the objective function and thus a better fit to the observed data. The largest predictors for the full set of model runs on head based objective functions were the conductivity of the QALCL (positive correlation) and recharge (negative correlation). The surface water flow components for the full set of model runs are almost exclusively controlled by recharge (positive correlation). This highlights the conflict between the surface water flows and the groundwater heads, as the optimisation wanted to increase recharge to fit the heads, but decrease recharge to fit the surface water flows.

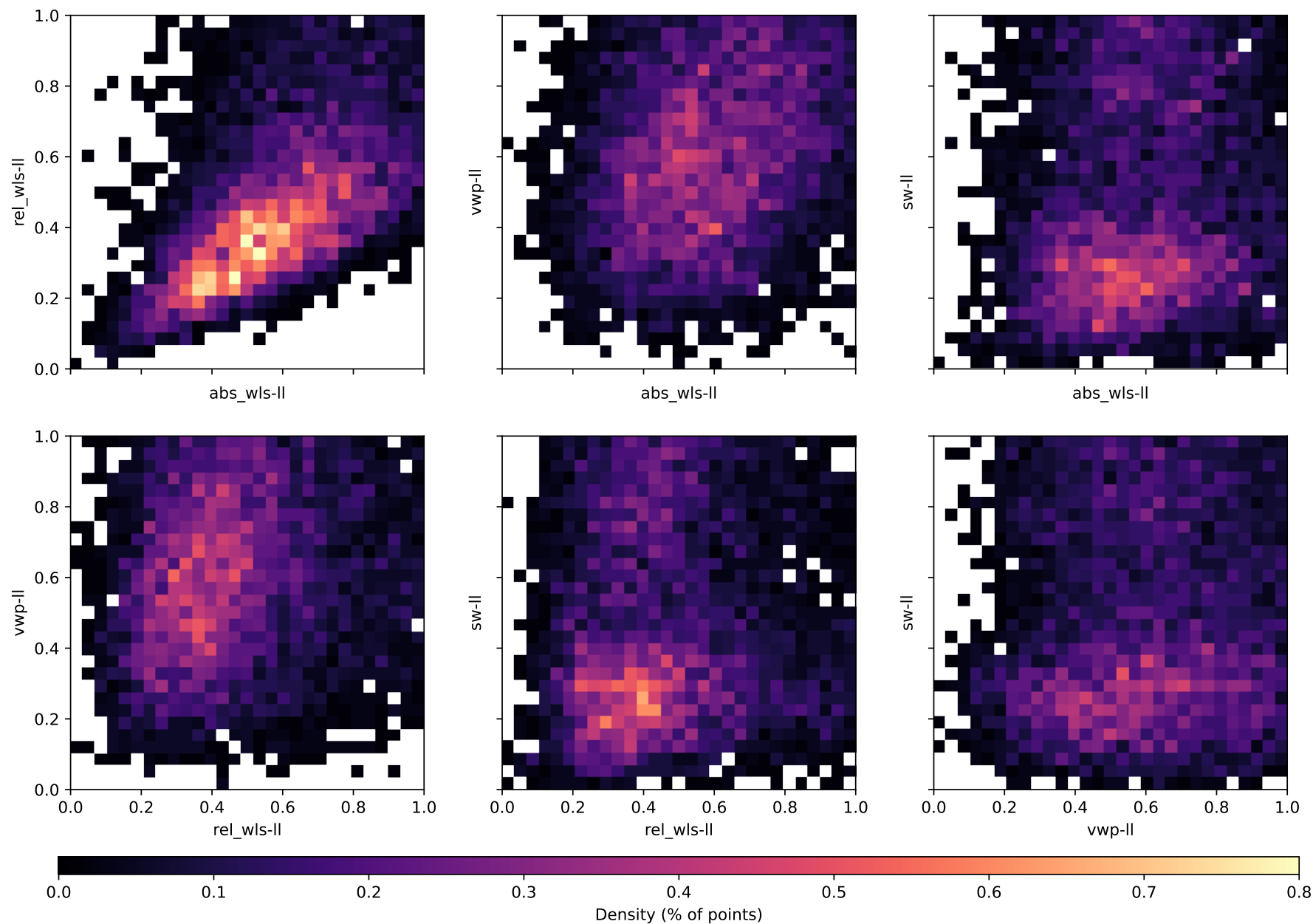
Figure B.25 to Figure B.28 show the sensitivity analysis of the posterior distribution of the model parameters against the different components of the objective function. The head based objective functions show some sensitivity to head based parameters (positive correlation), but also show significant sensitivity to recharge (negative correlation). The surface water flow components show significant extreme sensitivity to recharge (positive correlation). The total objective function ($sw*10$) maintains a positive correlation with recharge. This reinforces the conflict between the surface water flows and the groundwater heads. Such a conflict suggests a structural error in the model. Higher recharge is required to fit the groundwater heads, but lower recharge is required to fit the surface water flows. Some possible mechanisms limiting this tradeoff include:

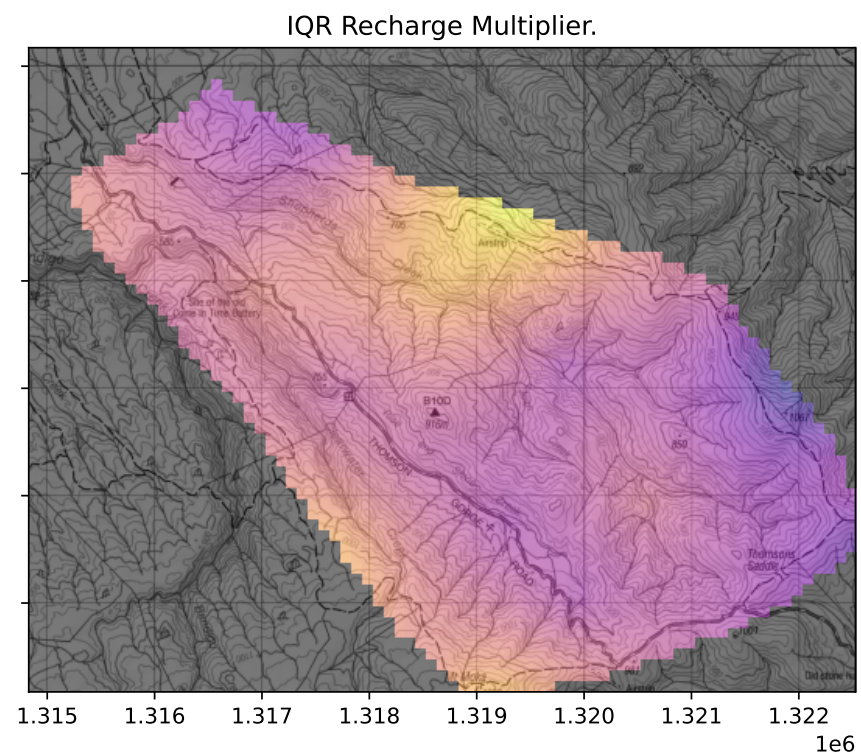
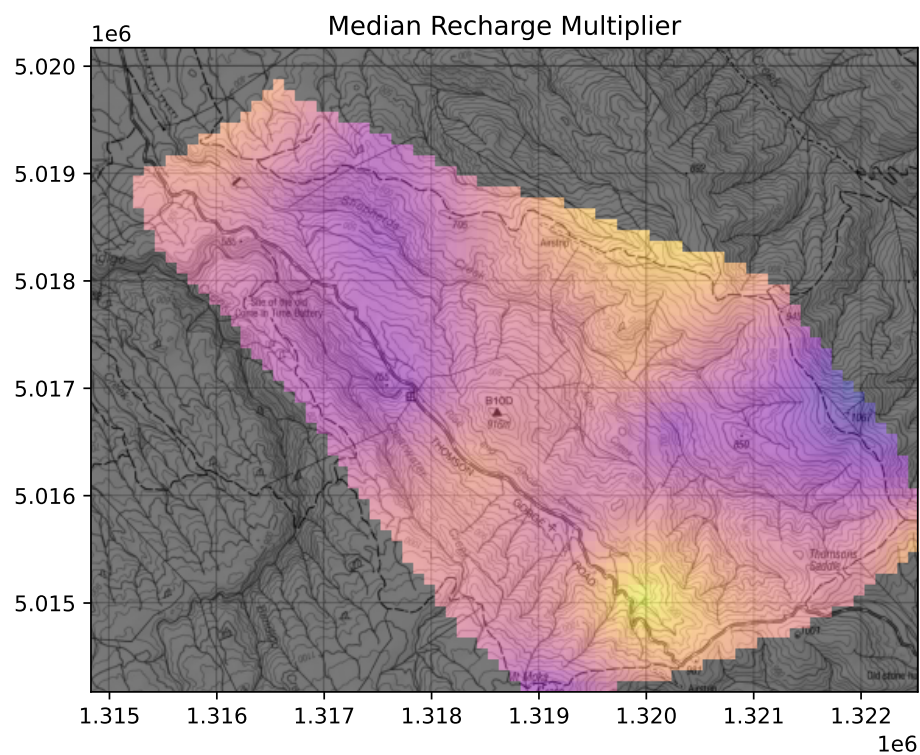
- The coarse parametrisation of the QALCL in the layer
- The simplification of the surface water routing where any head over-heights in the QALCL instantaneously discharge to the surface water drains
- The lack of more complex spatially variable recharge accounting for slope and aspect
- The lack of more complex groundwater-surface water interactions (e.g., gaining and losing streams).
- The simplification to steady-state conditions as the high groundwater heads may be more affected by wet periods than dry periods.
- Observational error in the open hole groundwater level surveys and spot measurements.
- Very fine scale heterogeneity in the system that cannot be represented in the model.

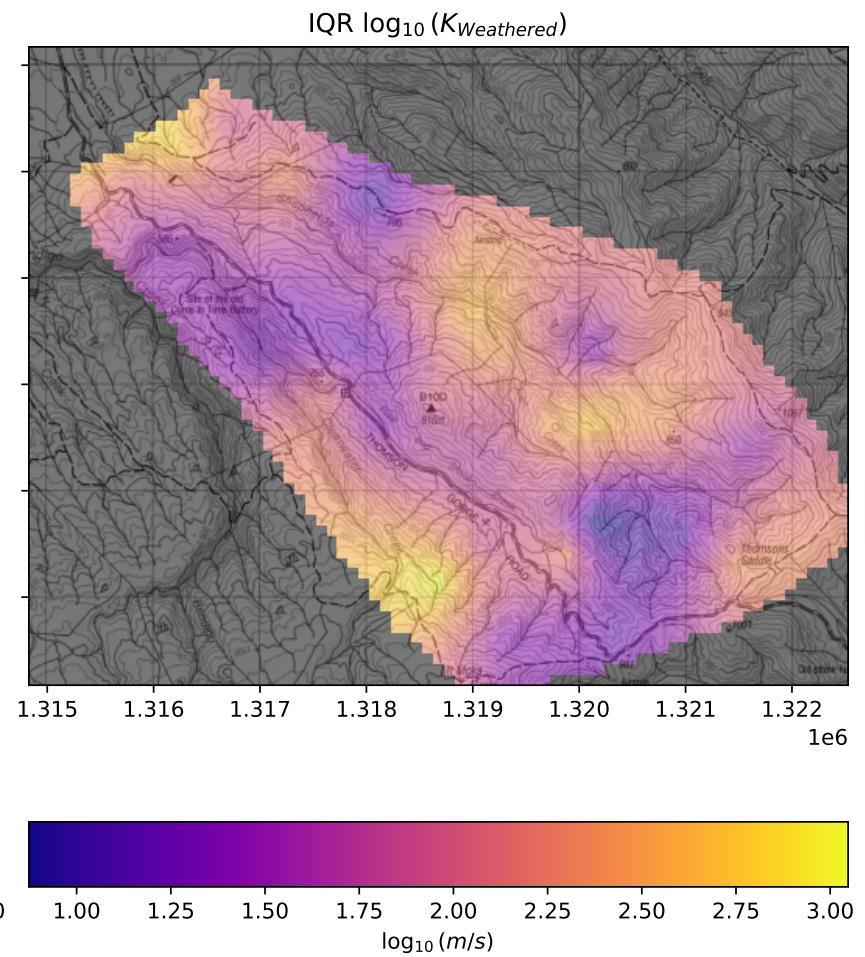
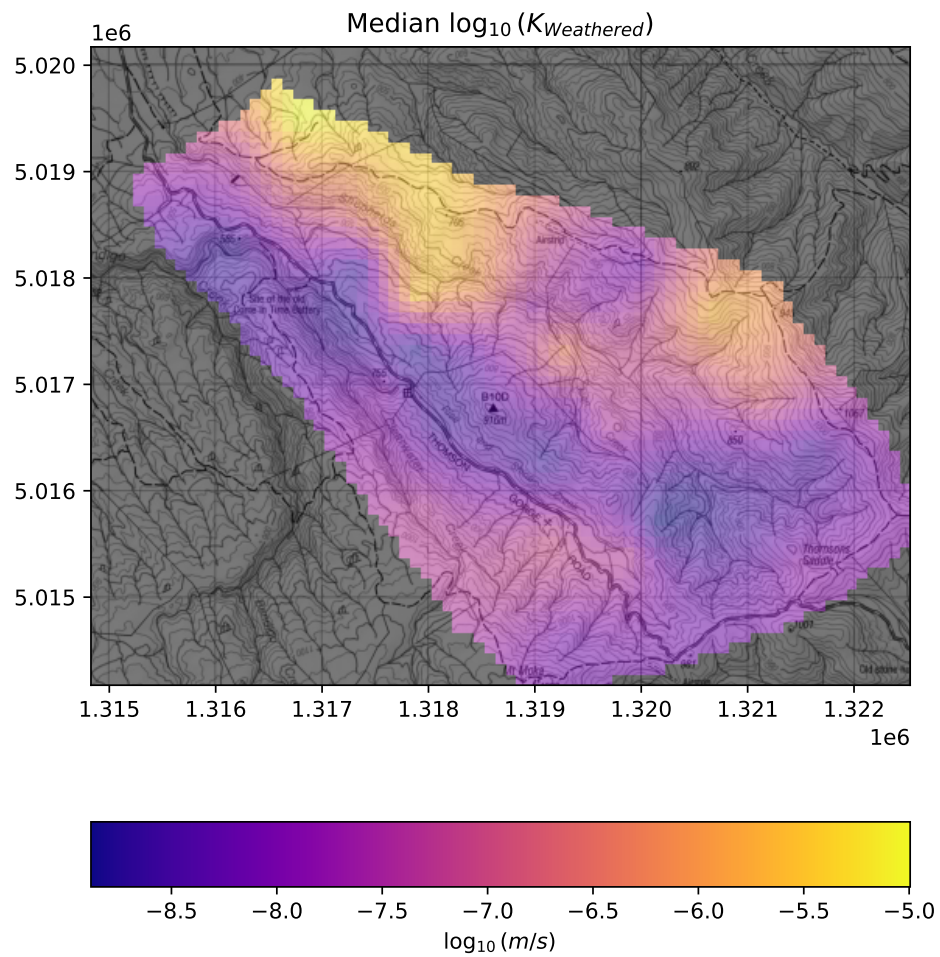
We suggest that given the current understanding of the system, resolving this conflict will be difficult to resolve without substantive additional data collection. However, we are using the model to predict mass transport pathways rather than absolute concentration so the excess fluxes will not have a direct dilution effect on the predictions of interest. We use a stochastic suite of model realisations for the forward predictions. If the excessive fluxes indirectly affect the prediction of interest, then the stochastic suite of model realisations will capture this affect and the associated uncertainty in the predictions of interest.

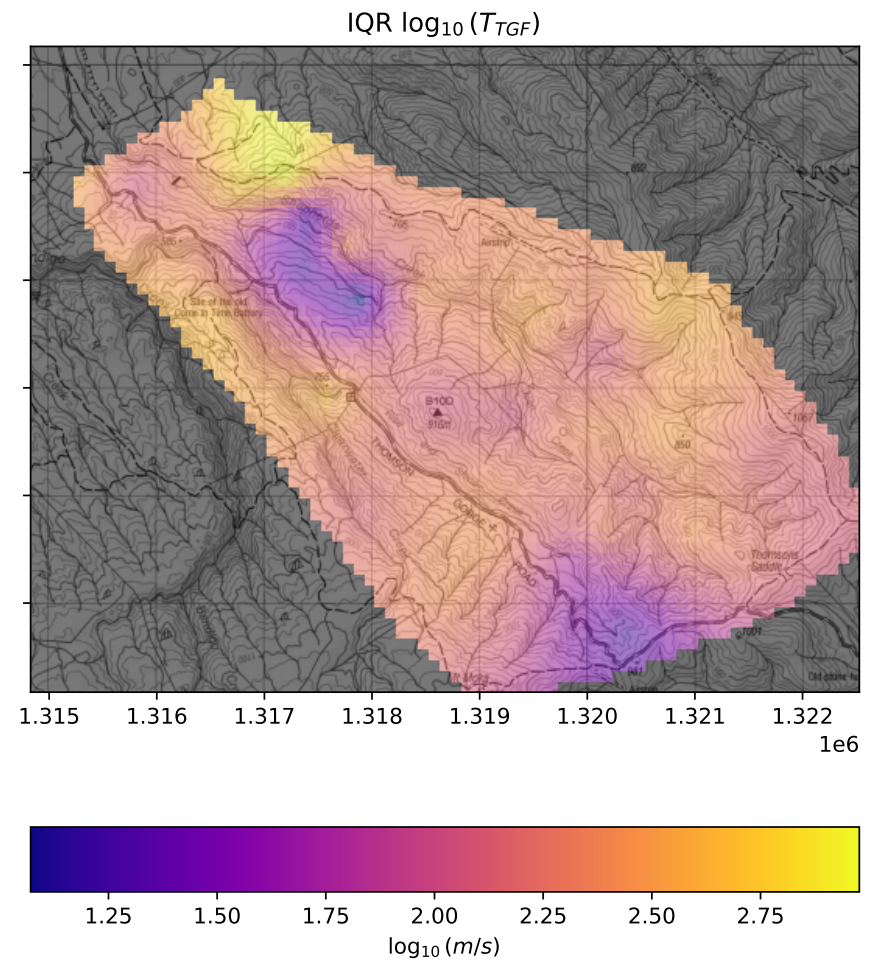
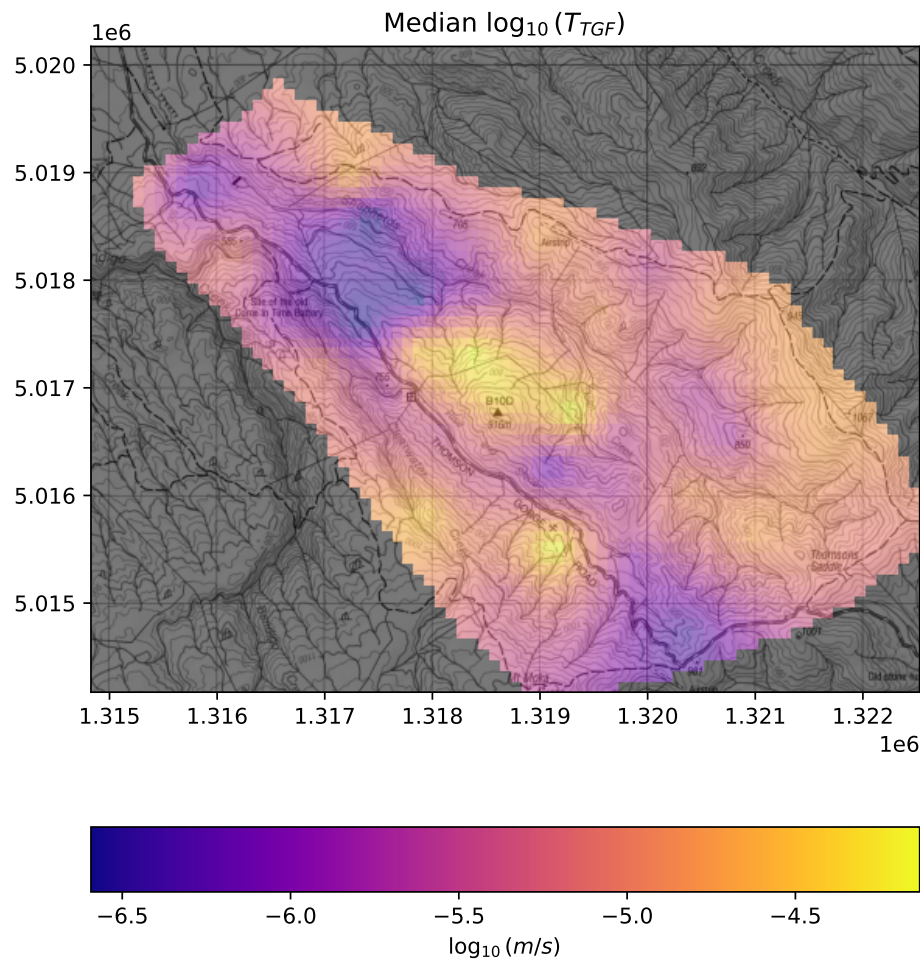
Figure B.18 to Figure B.24 show the spatially interpolated recharge multiplier and hydraulic conductivity parameters for the posterior distribution. The recharge multiplier is generally higher in the southern part of the model domain (Rise and Shine Creek) and lower in the northern part of the model domain (Shepherds Creek). This is consistent with the challenges of fitting the surface water flows, but higher recharge seems necessary in the upper portion of the Rise and Shine Creek catchment to fit the observed water levels. There are a few areas with a smaller IQR (Inter Quartile Range), indicating that the posterior distribution is more tightly constrained in these areas and is therefore more sensitive to the observed data. The aforementioned areas in the upper Shepherds Creek catchment are generally more sensitive to the observed data. The weathered rock hydraulic conductivity is generally on the lower end of the prior distribution, and the IQR is generally quite low

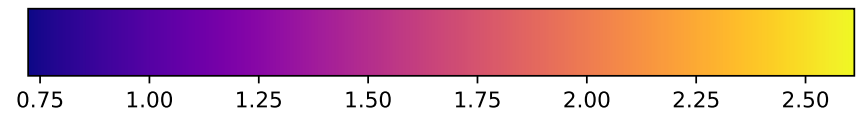
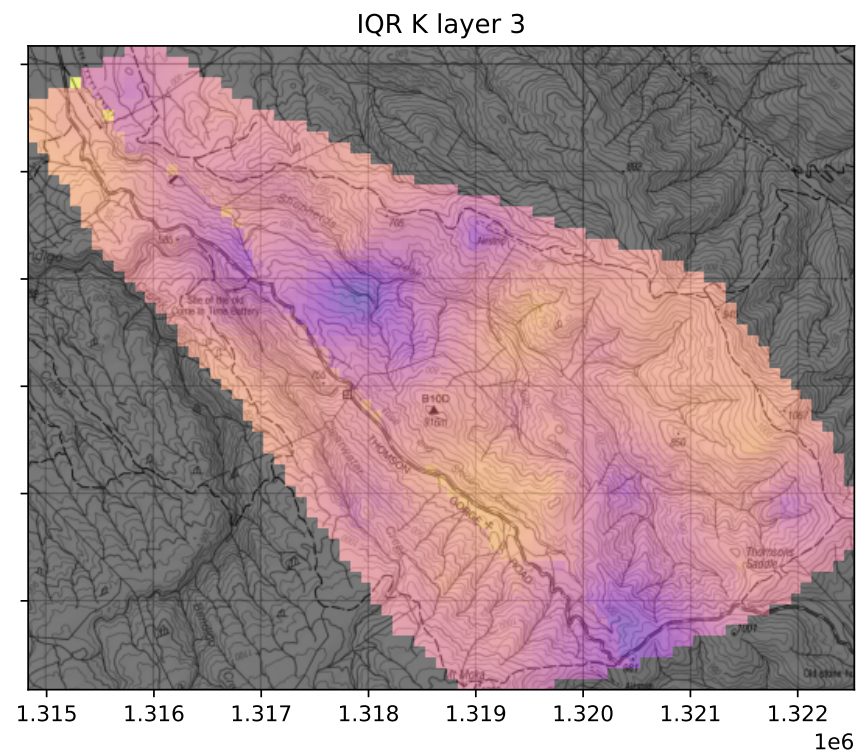
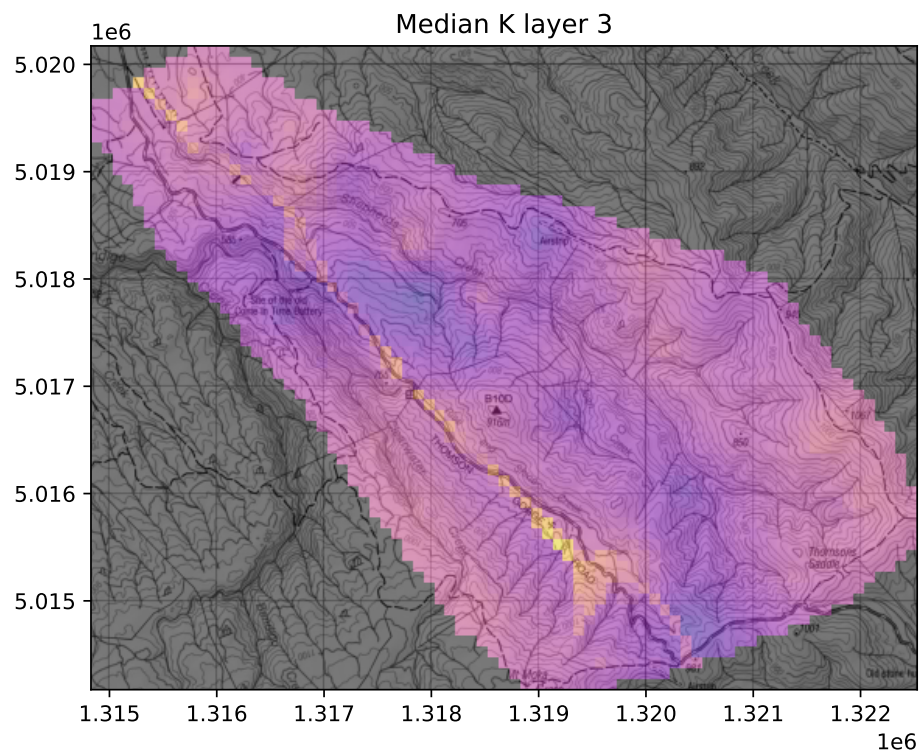
except for the slopes of Mt. Moka and two bands across Shepherds Creek. Neither of these areas have significant observed data, so the posterior distribution is not well constrained in these areas. The transmissivity ($thickness \times k_h$) of the TGF is generally very poorly constrained except in the areas near the main RAS and the near the summit of Thompson Gorge Road. The area near the RAS as significant observed data intersecting the TGF, so significant constraints here makes sense. The area near the summit of Thompson Gorge Road has some observed data, and the TGF is very near to the surface, so additional sensitivity here is also reasonable. In both these areas the conductivity is lower than the prior distribution. While the hydraulic conductivity of the TGF is higher than that of the TZ-3 and TZ-4 units in the posterior suite, it is also generally quite poorly constrained (2-3 orders of magnitude range in the IQR). This suggests that the data does require the TGF to be more conductive than the surrounding units, but the data does not provide strong constraints on the exact value of the TGF hydraulic conductivity. The posterior distribution covers a wide range of possible TGF hydraulic conductivities, so if the predictions of interest are sensitive to the TGF hydraulic conductivity, the posterior distribution should be used to ensure the uncertainty is captured in the predictions. The hydraulic conductivity of the TZ-3 and TZ-4 units are generally lower than the prior distribution, and the IQR is typically lower in the areas with significant observed data and higher at depth.

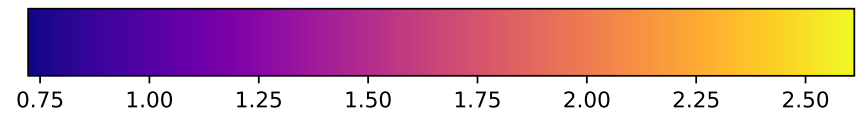
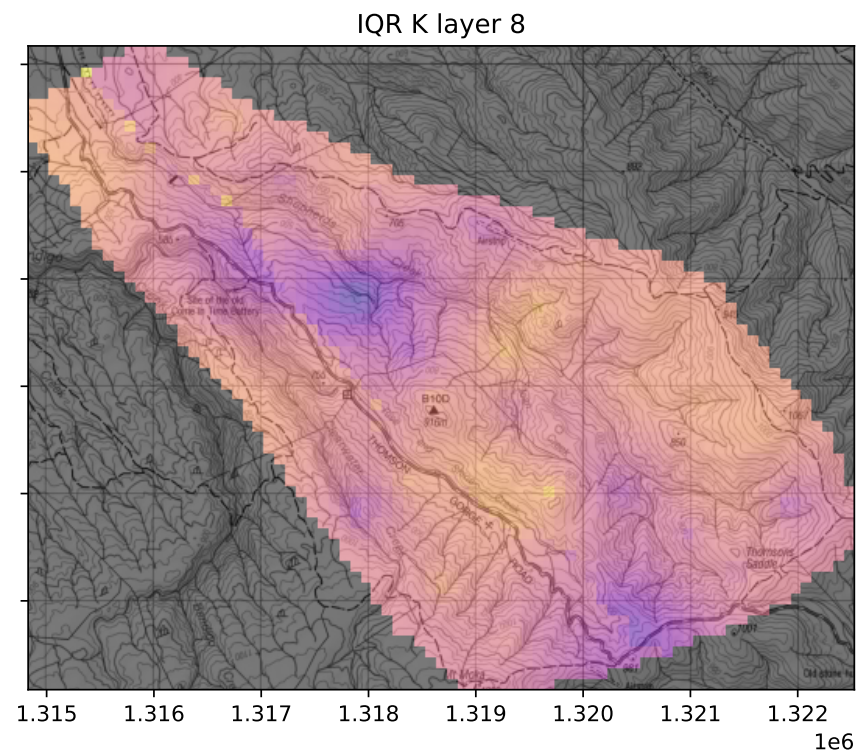
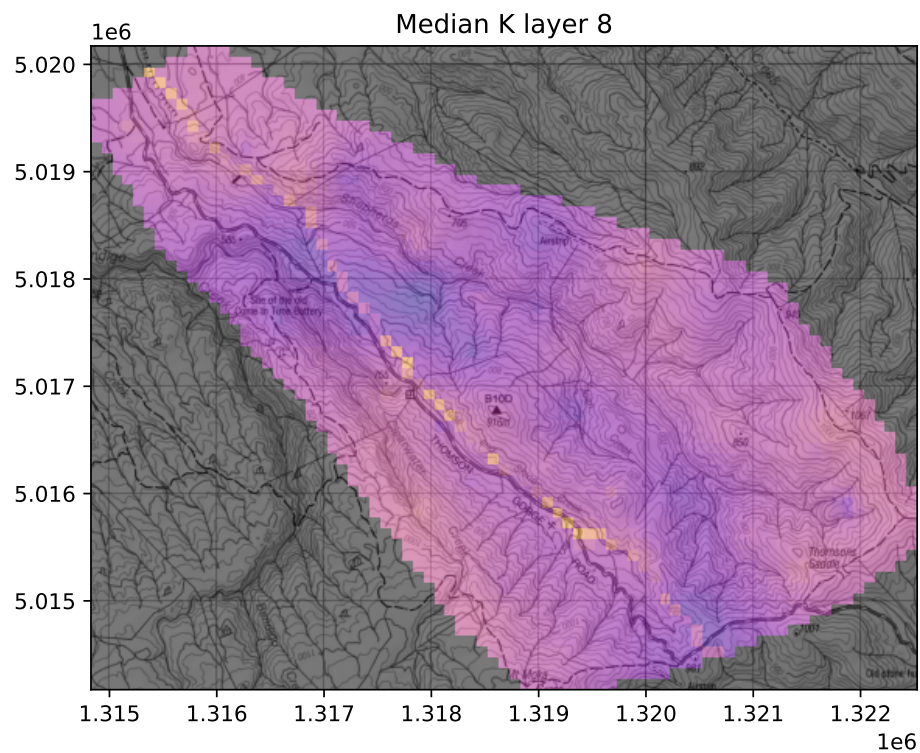


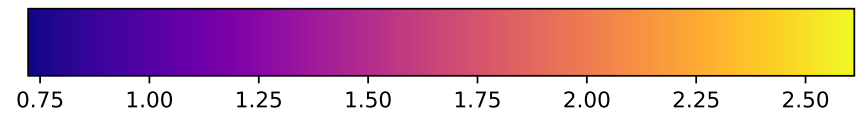
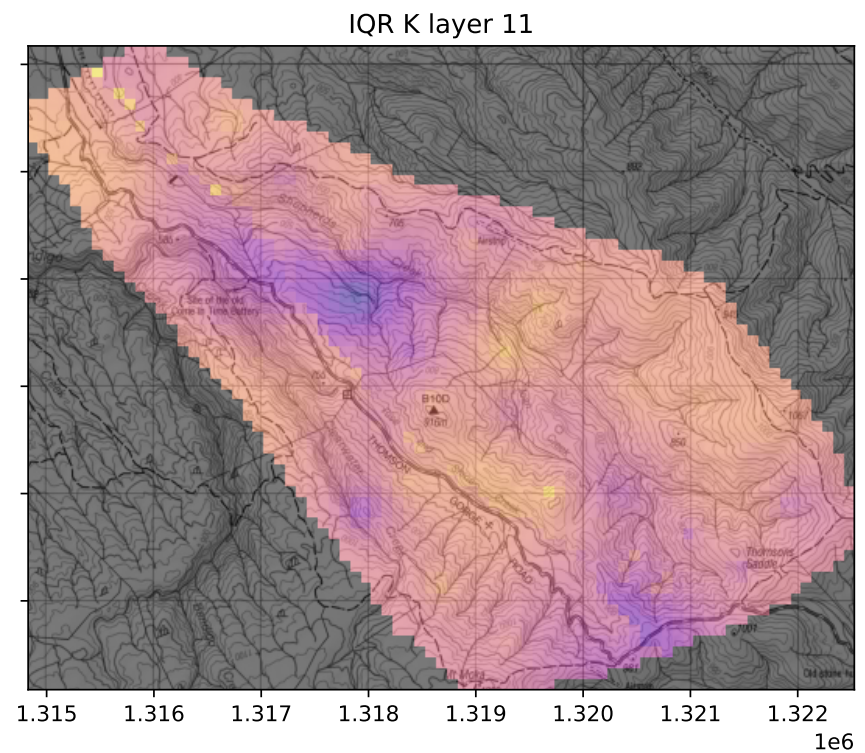
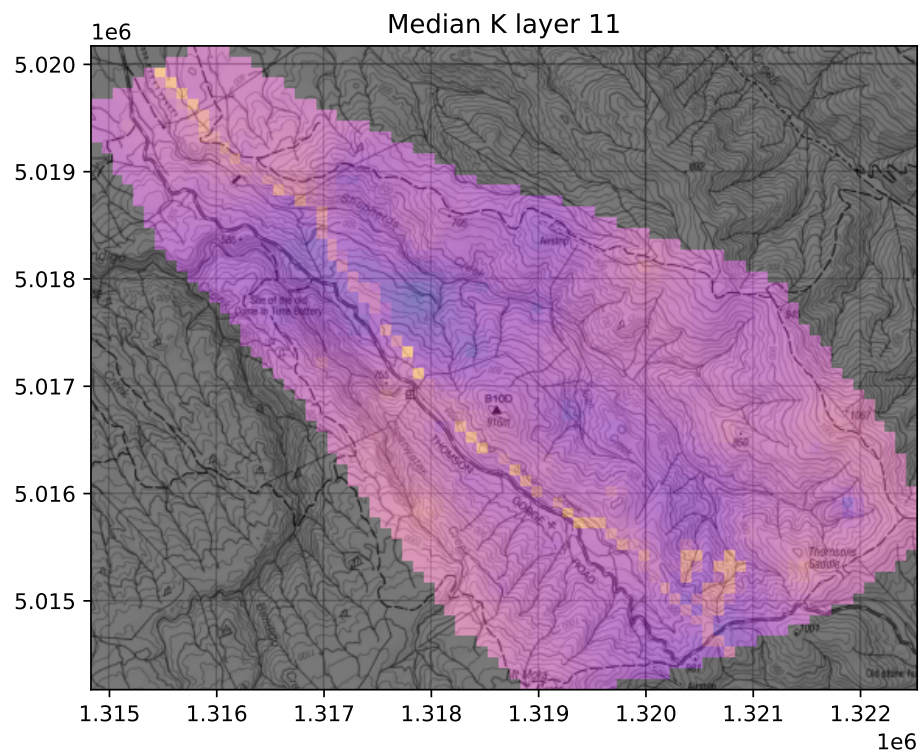


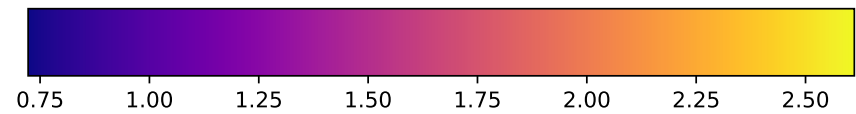
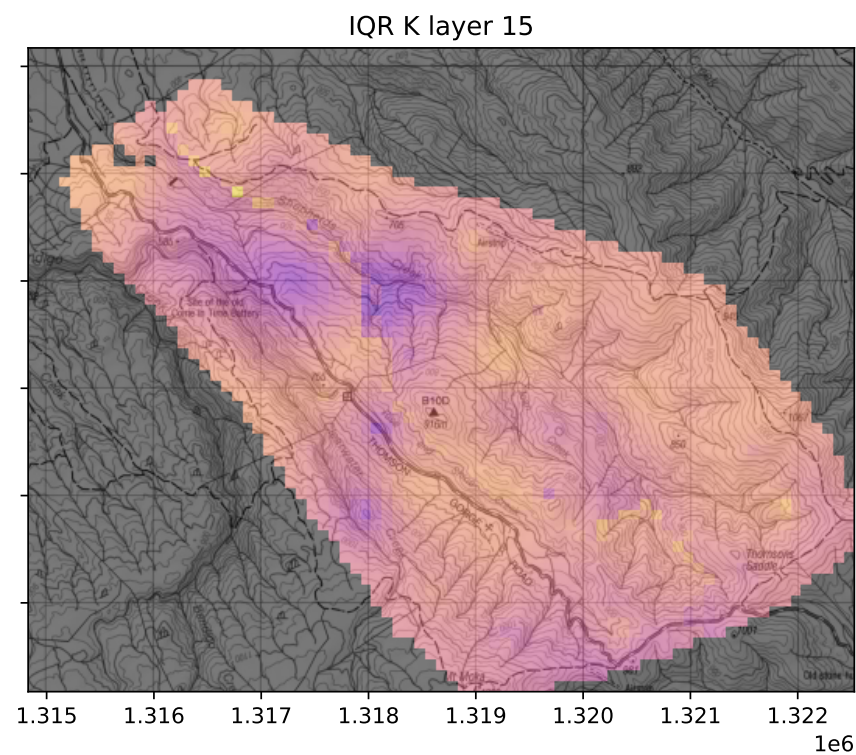
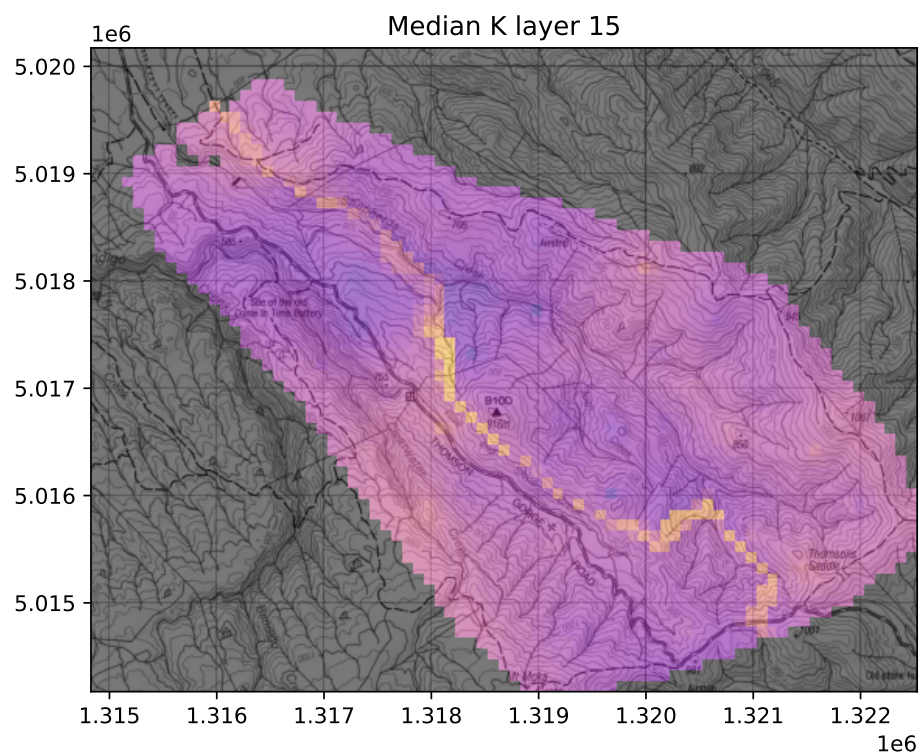


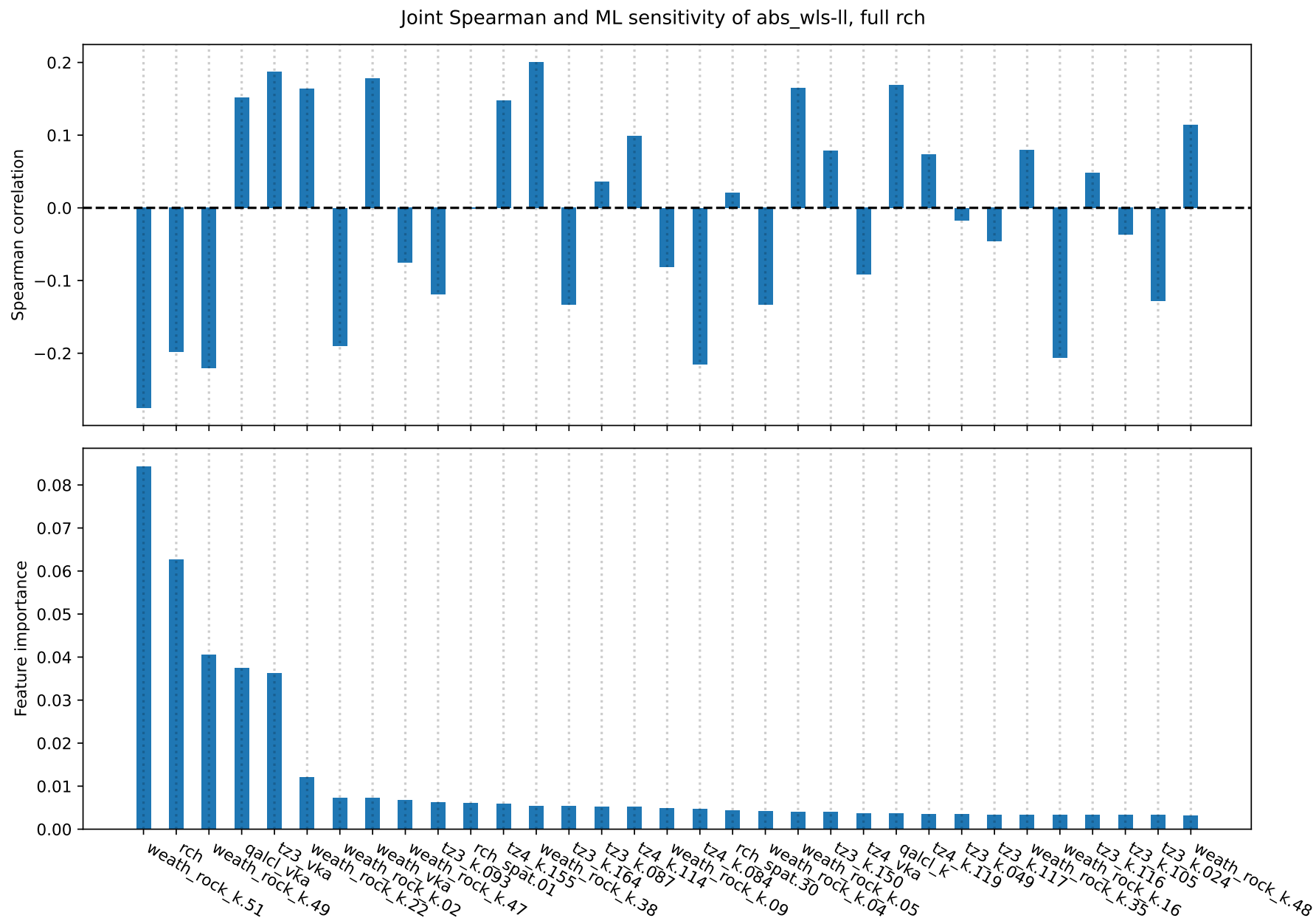




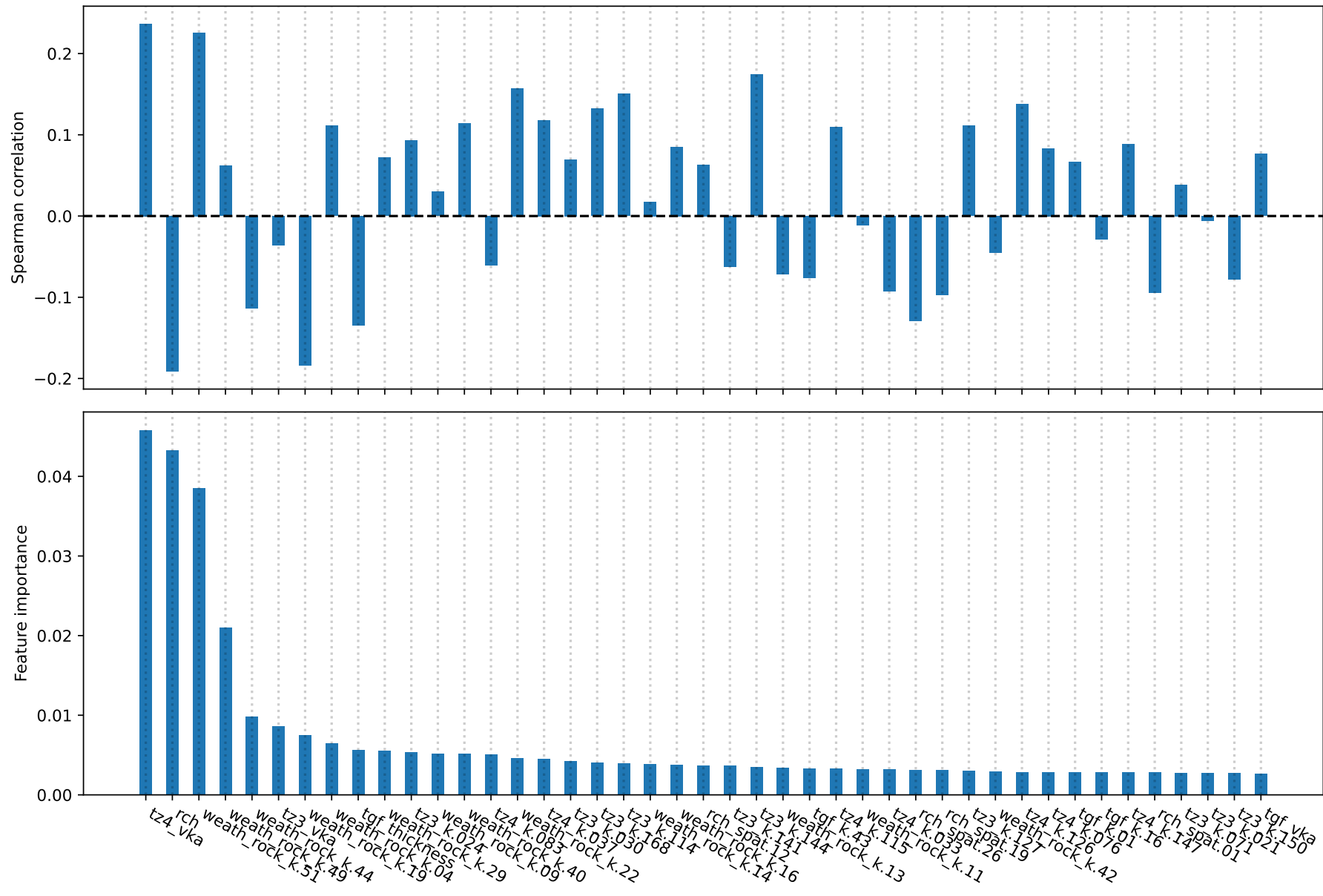




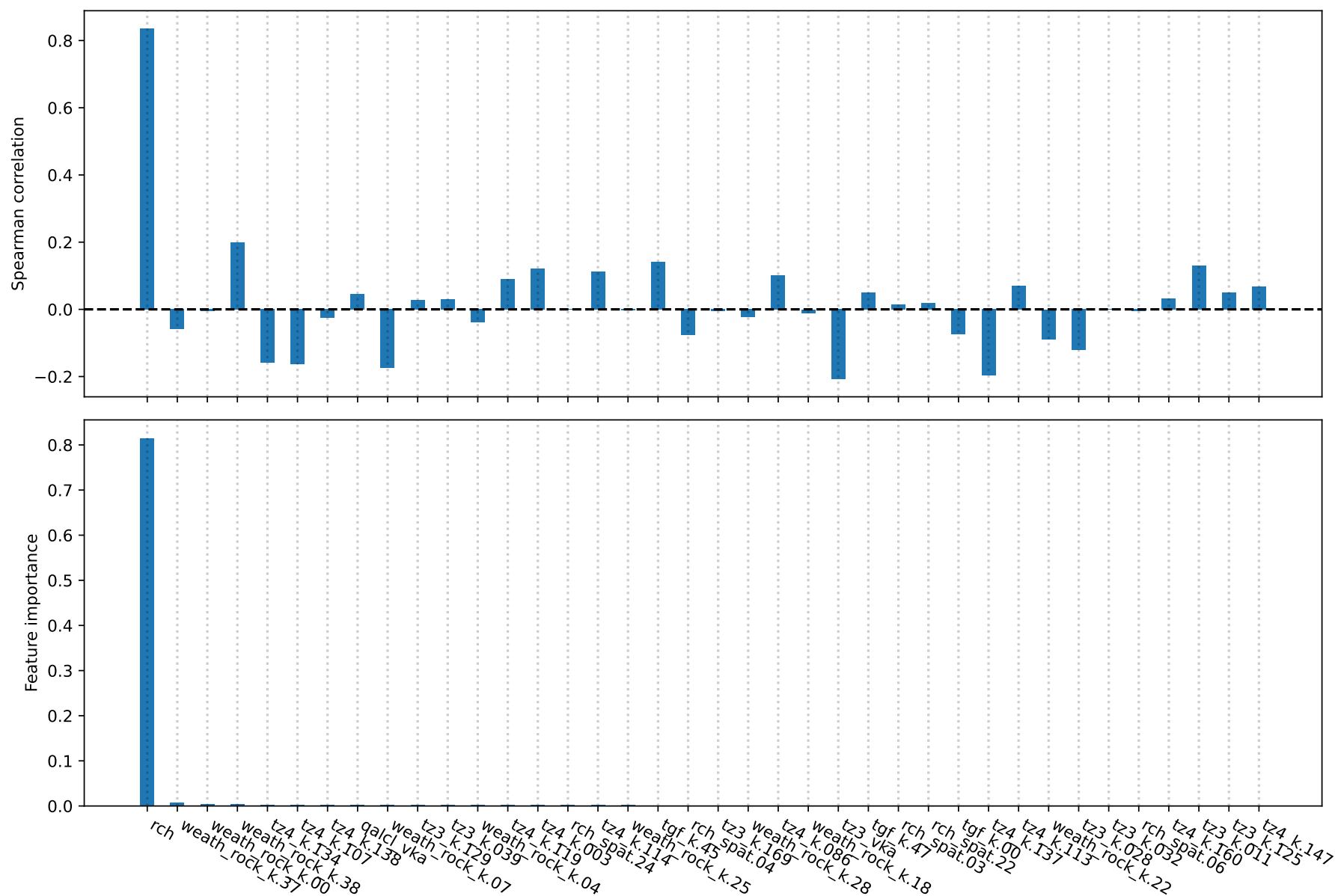


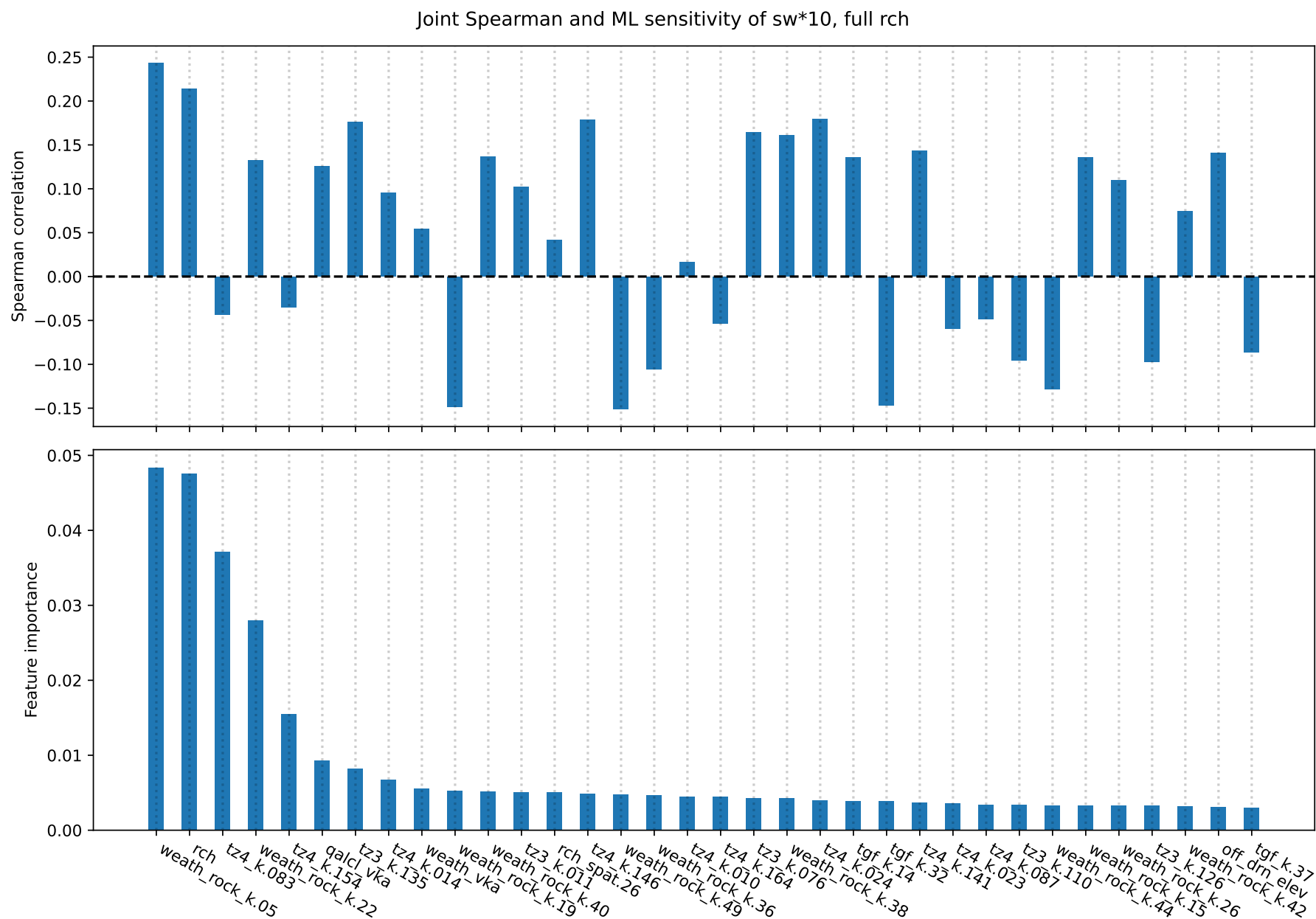


Joint Spearman and ML sensitivity of vwp-II, full rch



Joint Spearman and ML sensitivity of sw-II, full rch

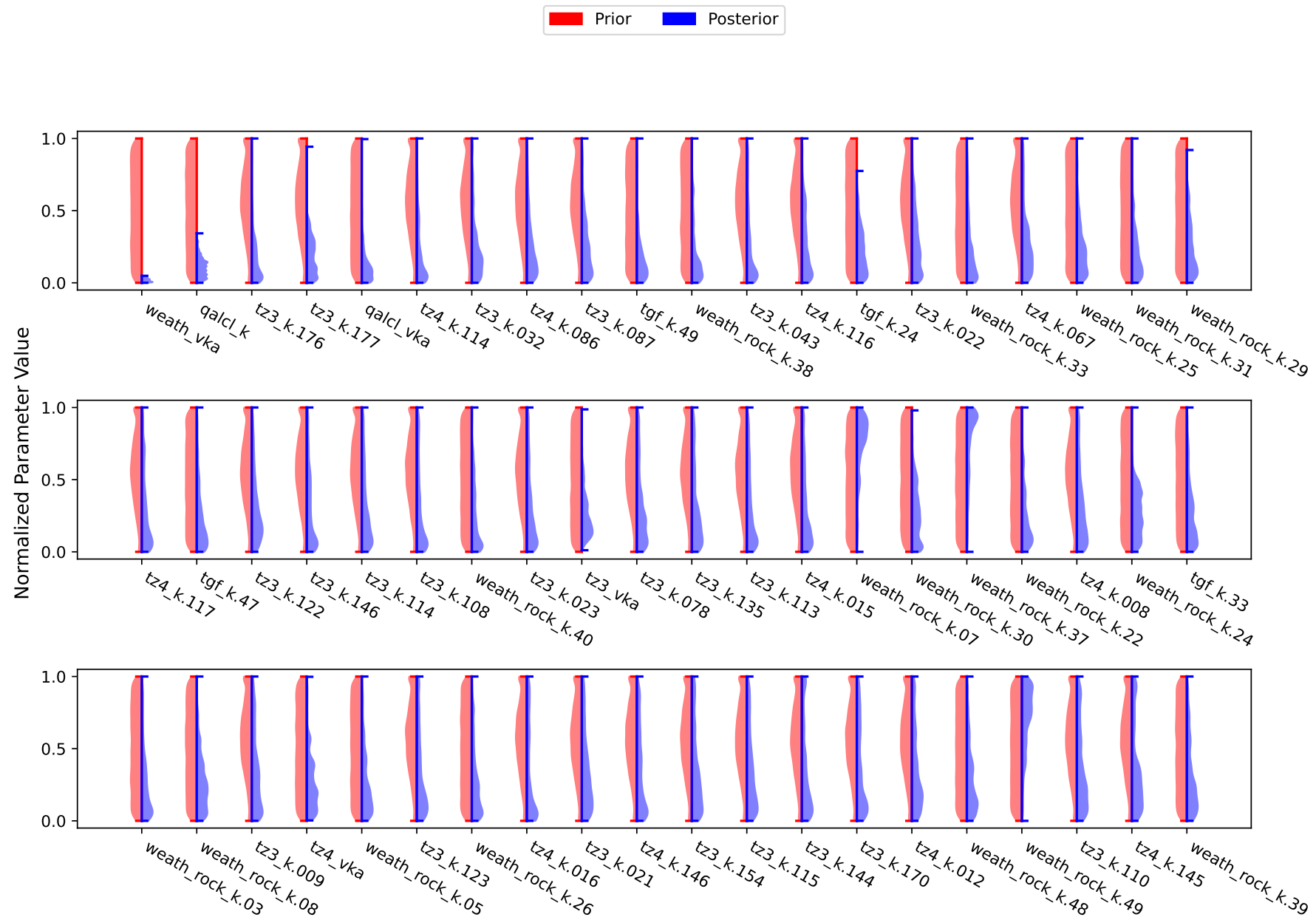


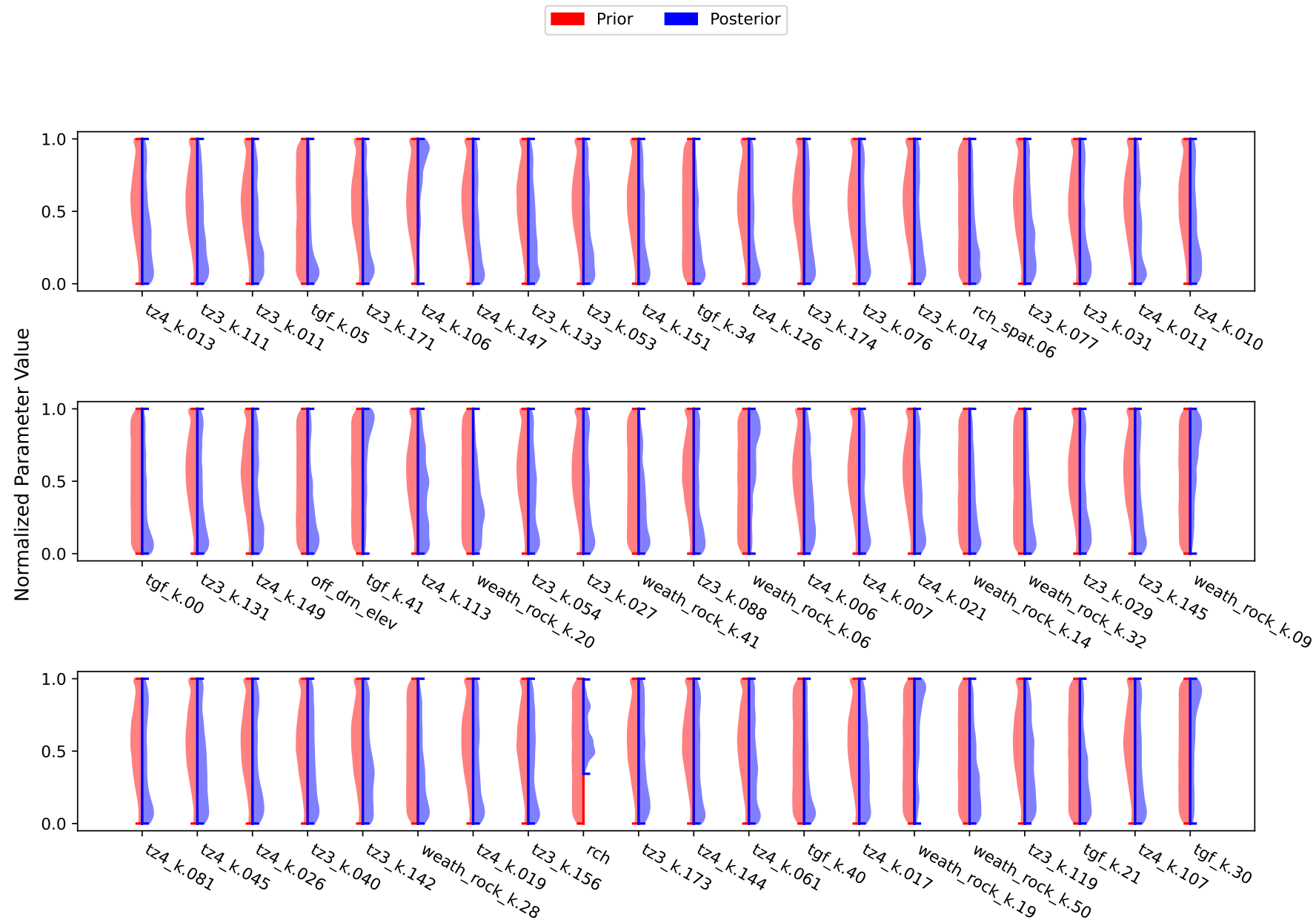


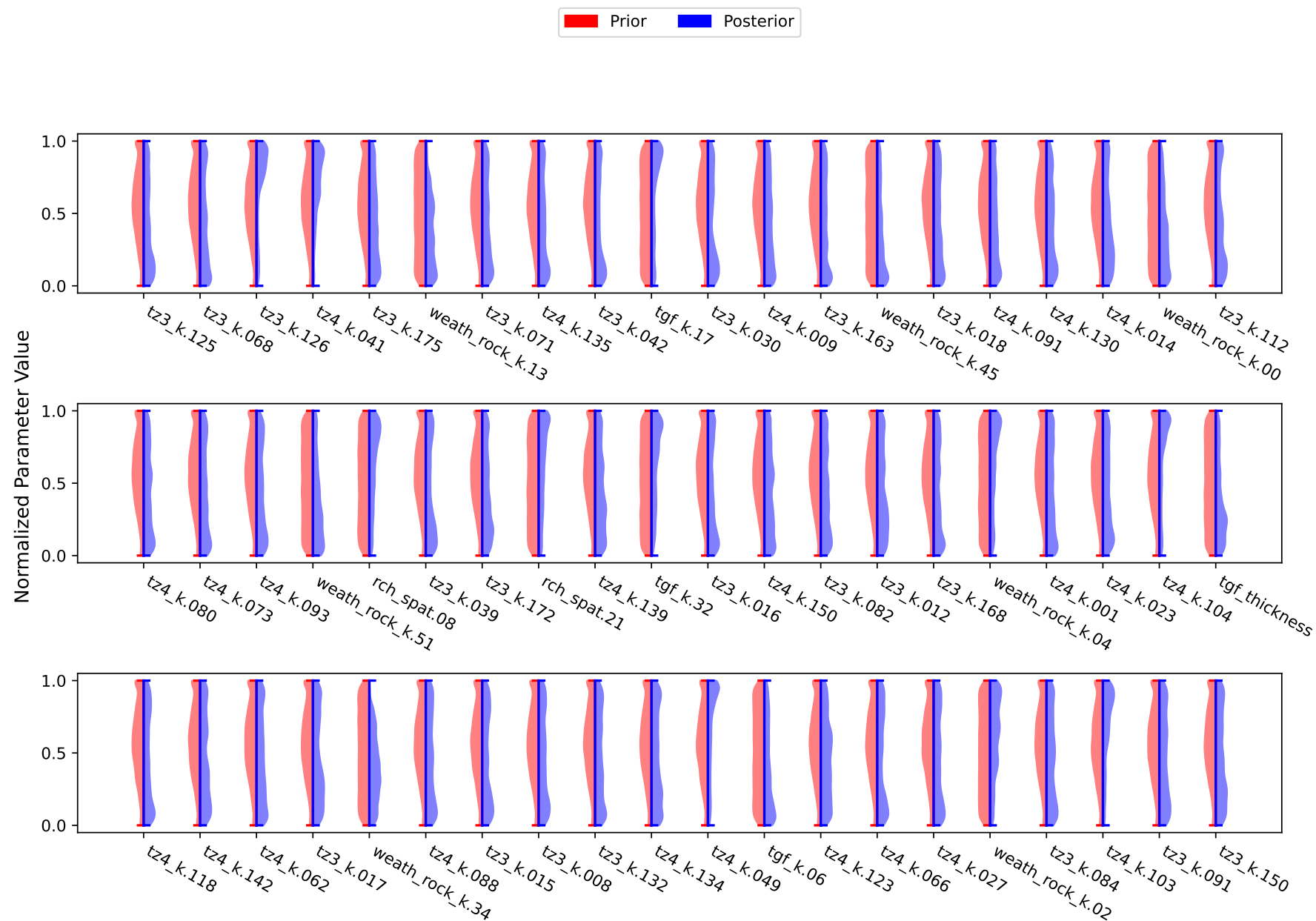
B.3.1 Deep Model Prior vs Posterior Distributions

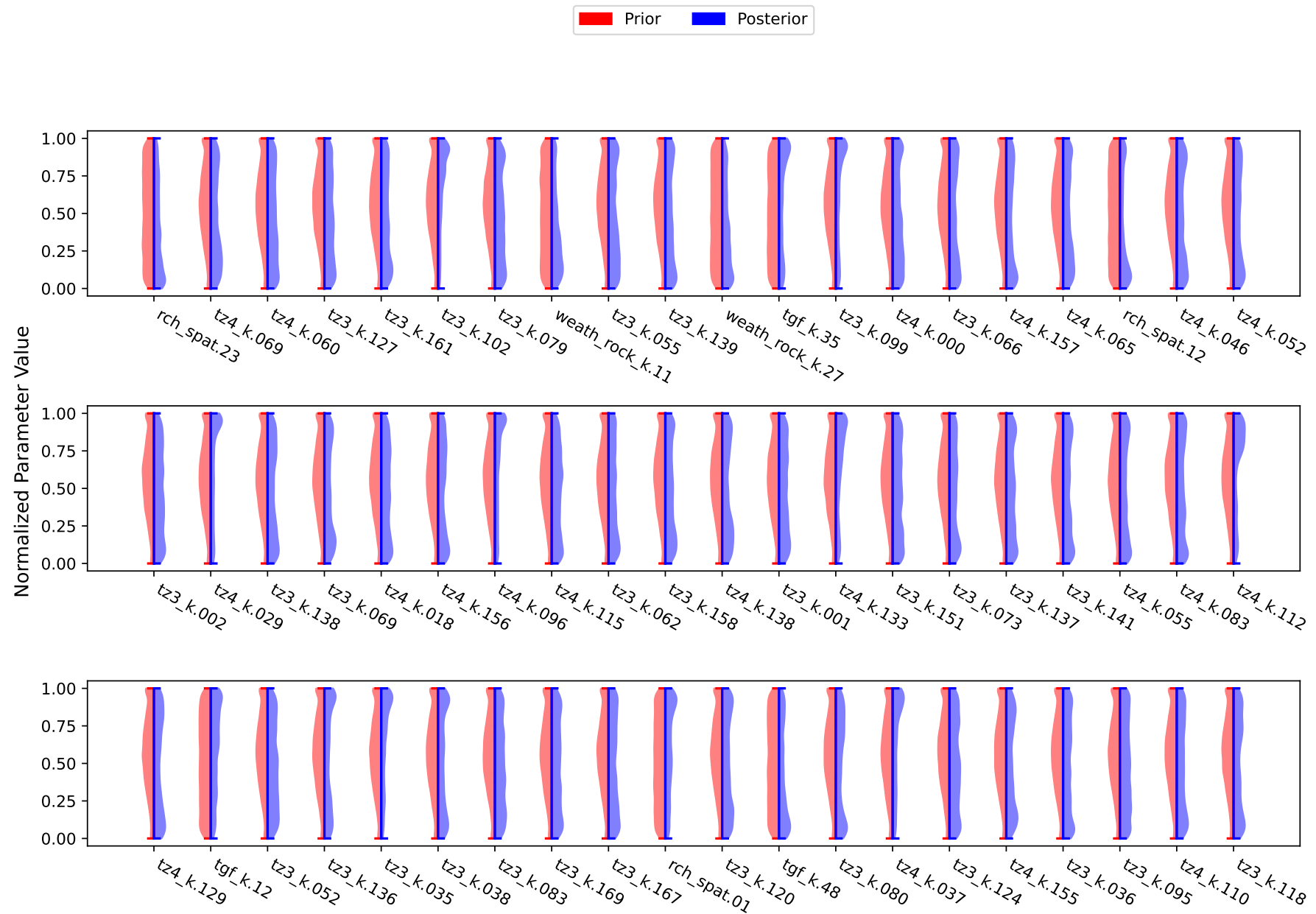
The following figures show the min-max normalised (0-1) prior and posterior distributions for the model parameters. The parameters are ordered by decreasing Wasserstein distance between the prior and posterior distributions. The Wasserstein distance is a measure of how different two distributions are, a larger distance means that more “work” would be required to transform one distribution into the other. Parameters with a larger Wasserstein distance are more informed by the observed data, while parameters with a smaller Wasserstein distance are less informed by the observed data.

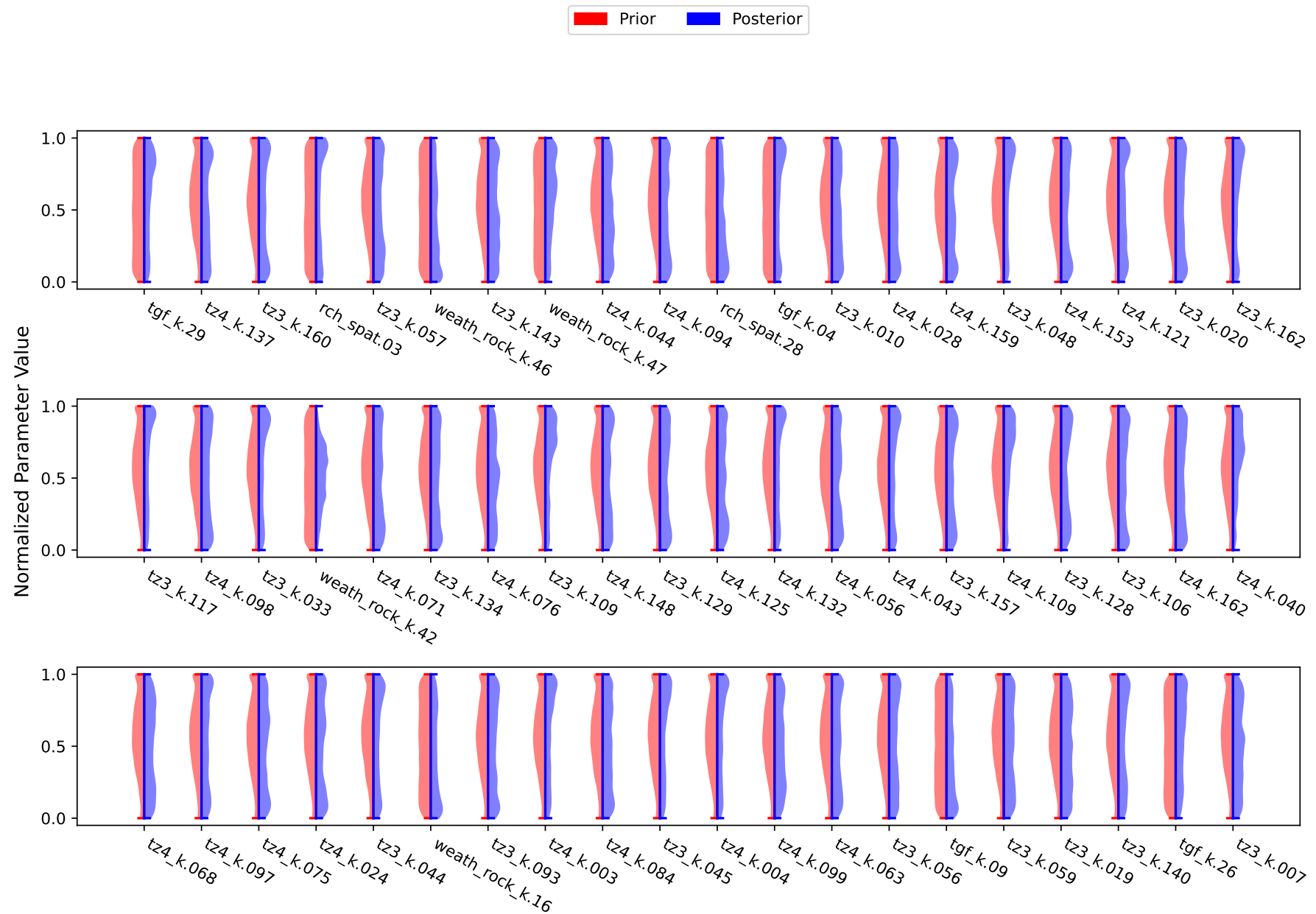
Of interest, the parameters with the largest Wasserstein distance are the weathered rock and top layer vertical hydraulic conductivity modifiers. These fall at the lower end of the prior distribution, suggesting that the model preferentially selects a more isotropic system. This likely occurs because the conductivity interface between the different geological units is more likely to be controlling than the vertical flow within the unit. Many of the pilot point parameters were also significantly constrained by the data, but importantly none of these show a hard preference for the upper or lower end of the prior distribution. This suggests that our prior parametrisation is not overly restrictive. Recharge [Figure B.30](#) is significantly constrained with a distinct preference for the middle of the parameter range (approximately 30–50 mm/year).

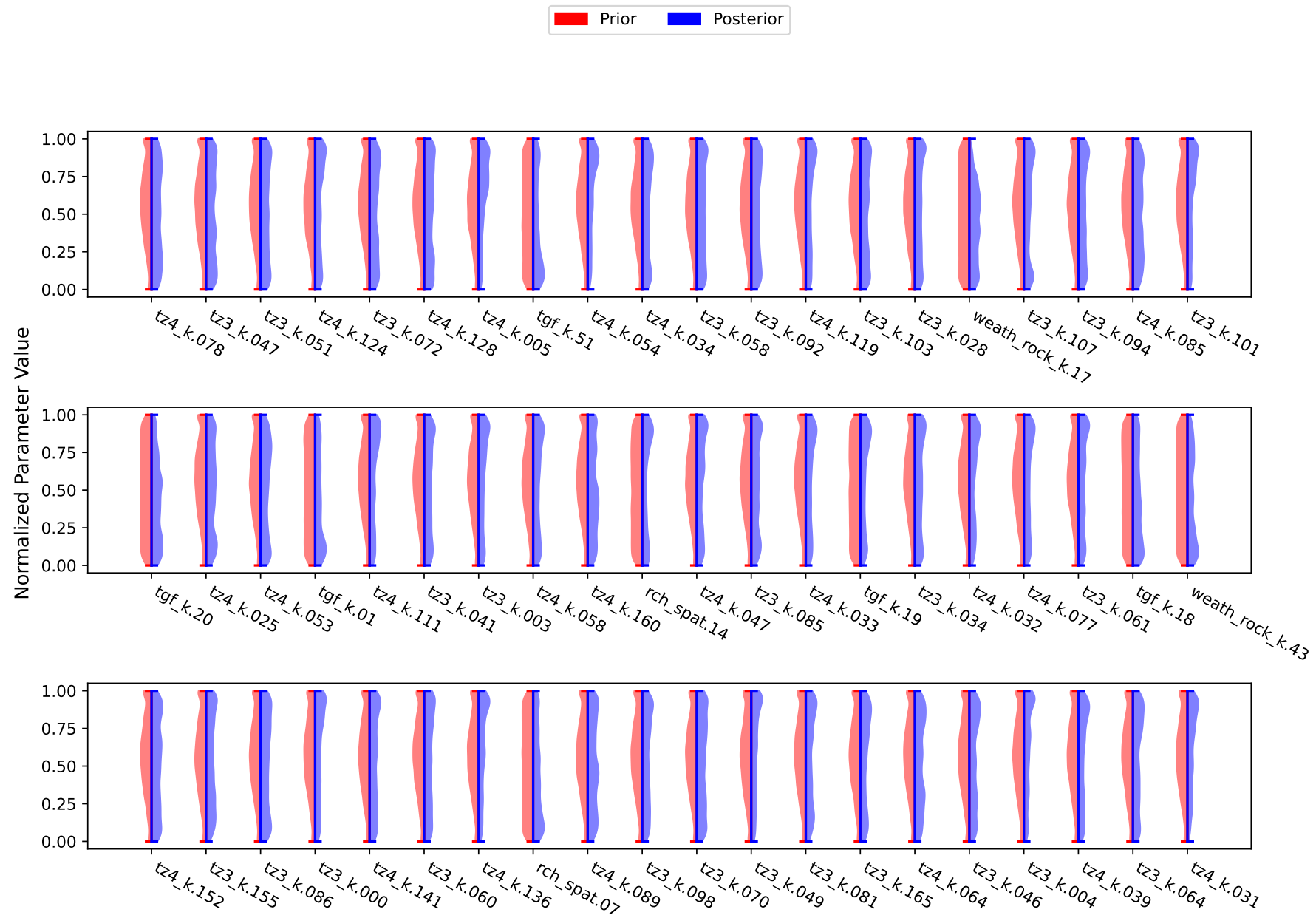


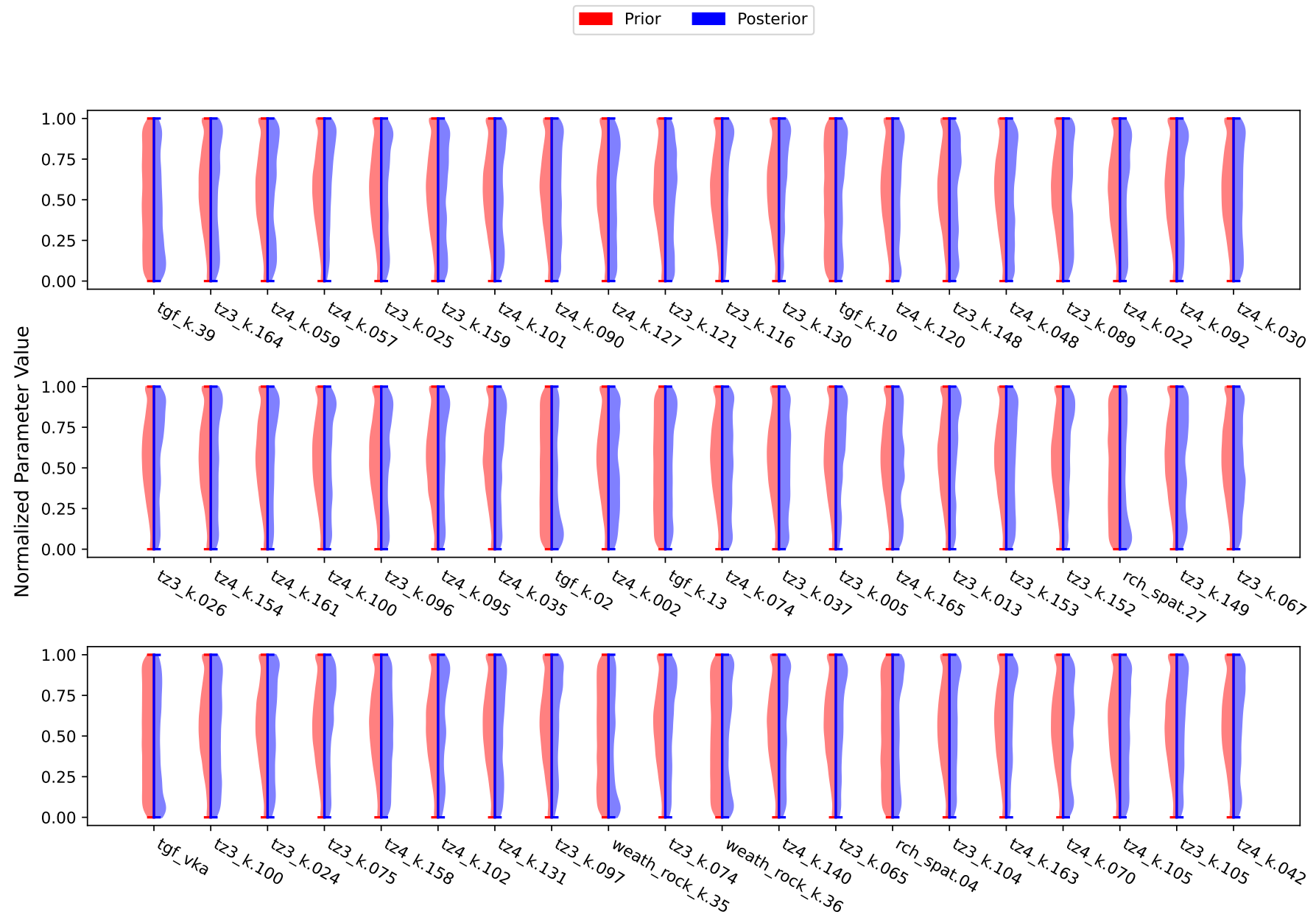


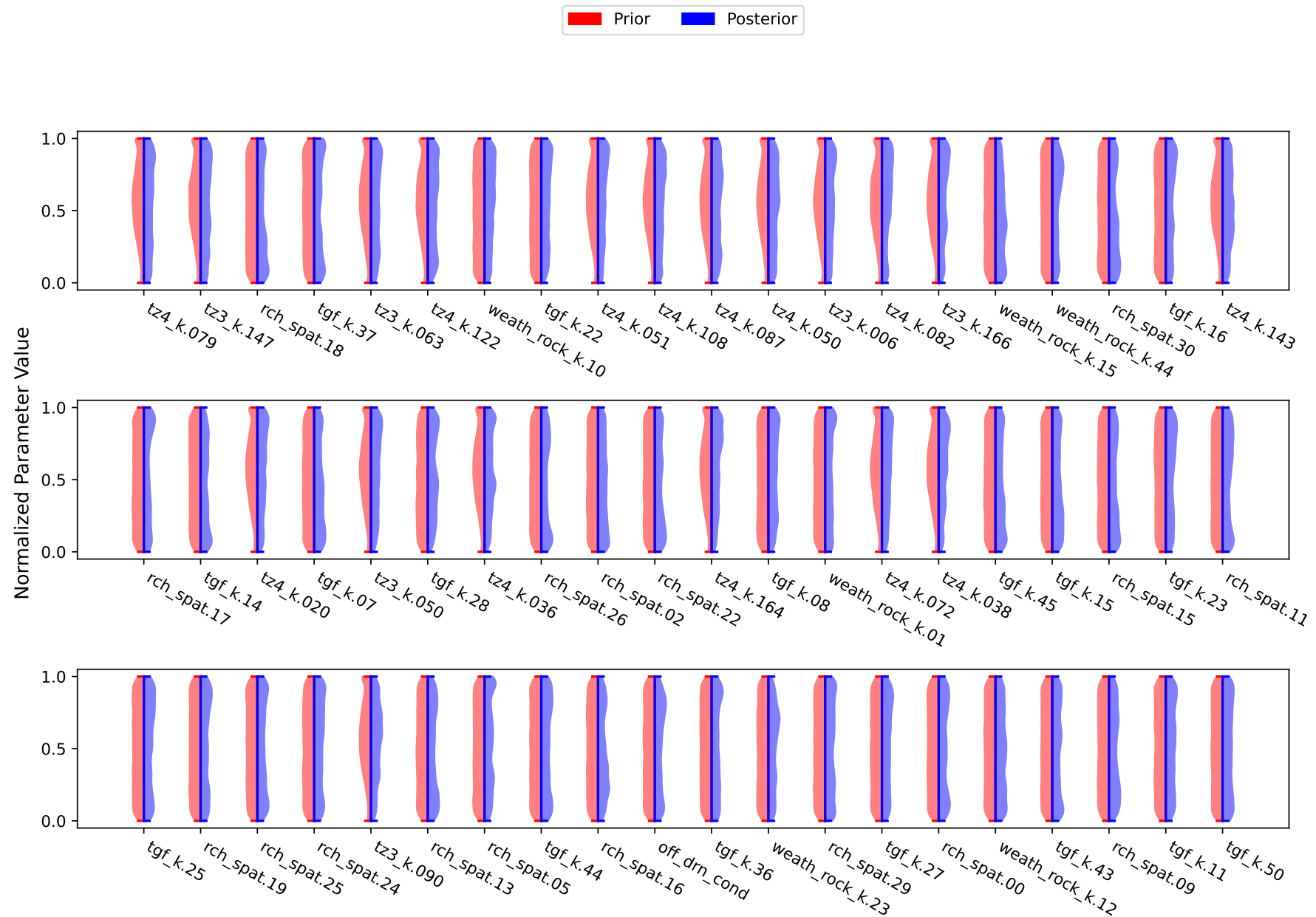


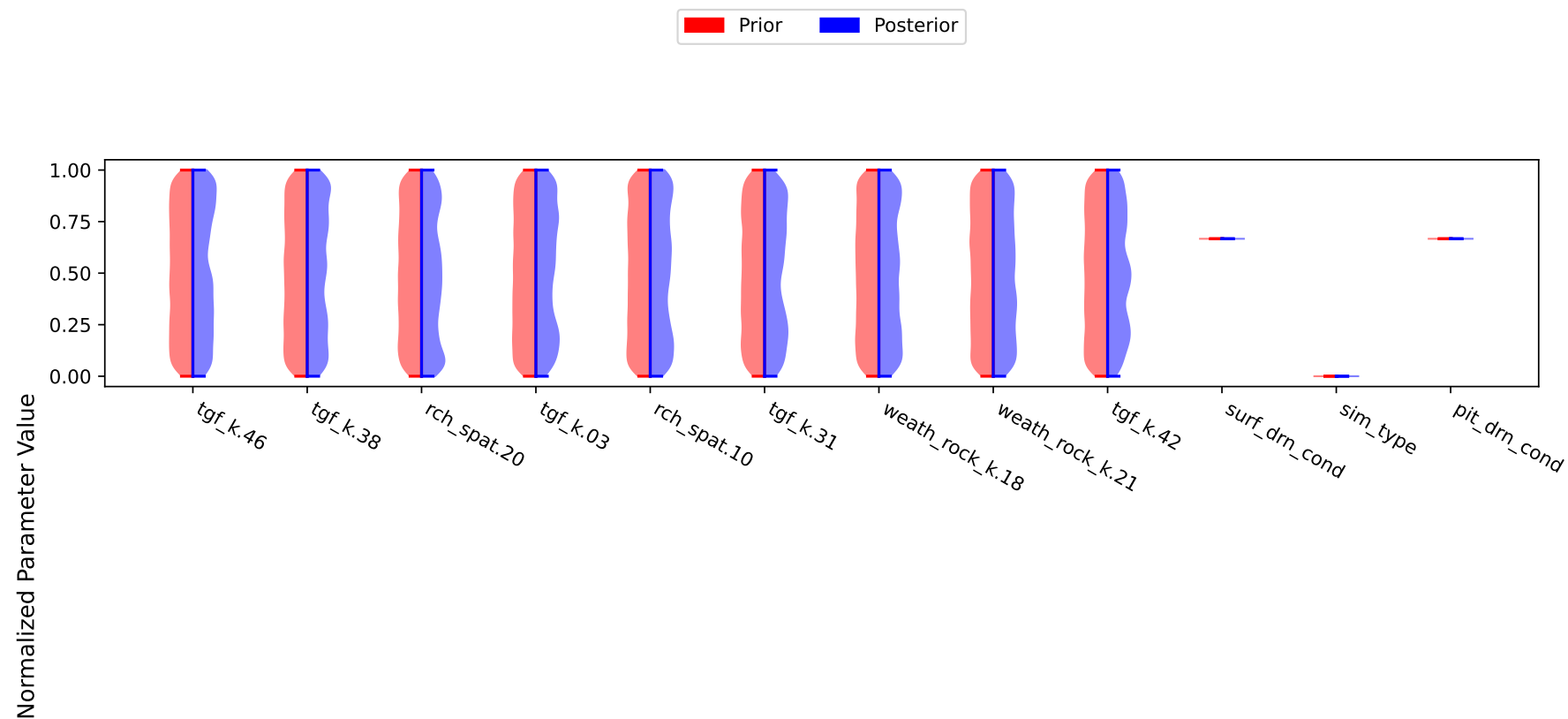












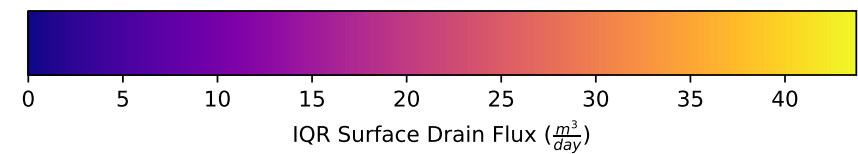
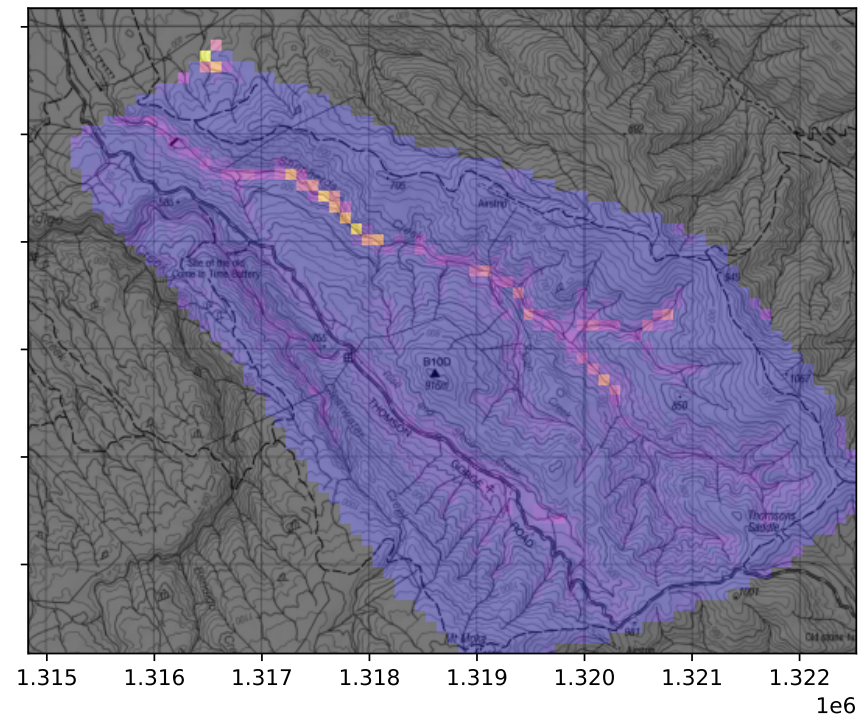
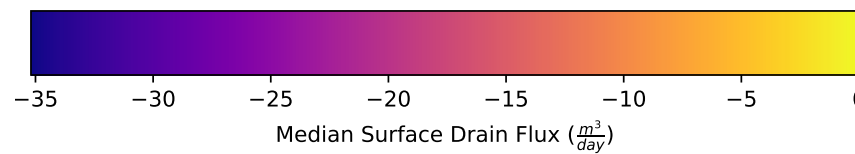
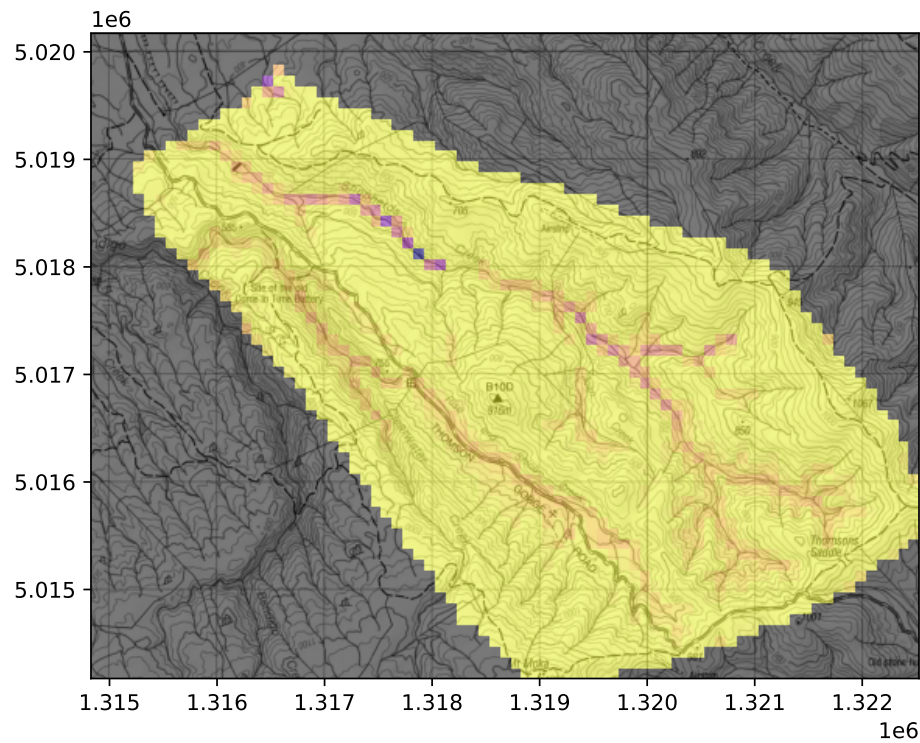
B.4 Posterior for Future Predictions

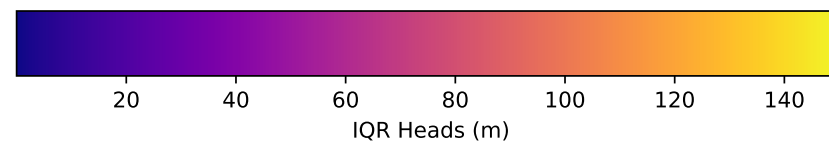
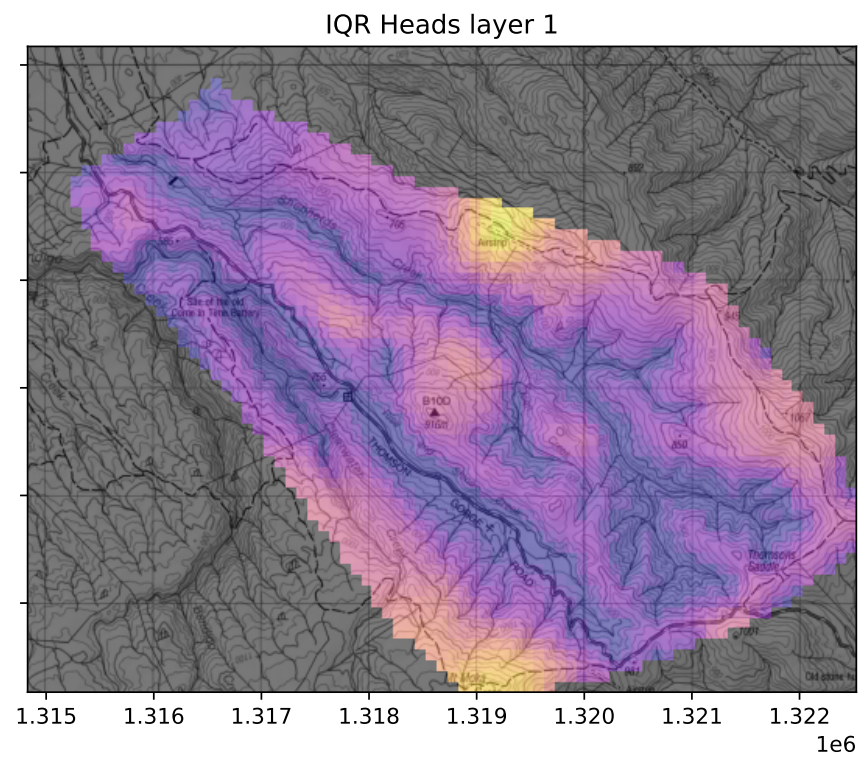
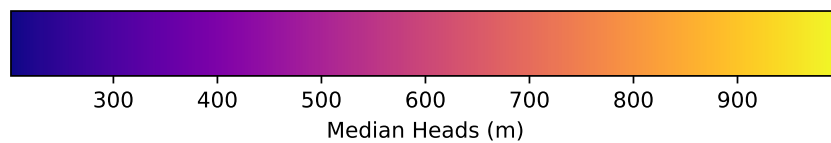
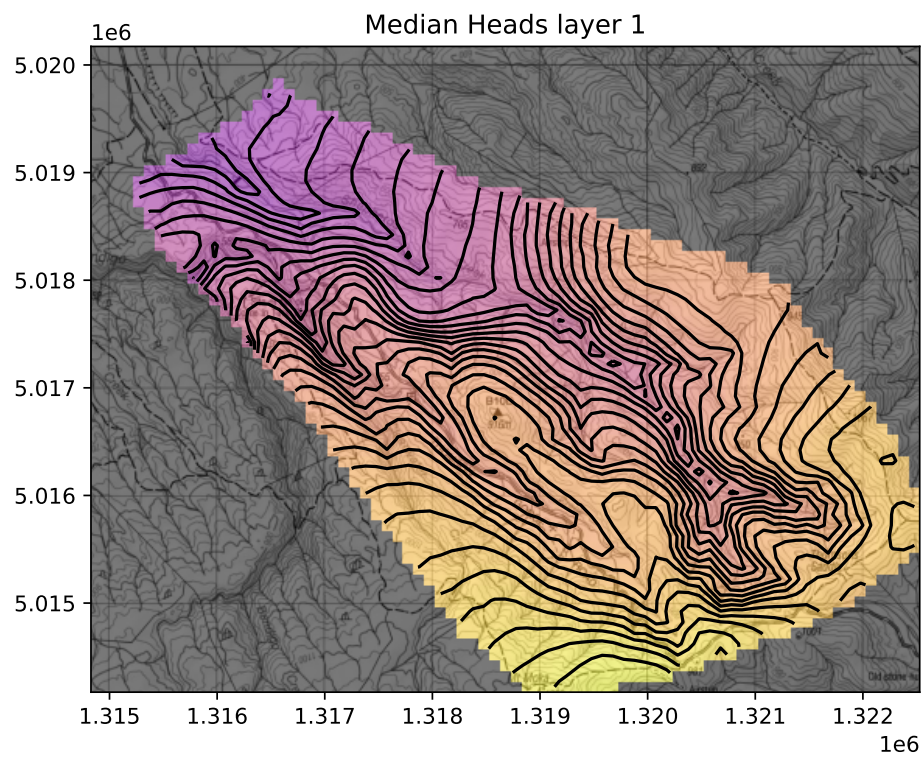
Using the full posterior distribution of model parameters (10% of all model runs) would be computationally expensive for future predictions. Therefore, we have selected a subset of 500 parameter sets to use for future predictions. The choice of 500 is somewhat arbitrary, but it provides a reasonable balance between exploring parameter space and computational efficiency. The posterior subset was selected from the full posterior distribution based on a weighted combination of minimizing the objective function (best fit models) and maximizing the normalised distance from previously run parameter sets (to ensure exploration of the parameter space). Here the weighting was defined as 5:1 (distance:objective function). The focus on distance is to ensure that the posterior subset is representative of the full posterior distribution, rather than just tightly clustered around the best fitting parameter set.

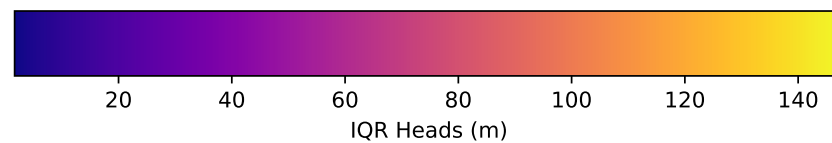
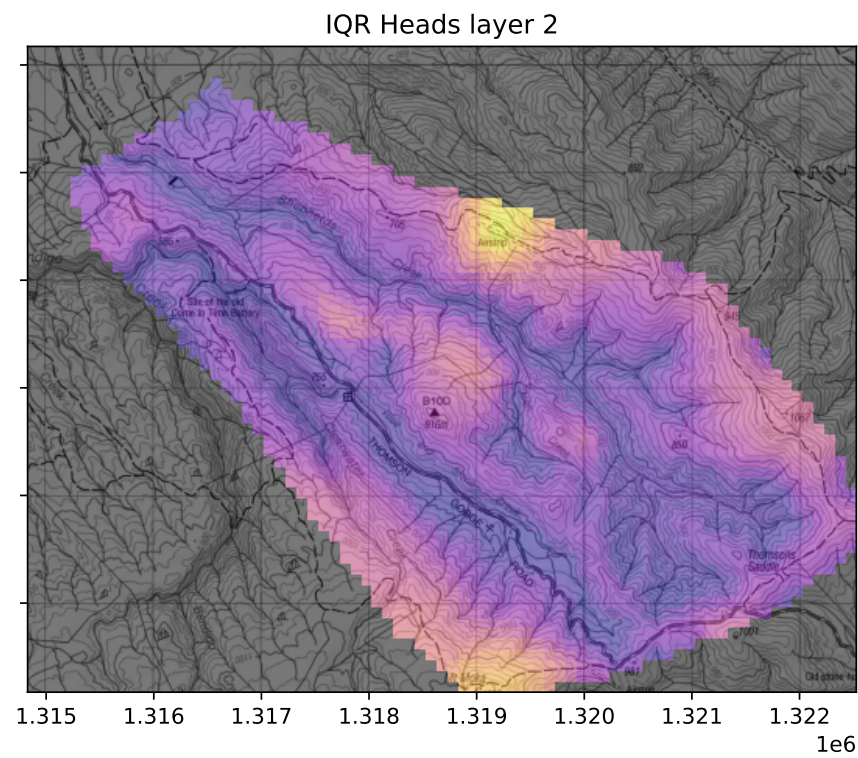
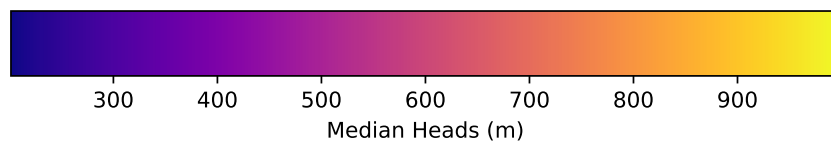
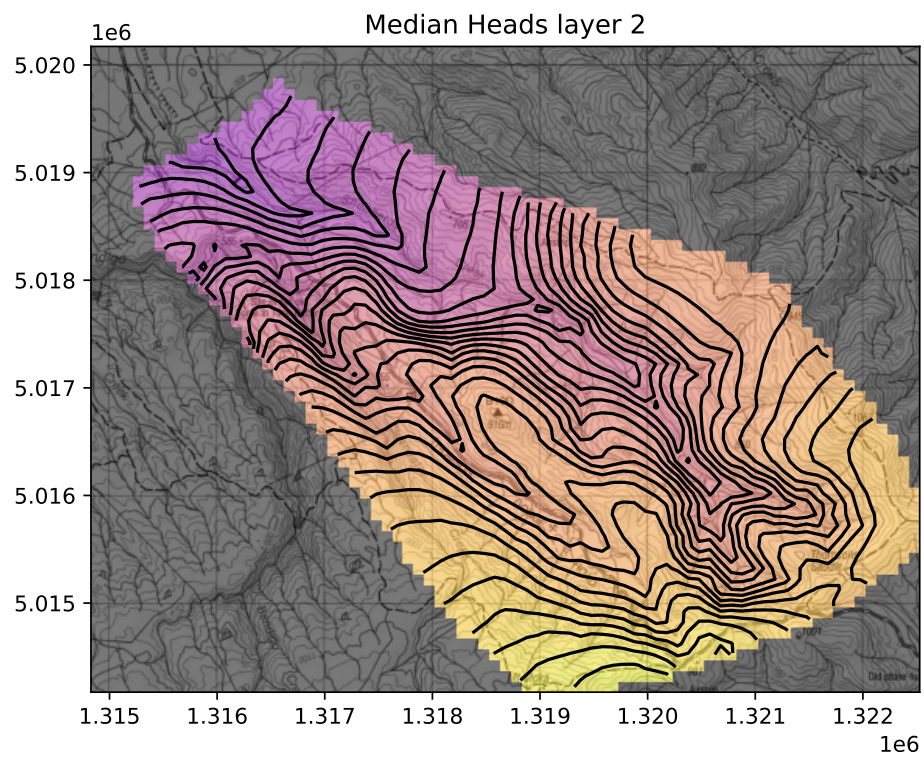
B.5 Posterior Visualisation

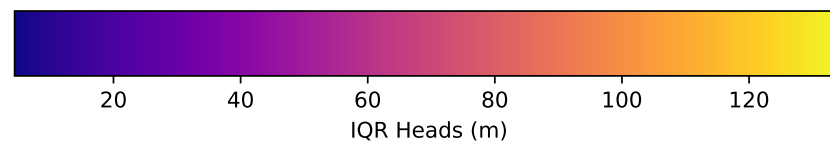
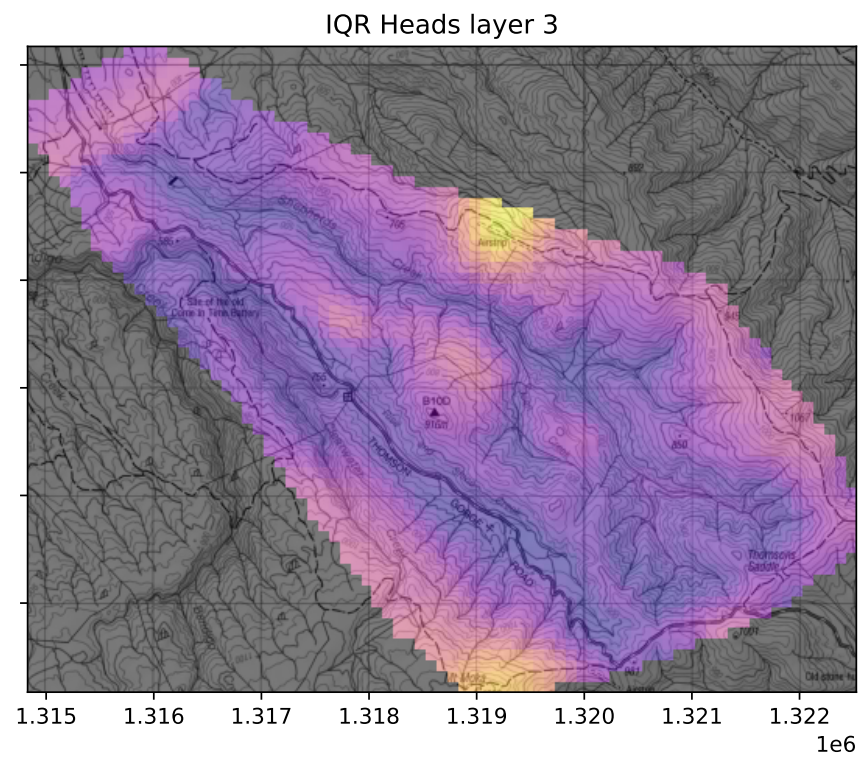
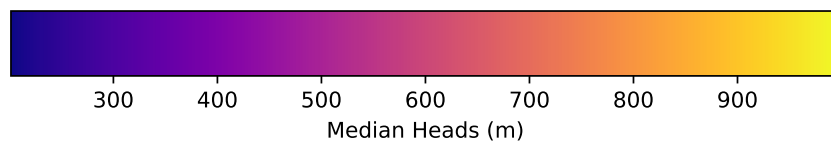
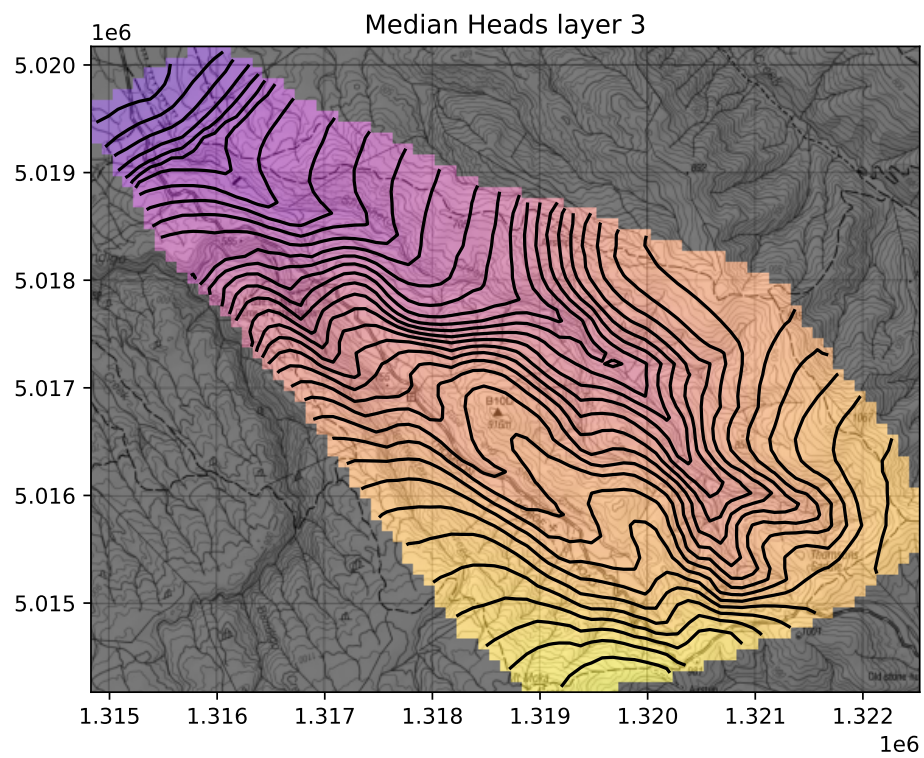
Figure B.38 shows the posterior distribution of the surface drain fluxes out of the deep model (negative means flow out of model). For most of the model domain, the posterior distribution has very low discharge to the surface drains, with the exception of the creek bottoms (Shepherds Creek, Rise and Shine Creek, and the tributaries to these creeks). This suggests that the model recharge is generally reasonable and the model is not compensating for high recharge by refusing the recharge to the surface drains. There are two main discharge areas in Shepherds Creek. The first is just upgradient of the confluence with Jean Creek. Importantly this discharge is primarily occurring in the main stem of Shepherds Creek, and on the northern tributaries. This is consistent with the observations of [Rekker \(2025\)](#) that the northern aspects of Shepherds Creek have a higher contribution to the creek flow and that most of the observed springs are located on the northern aspects of Shepherds Creek. The second discharge area in Shepherds Creek begins at approximately 1.318E6 mE and continues to 1.317E6 mE, which is where the Shepherds Creek valley widens. This area is the approximate location of the SHFILL and downstream of the proposed SiltPond. The model is suggesting that most of the discharge from the catchment occurs in this area, though it is worth noting that the model overpredicts the discharge in the lower Shepherds Creek catchment. This is further discussed in [Section B.6](#). There is significant variability in the lower Shepherds Creek catchment (IQR), which suggests the model is not very well constrained in this area. There is also significant discharge to the surface drains on the north side of northern ridge above Shepherds Creek. This is likely a proxy for the poorly detailed discharge from the north facing slope which drains to the Lindis valley beyond Shepherds Creek.

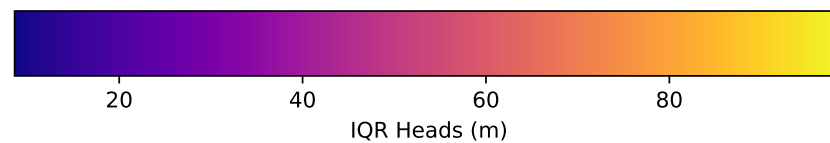
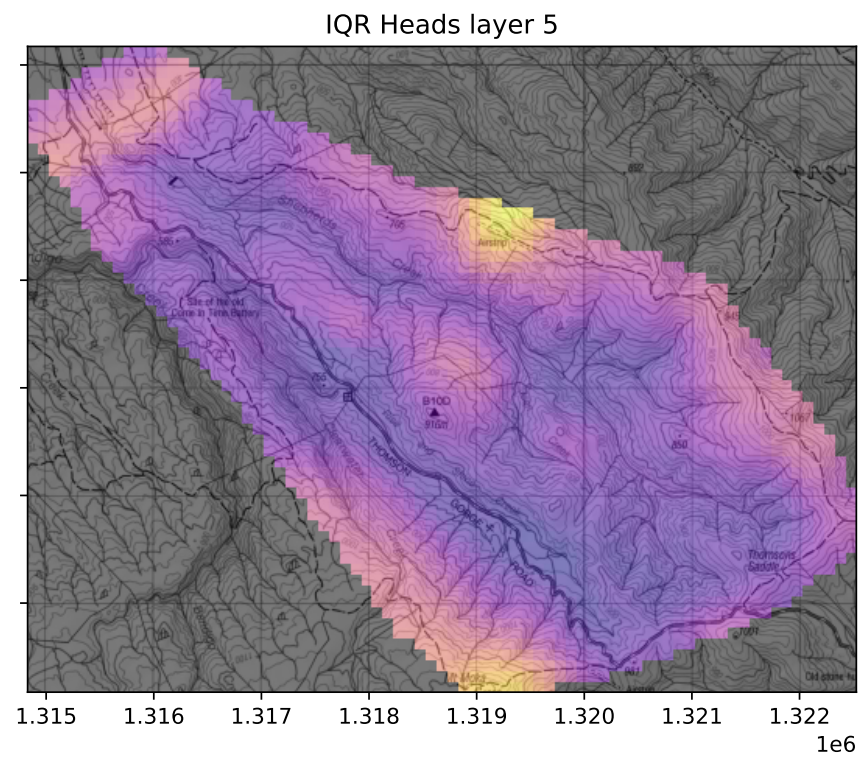
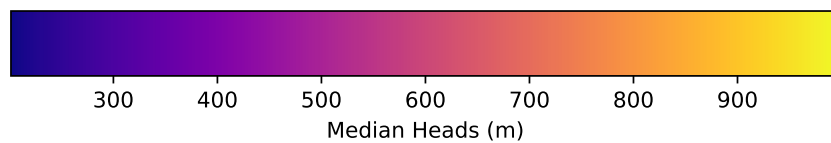
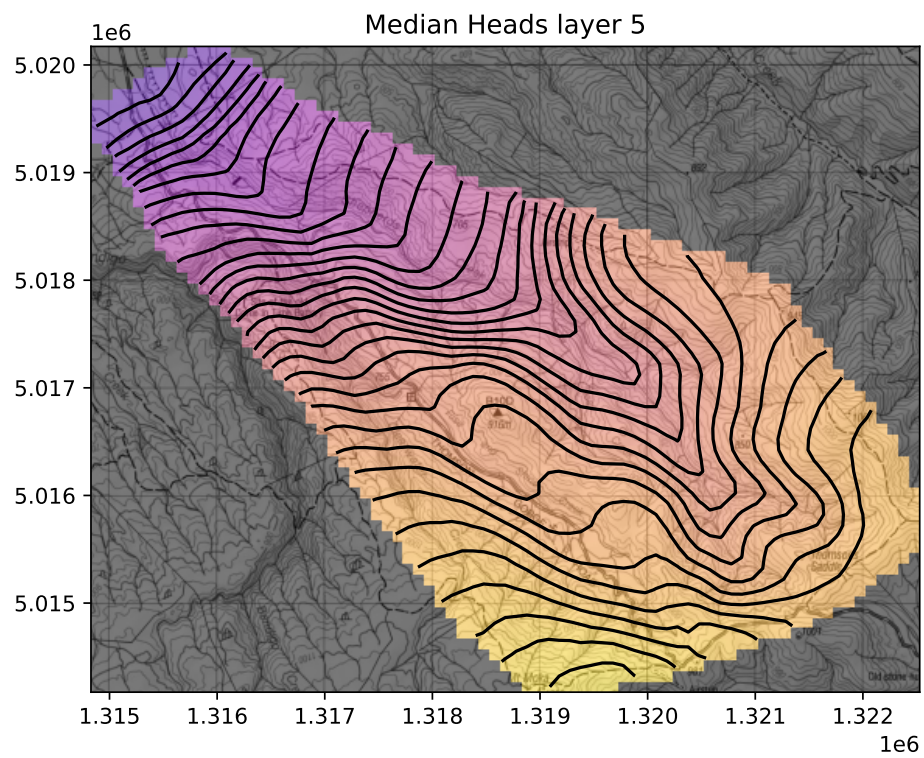
Figure B.39 to Figure B.45 show the posterior distribution of the modelled heads for layers 1, 2, 3, 5, 8, 11, and 15. These layers were selected to provide detail in the top of the model where there is the most variability in heads, and then to provide a representative sample of the deeper layers. Visual inspection of the missing layers suggests that the modelled heads are generally consistent with the plotted layers. The modelled heads generally confirm the expected topographically controlled head and thus flow paths. There is typically more variability in the modelled heads on the ridge tops and other high points, particularly the top to Mt. Moka and the top of the northern ridge above Shepherds Creek. These areas are poorly constrained and likely have boundary errors (e.g., some flow may go beyond the domain.) The variability of the modelled heads is significantly lower in the valley bottoms, and generally reduces with depth. Additionally, the topographically defined head features along Shepherds Creek, Rise and Shine Creek, their tributaries, and Clearwater Creek, become less pronounced with depth.

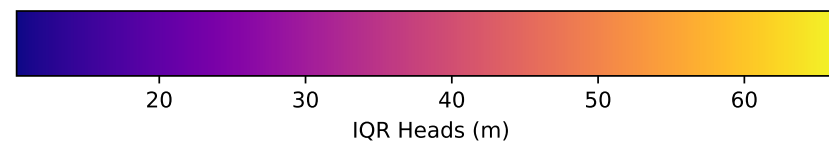
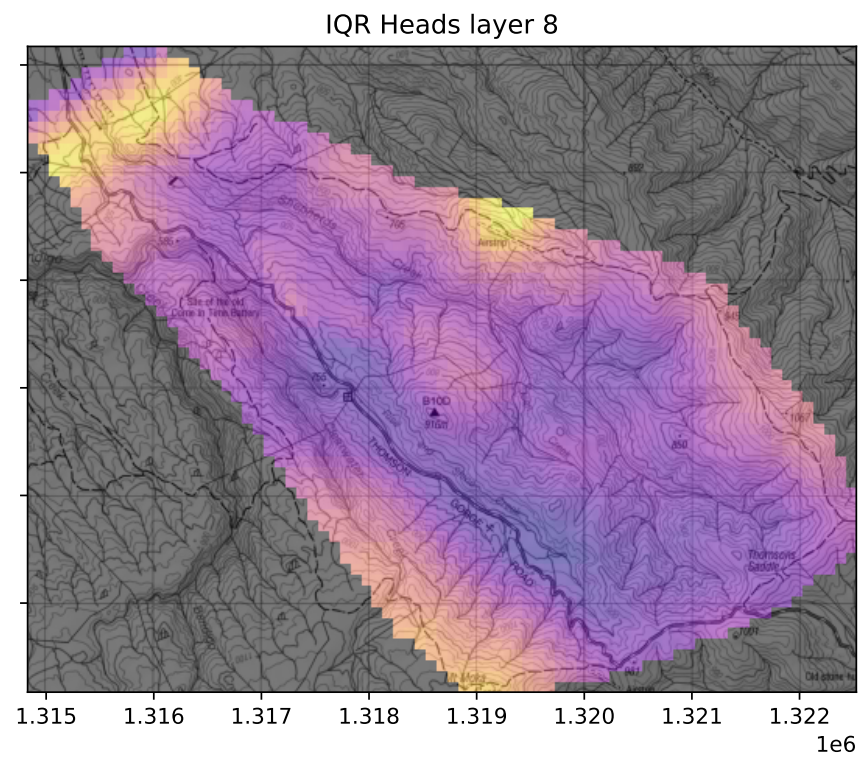
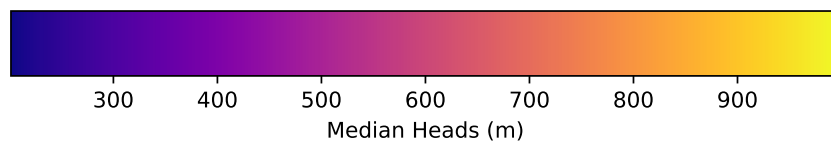
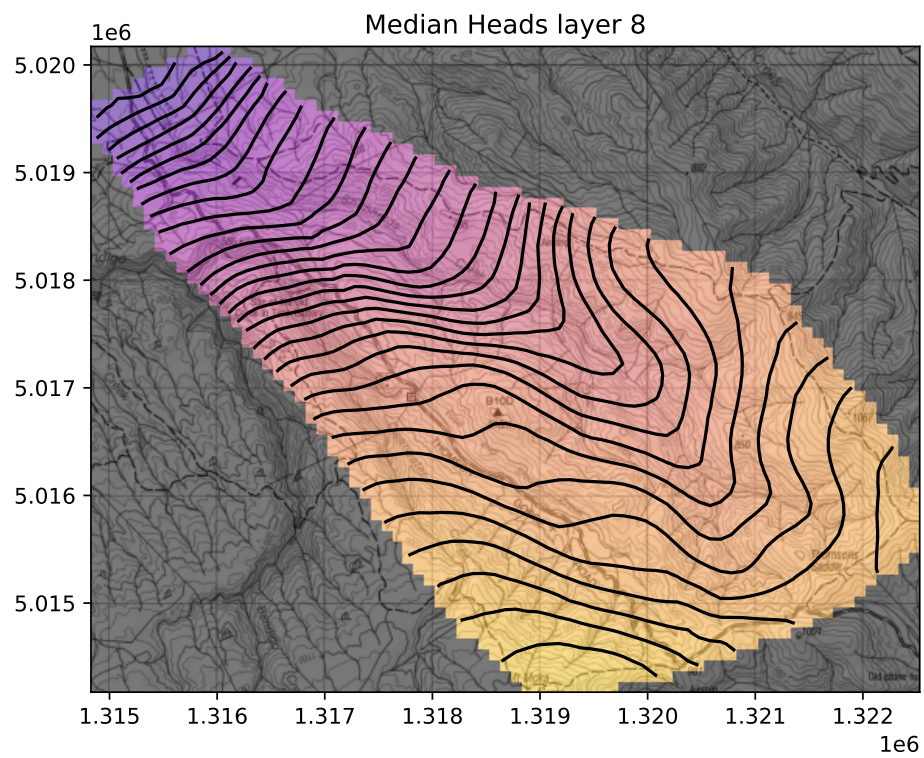


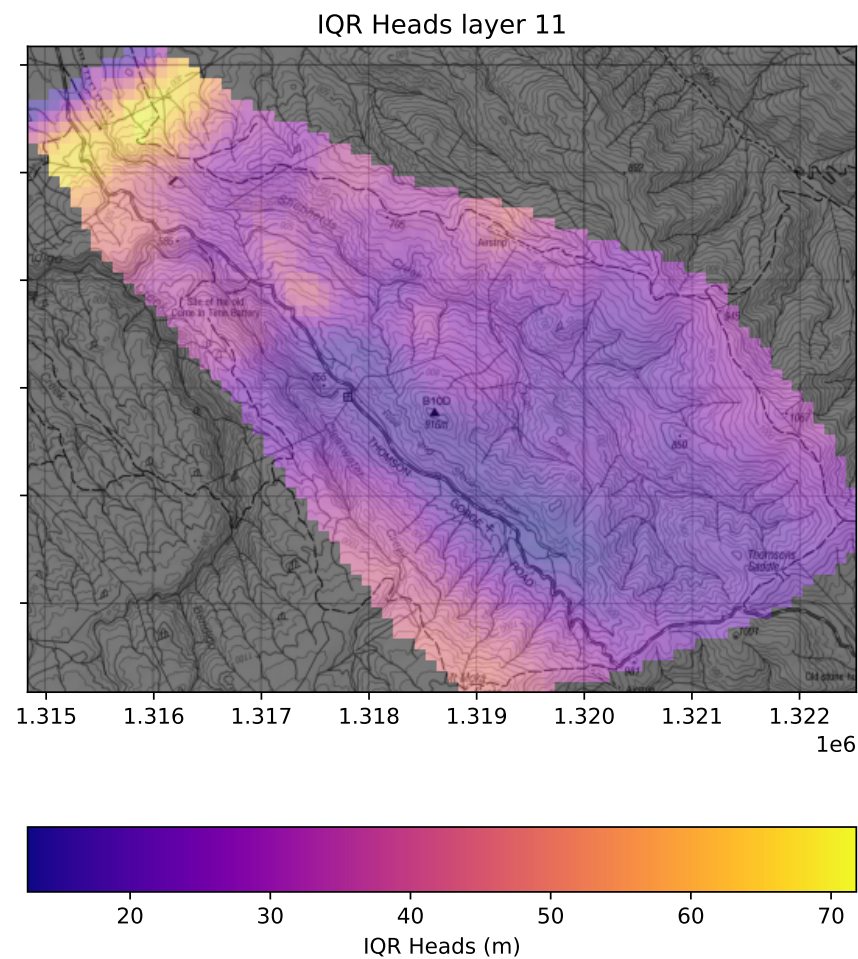
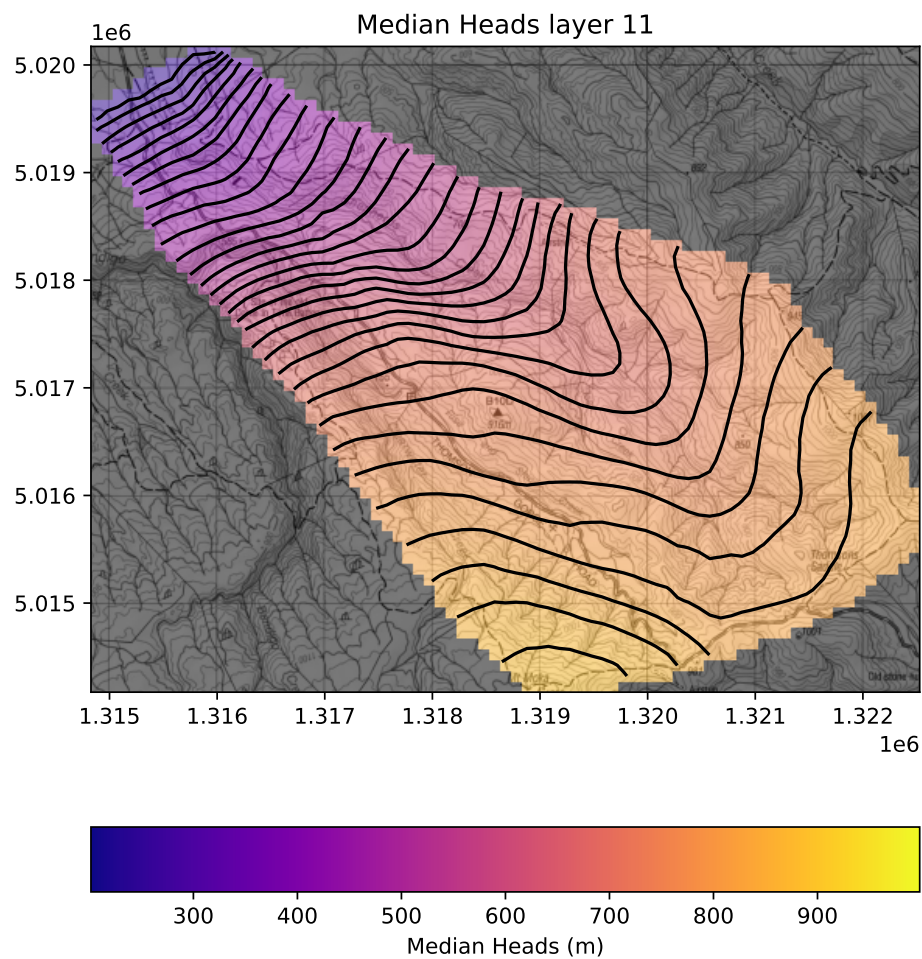


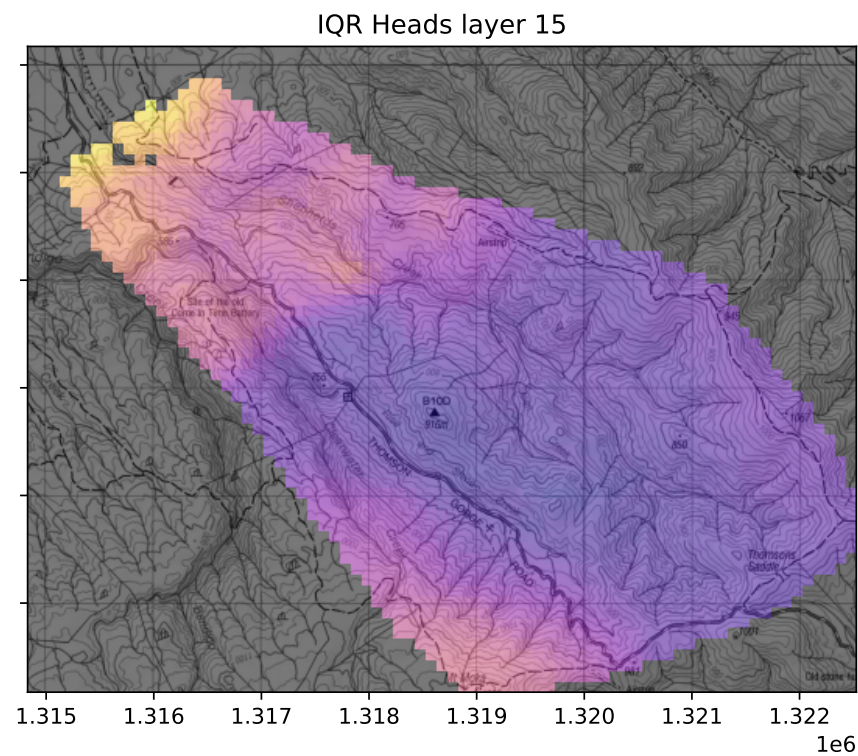
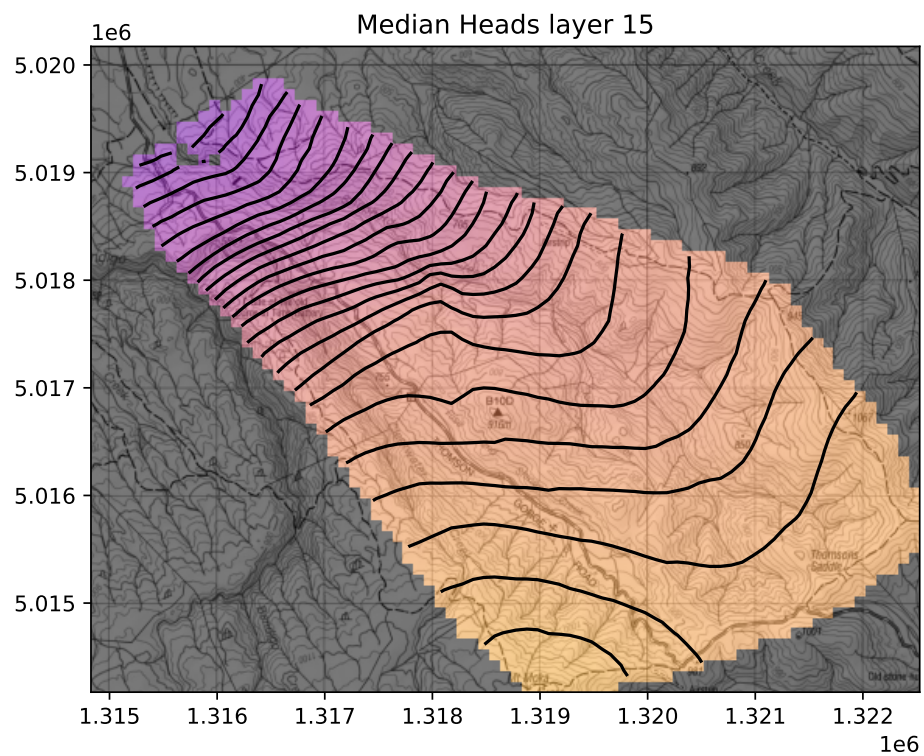












B.6 Optimisation Discussion

Overall the optimisation does a reasonable job fitting the observed data, though there are some areas where the model struggles to fit the observed data. The fits to the water level survey and spot heads are generally good given the diversity and uncertainty of these targets (Figure B.8). The fits within the RAS pit area are generally consistent though there is some conflicting data between various bores in the water level survey. Heads are generally a bit low on the highpoint of the RAS pit area (south of B10D), but are then a bit too high adjacent where Thompson Gorge Road crosses Rise and Shine Creek. This area represents very large head gradients in a very small area, so it is not surprising that the coarse discretisation of the model struggles to fit these observations. Similarly, observations at the top of CIT pit area (above the site of the old Come in Time Battery) are underpredicted. Observations in the base of Shepherds Creek are generally over-estimated. This pattern of under-estimating heads at topographic highs and over-estimating heads at topographic lows in steep topography is relatively common. However, the over/under prediction does not alter the flow direction, paths or gradients – it simply lessens the magnitude of the gradient. The largest misfit occurs along the ridge north of Shepherds Creek between B10D and Thompson's Saddle. The model is not able to replicate the steep head gradients in this area, but it is still maintaining the observed hydrogeological divide between Rise and Shine Creek and Shepherds Creek catchments. Finally, the overestimates of head in the upper Rise and Shine Creek valley are likely due to a structural error in the model. We have not diligently represented the variability of alluvium in this area, nor have we allowed for a spatially variable hydraulic conductivity in the QALCL layer. Rise and Shine Creek has a much thicker alluvium layer than many other areas of the model. This likely leads to the over-estimation of the heads in this area. Note that such local overestimation is unlikely to affect the prediction of interest as seepage would be required to move up to 200 m up gradient to enter the Rise and Shine Creek valley. There is also considerable uncertainty in the water levels taken from these boreholes. They are open holes, likely intersect very fine scale which cannot be represented in the model, and there is the potential for surface infiltration to influence the observed water levels.

The VWP records provide a much more targeted record of the water levels in the system. The model does an excellent job reproducing the water level in upper Shepherds Creek Figure B.12. The model generally fits the average water level across each bore, and it replicates the upwards gradients of water levels with increasing depth. The anomalies in this group are the middle VWP in Bore MDD491 and the reverse gradient in Bore MDD399. We suggest that the variability of MDD491 is likely due to localised heterogeneity in the system and/or observational error. In either case it is not surprising that the model cannot replicate this variability. The downward gradient of MDD399 is surprising as all other bores in this area (within several hundred meters) show an upward gradient with depth. If this downward gradient is correct, then it must be due to a very localised feature. This bore is directly adjacent to the proposed TSF-D so further investigation of these results are warranted.

The mid-Shepherds Creek VWP group (Figure B.13) also reasonably fit by the model in absolute terms. The model slightly underpredicts the water levels in MDD290 and MDD289, but it does an excellent job replicating the observations in GWO4 and GWO5. The lower Shepherds Creek VWP group (Figure B.14) is also well fit by the model, though the model has some difficulty replicating the upward gradients in the very shallow VWP of MDD499, MDD508, and MDD511. It does replicate the observed upward gradients in the deeper VWP of MDD362, and predicts upward gradients in MDD365 despite the observed downward gradients. MDD365 is directly adjacent to MDD511 and MDD499. The gradient reversals between these bores will have been a prior data conflict that the model would really struggle to resolve. Shallow Piezometers are much more likely to be influenced by localised heterogeneity, so this observational error is unsurprising. The overall upward gradient of the model in this area is consistent with MDD362 and the conceptual understanding of the system. Therefore, we suggest that this misfit is likely due to localised heterogeneity and will not affect the larger scale predictions of interest in Shepherds Creek. Finally, there are moderate fits to the Rise and Shine Creek VWP group (Figure B.15). The model underpredicts MDD327, but this is in the same area where the model is overpredicting water levels in the water level survey. This prior data conflict is difficult to resolve, but is unlikely to affect the predictions of interest in Shepherds Creek.

The model struggles to replicate the observed surface water flows, particularly in lower Shepherds Creek (SCO1,

Figure B.7). The model significantly overpredicts the flow measured in SCO1, at slightly more than twice the observed flow (median). It should be noted that early in the optimisation process the model was able to replicate the head observations in the model adequately, while predicting surface water flows in SCO1 at 8000 m³/day, which is almost ten times the observed flow. Subsequent iterations revised the recharge limits to ensure lower recharge values were considered, which yielded the better fits to the surface water flows. There are a number of possible reasons for the model's difficulty in fitting the lower Shepherds Creek surface water flows in particular. First any water discharged to the drains are considered to be routed directly to the surface water flow targets. In reality, Shepherds Creek may lose water as it exits the steep gorge and enters the wider lower valley. Additionally, there may be significant evaporation and transpiration losses from the shallow ground-water system and/or creek bed and irrigation storage pond. Nevertheless, we believe that the model is likely overpredicting the surface water flows in lower Shepherds Creek. The modelled values are in excess of the observed mean flow (as opposed to the median used for the target). It is also possible that the deep schist system is preferentially impacted by the higher recharge periods, which would explain the model overpredicting the surface water flows in lower Shepherds Creek. This issue may be resolved with higher precision modelling, including potential transient modelling, but this is beyond the scope of this assessment. Additionally more concurrent surface water flow gauging, particularly above and below the lower gorge, would help to constrain this issue. However, this is unlikely to affect the predictions of interest in Shepherds Creek. Our assessment of lost seepage is done on a percentage contaminant mass basis, so the absolute flow rates will not *a. priori* dilute the lost seepage predictions.

C Seepage Model Build

C.1 Software and Implementation

The seepage model is built as a MODFLOW 6 groundwater flow and transport simulation using FloPy.

Model construction is modular: groundwater flow is solved in a primary flow model, and source-specific transport model to track seepage contributions from key sources (TSF, SHELF, SiltPond, SHFILL). Rather than explicitly modelling contaminant concentrations, a proxy transport approach is used to track seepage mass accounting from each source. Here a unit concentration is assigned to each source, and the transport solution is used to track the partitioning of seepage mass from each source through the model domain.

C.2 Structure and Geometry

The seepage domain is represented on a regular 20 m grid with 5 vertical layers. This yields a final model shape of 5 layers by 195 rows by 280 columns.

The layering is conceptual rather than purely numerical, and is intended to preserve hydrogeologic meaning:

- Layer 1: PROCESS landform and near-surface engineered materials,
- Layer 2: alluvium/colluvium,
- Layer 3: weathered schist,
- Layers 4, 5: deeper fresh hard rock.

Current ground elevation, based on a site LiDAR DEM resampled to the model grid (min in each cell) is used to define the top of layer 2. The top of Layer 1 is defined by the proposed PROCESS landforms and engineered surfaces provided by other members of the wider project team. The thickness of layer 2 (QALCL) is defined as a constant thickness of 5 m. This thickness was informed by the results of the previous site investigations and drilling and represents a conservative (thicker) estimate of the unconsolidated material thickness. The thickness of layer 3 (weathered schist) is defined as a constant thickness of 20 m, which is the average thickness of the weathered schist across the site based on previous investigations and drilling. The thickness of layers 4, 5 (fresh hard rock) is defined as an arbitrary thickness of (10, 10), respectively. The model domain is shown in Figure 4.1 and a conceptual cross-section of the model domain is shown in Figure C.1.

C.3 Boundary Conditions

Boundary conditions represent potential inflows and outflows of water from the groundwater system. [Figure C.1](#) shows a conceptual diagram of the seepage model and the boundary conditions applied to the model domain. A CHB applies water at the specified head to the model cell and acts as both a potential source and sink of water. A DRN applies a head-dependent outflow to the model cell and acts as a potential sink of water. Finally, a RCH applies a specified flux of water to the model cell and acts as the dominant source of water to the model domain. Here we have included the following boundary conditions for the PROCESS components of the seepage model.

- **TSF - recharge (RCH|CHB):** The TSF can either be represented as a RCH or a CHB. The advantages of using a RCH boundary is that it allows for a more water mass balanced representation of the seepage model, but requires a more complex representation of the TSF to ensure reasonable heads are applied to the model domain. A CHB removes this concern by specifying the head in a given cell, but it is a potential infinite sink of water so it may yield higher than realistic seepage rates. The choices between these two boundary conditions is controlled by the `sim_type` parameter in the model parameterisation. The RCH is parameterised by `tsf_rch` and the head of the CHB is parameterised by `tsf_chb_head` in the model parameterisation. After initial testing, it was found that using a CHB boundary was producing a higher than credible water mass flux (e.g., greater than the total rainfall on the TSF). Therefore, a RCH boundary is used for the TSF in the final model build.
- **TSF - drains (DRN):** If the TSF recharge is represented as a RCH, then the TSF drains must be explicitly represented as a DRN to allow for the seepage from the TSF to be captured by the seepage collection system. There are two different types of drains in the TSF seepage collection system, the “toe drains” and the “underdrain”. The toe drains are located at the base of the TSF-D, while the underdrain is located along the base of Shepherds Creek to capture seepage from the TSF without having to flow all the way to the toe drains ([Hope and Torvelainen, 2025](#)). These “underdrains” may suffer damage and/or blockage during their operational life, so we have included as unique parameter for the conductance of the “underdrain” (`tsf_udrn_cond`) to allow for the potential for reduced seepage collection efficiency. The exact extent of the “underdrain” is still being finalised, so we have included a discrete parameter to control for the extent of the “underdrain” (`tsf_drn_extent`) in the model parameterisation ([Figure C.6](#)). If the TSF recharge is represented as a CHB, then the TSF drains are not implemented. The conductance of the TSF drains is parameterised by `tsf_drn_cond`.
- **SHELF recharge (RCH):** Recharge to the SHELF is represented as a RCH and parameterised by `rch_shelf` in the model parameterisation.
- **SHELF drains (DRN):** The SHELF seepage collection system incorporate an “underdrain” to capture seepage from the SHELF and direct it to the SUMP ([Zou and Carter, 2025](#)). This underdrain is represented as a DRN and the conductance and invert elevation of the DRN is parameterised by `shelf_drn_cond` and `shelf_drn_elev` in the model parameterisation, respectively.
- **SiltPond - recharge and discharge (CHB):** The SiltPond is represented as a CHB in the model and the head of the CHB is parameterised by `silt_pond_head`.
- **SHFILL - recharge (RCH):** Recharge to the SHFILL is represented as a RCH and parameterised by `rch_shfill` in the model parameterisation.
- **SHFILL - drains (DRN):** The SHFILL seepage collection system includes a “underdrain” to capture seepage from the SHFILL as it intersects the Shepherds Creek Valley Fill - Seepage Dam.
- **Shepherds Creek Diversion - (DRN):** The clean water diversions of Shepherds Creek and its tributaries will be benched into the weathered schist. There is the possibility of these diversions intercepting a significant amount of the shallow groundwater flow from upgradient of the PROCESS landforms (e.g., TSF). These diversions are represented as a DRN with an invert at the current ground elevation of the model cell with a parameterised offset (`bypass_elev_offset`) and conductance (`bypass_drn_cond`). We considered whether these diversions could also act as a source of clean water to the system, but given the low conductivity of the weathered schist and the fact that the diversions will be built on low conductivity material (10^{-7} m/s), we do not expect any significant inflow from the diversions to the groundwater system. Additionally, excluding a clean water source from the model is a more conservative approach, as it will yield higher concentrations and therefore higher potential lost seepage mass fluxes.

- **SHFILL - lateral drainage or underdrain (DRN):** The deep model has significant discharge to the SHFILL area in the unmodified system (Figure B.38). In the deep model this discharge occurs to general surface drains, which are a non-explicit representation of discharge to Shepherds Creek. In the seepage model, such large scale discharge is no longer appropriate, as the goal is to explicitly represent the seepage collection system and drainage. Early model realisations showed significantly elevated heads in the SHFILL area due to the discharge from the deep model. There must be an explicit mechanism for this discharge to leave the groundwater system or the heads will become strongly artesian, which is not a credible representation of the system. Therefore, we have included two mechanism for this discharge to leave the system. The first are a set of lateral drains along the edge of the SHFILL area, which can represent discharge to the steep slopes above the SHFILL area and/or explicit drainage. These drains have their invert at 5 m above the top of the SHFILL. The second is the inclusion of explicit underdrainage along the base of the SHFILL to capture seepage from the SHFILL. These drains have their invert at the current land surface elevation of the model cell with a parameterised offset (`shfill_udrn_offset`) and conductance (`shfill_udrn_cond`). In reality, the “underdrain” implemented here could be explicit drainage, a higher conductivity layer of fill, or a combination of both. The model can include one, the other, or both of these mechanisms depending on the `shfill_lat_udrn` parameter. By parameterising the lateral drains and underdrains, we can assess the sensitivity of the model to these mechanisms and their impact on the seepage collection system.

We have included the following boundary conditions for the natural components of the seepage model.

- **Non-PROCESS recharge (RCH):** Land surface recharge is applied to the active model domain not covered by the process landforms. This is parameterised by `non_process_rch`.
- **Shepherds Creek surface (DRN):** Potential discharge to Shepherds Creek downstream of SHFILL is implemented as a DRN with an invert at the current ground elevation of the model cell. The conductance of the DRN is parameterised by `weath_drn_cond`
- **Shallow groundwater flow out of the model domain (DRN):** There is potential for shallow groundwater flow out of the model in the weathered schist. This is implemented as a DRN with an invert at the top of layer 3 (weathered schist) cells and a conductance parameterised by `weath_drn_cond`.

Figure C.2–Figure C.5 show the boundary conditions applied to the model domain for each layer and a cross-section along Shepherds Creek. Note there are no boundary conditions applied to layers 4, 5 (hard rock).

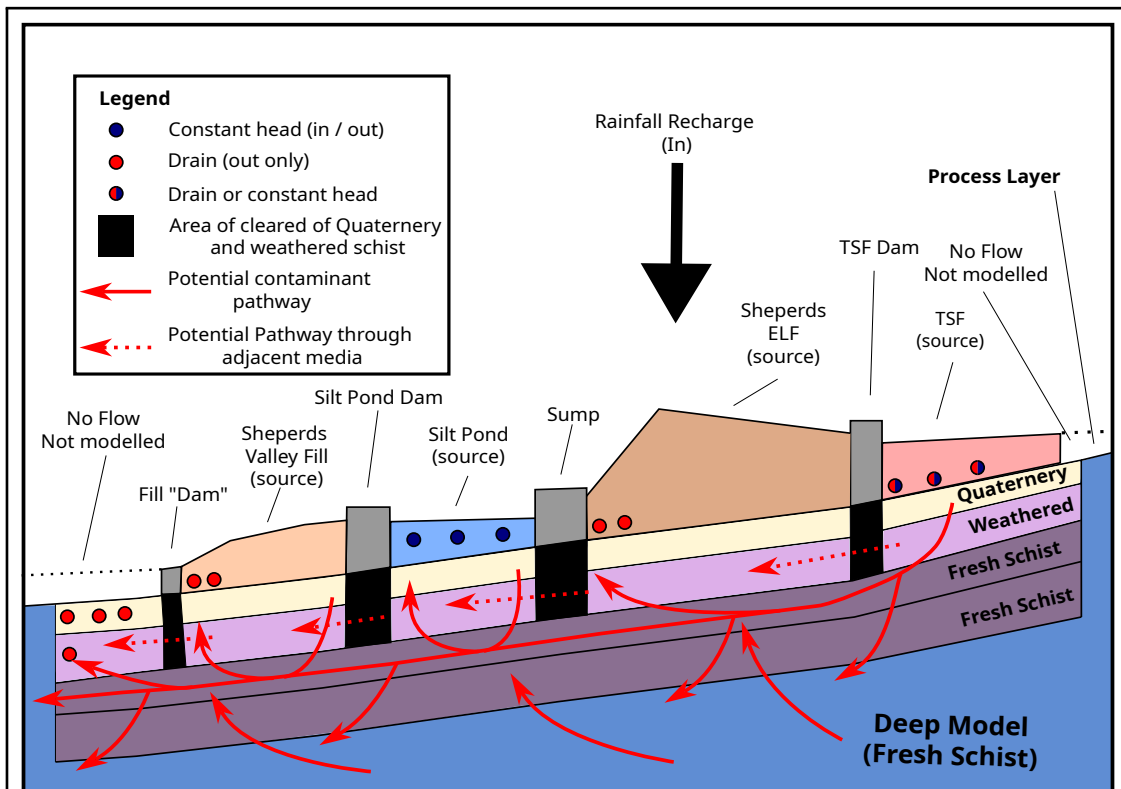
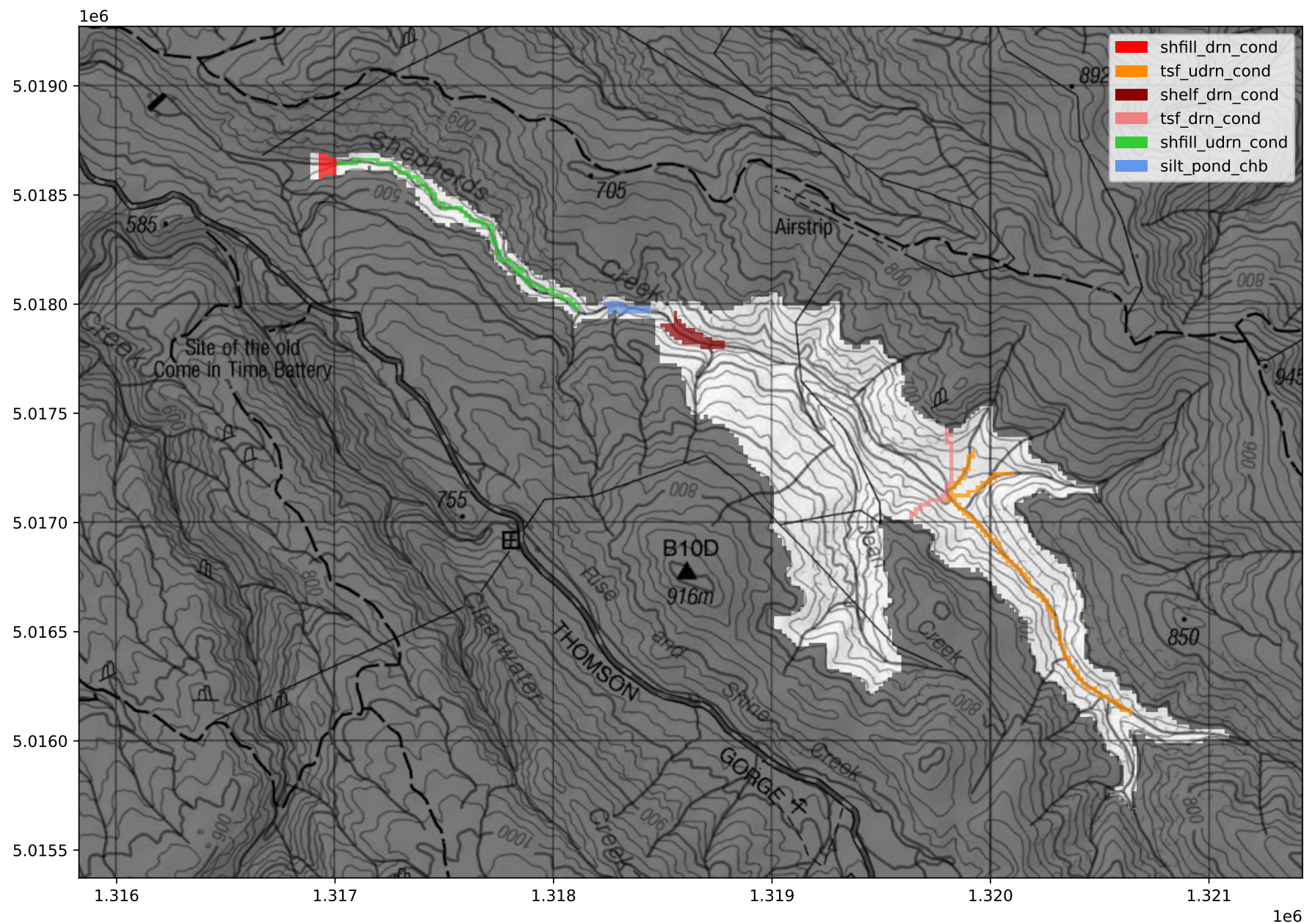


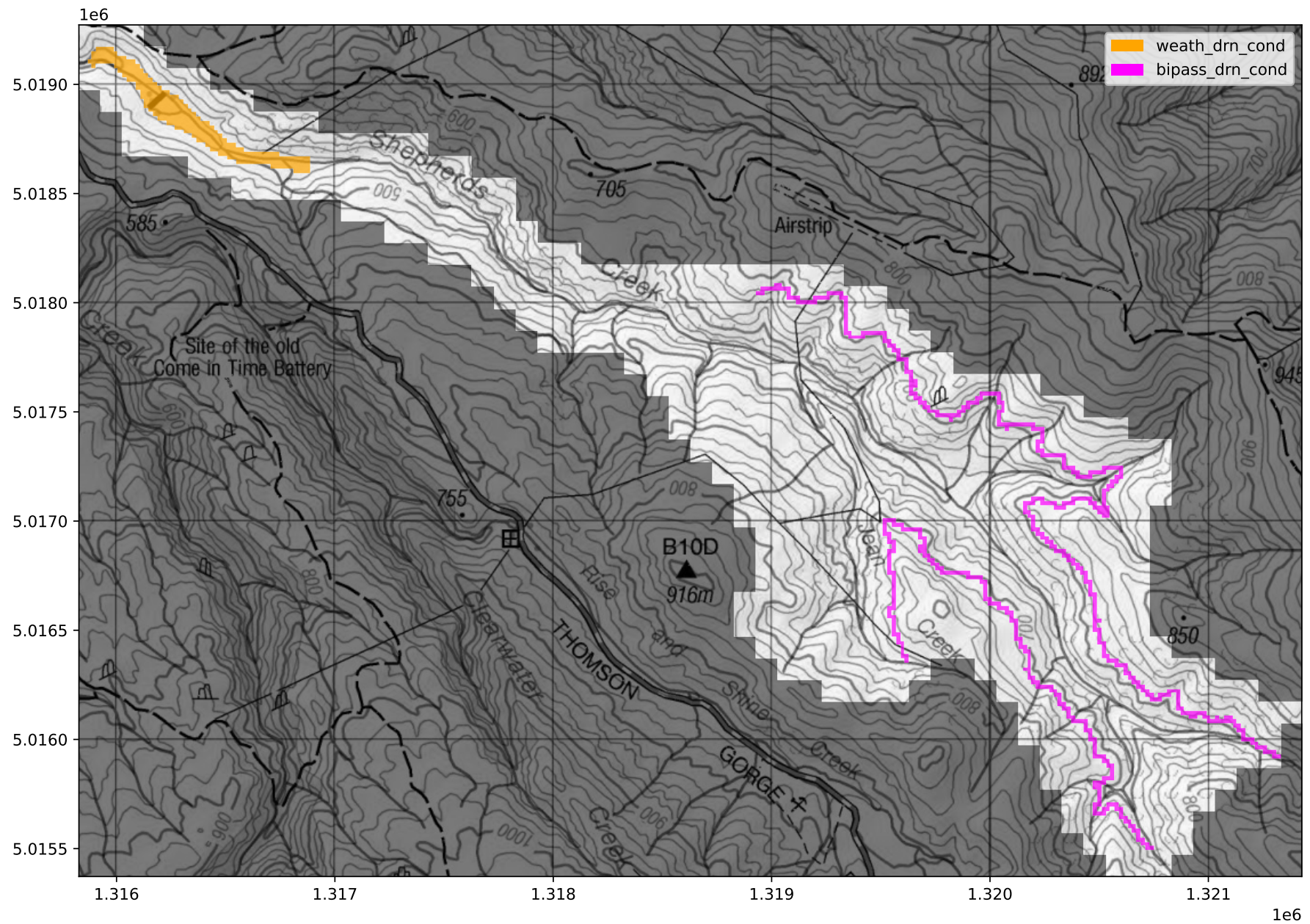
Figure C.1: A conceptual model of the seepage model

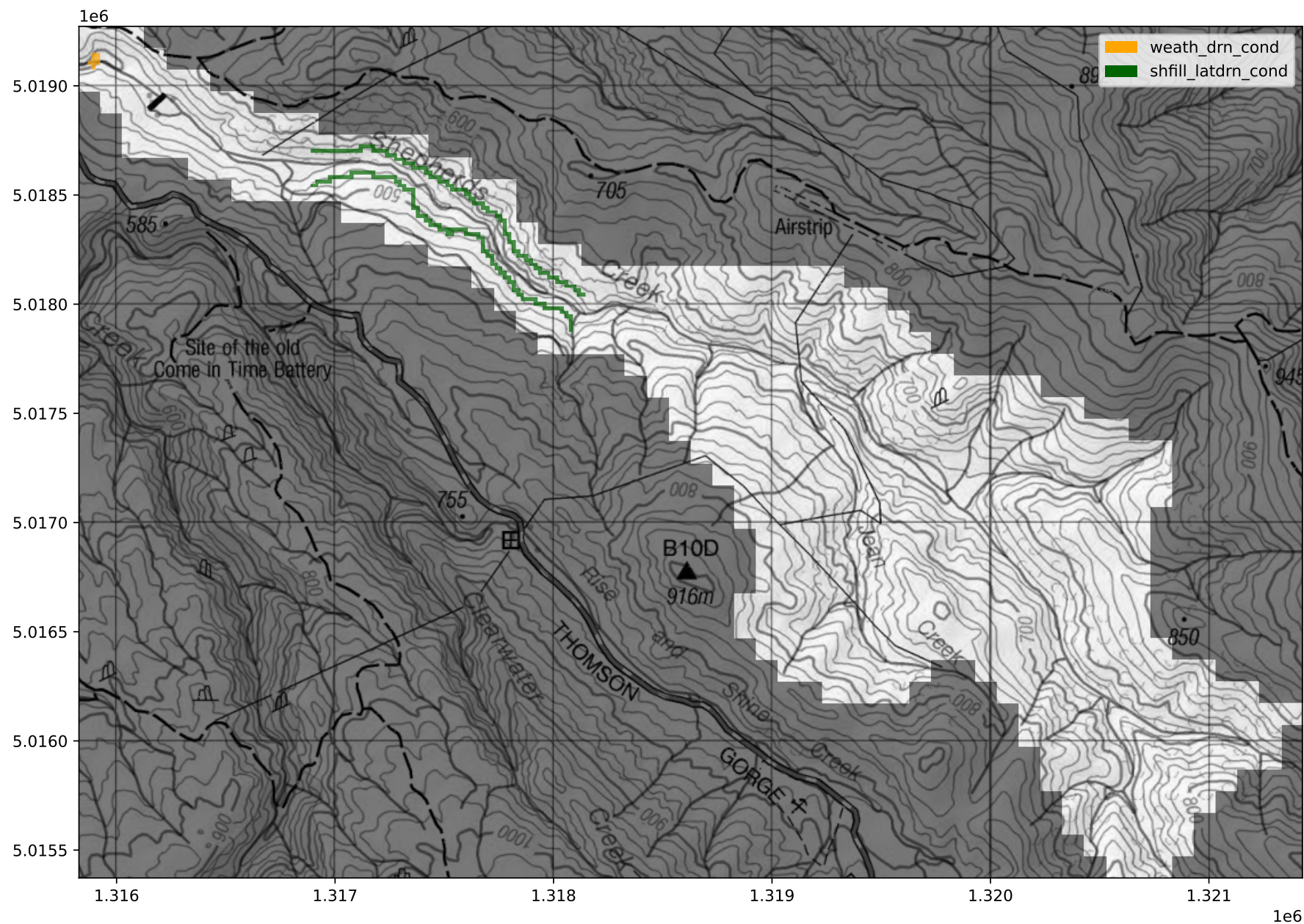
This is a conceptual cross-section of the seepage model running parallel to Shepherds Creek (not to scale).

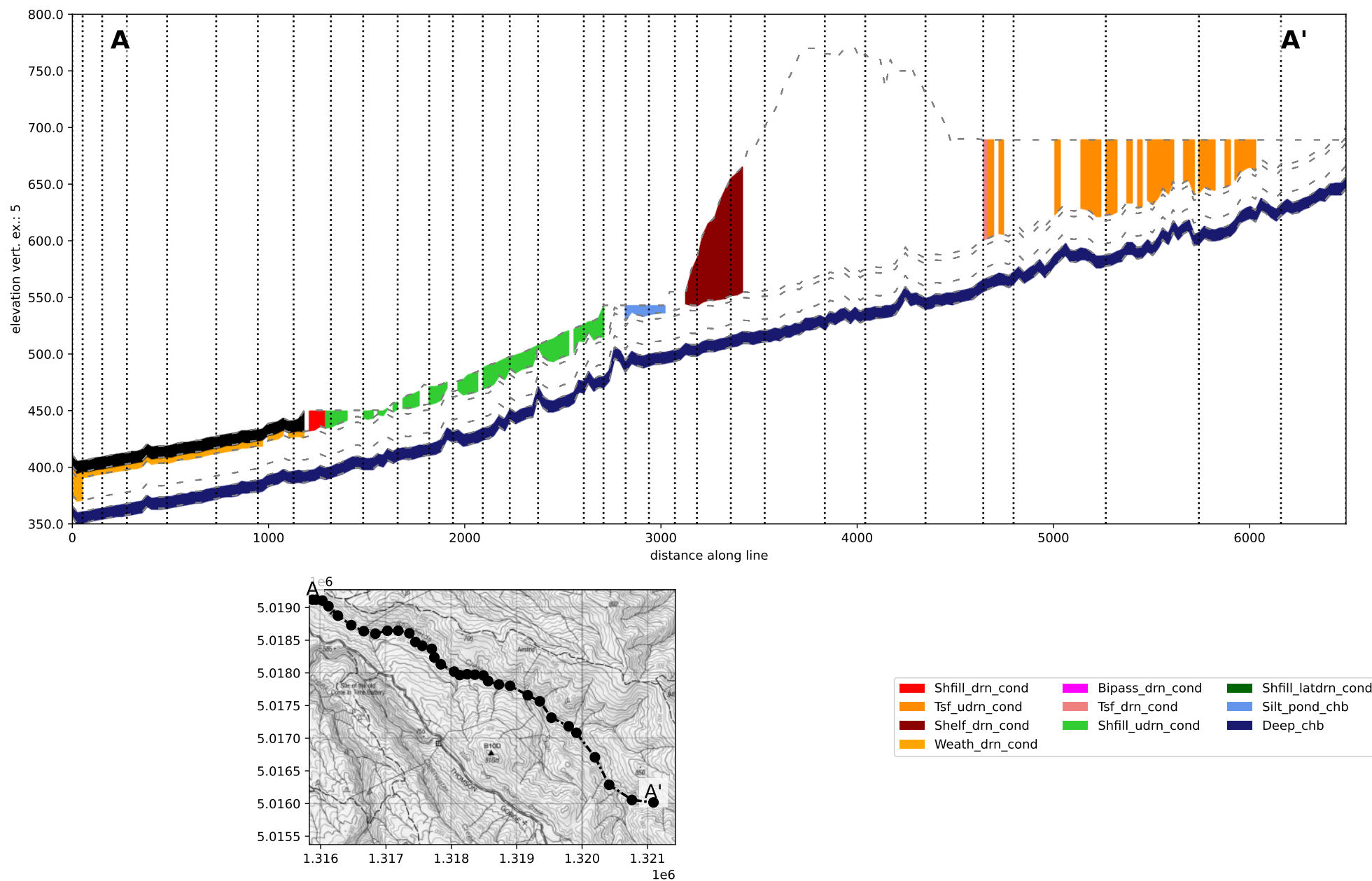
KSL

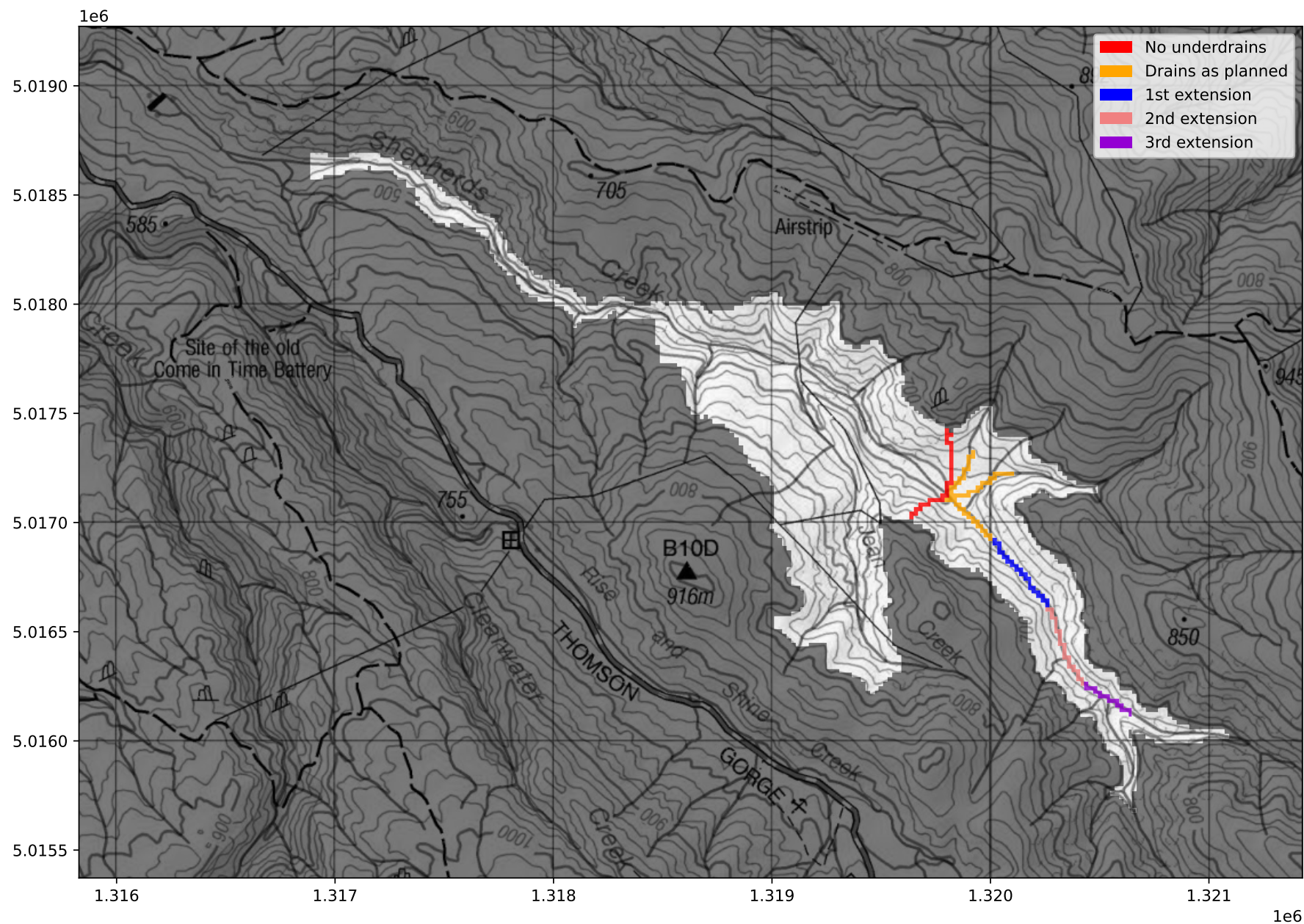
Project: Bendigo Ophir Gold
Client: Matakanui Gold Ltd.
Date: 14/08/2026









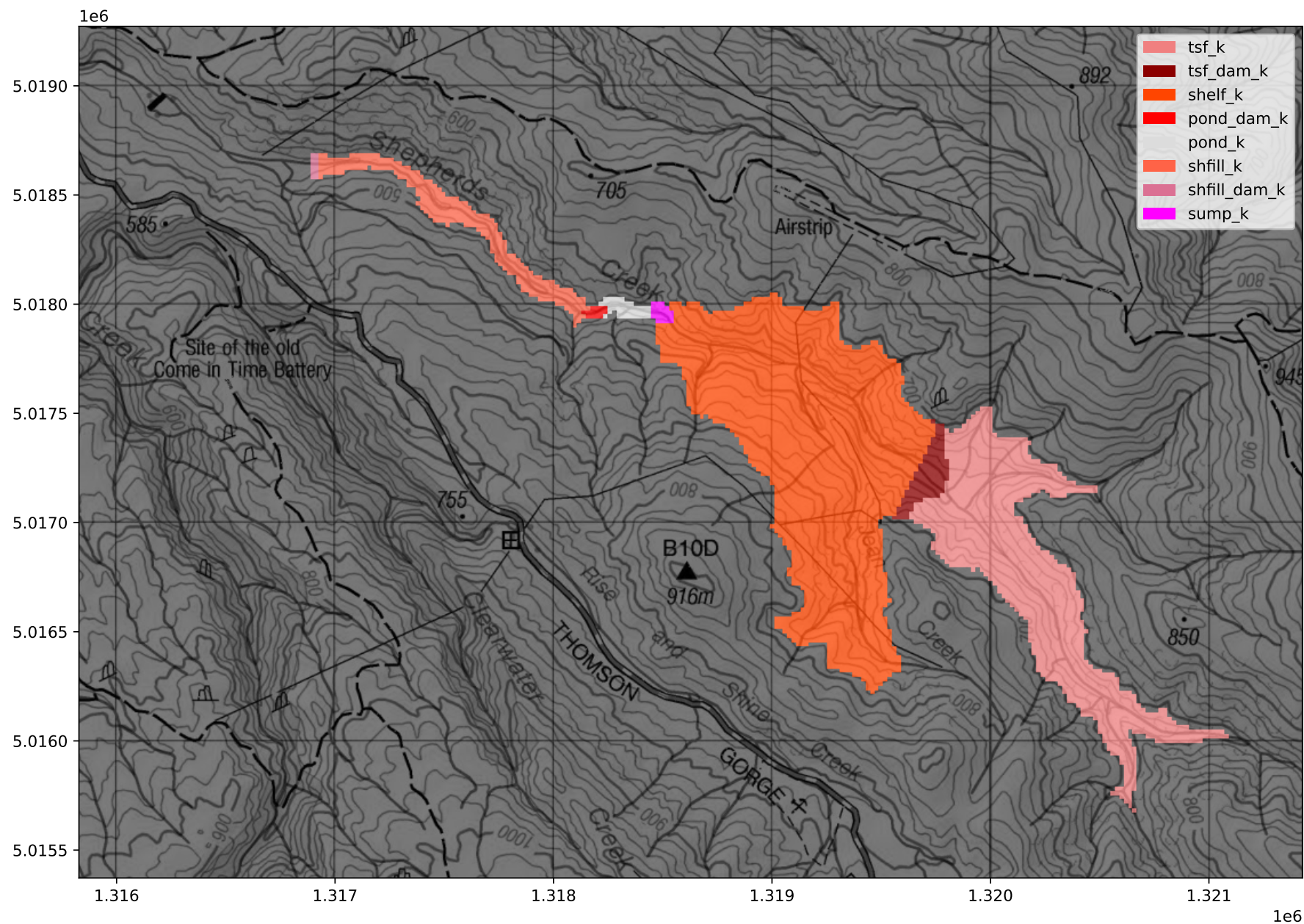


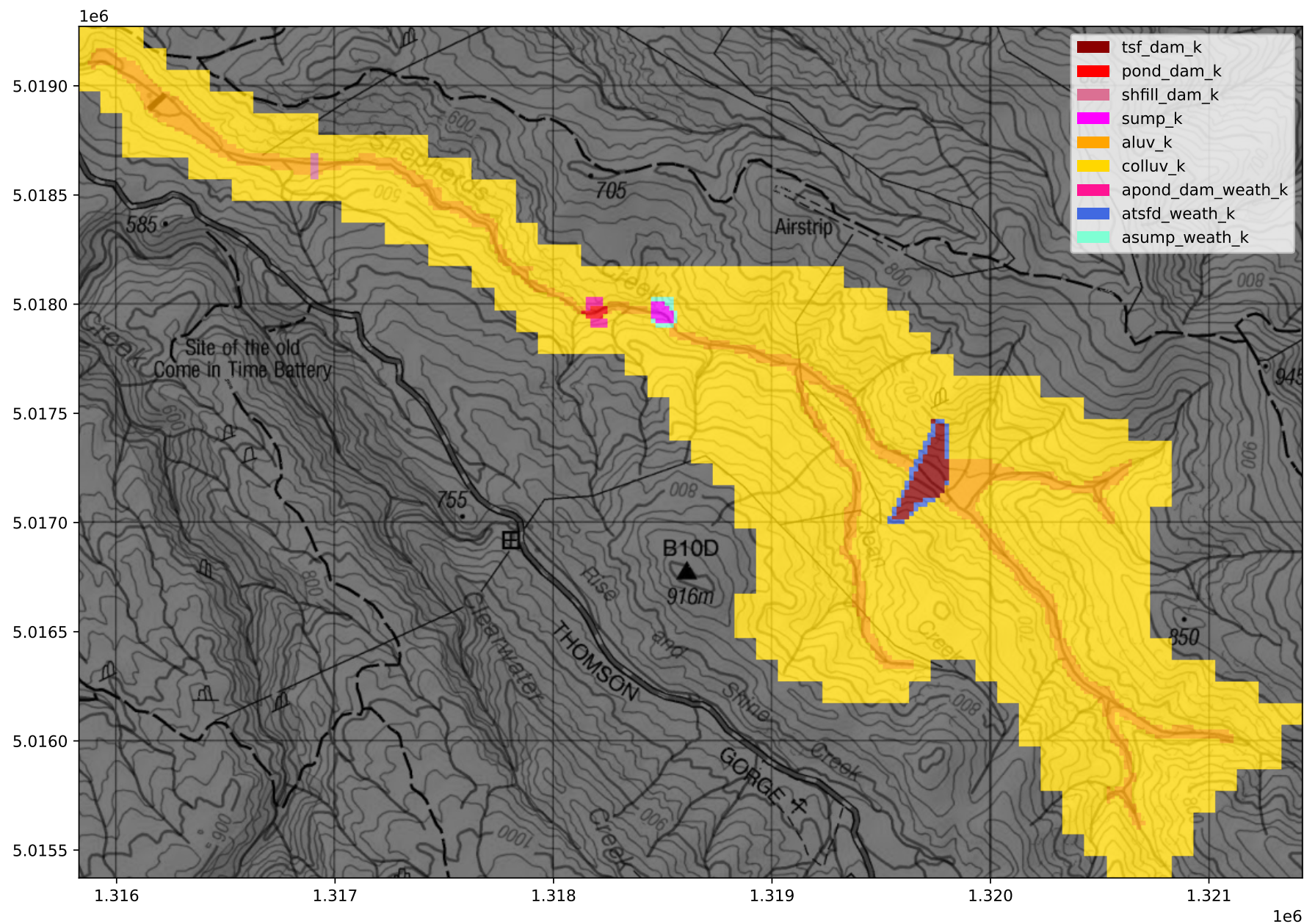
C.4 Parameterisation

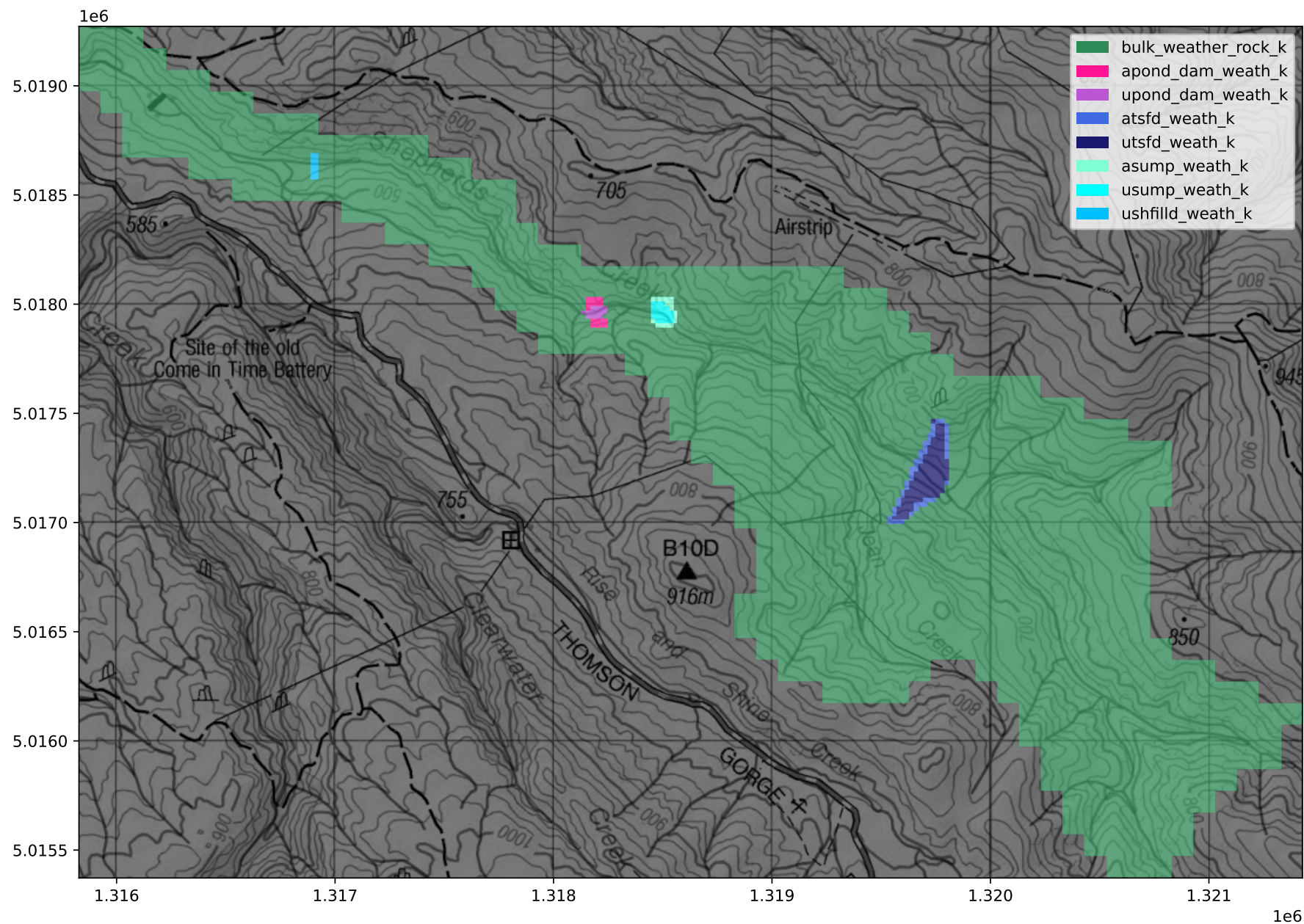
There are broadly 5 categories of parameters in the seepage model:

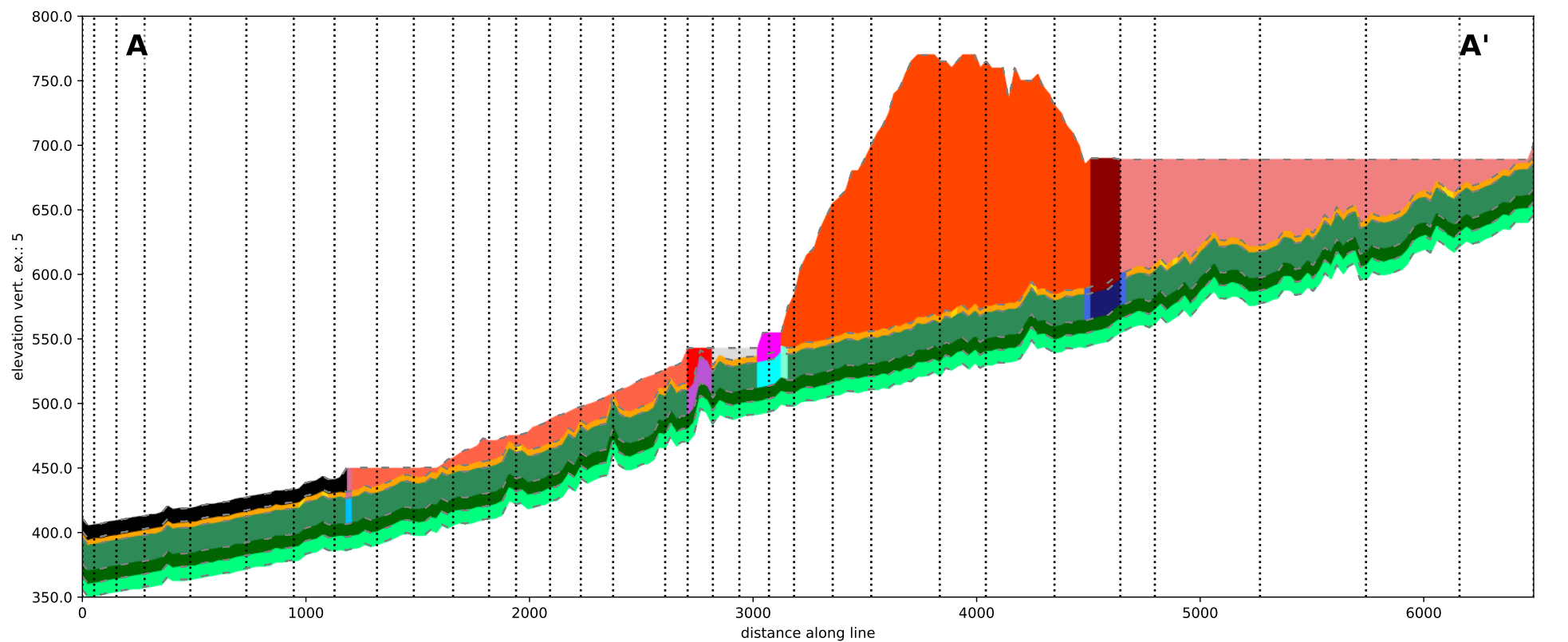
- **Boundary condition parameters (bnd):** These parameters control the boundary conditions applied to the model domain, including the head of the CHB boundaries, the conductance of the DRN boundaries, offsets to the DRN invert elevations, and the flux of the RCH boundaries.
- **Hydraulic conductivity parameters (knat | kpro):** Bulk hydraulic conductivity of the different model layers, for the most part these parameters are varied in log10 space.
- **Modification parameters (kmod):** In the areas where the QALCL and much of the weathered schist is removed to construct the PROCESS landforms (TSF-D, SUMP, SiltDam), the hydraulic conductivity of layer 2 (QALCL) is set to the hydraulic conductivity of layer 1 (PROCESS landform materials) to represent the removal of the QALCL. Layer 3 (weathered schist) is also affected, but not completely removed. Here the modification parameters act as a multiplier to the bulk hydraulic conductivity of the weathered schist. $k_{new} = k_{ws} \times k_{mod}$ where k_{new} is the revised hydraulic conductivity, k_{ws} is the bulk conductivity of the weathered schist, and k_{mod} is the modifier parameter. This represents both a reduction in thickness and/or potential reduction in hydraulic conductivity due to the removal of more fractured material and/or grouting of the remaining weathered schist. Two parameters are applied, one to layer 3 below the feature and a second to layers 2 and 3 in the adjacent cells to represent the potential for reduced hydraulic conductivity in the weathered schist due to the construction of the PROCESS landforms.
- **Anisotropy parameters (vka):** These parameters control the ratio of horizontal to vertical hydraulic conductivity in the model layers ($k_v = k_h/vka$, where k_v is the vertical hydraulic conductivity, k_h is the horizontal hydraulic conductivity, and vka is the anisotropy parameter).
- **Simulation control parameters (sc):** These parameters control simulation settings, currently only `sim_type` exists to control the choice of RCH or CHB for the TSF.
- **Parameters Inherited from the Deep Model:** The seepage model is a sub-model of the deep groundwater model, and therefore inherits some parameters from the deep model. Specifically it inherits the hydraulic conductivity (and anisotropy) of the weathered schist layer (`bulk_weather_rock_k`, `weath_vka`) and the fresh rock layers (`fresh_rock_k`, `fresh_vka`). Though the modifiers to the weathered schist layer are applied in the seepage model, but not in the deep model when run as a standalone model. Similarly, the model inherits the colluvium conductivity and anisotropy (`colluv_k`, `quat_vka`) from the deep model, but the thin strip of alluvium along Shepherds Creek is not included in the deep model, which is separately parameterised in the seepage model (`aluv_k`). Finally, the seepage model inherits the groundwater recharge from the deep model for all areas not covered by the PROCESS landforms (`non_process_rch`). All cells of the seepage model directly map to a single cell in the deep model, so the inherited parameters are sampled from the deep model at the corresponding cell.

These parameters can either be varied in the stochastic suite or fixed to a single “default” value. [Figure C.7–Figure C.10](#) shows the hydraulic conductivity parameterisation for each layer and a cross-section along Shepherds Creek. Note that layers 1 (hard rock) are not shown in plan view as they have a uniform hydraulic conductivity. [Figure C.11](#) shows the recharge parameterisation applied to the model domain.









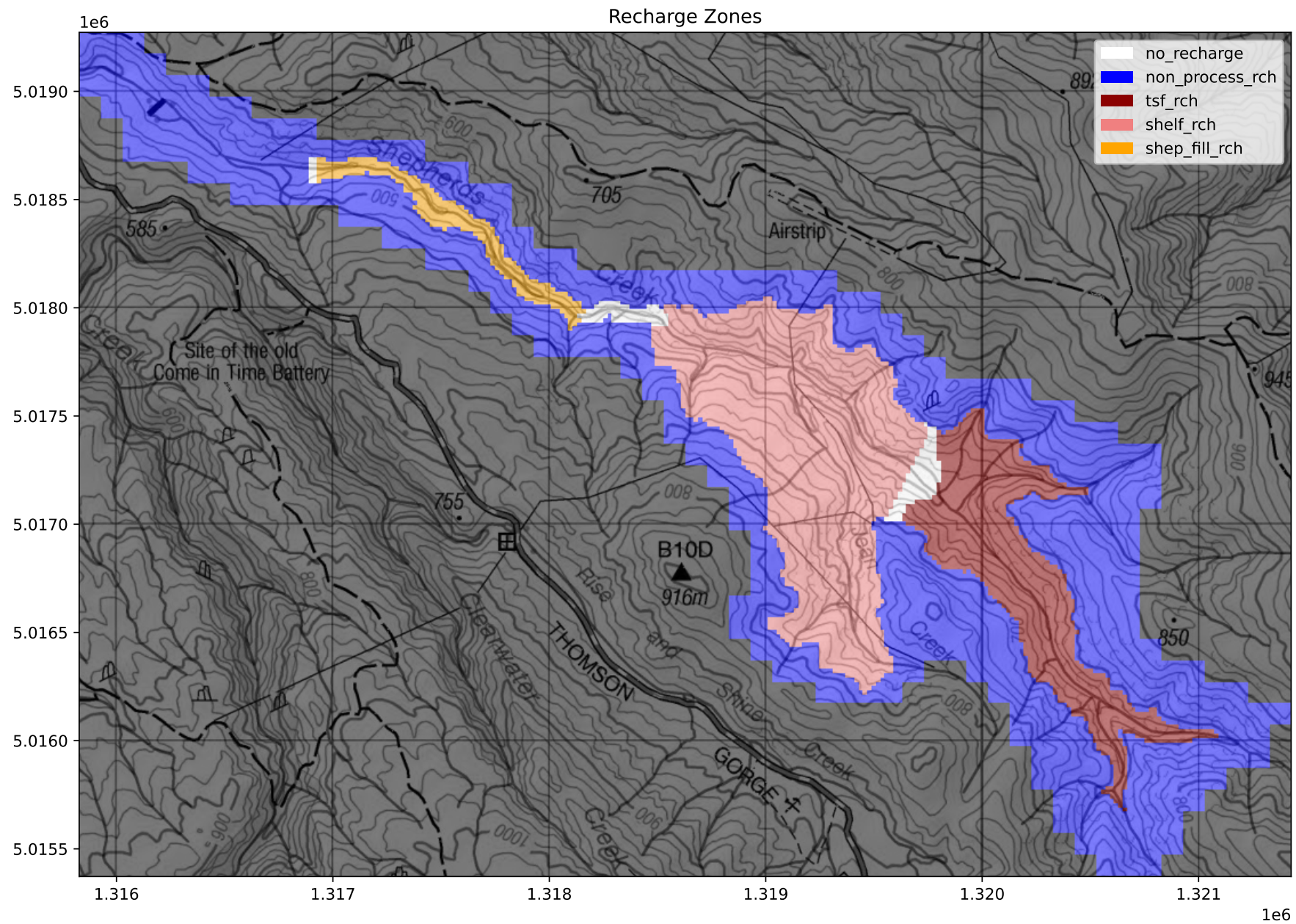


Table C.1: Overview of parameters for the seepage model. Frozen values are fixed to the default value.

Parameter	Group	Min	Max	Default	Unit	Distribution	Frozen	Description	Source
bypass_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Conductance for bypass drains	Set arbitrarily high
bypass_elev_offset	bnd	-4.0	5.0	0.0	m elev	uniform(-4.0 - 5.0)	False	Offset for bypass drains invert elevation relative to the top of the cell, for instance -1 means bypass drains in all cells = cell top -1m	Low set at bottom of quaternary high is arbitrary sensitivity
shelf_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Drain conductance for shepherds elf drains, if 0 then no drains in simulation	Set arbitrarily high, use invert elv to parameterise it instead
shelf_drn_head	bnd	543.0	555.0	545.0	m elev	uniform(543.0 - 555.0)	False	Head value for the invert of the shepherds elf drains	Zou and Carter (2025)
shelf_rch	bnd	102.0	255.0	102.0	mm/year	uniform(102.0 - 255.0)	False	Recharge applied to the shepherds elf area	weber (2025)
shep_fill_rch	bnd	102.0	255.0	102.0	mm/year	uniform(102.0 - 255.0)	False	Recharge applied to the shepherds fill area	weber (2025)
shfill_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Drain conductance for shepherds valley fill drains, if 0 then no drains in simulation	Arbitrarily high
shfill_drn_head	bnd	433.0	440.0	435.0	m elev	uniform(433.0 - 440.0)	False	Drain invert for shepherds valley fill drains	Range of possible elevations
shfill_lat_udrn	bnd	0.0	2.0	0.0		uniform(0 - 2)	False	Identifier shfill lateral / underdrain 0=lateral drains only; 1=underdrain only; 2=lateral and underdrain	
shfill_latdrn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Drain conductance for shfill lateral drains	Set arbitrarily high
shfill_udrn_cond	bnd	-1.0	3.0	1.0	log10(m2/day)	uniform(-1.0 - 3.0)	False	Drain conductance for shfill under drains, if 0 then no drains in simulation	based of TSF drains in Hope and Torvelainen (2025)
shfill_udrn_offset	bnd	0.0	5.0	0.0	m elev	uniform(0.0 - 5.0)	False	Offset from current creek elevation for shfill under drains	Sensitivity parameter
silt_pond_head	bnd	538.5	542.1	540.5	m elev	uniform(538.5 - 542.1)	True	Head value for the silt pond chd boundary conditions	Carter et al. (2025)
tsf_chb_head	bnd	680.0	690.0	683.0	m elev	uniform(680.0 - 690.0)	True	Head value for the tsf chd boundary conditions	Hope and Torvelainen (2025)
tsf_drn_cond	bnd	2.0	4.0	3.0	log10(m2/day)	uniform(2.0 - 4.0)	False	Drain conductance for tsf drains, if 0 then no drains in simulation	Hope and Torvelainen (2025)
tsf_drn_extent	bnd	0.0	4.0	0.0		uniform(0 - 4)	False	Identifier for the extent of TSF underdrains: 0=no underdrains; 1=drains as planned; 2=1st extension; 3=2nd extension; 4=3rd extension	
tsf_drn_offset	bnd	-4.0	10.0	0.0	m elev	uniform(-4.0 - 10.0)	False	Offset elevation for tsf drain inverts relative to the bottom of the process cell: $drn_{elev} = bot + offset$	Sensitivity analysis
tsf_rch	bnd	102.0	255.0	102.0	mm/year	uniform(102.0 - 255.0)	False	Recharge applied to the area not covered by process sites	weber (2025)
tsf_udrn_cond	bnd	-1.0	3.0	1.0	log10(m2/day)	uniform(-1.0 - 3.0)	False	Drain conductance for tsf under drains, if 0 then no drains in simulation	Hope and Torvelainen (2025)
weath_drn_cond	bnd	1.0	4.0	3.0	log10(m2/day)	uniform(1.0 - 4.0)	True	Drain conductance for shepherds valley top drains (in quaternary) and end of model weathered schist drains. these are below process sites.	Arbitrarily high

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Table C.1: Overview of parameters for the seepage model. Frozen values are fixed to the default value. (Continued)

Parameter	Group	Min	Max	Default	Unit	Distribution	Frozen	Description	Source
apond_dam_weath_k	kmod	-2.0	0.0	0.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock adjacent to the silt pond dam (not under it)	Up to 2 order of magnitude reduction
asump_weath_k	kmod	-2.0	0.0	0.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock adjacent to the silt pond dam (not under it)	Up to 2 order of magnitude reduction
atsfd_weath_k	kmod	-2.0	0.0	0.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock adjacent to the tsf (not under it)	Up to 2 order of magnitude reduction
upond_dam_weath_k	kmod	-2.0	0.0	-1.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock under the silt pond dam	Up to 2 order of magnitude reduction
ushfilld_weath_k	kmod	-2.0	0.0	0.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock under to the shfill dam	Up to 2 order of magnitude reduction
usump_weath_k	kmod	-2.0	0.0	-1.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock under the silt pond dam	Up to 2 order of magnitude reduction
utsfd_weath_k	kmod	-2.0	0.0	-1.0	log10()	uniform(-2.0 - 0.0)	False	Single k value multiplier $k = 10^{(bulk_weather_rock_k+k0)}$ for the weathered rock under the tsf	Up to 2 order of magnitude reduction
aluv_k	knat	-6.0	-4.0	-5.0	log10(m/s)	uniform(-6.0 - -4.0)	False	K for the alluvium dominated component of the existing quaternary sediments	Freeze and Cherry (1979)
pond_dam_k	kpro	-8.0	-6.0	-7.0	log10(m/s)	normal(-7,0.5)	False	Single k value for the silt pond dam, this will overwrite the quaternary sediments	Zou and Carter (2025); Carter et al. (2025)
pond_k	kpro	2.0	4.0	3.0	log10(m/s)	uniform(2.0 - 4.0)	True	Single k value for the silt pond (sediments and water)	Set arbitrarily high
shelf_k	kpro	-6.0	-4.0	-5.0	log10(m/s)	uniform(-6.0 - -4.0)	False	Single k value for the sheperds engineered landform k	Freeze and Cherry (1979)
shfill_dam_k	kpro	-8.0	-6.0	-6.5	log10(m/s)	normal(-7,0.5)	False	Single k value for the shepherds fill dam embankment, this will overwrite the quaternary sediments	Torvelainen (2026)
shfill_k	kpro	-6.0	-4.0	-5.0	log10(m/s)	uniform(-6.0 - -4.0)	False	Single k value for the shepherds creek valley fill (downstream of sump)	Freeze and Cherry (1979)
sump_k	kpro	-8.0	-6.0	-7.0	log10(m/s)	normal(-7,0.5)	False	Single k value for the sump/seepage collection at end so shelf, this will overwrite the quaternary sediments	Zou and Carter (2025)
tsf_dam_k	kpro	-8.0	-6.0	-7.0	log10(m/s)	normal(-7,0.5)	False	Single k value for the tsf dam embankment, this will overwrite the quaternary sediments	Hope and Torvelainen (2025)
tsf_k	kpro	-7.0	-5.5	-6.4	log10(m/s)	uniform(-7.0 - -5.5)	False	Single k value for the tsf sediments	Hope and Torvelainen (2025)
sim_type	sc	0.0	1.0	0.0		uniform(0 - 1)	True	Identifier for the simulation type: 0=recharge inflows only; 1=chb for tsf (no drains in tsf)	

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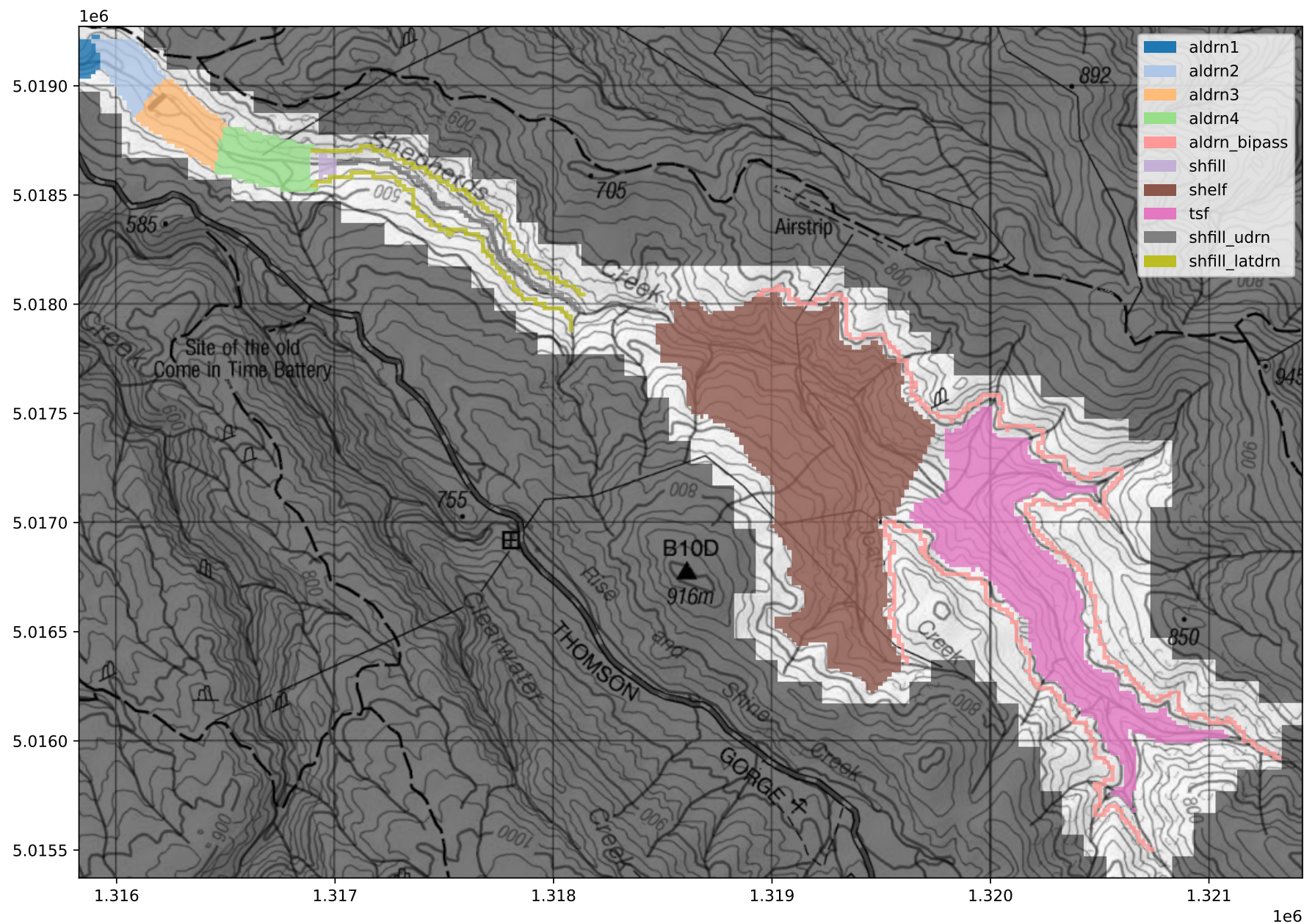
Table C.1: Overview of parameters for the seepage model. Frozen values are fixed to the default value. (Continued)

Parameter	Group	Min	Max	Default	Unit	Distribution	Frozen	Description	Source
process_vka	vka	1.0	10.0	1.0		uniform(1.0 - 10.0)	False	Single kv multiplier for process layer $kv = \frac{k}{vka}$	Typical range of 1-10

C.5 Observations / Outputs

The seepage model is a purely predictive model (e.g., no inversion is preformed), so there are no target observations in the typical sense. Instead, we capture a series of model prediction values for each simulation; these predictions are:

- **Total input contaminant mass for each source:** The total contaminant mass flux into the model for each potential source of seepage (e.g., TSF and SHFILL)
- **Semi-discretised contaminant mass flux to the seepage collection system from each source:** The contaminant mass flux to the seepage collection system is semi-discretised into the different PROCESS components (i.e., TSF drains, SHELF drains, SHFILL drains, and SiltPond). See [Figure C.12](#) for the spatial locations of these zones.
- **Semi-discretised contaminant mass flux to the shallow groundwater system from each source:** The contaminant mass flux to the shallow groundwater system is semi-discretised into coarse zones. See [Figure C.12](#) and [Figure C.13](#) for the spatial locations of these zones.
- **Water flux volumes at all contaminant mass flux locations:** The water flux volumes are captured at all locations where contaminant mass flux is captured, to allow for the calculation of contaminant concentrations.
- **Indicative groundwater concentrations at key locations for each source:** The modelled concentration for each source is extracted for each layer at key observation points. See [Figure C.14](#) for the spatial locations of these zones.
- **Indicative groundwater heads at key locations:** The modelled groundwater head is extracted for each layer at key observation points. These points are the same as the contaminant concentration observation points, and are shown in [Figure C.14](#).



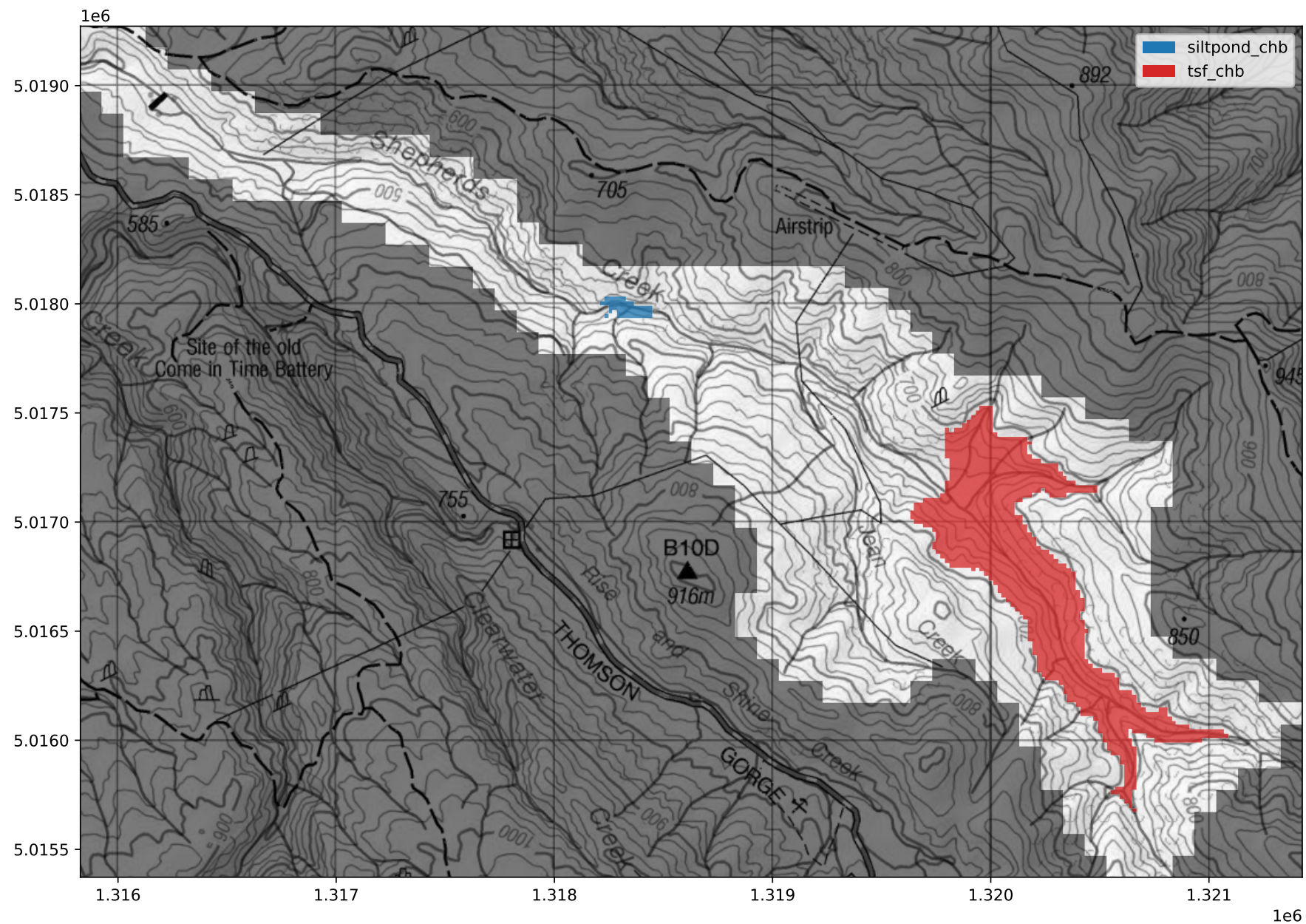
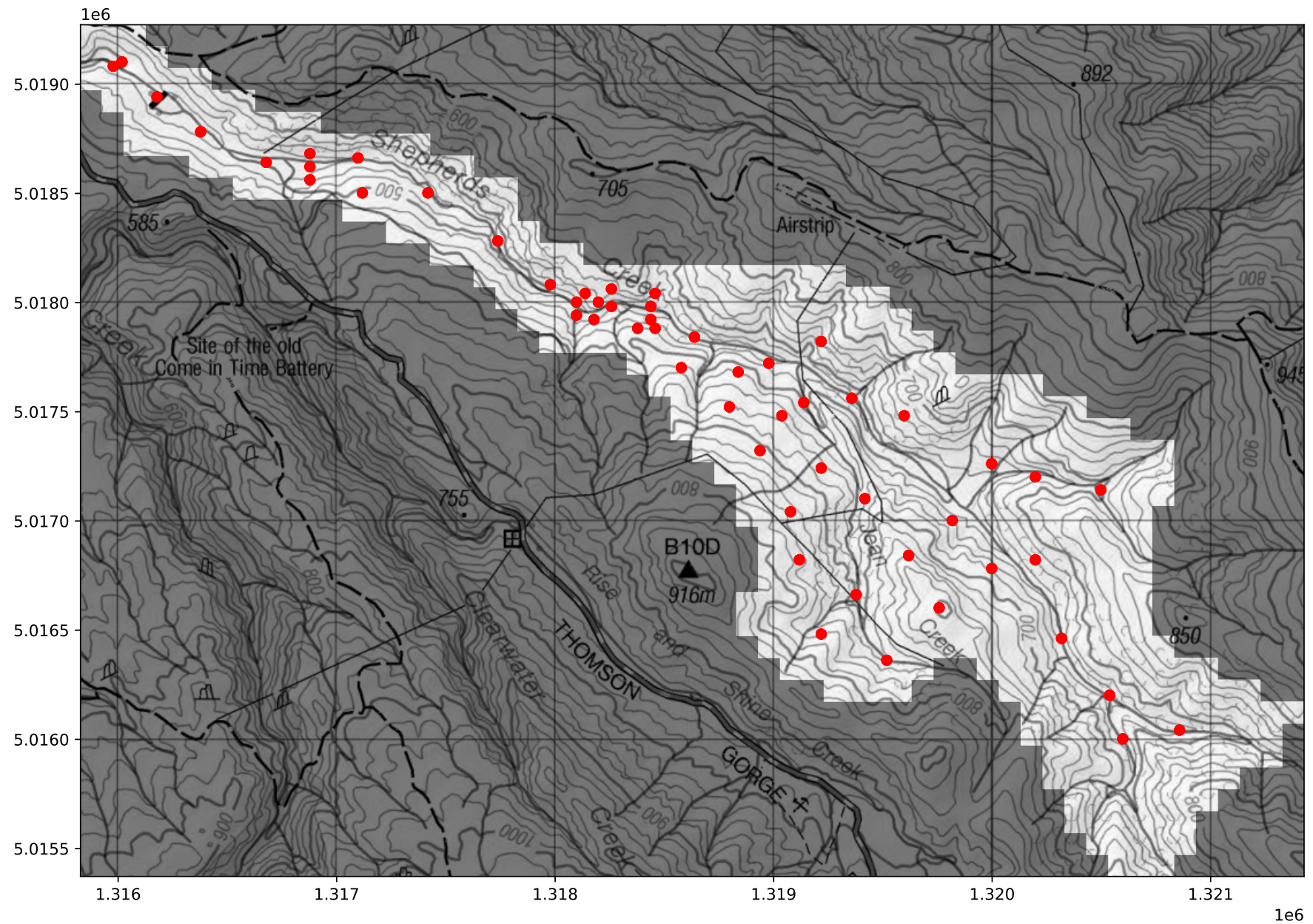


Figure C.13: PROCESS and shallow groundwater mass flux observation points (CHB)

Note that the CHB zones do not necessarily have a CHB cell in all cells in the zone, but rather the zone captures all CHB cells in the zone and in the PROCESS layer.



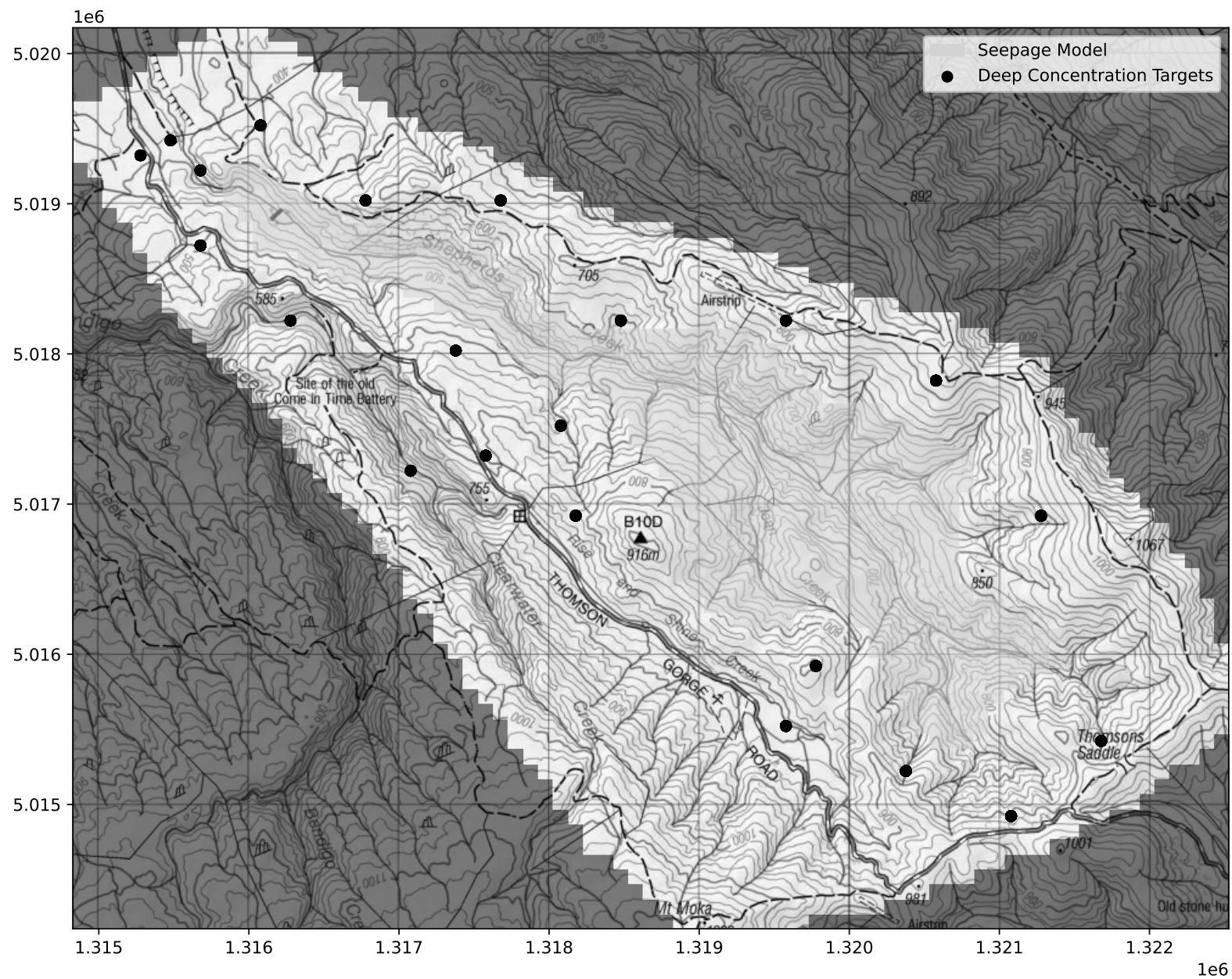
D Coupled Model Build

The coupled model build is a direct combination of both the seepage and deep groundwater models. The model structure of seepage model is identical to the coupled model (where it exists), while the areas of the deep groundwater model which are covered by the seepage model are replaced with no flow cells (e.g., flow and transport handled by the seepage model). All boundary conditions from both models are identical (where they exist), but the CHB used to represent the potential pit lake in the deep groundwater model is included as a potential seepage source. There are several cells (<5) in the deep model which contain a CHB or DRN boundary condition associated with the outflow of the underground workings and which fall inside the seepage model domain. The boundary conditions for these specific cells are removed from the coupled model. The removal of these boundary conditions should not significantly affect the results of the coupled model, as the boundary conditions located in the adjacent cells are still present in the coupled model – it is essentially a discretisation issue.

D.1 Additional Observations

The coupled model inherits all observations described in the seepage model ([Section C.5](#)). The deep model observations focused on the optimisation of the deep model and are not relevant to the coupled model. Instead, a new set of observations are included in the deep component of the coupled model to assess the potential for seepage from the deep model to the seepage model. These observations have the same structure as those of the seepage model:

- **Total input contaminant mass for each source:** The total contaminant mass flux into the model, only relevant for the “pit” CHB source.
- **contaminant mass fluxes to the mine excavations for each source:** This is broken up into the contaminant flux to the RAS, CIT, and SREX pits; and the RAS underground workings. The RAS pit and underground workings are also broken up into those cells which are represented by a CHB and DRN boundary condition in the deep model. Note that only the post closure model has a CHB representing the pit lake. See [Figure A.4 & Figure A.5](#) and [Figure A.6 & Figure A.7](#) for the spatial locations of these zones for the post closure and during mining simulations, respectively.
- **Semi-discretised contaminant mass flux to the shallow groundwater system from each source:** The contaminant mass flux to the shallow groundwater system is semi-discretised into coarse zones([Figure D.1](#)).
- **contaminant mass flux to the OFFSHORE zone:** The contaminant mass flux to the OFFSHORE zone is captured to assess the potential for contaminant mass flux out of the Shepherds Creek catchment without passing through the shallow groundwater system ([Figure A.3](#)).
- **Water flux volumes at all contaminant mass flux locations:** The water flux volumes are captured at all locations where contaminant mass flux is captured, to allow for the calculation of contaminant concentrations.
- **Indicative groundwater concentrations at key locations for each source:** The modelled concentration for each source is extracted for each layer at key observation points. See [Figure D.2](#) for the spatial locations of these zones.
- **Indicative groundwater heads at key locations:** The modelled groundwater head is extracted for each layer at key observation points. These points are the same as the contaminant concentration observation points, and are shown in [Figure D.2](#).



D.2 Additional Parameters

The coupled model directly inherits all parameters of the seepage model. These parameters are described in [Section C.4](#) and summarized in [Table C.1](#). When referenced in the context of the coupled model, these parameters are prepended with “seep” to preclude and parameter naming conflicts and to avoid confusion with the deep model parameters.

The deep model parameters are constrained by the optimisation of the deep model. These parameters are described in [Section A.4](#) and summarised in [Table A.1](#). The parameters are inherited from the deep model via a unique identifier parameter `deep_post_upid` which ranges from 1 to 500 and corresponds to the 500 unique posterior parameter sets selected from the deep model optimisation posterior ([Section B.4](#)). Additionally, the deep model simulation type parameter `deep_sim_type` is unfrozen for the forward predictions and allowed to vary between the two mining related simulation types (e.g., `deep_sim_type` = 1 or 2). Finally additional parameters for the porosity of the different components of the model are included. A summary of the coupled model parameters is provided in [Table D.1](#).

Table D.1: Overview of additional parameters for the coupled model. Frozen values are fixed to the default value.

Parameter	Group	Min	Max	Default	Unit	Distribution	Frozen	Description	Source
por_alcol	por	0.1	0.3	0.2		uniform(0.1 - 0.3)	True	Porosity of the alluvium / colluvium members	Indicative value
por_proc	por	0.1	0.3	0.2		uniform(0.1 - 0.3)	True	Porosity of the non-zone-a process components	Indicative value
por_tgf	por	0.0	0.2	0.1		uniform(0.01 - 0.25)	True	Porosity of the TGF schist	Indicative value
por_tz3	por	0.0	0.2	0.1		uniform(0.01 - 0.25)	True	Porosity of the tz3 schist	Indicative value
por_tz4	por	0.0	0.2	0.1		uniform(0.01 - 0.25)	True	Porosity of the tz4 schist	Indicative value
por_weath	por	0.0	0.2	0.1		uniform(0.01 - 0.25)	True	Porosity of the weathered schist	Indicative value
por_zonea	por	0.0	0.2	0.1		uniform(0.01 - 0.25)	True	Porosity of the zone-a process components	Indicative value
deep_post_upid	sc	1.0	500.0	1.0		uniform(1 - 500)	False	Unique identifier for the the posterior deep model used.	
deep_sim_type	sc	1.0	2.0	1.0		uniform(1 - 2)	False	Identifier for the simulation type: 1=post mining - pit/lake hds = 490; 2=during mining - pit/underground fully dewatered	

D.3 Simulation Characteristics

The model is a steady-state groundwater flow coupled with 3 independent pseudo-steady-state transport simulations. The flow model is run using a fully confined solution (e.g., cells are always fully saturated and cannot go dry). A fully confined solution provides a more numerically stable solution, but because no cells can become inactive (go dry), some flow paths may be overestimated. Additionally, the saturated thickness used for the calculation of transmissivity is the full cell thickness, which may also lead to higher than realistic flow rates in some areas. The dominant areas which may be unsaturated are the valley side QALCL, possibly the valley sides weathered schist, and portions of the PROCESS landforms. The increased transmissivity in the valley sides is unlikely to significantly affect the results. The increased transmissivity of the PROCESS landforms is more likely to affect the results, but will yield higher than realistic seepage rates through low permeability engineered materials. This will yield a more conservative estimate of seepage rates, which is appropriate for the purpose of this assessment.

The transport simulations include the effects of advection, but do not include dispersion, chemical reactions, or decay. The choice to exclude dispersion from the transport simulation was primarily to reduce their computational cost. The fine grid resolution and large scale of the seepage model component (20 m) means that running the model to pseudo-steady-state requires a very large number of time steps to maintain numerical stability, excluding dispersion allows for larger time steps to be used. The analysis here is about the potential to lose seepage from the PROCESS landforms, not to develop a spatially detailed contaminant plume, so the exclusion of dispersion is not expected to significantly affect the results. Additionally, at the scale of the seepage model, the effects of numerical dispersion (a by-product of the numerical solution) are likely to account for the majority of the dispersion effects, so the exclusion of physical dispersion is not expected to significantly affect the results. If dispersion was included in the model, the shape of the plume from different may change slightly. However, this is not expected to significantly influence the modelled fate of seepage, which is dominated by advective pathways between sources and sinks.

To achieve a pseudo-steady-state solution, the transport simulations are run using a TVD advection scheme for 1 day simulation. We ran multiple tests models across the parameter space to ensure that the simulation length was sufficient to achieve a pseudo-steady-state solution. After of 365000 days, mass fluxes in the model are stable and do not change significantly with further simulation time. It should be noted that the simulation length and porosity are coupled and the values used here are reasonable, but mostly set for computational efficiency. As long as the simulation length is sufficient to achieve a pseudo-steady-state solution, the porosity does not affect the results of the transport simulations. Finally, the input concentration for each source is set to 1, and each source is modelled as a separate transport simulation to track the mass partitioning of seepage from each source. This way true seepage concentrations can be calculated by multiplying the seepage mass flux from each source by the concentration of the source.

E Forward Stochastic Suite

There is minimal data to support an inversion. Instead, the assessment of effects is undertaken through a stochastic prior parameter suite. This suite assesses the potential range of lost seepage rates across the reasonable parameter space, and is used to define the expected seepage rates, the uncertainty in the seepage rates, and the sensitivity of the seepage rates to the model parameters.

Due to the complexity and large number of parameters in the seepage model, a full exploration of the parameter space is not feasible. Instead, we implement a guided stochastic suite which will explore the parameter space in a more efficient manner. This process has three components:

1. **Random Set:** Random sampling of the parameter space to develop a prior understanding of the parameter space and the sensitivity of the model to the parameters ($n = 1,620$).
2. **Proxy model uncertainty reduction for minimizing lost seepage:** Machine learning proxy guided sampling of the parameter space to reduce the uncertainty of the proxy model for predicting the minimization of lost seepage ($n \geq 2,025$ in 5 steps)

3. **Proxy model uncertainty reduction for maximizing lost seepage:** Machine learning proxy guided sampling of the parameter space to reduce the uncertainty of the proxy model for predicting the maximization of lost seepage ($n \geq 2,025$ in 5 steps)
4. **Repeat steps 2-3 5 times.**

Note the number of simulations in each step may change based on the results of the previous steps. Both the initial random set and the uncertainty reduction steps are based on a random sampling of the parameter space. The distributions used for the random sampling are based on prior knowledge (where applicable) and are otherwise uniform distributions across the parameter space. Details of the distributions used are provided in [Table C.1](#) and [Table D.1](#). The random set is simply a random sampling of the parameter space.

All other steps are guided by a machine learning proxy model which is updated after each step to ingest the new information from the previous step. Here a random forest regression model is used to predict the objective function (e.g., the lost seepage rates) for novel parameter combinations. Additionally, a random forest classification model is used to predict whether a novel parameter combination will be likely to converge or not. Non-convergence is a common issue in groundwater flow and transport models; by using a classification model to predict non-convergence, we can avoid wasting computational resources on parameter combinations which are unlikely to converge. Such parameter sets are often physically implausible and result in very high or low heads which cause numerical instability in the model. For the uncertainty reduction components, the machine learning model is evaluated at 12,150 random parameter combinations and the “best” 405 parameter combinations are selected to run for the physical model. Here “best” is defined as the weighted combination of the minimum normalised objective function (either maximising or minimising lost seepage), the likelihood of convergence, and the uncertainty of the machine learning model prediction, with weights of 1:4:10, respectively. This way we preferentially evaluate parameter sets which have a high likelihood to converge, either maximizing or minimizing the loss seepage, and are in an uncertain part of parameter space. The uncertainty of the machine learning model prediction is defined as the standard deviation of the predictions from 7 different random forest models trained on a random 75% of the training data.

Each step of the stochastic suite ensures that the parameter space is well sampled in areas of interest (e.g., where the lost seepage rates are minimized or maximized) and that the machine learning proxy model is well-informed to either predict lost seepage rates and/or to assess parameter sensitivity.

It is important to note that by “optimising” the lost seepage rates, we are encouraging the model to find parameter combinations which minimize or maximize the lost seepage rates. This does not mean that these parameter combinations are likely to occur in reality. In some cases it will be likely that the combination of parameters produce a physically implausible result. For instance, a combination of very low hydraulic conductivity and very high recharge would yield very high heads and thus drive very high seepage rates. In reality, a very low hydraulic conductivity would likely result in very low recharge, and thus the combination of very low hydraulic conductivity and very high recharge is physically implausible. We have allowed the model to explore these physically implausible parameter combinations to fully understand the drivers of lost seepage. Just because the model can create a physically implausible result, the model outcomes do not mean that the predicted seepage is likely to occur.

E.1 Sensitivity Analysis Methods

The stochastic suite provides a large number of simulations across the parameter space, which can be used to assess the sensitivity of the lost seepage rates to the model parameters. We use two methods to assess the sensitivity of the relative mass partitioning of lost seepage to the model parameters. The first is a simple Spearman rank correlation coefficient between the model parameters and the lost seepage rates. This provides a non-parametric measure of the strength and direction of the monotonic relationship between the model parameters and the lost seepage rates (e.g., as the parameter increases, the proportion of the seepage that discharges to the PROCESS drains increases). A Spearman rank correlation coefficient cannot easily distinguish the relative importance of the parameters, particularly when the parameter responses co-vary with each other. To assess the relative importance of the parameters, we also use a machine learning model to predict the

lost seepage proportions based on the model parameters. Here we use the same model that was used in the machine learning proxy-guided sampling of the stochastic suite, a random forest regression model. This provides a very non-linear model which can capture complex relationships between the model parameters and the lost seepage rates. Importantly, the random forest regression model also provides a measure of the relative importance of the model parameters in predicting the lost seepage rates, which can be used to understand the parameter sensitivities in the non-linear parameter space.

F Stochastic Suite Results

F.1 Raw Suite Results

The raw stochastic suite results are shown in [Figure F.2](#), [Figure F.3](#), and [Figure F.4](#). The flux gains and losses from the CHB are shown in [Figure F.1](#). Note that these results include parameter sets that may not be physically realistic, and the extrema of the results should not be considered as *a. priori*. likely, plausible, or possible. We undertake further analysis and discussion here and in [Section F.3](#). Also, while the results show the 5th and 95th percentiles, the raw suite results are not a true sampling of parameter space. By optimising the coupled model to identify the highest lost seepage and the lowest lost seepage, we have biased the sampling towards the extrema of the parameter space. In particular, the very high and very low outliers are likely to be over-represented in the raw suite results, and the 5th and 95th percentiles should be interpreted with caution. Nevertheless, the raw suite results provide a useful starting point for understanding the likely range of lost seepage and the potential drivers of this behaviour. The discharge fraction is measured at seven points:

- **process_drn** - the mass partitioning to the PROCESS drains in the seepage model [Figure C.2](#). This includes the TSF, SHELF, and SHFILL drains, but excludes the SiltPond.
- **quat_weth_drn** - the mass partitioning to the surface drains and weathered drainage in the seepage model [Figure C.3](#)
- **siltpond** - the mass partitioning to the SiltPond in the seepage model [Figure C.2](#)
- **deep_surf** - the mass partitioning to the deep model surface drains [Figure A.2](#)
- **pits** - the mass partitioning to the RAS pit and/or underground workings [Figure A.4](#)
- **deep_offshore** - the mass partitioning to the deep model OFFSHORE drains [Figure A.2](#)
- **lost** - The total lost seepage, which is the sum of **quat_weth_drn**, **deep_surf**, and **deep_offshore** seepage.

We include three versions of the default parametrisation of the seepage model in all figures. “Default-lat” is the default parametrisation (as per [Table C.1](#)) with lateral drains only for the SHFILL region (**shfill_lat_udrn** = 0). “Default-udrn” is the default parametrisation with underdrains only for the SHFILL region (**shfill_lat_udrn** = 1). “Default-both” is the default parametrisation with both lateral and underdrains for the SHFILL region (**shfill_lat_udrn** = 2). Note that the default parametrisation is not necessarily the most likely or plausible, but rather the “best guess” based on the available information. Key results for each seepage source are:

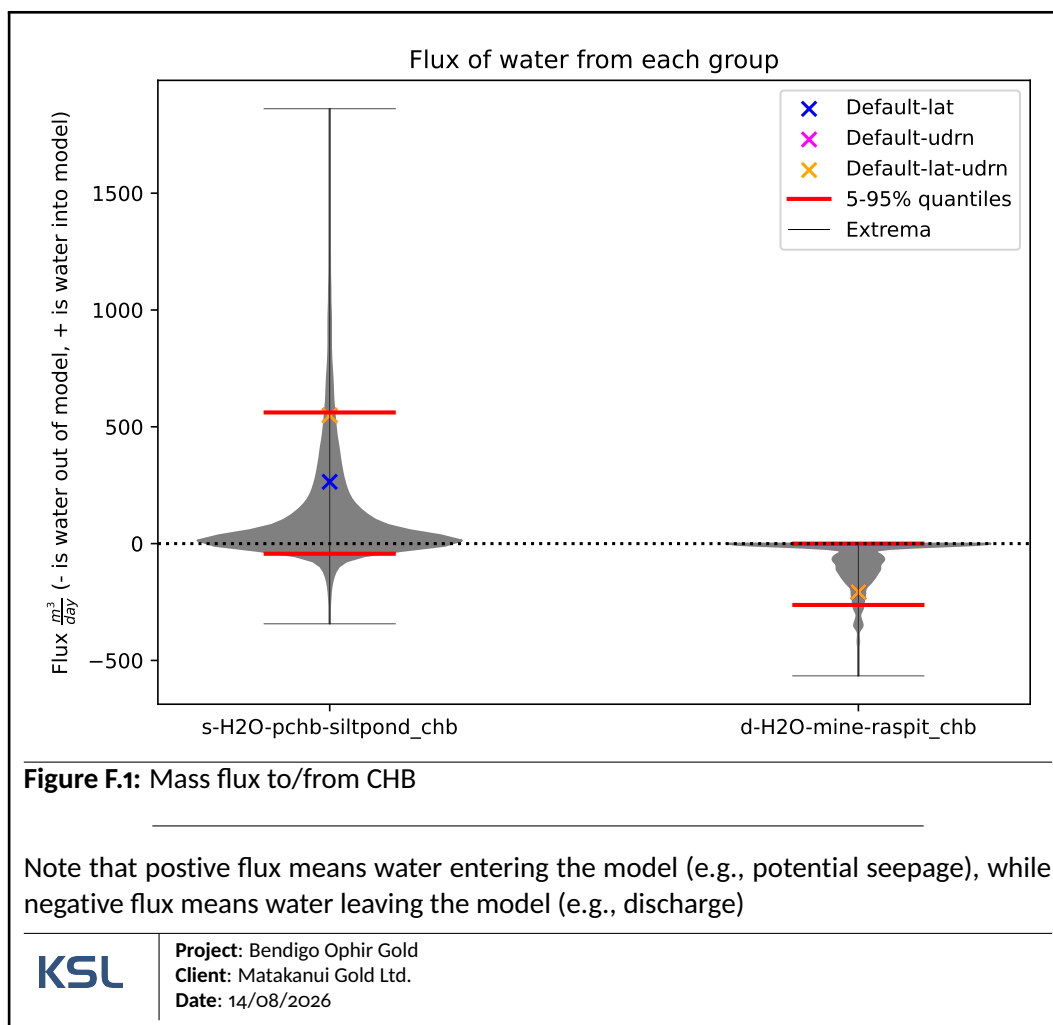
- **TSF**: Approximately 10% of the seepage is lost to the quaternary and weathered drains in the seepage model. There is negligible seepage partitioned to all other discharge points with approximately 90% of seepage captured by the PROCESS drains. The different parametrisation of the SHFILL lateral and underdrains has a negligible impact on the TSF seepage partitioning.
- **SHELF**: For the default parametrisation with only lateral drains, approximately 18% of the seepage is lost to the quaternary and weathered drains (including the lateral drains) and the remainder is captured by the PROCESS drains. Including underdrains in the SHFILL region (with or without lateral drains) reduces the lost seepage to negligible levels. There is negligible seepage partitioned to all other discharge points for default values.
- **SHFILL**: For the default parametrisation with only lateral drains, approximately 40% of the seepage is lost to the quaternary and weathered drains in the seepage model. Introducing underdrains in the SHFILL region (with or without lateral drains) reduces the lost seepage to approximately 2% of the seepage. The remainder is captured by the PROCESS drains. There is negligible seepage partitioned to all other

discharge points.

- **RAS and underground workings:** We did not model contaminant transport of water derived from the RAS pit and underground workings, but the default model suggests that these features will act as a net sink of water and will therefore not be a potential source of seepage.
- **SiltPond:** We did not model contaminant transport of water derived from the SiltPond, but the default model with lateral drains suggests that the SiltPond will discharge approximately 250 m³/day into the seepage model. Including underdrains in the SHFILL region (with or without lateral drains) increases the lost discharge from the SiltPond to approximately 575 m³/day. Note that the SiltPond is implemented as a CHB in the seepage model, which is a potential infinite source of water. Additionally, the SiltPond is likely to be a cleaner source of water than the seepage sources. Therefore, any minor loss of water from the SiltPond is unlikely to be significant, but monitoring of the water quality in the SiltPond is recommended to ensure that it is not significantly contaminated. Finally, the SiltPond loss may discharge to other PROCESS drains in the seepage model and will not necessarily be lost to the environment.

F.1.1 Raw RAS and Underground Workings Seepage Partitioning

The range of mass flux to/from the CHB is shown in Figure F.1. For the RAS pit and underground workings, no model predicts any discharge from the pit or workings into the model. Therefore, these workings are a sink of water and are very unlikely to contribute to lost seepage. The CHB representing the SiltPond can be a net sink or source of water depending on the parametrisation of the model. Most of the model parametrisation suggest the SiltPond is a significant net source of water. The flow can be considerable to the point of straining credibility. We revisit the SiltPond flux in Section F.3.4 and discuss the implications of this flux on the seepage partitioning.



F.1.2 Raw TSF Seepage Partitioning

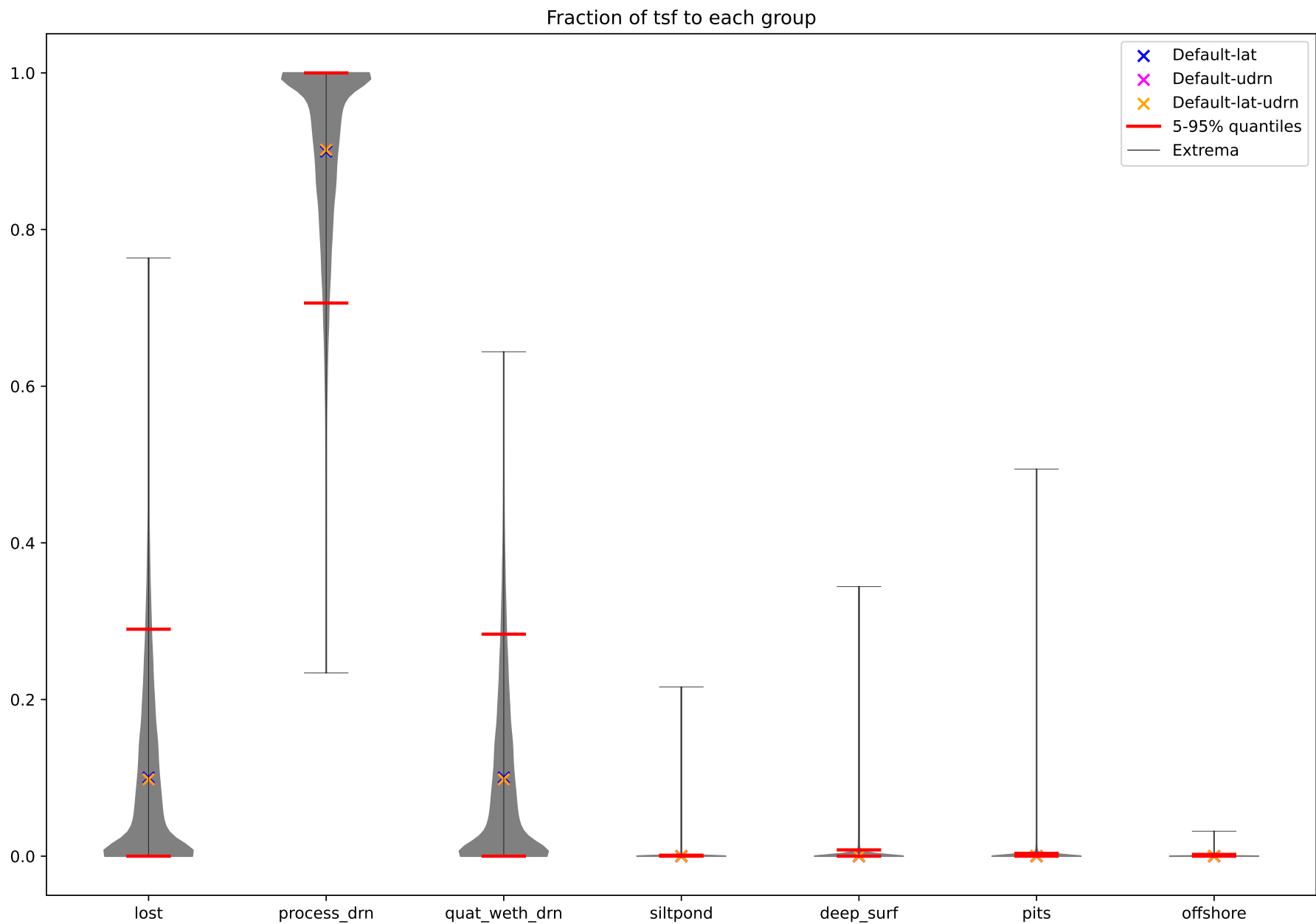
Starting with the TSF seepage partitioning, the model has found extreme parametrisations which can yield very high proportions of lost seepage (> 75%), but these are extreme outliers. The biased 95th percentile loss is closer to 30%, though as discussed in [Section F.3](#) these values are likely to be unrealistic. Importantly, even where these extreme parametrisations are found, the model almost exclusively suggests that mass is discharged to the quaternary and weathered drainage within the seepage model. This means that even if one of these extreme outcomes were to occur, the lost seepage would almost certainly be detected by the monitoring network proposed for Shepherds Creek. It is very unlikely that TSF seepage will be lost to the deep schist system and not be detected by the monitoring network.

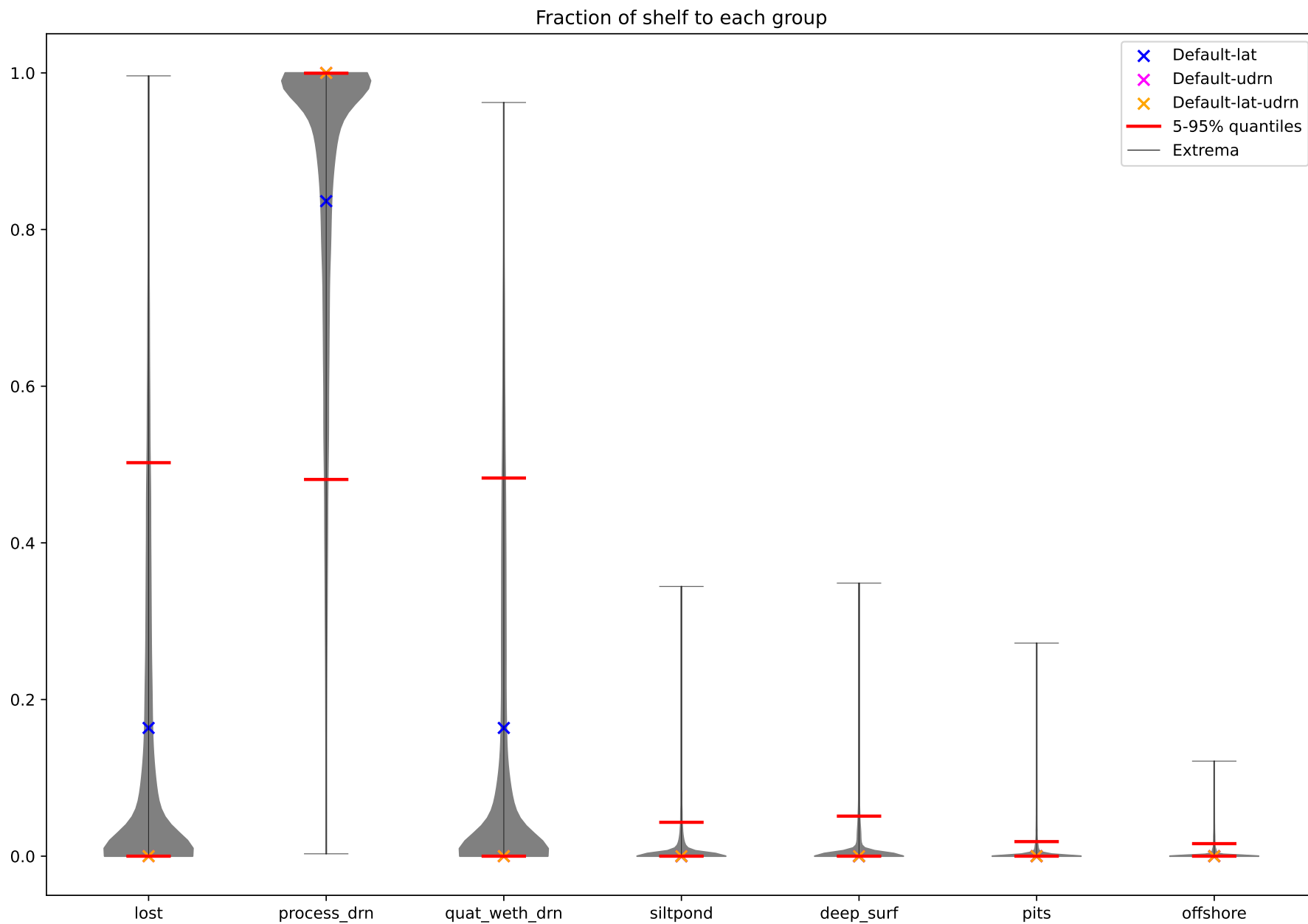
F.1.3 Raw SHELF Seepage Partitioning

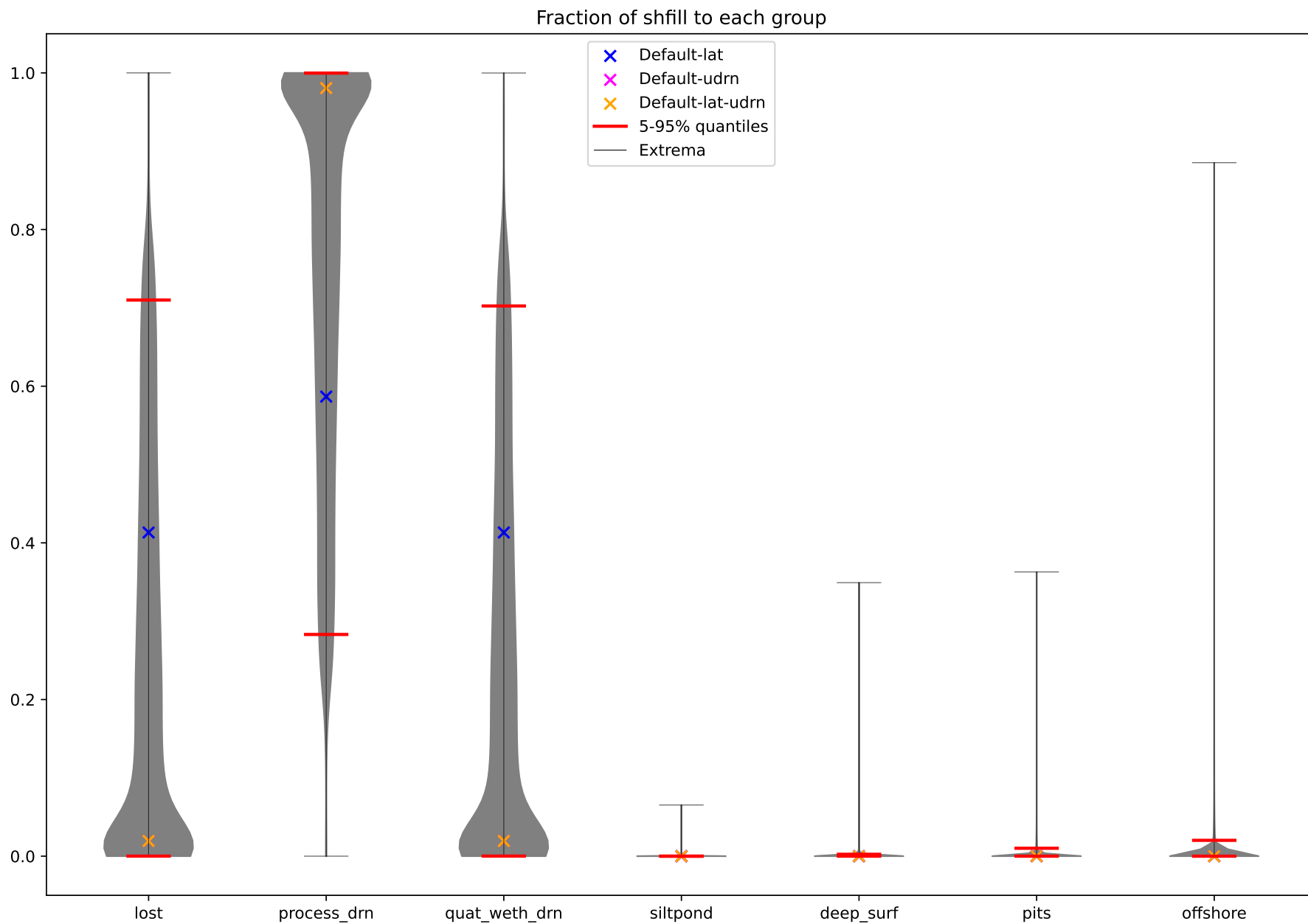
The SHELF seepage partitioning shows similar extreme outliers, (maximum lost seepage up to 100%), but unlike the TSF the biased 95th percentile is closer to 55%. Note that the biased 95th percentile of the SHELF seepage discharged to the SiltPond and to the surface drains in the deep model is also around 5%. There is negligible lost seepage to both the RAS pit and underground workings and discharging to the deep model OFFSHORE drains (approximately 1% for the biased 95th model). The component of lost seepage to the deep model surface drains is primarily being captured by the sc-1 catchment, which is beyond the seepage model boundary (outwards from Shepherds Creek). This is most likely discharging up gradient due to longer flow paths and higher heads in the SHELF.

F.1.4 Raw SHFILL Seepage Partitioning

The partitioning of SHFILL seepage is much more variable than the TSF and SHELF seepage. The model has found extreme parametrisation which can yield the full loss of SHFILL seepage, but the biased 95th percentile is closer to 72%. The main sinks of lost SHFILL seepage are the quaternary and weathered drainage within the seepage model, though some models also show losses to the deep OFFSHORE drains (approximately 2% for the biased 95th model).

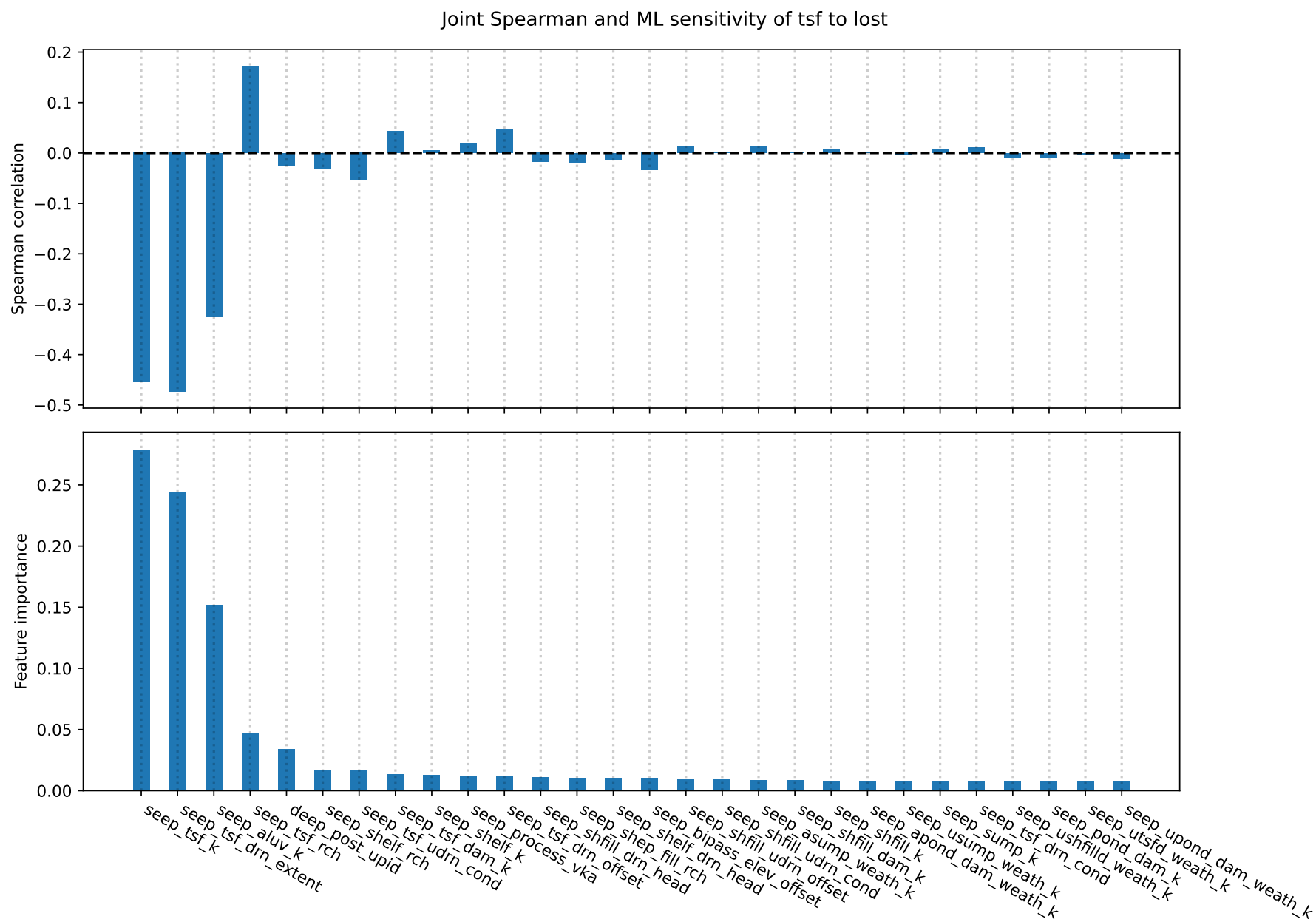




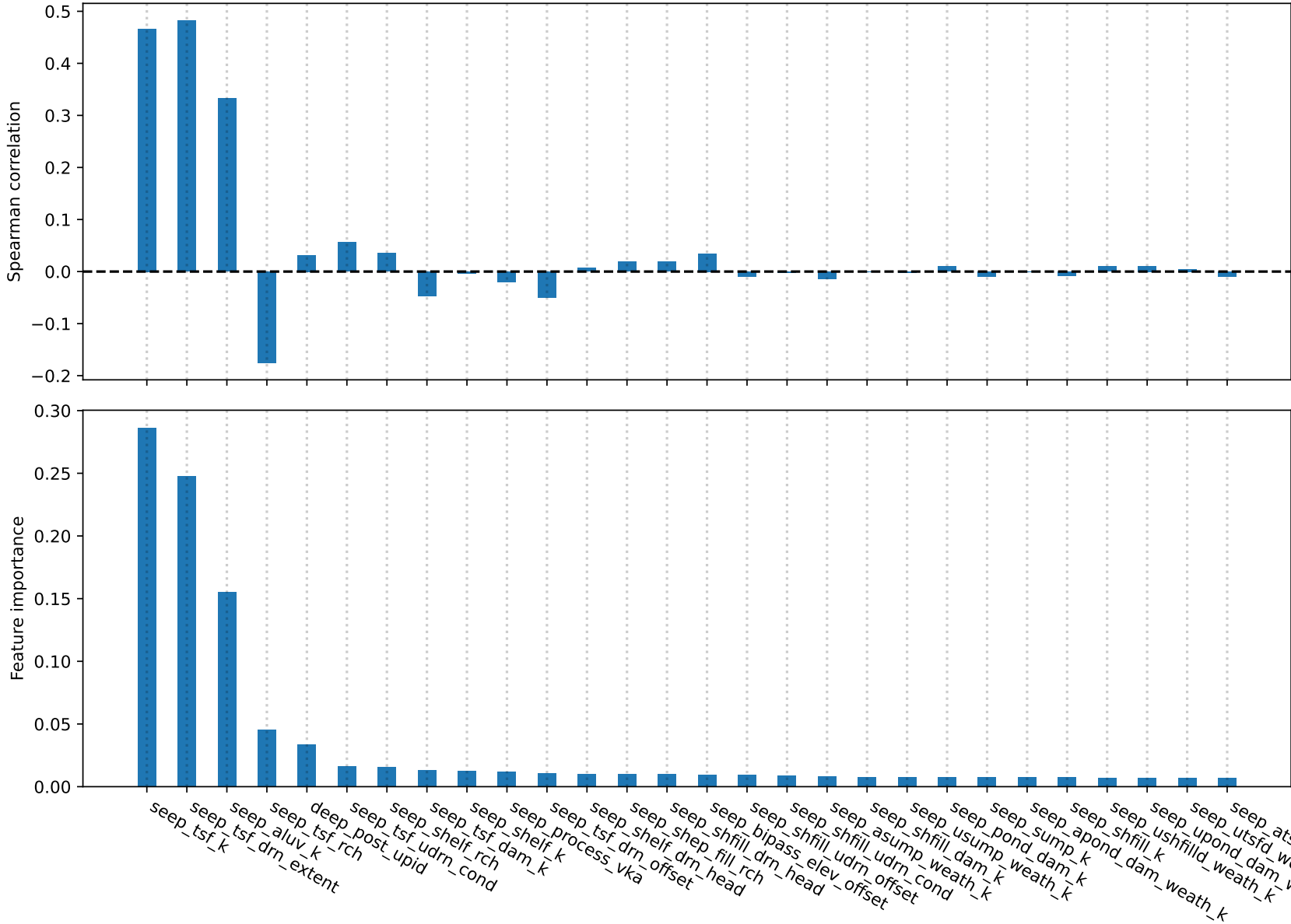


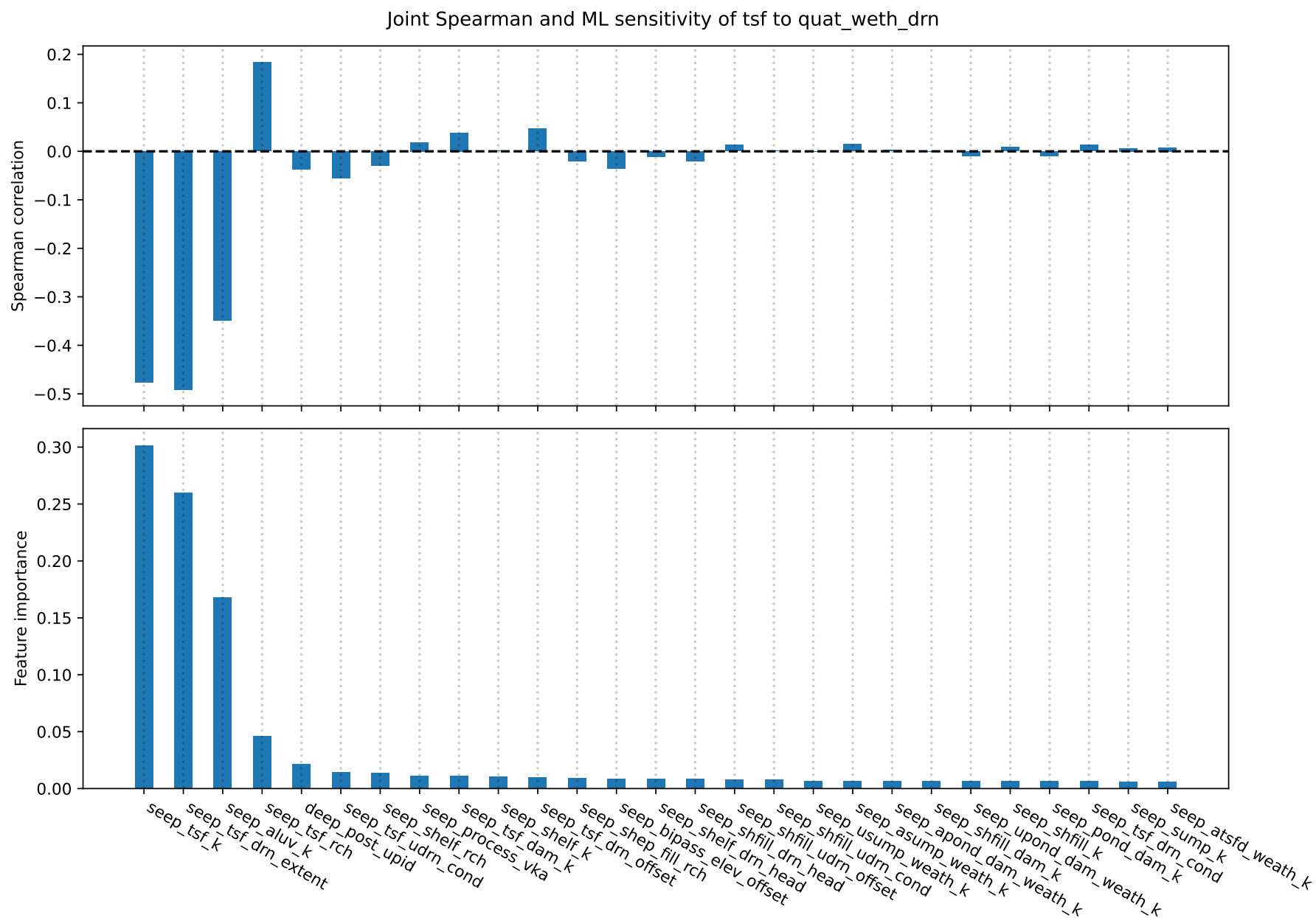
F.2 Parameter Sensitivity Analysis

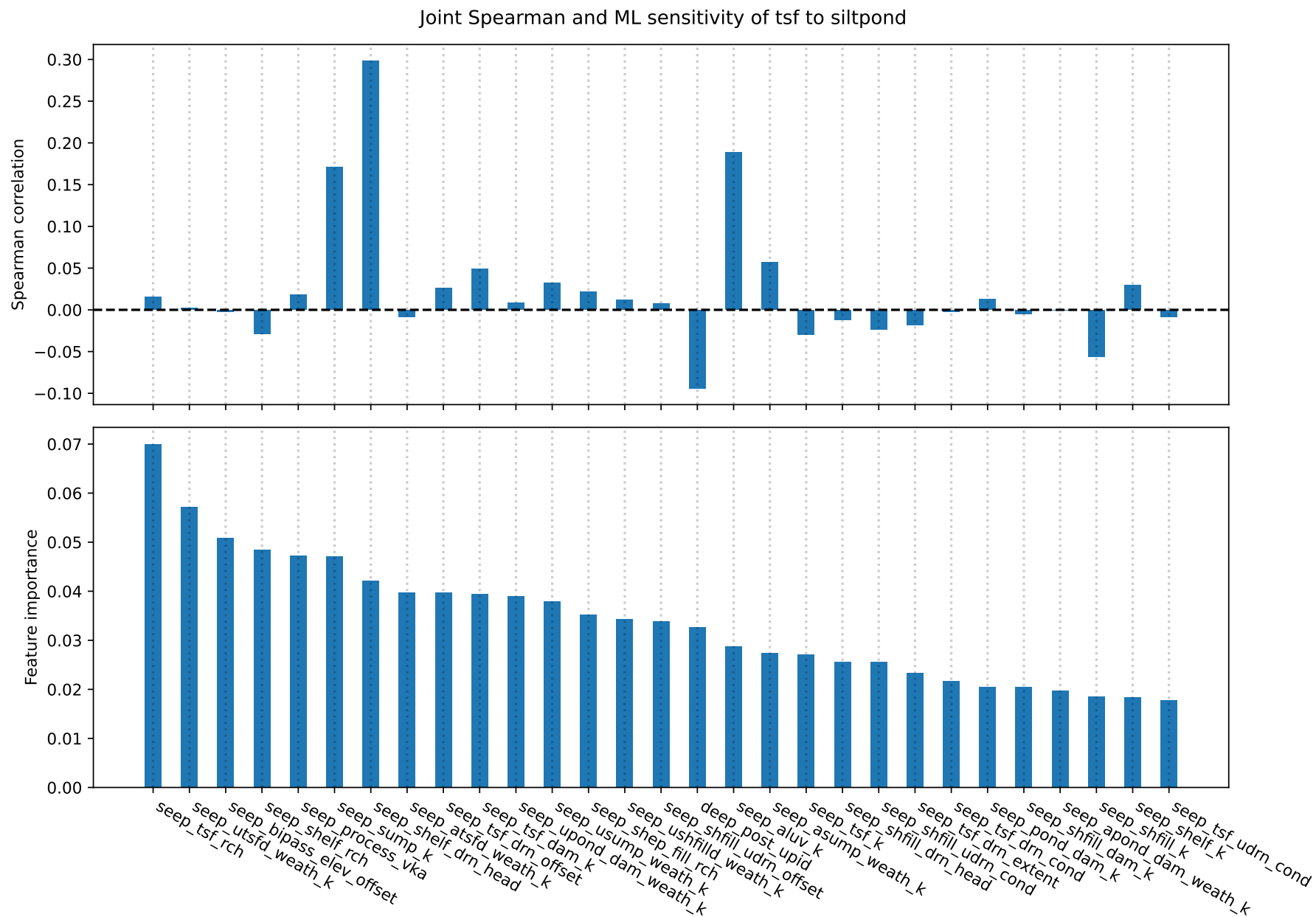
Figure F.5 to Figure F.12 show the results of the parameter sensitivity analysis for the stochastic suite of coupled models. The full results of the sensitivity analysis are not discussed as there is simply too much information, most of which is not really relevant to the predictions of interest. Instead, we focus on the key drivers of lost seepage from each of the three sources. Understanding the sensitivity of the model is a key prediction of interest, and it provides a mechanism to understand what action can be taken to reduce the risk of lost seepage.

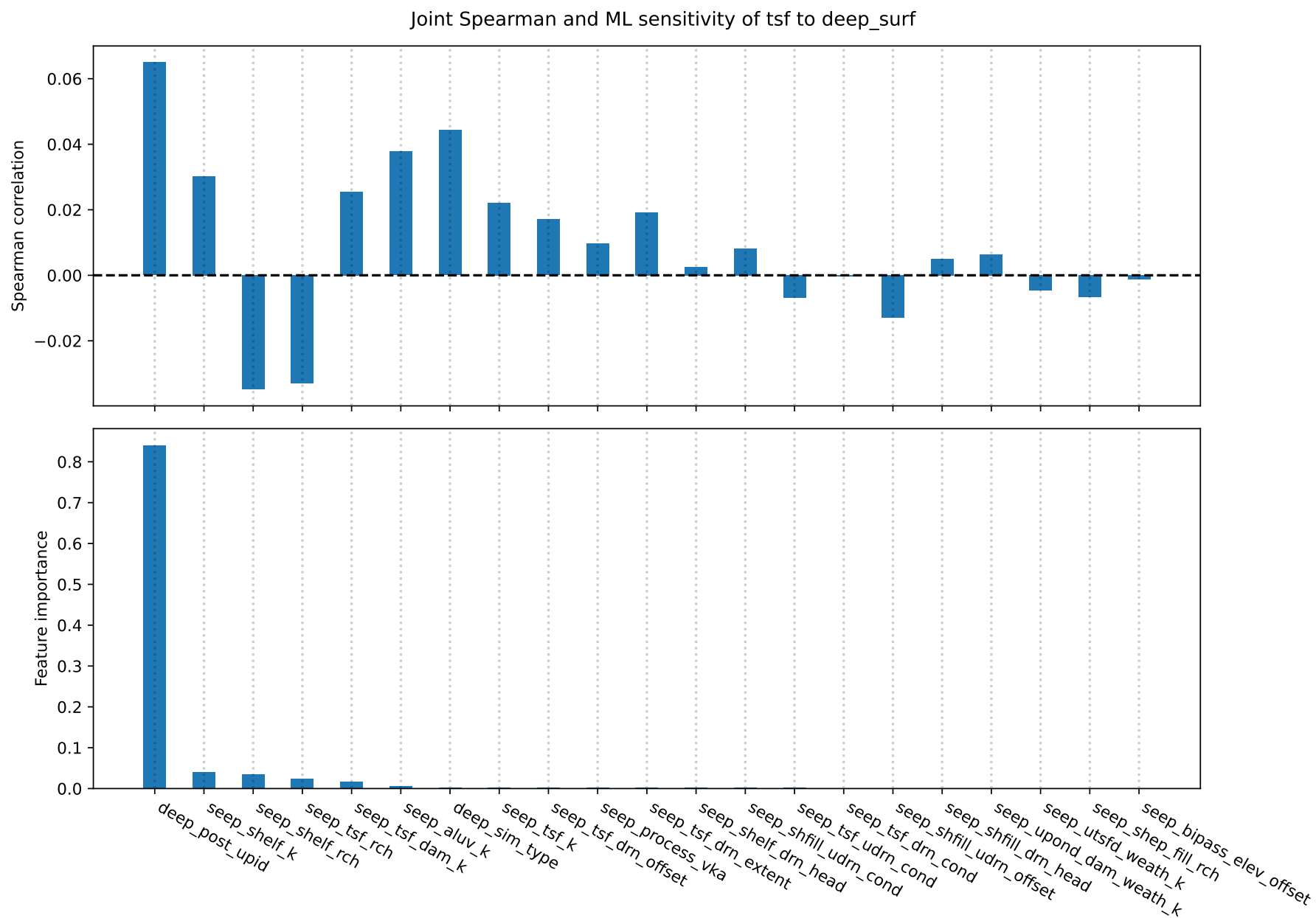


Joint Spearman and ML sensitivity of tsf to process_dr

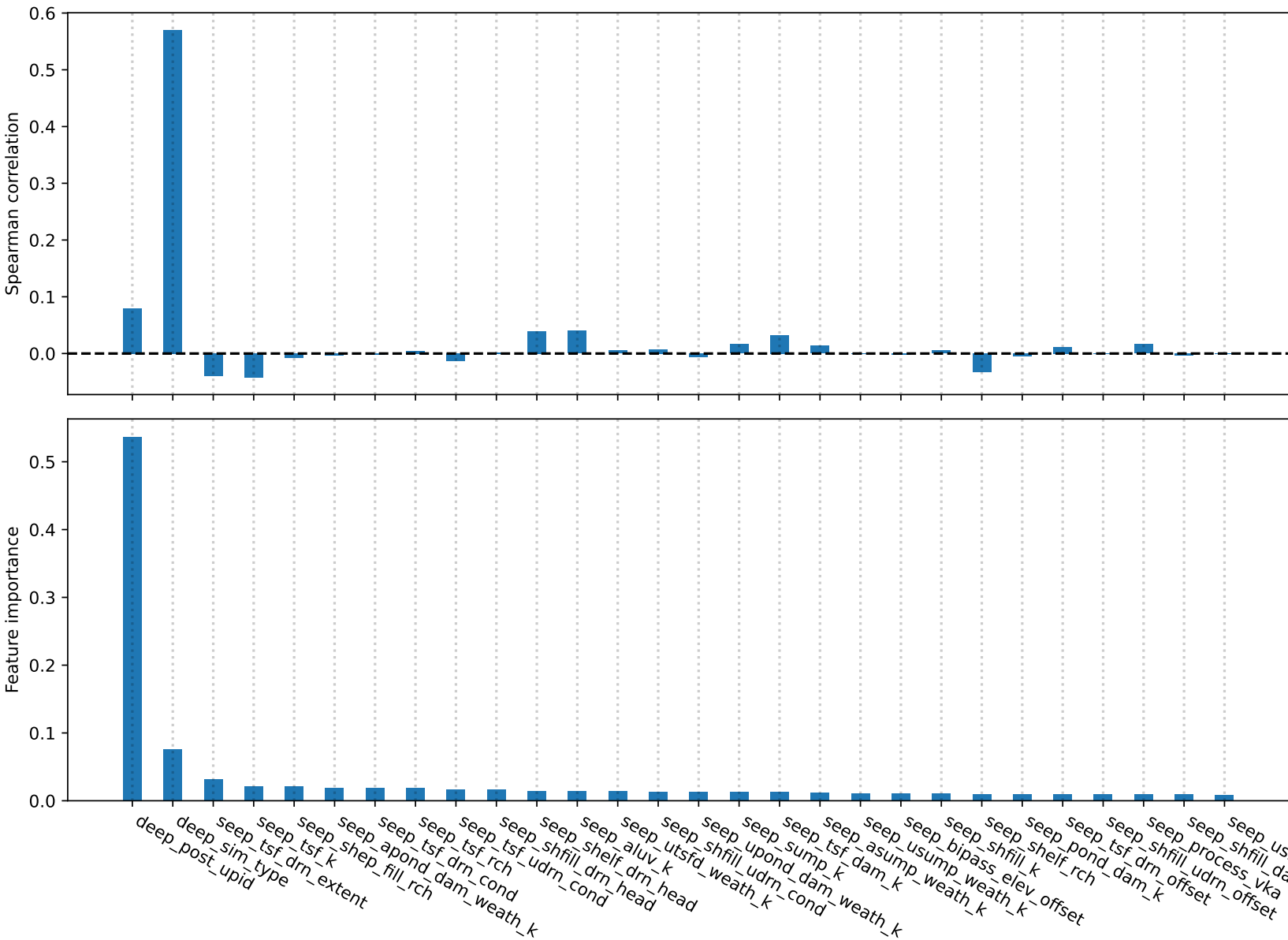


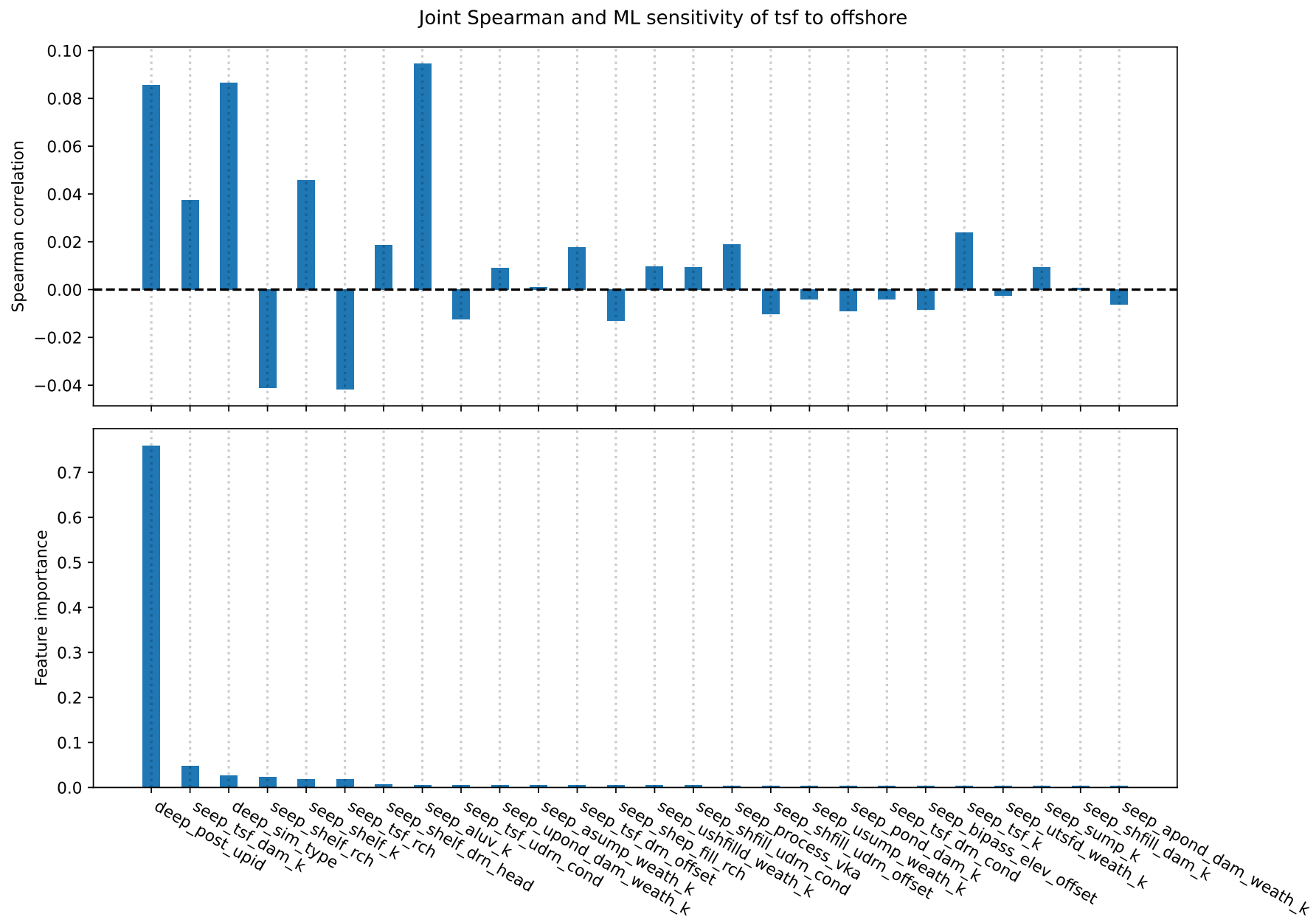




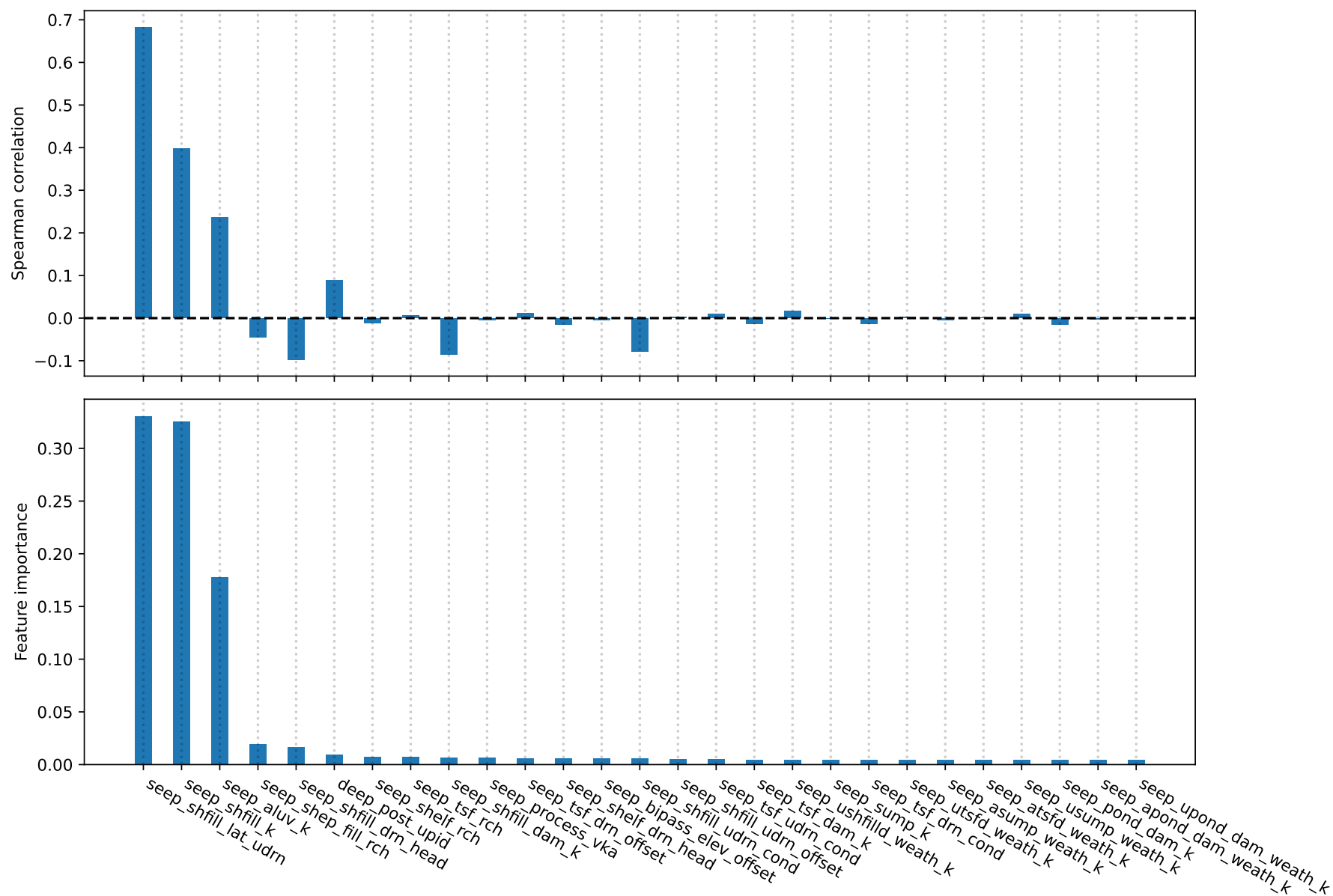


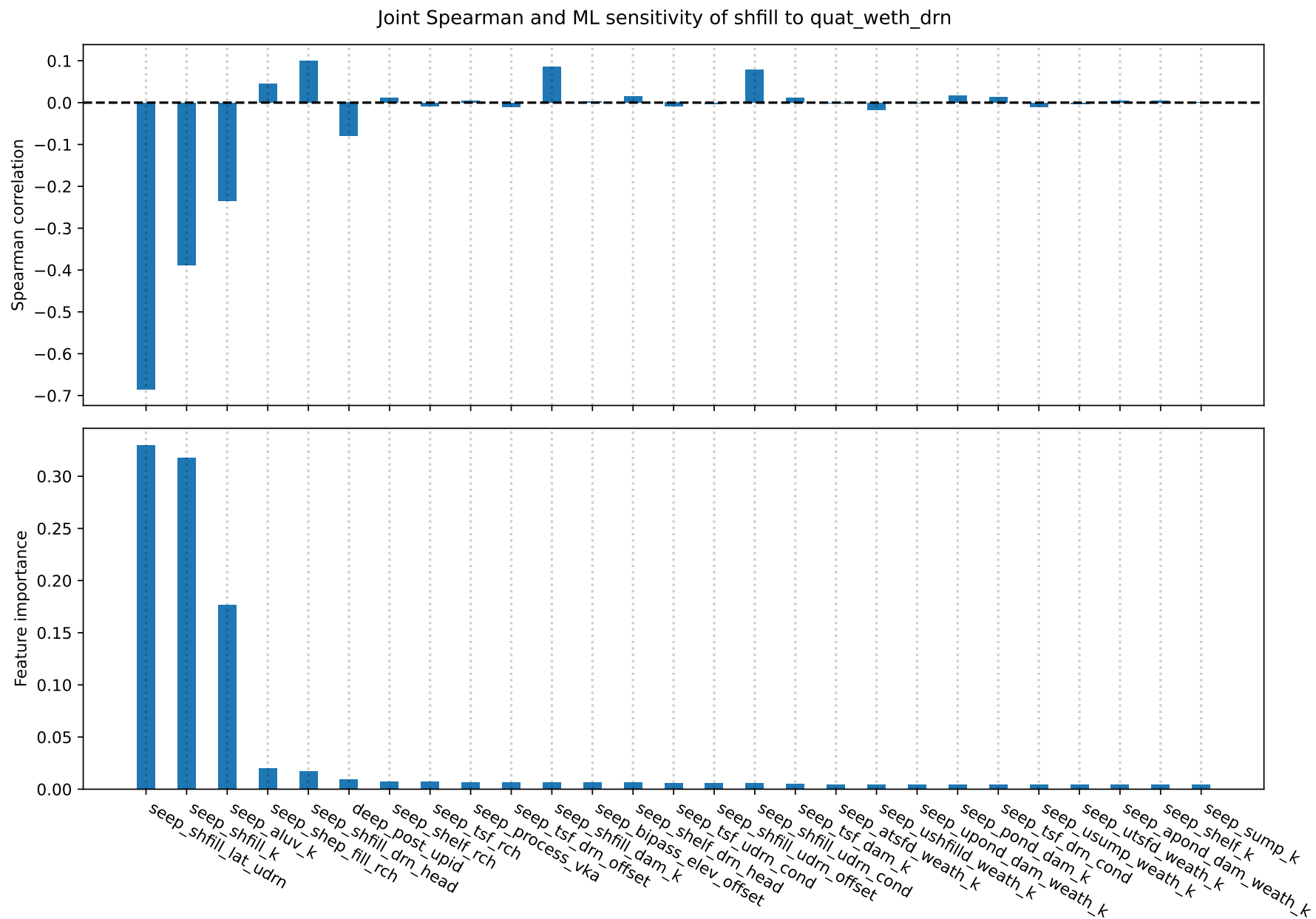
Joint Spearman and ML sensitivity of tsf to pits

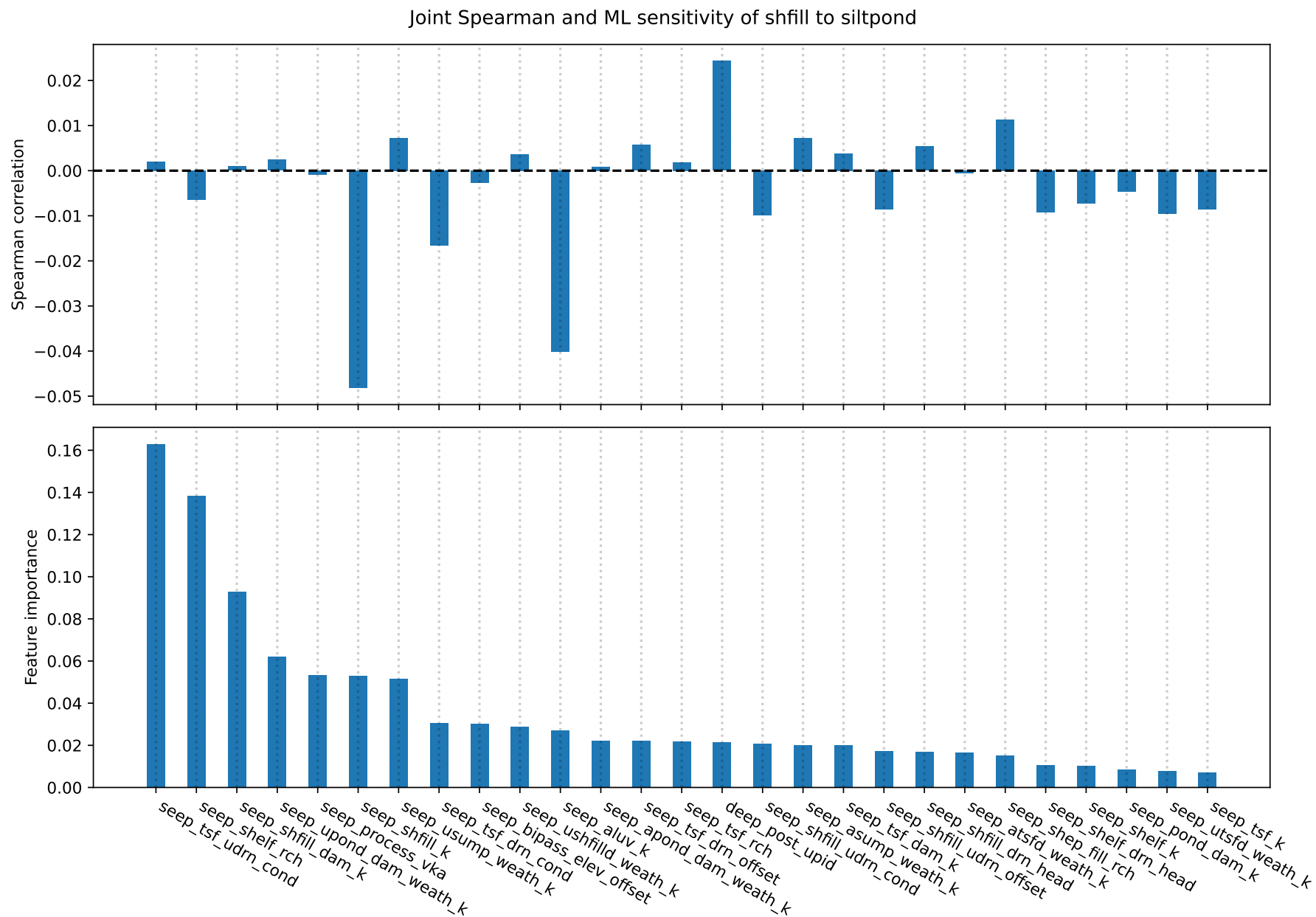




Joint Spearman and ML sensitivity of shfill to process_drn







The figure consists of two vertically stacked bar charts sharing a common x-axis of 30 features. The top chart displays the Spearman correlation for each feature, with values ranging from approximately -0.4 to 0.5. The bottom chart displays the Feature importance for each feature, with values ranging from 0.000 to 0.175. Both charts use blue bars and have a dashed horizontal line at zero.

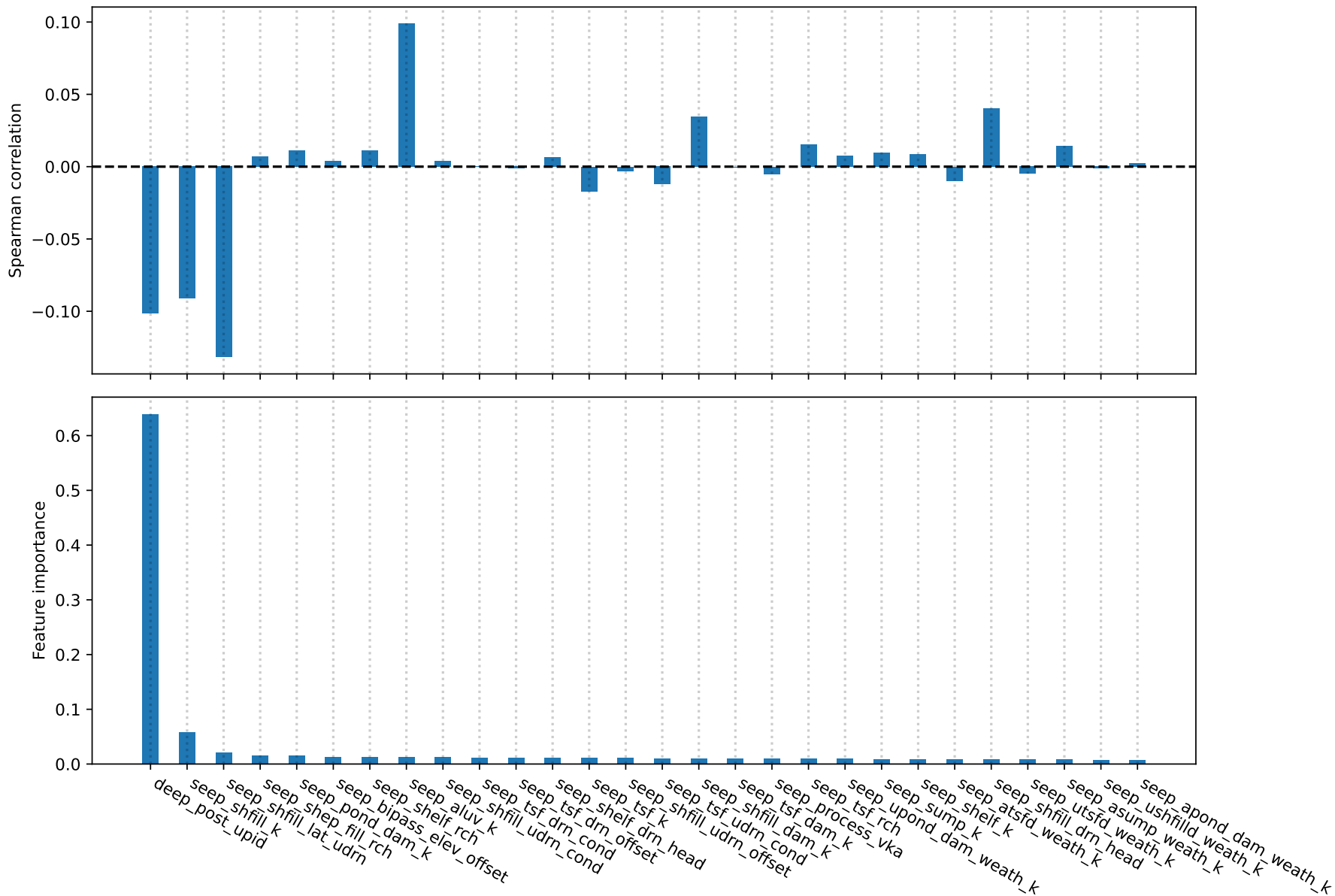
Top Chart: Spearman correlation

Feature	Spearman correlation
deep_post_upld	-0.02
seep_shfill_k	-0.23
seep_aluv_k	-0.09
seep_tsf_dm_offset	-0.01
seep_tsf_rch	0.01
seep_shelf_rch	0.05
seep_tsf_dm_rch	0.02
seep_shfill_rch	0.00
deep_process_vka	0.50
seep_sim_type	-0.01
seep_usump	0.00
seep_shfill_drn_head	0.01
seep_shelf_drn_head	0.00
seep_atstd_udrn_head	0.02
seep_pond_weath_k	-0.01
seep_ushfilld_dam_k	0.00
seep_bypass_weath_k	0.01
seep_shfill_dam_k	-0.41
seep_sump_k	-0.01
seep_shfill_dam_k	0.00
seep_tsf_upond_dam_k	0.00
seep_tsf_udrn_cond	0.02
seep_tsf_apond_dam_k	0.04
seep_shfill_dam_k	0.01
seep_asump_udrn_cond	0.00
seep_utsfd_weath_k	0.00
seep_tsf_k	0.01
seep_shelf_k	0.00

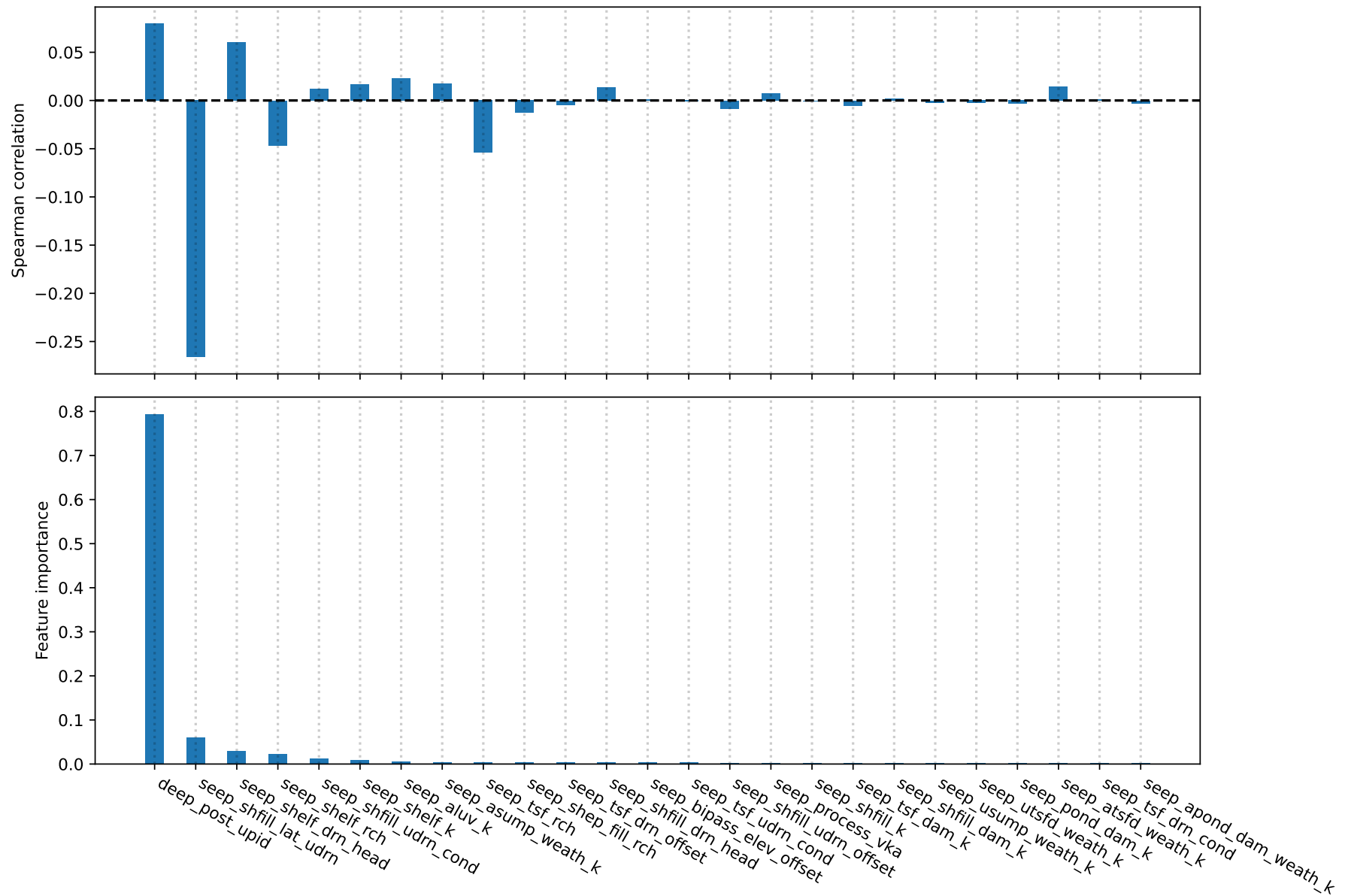
Bottom Chart: Feature importance

Feature	Feature importance
deep_post_upld	0.175
seep_shfill_k	0.050
seep_aluv_k	0.042
seep_tsf_dm_offset	0.041
seep_tsf_rch	0.036
seep_shelf_rch	0.035
seep_tsf_dm_rch	0.033
seep_shfill_rch	0.032
deep_process_vka	0.031
seep_sim_type	0.031
seep_usump	0.028
seep_shfill_drn_head	0.026
seep_shelf_drn_head	0.026
seep_atstd_udrn_head	0.026
seep_pond_weath_k	0.025
seep_ushfilld_dam_k	0.025
seep_bypass_weath_k	0.025
seep_shfill_dam_k	0.024
seep_sump_k	0.023
seep_shfill_dam_k	0.022
seep_tsf_upond_dam_k	0.021
seep_tsf_udrn_cond	0.021
seep_tsf_apond_dam_k	0.020
seep_shfill_dam_k	0.019
seep_asump_udrn_cond	0.018
seep_utsfd_weath_k	0.017
seep_tsf_k	0.015
seep_shelf_k	0.013

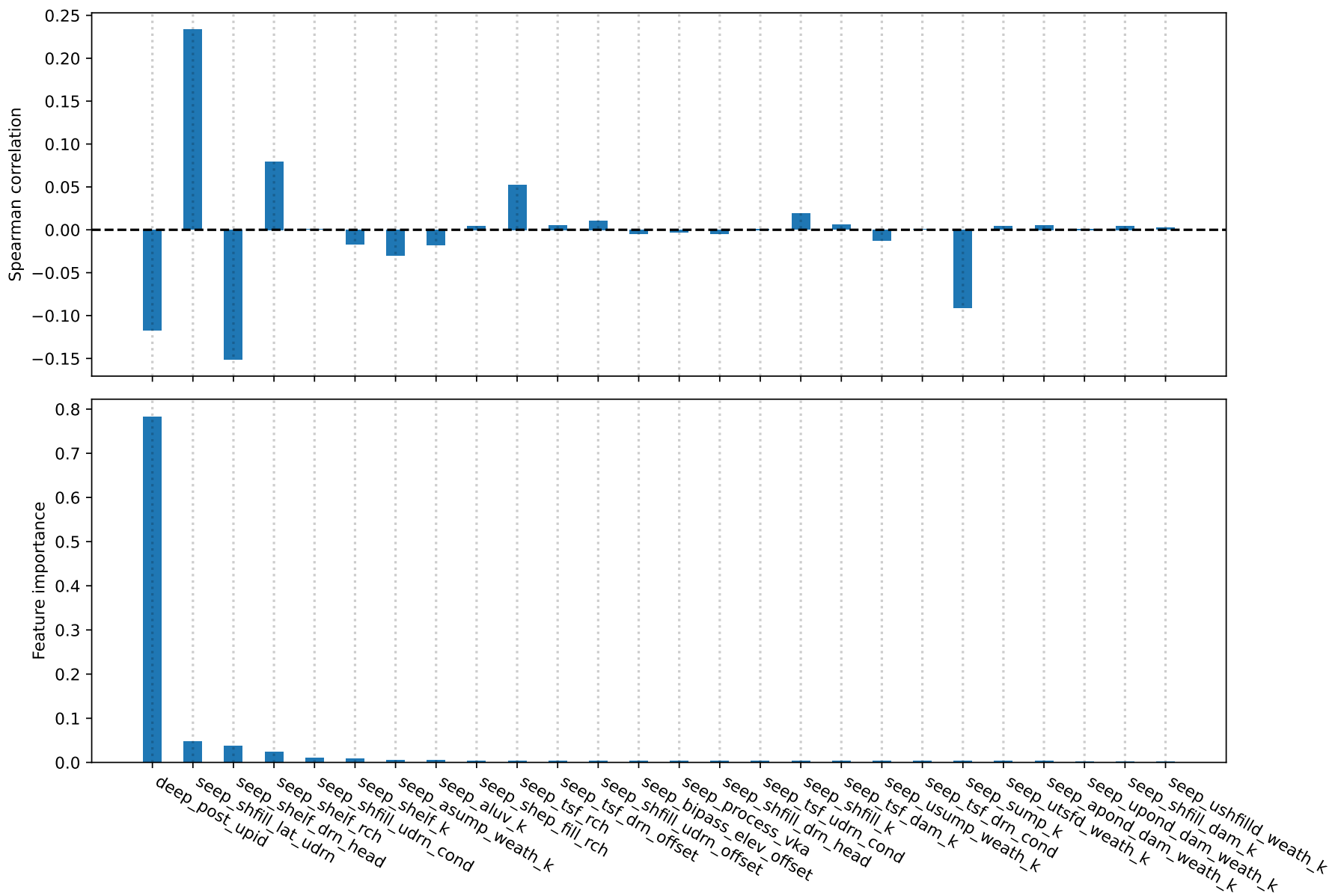
Joint Spearman and ML sensitivity of shfill to offshore



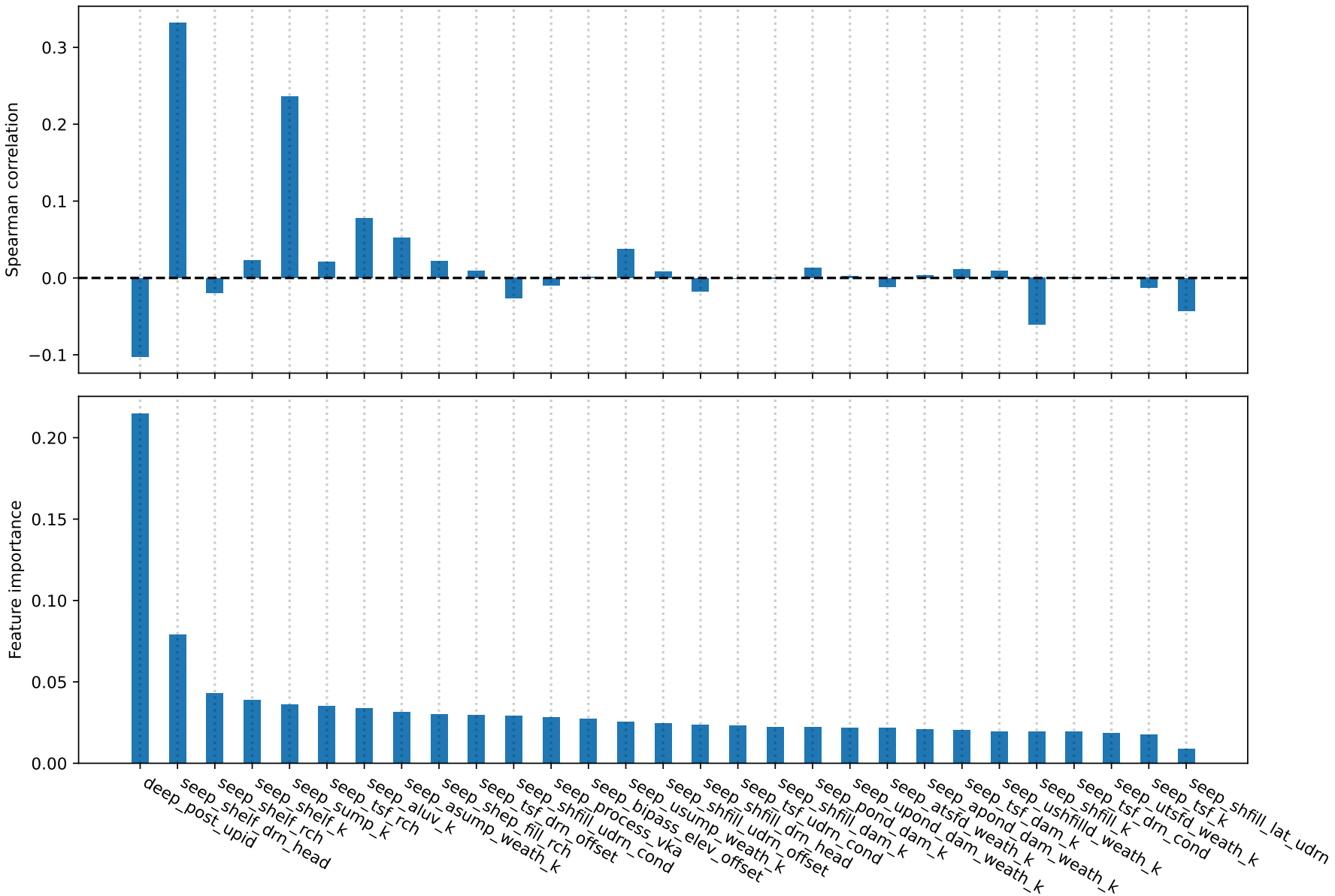
Joint Spearman and ML sensitivity of shelf to lost

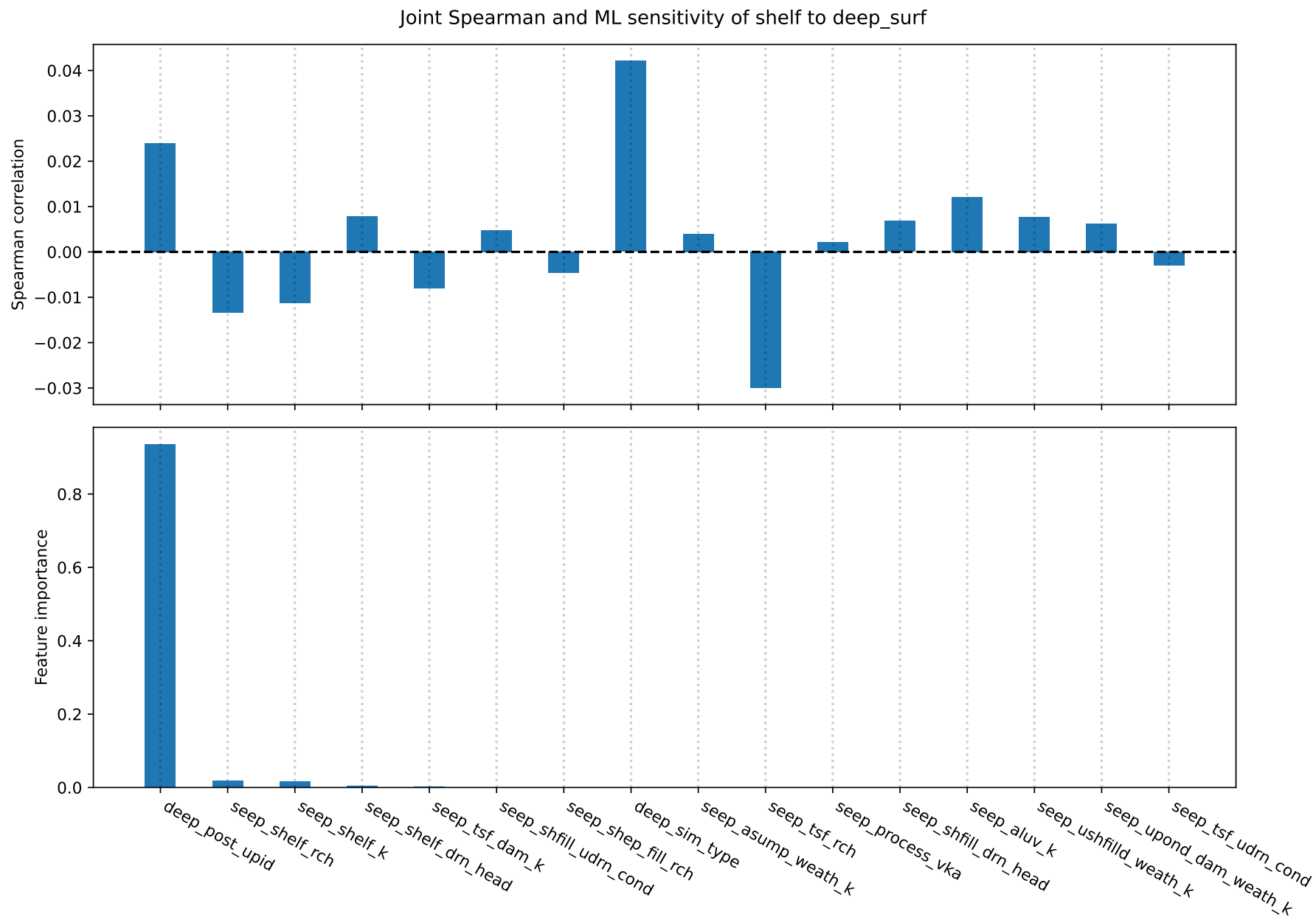


Joint Spearman and ML sensitivity of shelf to process drn

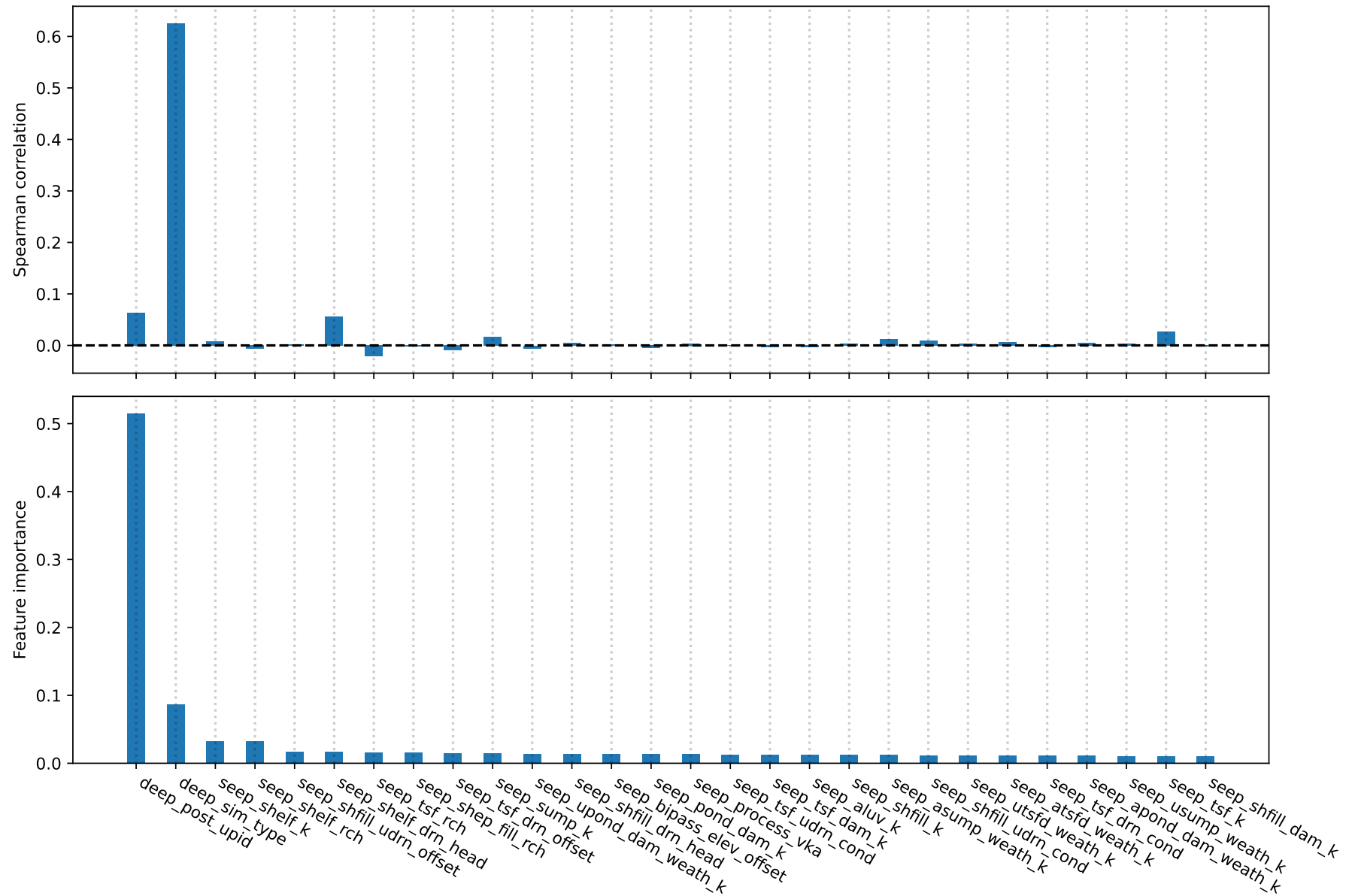


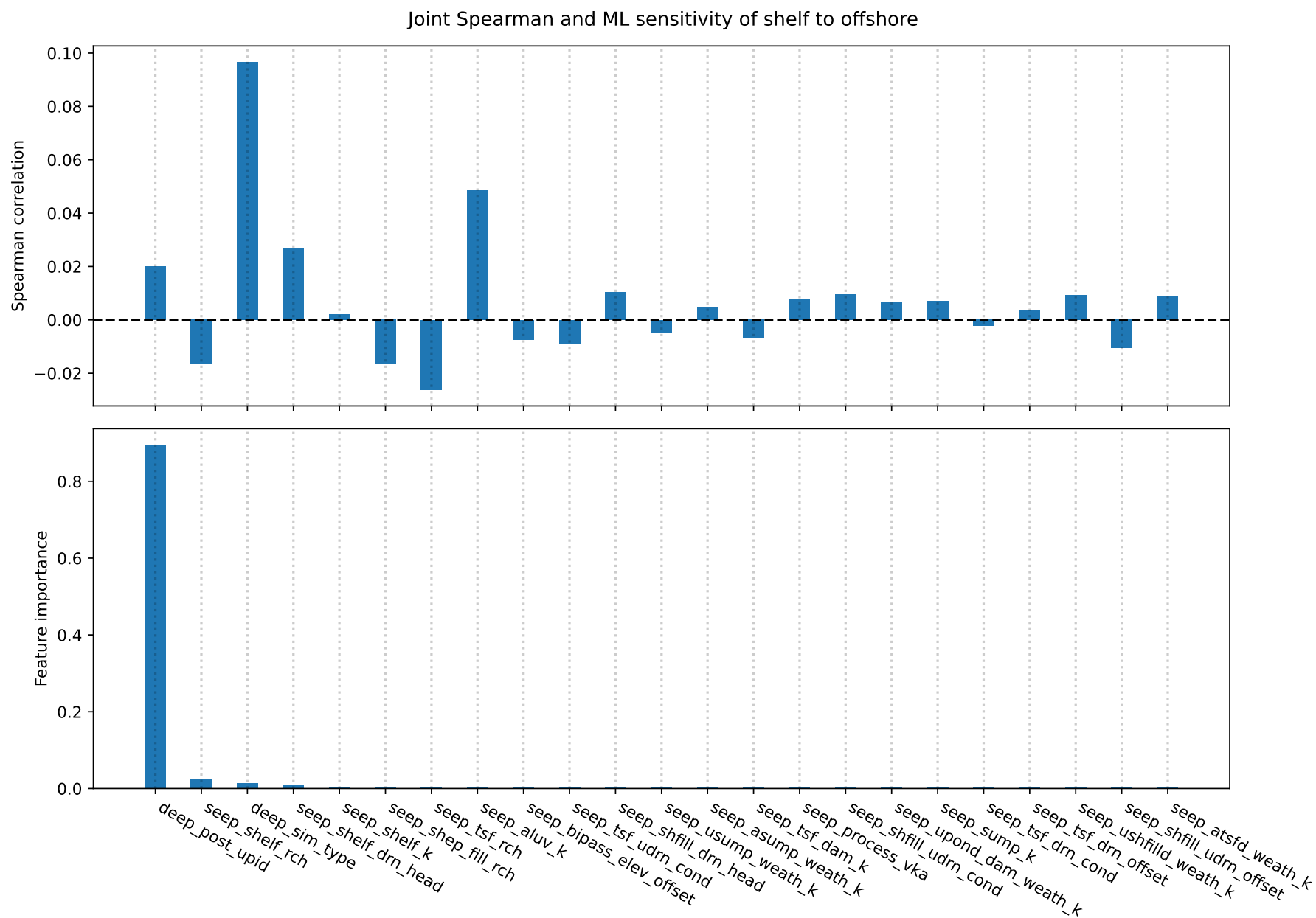
Joint Spearman and ML sensitivity of shelf to siltpond





Joint Spearman and ML sensitivity of shelf to pits





F.2.1 TSF lost seepage drivers

We focus on the drivers of seepage lost to the quaternary and weathered drains in the seepage model, as this is the dominant predicted discharge location of lost seepage from the TSF when it is not captured by the PROCESS drains. There are four major parameters of importance for lost seepage to the quaternary and weathered drains in the seepage model. The first is the extent of the TSF drains (`seep_tsf_drn_extent`). This parameter provides for a range of design options for the extent of underdrainage in the TSF: as the value increases, the area covered by the underdrainage increases (Figure C.6). The hydraulic conductivity of the TSF (`seep_tsf_k`) is also important, secondary to the extent of the TSF drains by a small margin. The next two parameters in order of importance are the hydraulic conductivity of the alluvium seepage model (`seep_aluv_k`) and the amount of recharge to the TSF (`seep_tsf_rch`). All parameters except the TSF recharge show a negative correlation with lost seepage, meaning that as the parameter value increases, the lost seepage decreases. TSF recharge shows a positive correlation with lost seepage, meaning that as the recharge increases, the lost seepage increases. This suggests that a major driver of lost seepage is higher heads in the upper portion of the TSF. These higher heads will be driven by higher recharge and reduced by more drainage, more conductive alluvium (essentially drainage), and more conductive TSF material. It is interesting that while the drainage is important, the conductivity of the drains (`seep_tsf_udrn_cond`) is not particularly sensitive. This suggests that any substantially more conductive material will significantly reduce the potential for lost seepage.

F.2.2 SHELF lost seepage drivers

Here we focus on the drivers of the lost seepage to the quaternary and weathered drains in the seepage model, seepage lost to the SiltPond, and seepage lost to the deep model surface drains. The two key parameters of importance for the fraction of seepage lost to the quaternary and weathered drains in the seepage model are the deep model realisation (`deep_post_upid`) and the lateral/underdrain configuration of the SHFILL (`shfill_lat_udrn`). The deep model id does not show a meaningful Spearman correlation as it is a container for other parameters. The correlation with the lateral/underdrain configuration is negative, meaning that as underdrains are implemented in the SHFILL region, the lost seepage to the quaternary and weathered drains decreases. The key parameters of importance for a fraction of seepage entering the SiltPond are the deep model realisation (`deep_post_upid`) and the SHELF drain invert (`seep_shelf_drn_head`). The Spearman rank correlation for the SHELF drain invert is strongly positive. This makes sense as the parameter is a proxy for raised heads in the SHELF due to less effective drainage. The fact that poor performance of the SHELF underdrains yields lost seepage to the SiltPond provides a significant safety factor as the SiltPond effectively captures seepage, is monitored, and provides an easy point for management. It should be noted that the default parametrisation yields < 1% of seepage to the SiltPond. The only key parameter for lost seepage to the deep model surface drains is the deep model realisation (`deep_post_upid`).

To better understand the parameters within the deep model that are driving lost seepage, we undertook a full sensitivity analysis (e.g., explicitly including the deep model parameters in the sensitivity analysis). The results of this analysis for lost seepage to the quaternary and weathered schist drains, the SiltPond, and the deep surface drains are shown in Figure F.21, Figure F.23, and Figure F.22, respectively. The key deep model parameters driving lost seepage are the hydraulic conductivity of the weathered schist, particularly at pilot points 9 and 10 (`deep_weath_rock_k.9` and `deep_weath_rock_k.10`). These pilot points control the weathered conductivity at and under the SUMP, SiltPond, and upper portions of the SHFILL. Higher conductivity here increases the potential underflow and/or adjacent flow through the weathered schist, which can then be lost to the quaternary and weathered drains in the seepage model. The key parameters for the lost seepage to the SiltPond are the hydraulic conductivity of the weathered schist at points 46, 6, and 9 (`deep_weath_rock_k.46`, `deep_weath_rock_k.6`, and `deep_weath_rock_k.9`). The spearman correlation for `deep_weath_rock_k.6`, and `deep_weath_rock_k.9` is negative, which means that as the conductivity of the weathered schist increases, the lost seepage to the SiltPond decreases. The spearman correlation for `deep_weath_rock_k.46` is positive. This suggests that discharge will only enter the siltpond if the conductivity of the weathered schist is sufficiently high to allow flow from the SHELF under the sump, but is lower down gradient preventing that discharge into the SHFILL and its associated drains. Finally, the key parameters for lost seepage to the deep model surface drains are TZ-3 and TZ-4 schist hydraulic conductivity

parameters. This suggests that this path represents a long deep flow path through the schist. This is further reinforced that the `deep_weath_rock_k.6`, and `deep_weath_rock_k.9` importance is lower than that of `deep_weath_rock_k.37`, `deep_weath_rock_k.25`, and `deep_weath_rock_k.4`, which are far removed from the SHELF to SHFILL locations.

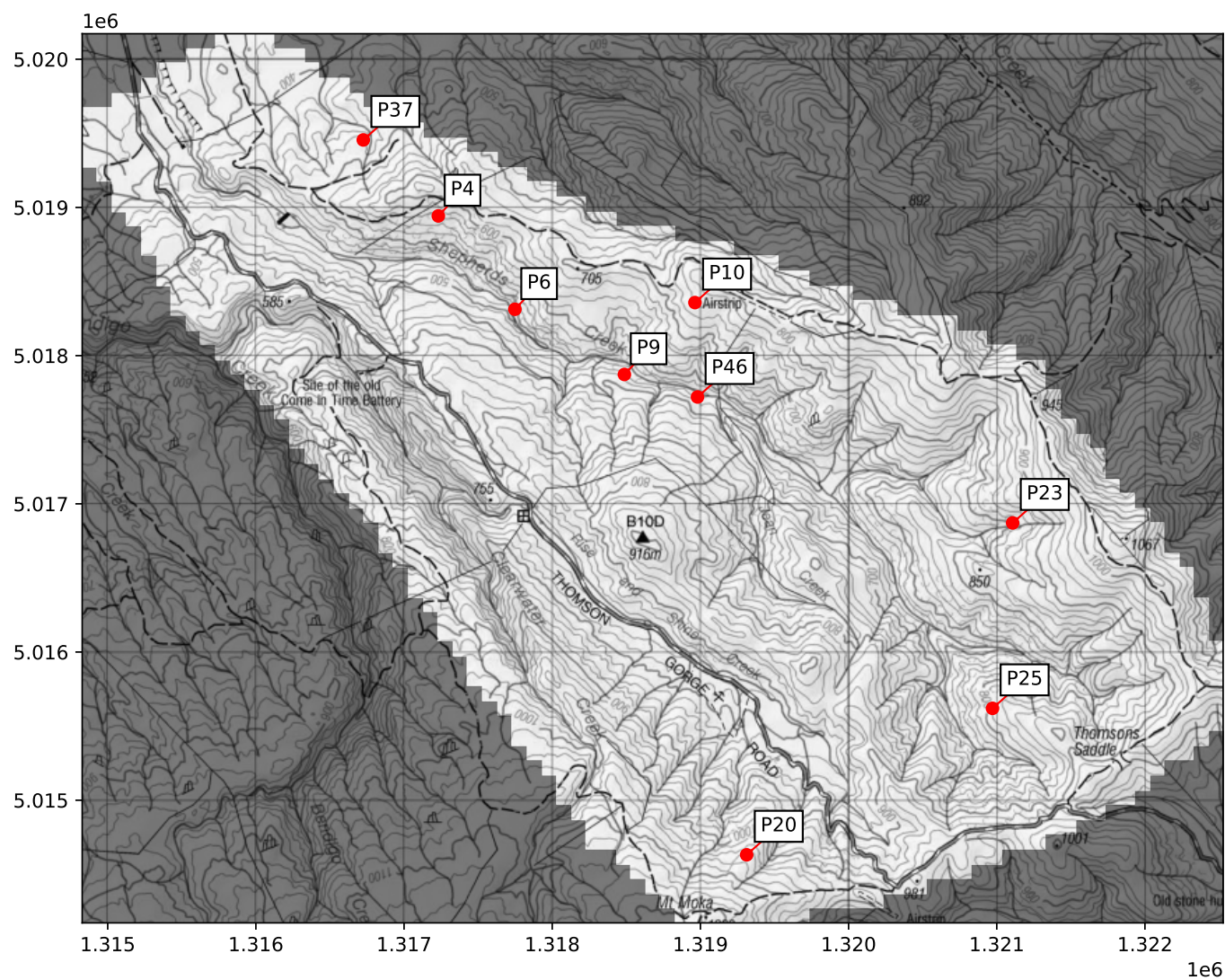
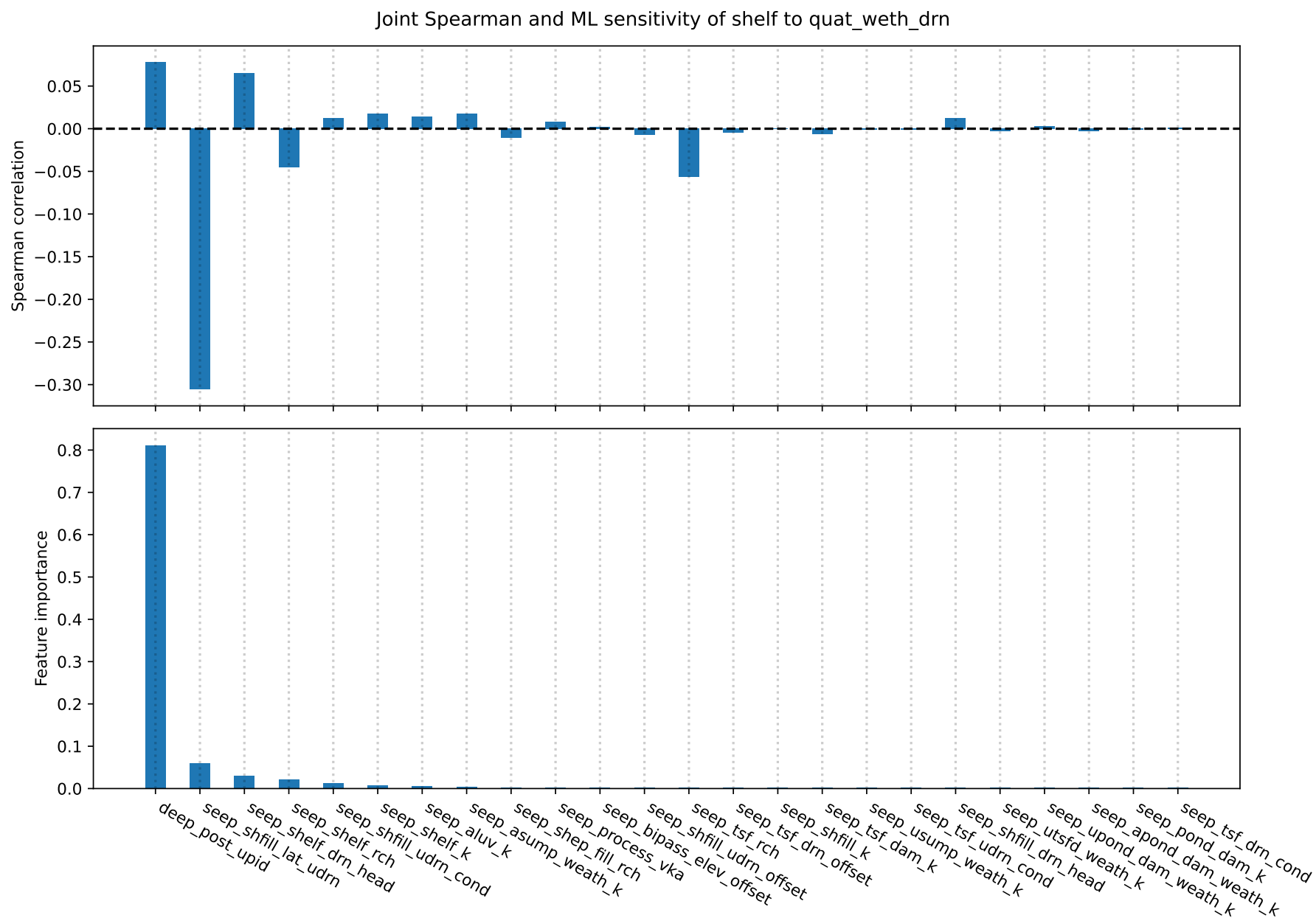
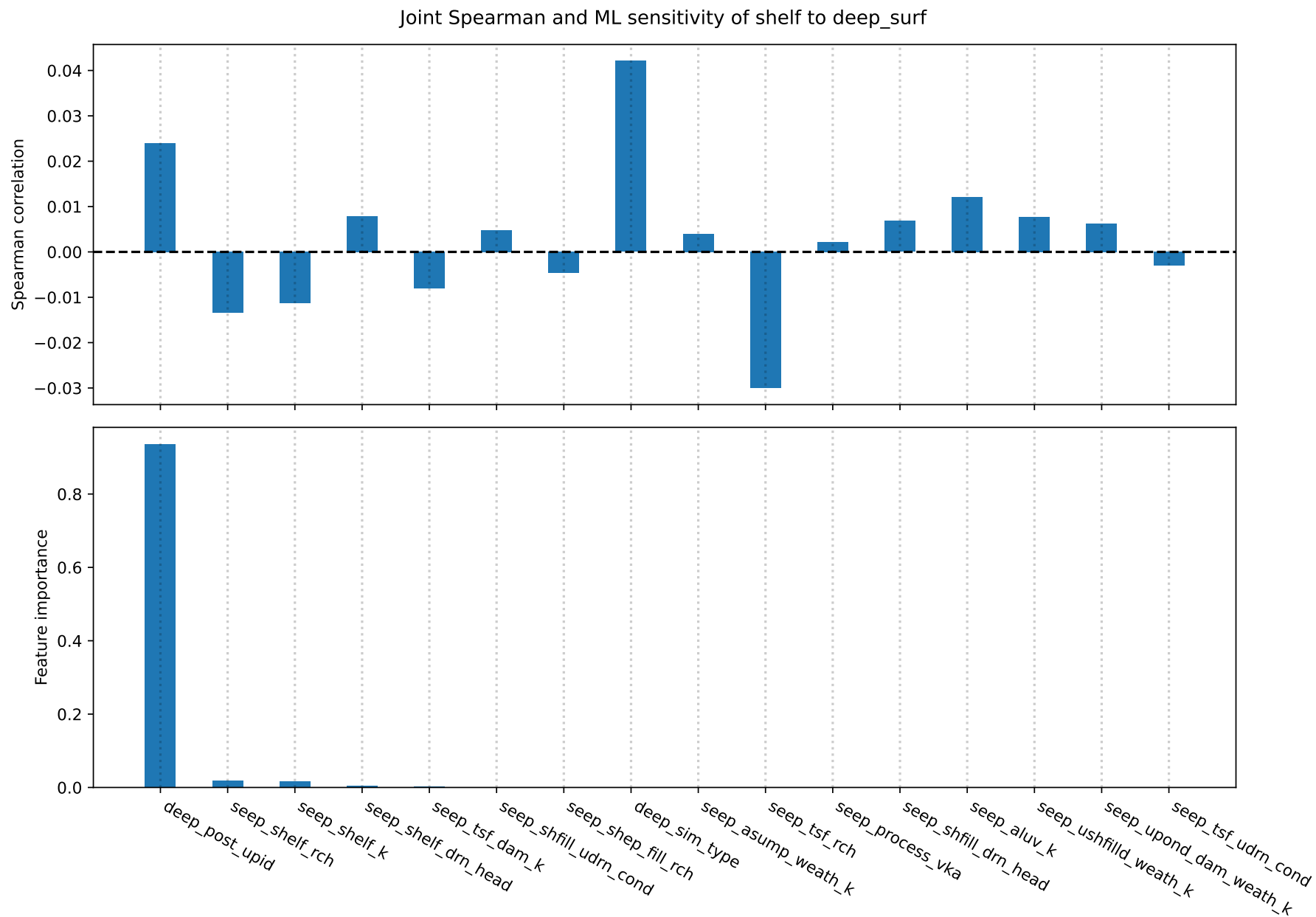
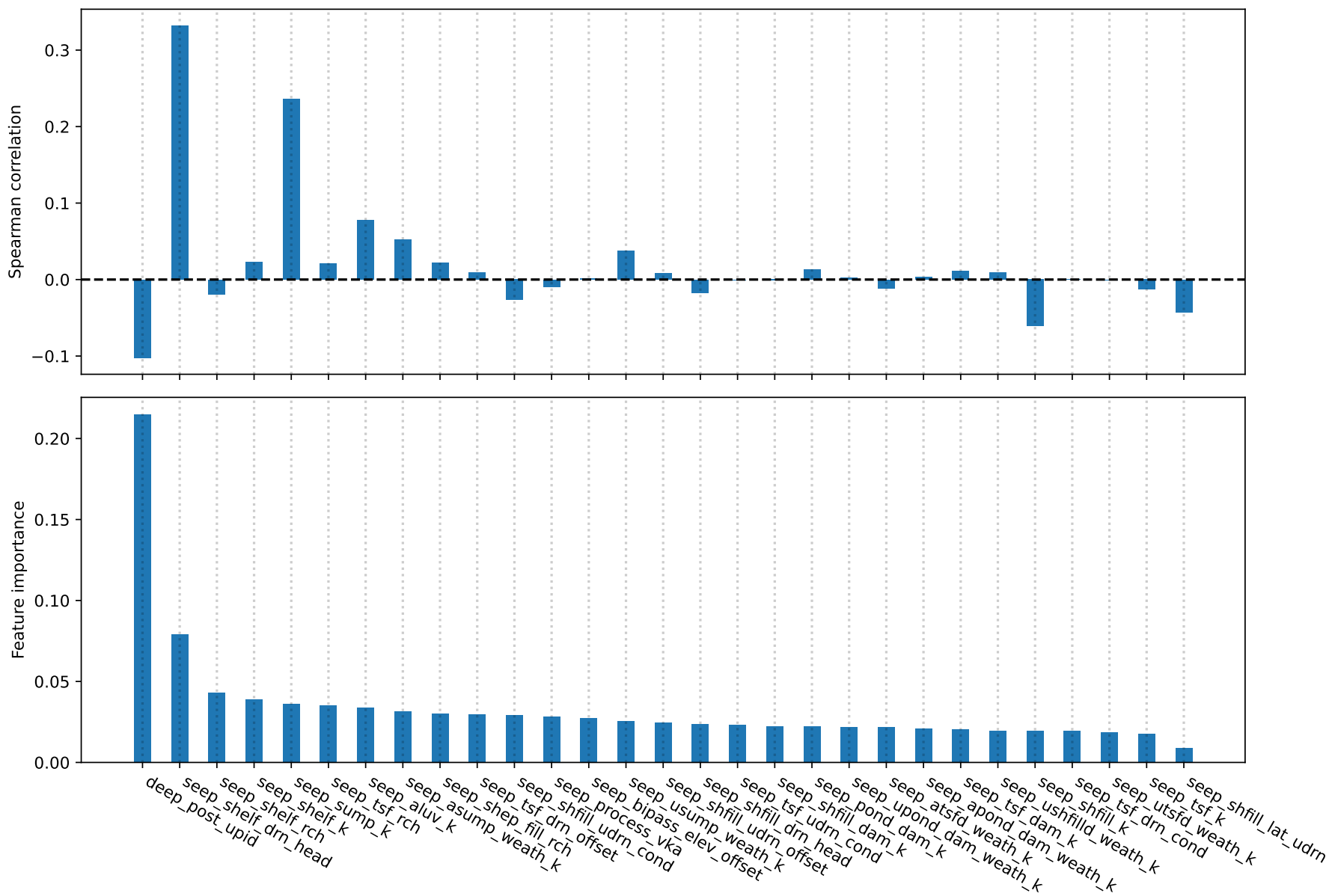


Figure F.26: Weathered Zone Pilot Points
 Weathered zone pilot points are shown in red. These points are selected pilot points which have high importance for SHELf.





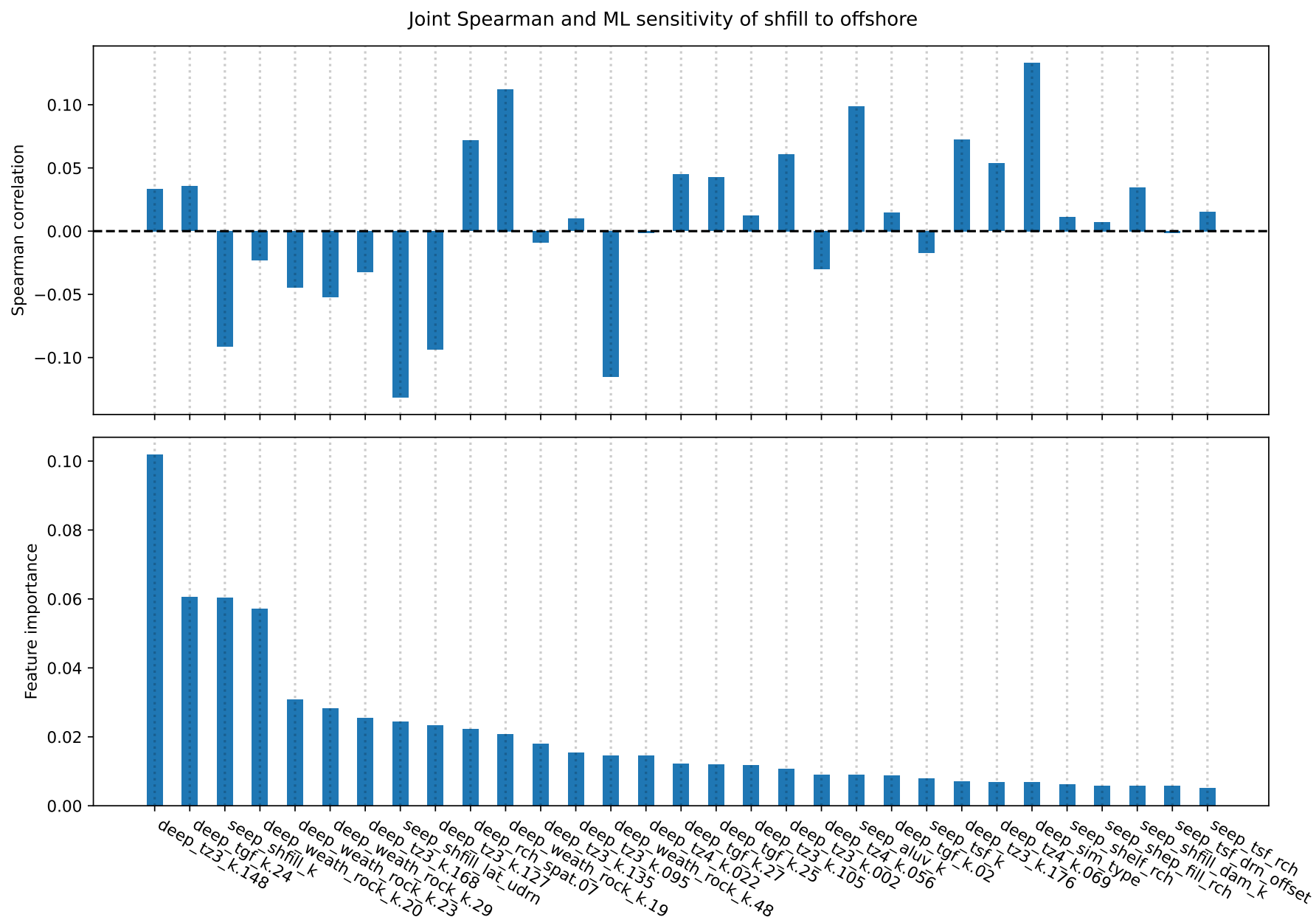
Joint Spearman and ML sensitivity of shelf to siltpond



F.2.3 SHFILL lost seepage drivers

The key parameters of importance for lost seepage from SHFILL to the quaternary and weathered drains are the implementation of the lateral and underdrains in the SHFILL region (`shfill_lat_udrn`), the conductivity of the SHFILL (`seep_shfill_k`), and the conductivity of the alluvium in the seepage model (`seep_aluv_k`). All three of these parameters show a negative correlation with lost seepage. This means that including an underdrain in the SHFILL region, increasing the conductivity of the SHFILL, and increasing the conductivity of the alluvium in the seepage model will all reduce lost seepage.

The key parameter of importance for lost seepage from SHFILL to the deep model OFFSHORE zone is the deep model realisation (`deep_post_upid`). [Figure F.30](#) shows the results of a full sensitivity analysis for lost seepage from SHFILL to the deep model OFFSHORE zone. The key parameters of importance from the deep model are the hydraulic conductivity of the TZ-3 and TGF at specific pilot points as well as the hydraulic conductivity of the weathered schist at pilot point 20 and 23 (`deep_weath_rock_k.20` and `deep_weath_rock_k.23`). This also elevates the importance of the SHFILL conductivity (`seep_shfill_k`). There are positive correlations with the schist conductivity (more seepage with higher schist conductivity) and negative correlations with weathered rock conductivity and SHFILL conductivity. This suggests that deep OFFSHORE discharge is associated with higher heads in the SHFILL which then can instigate downward flow for some of the deep model realisations.



F.3 Revised Suite Results

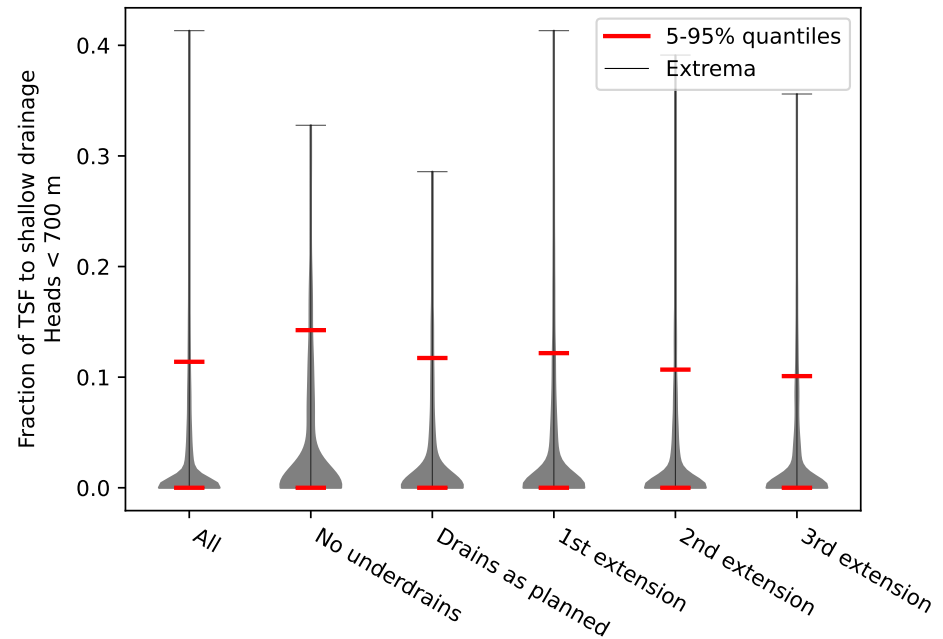
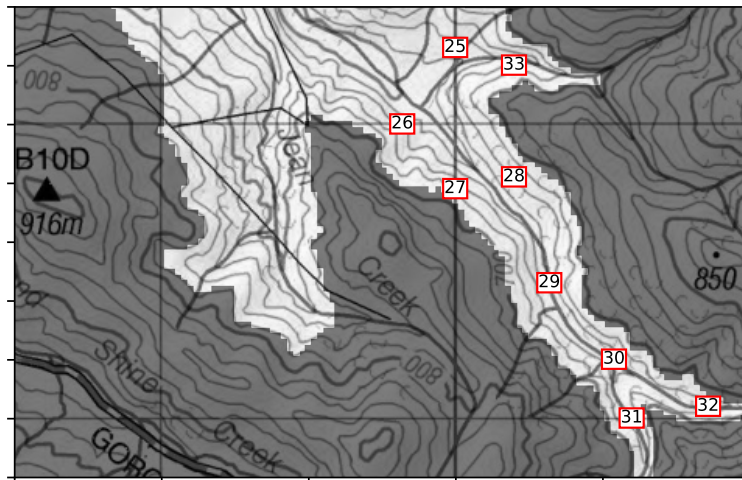
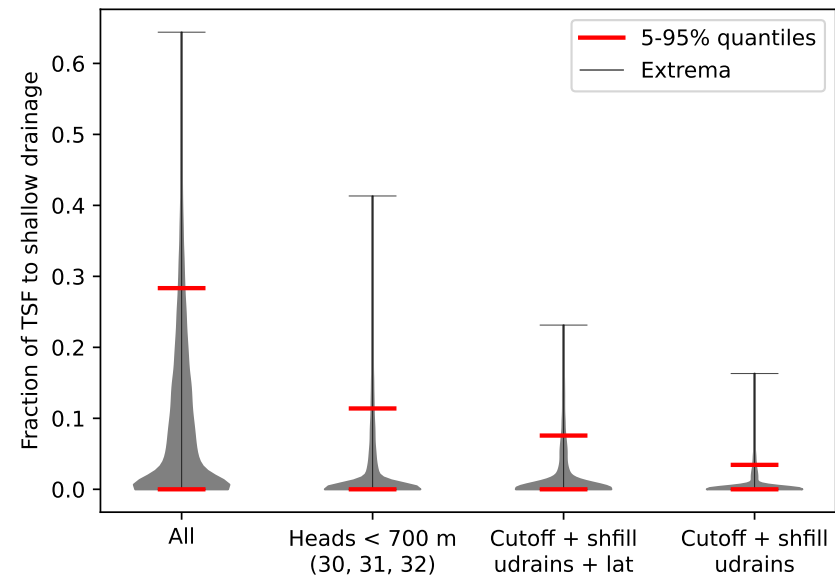
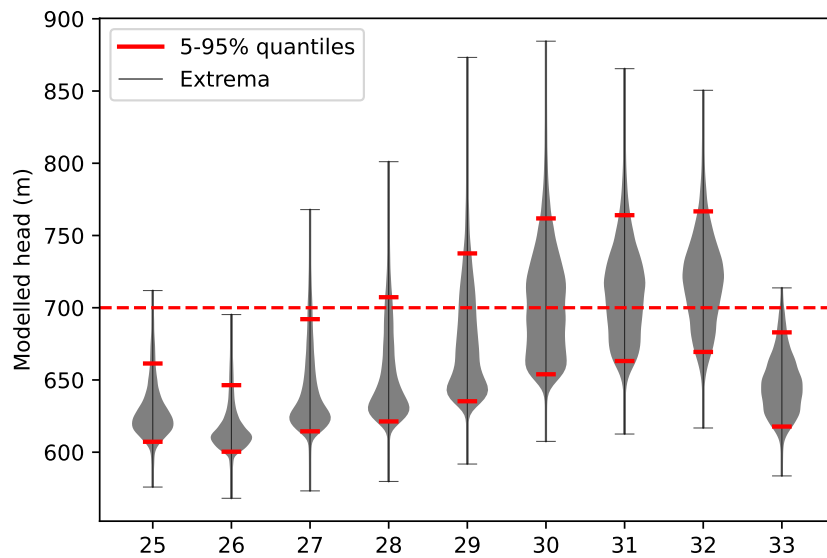
The raw suite results are likely biased, may contain physically unrealistic parameter sets, and may not provide a realistic representation of the likely range of lost seepage. We therefore undertook further investigation to reduce the uncertainty of the lost seepage predictions and to provide a more realistic representation of the likely range of lost seepage.

F.3.1 Revised TSF Seepage Partitioning

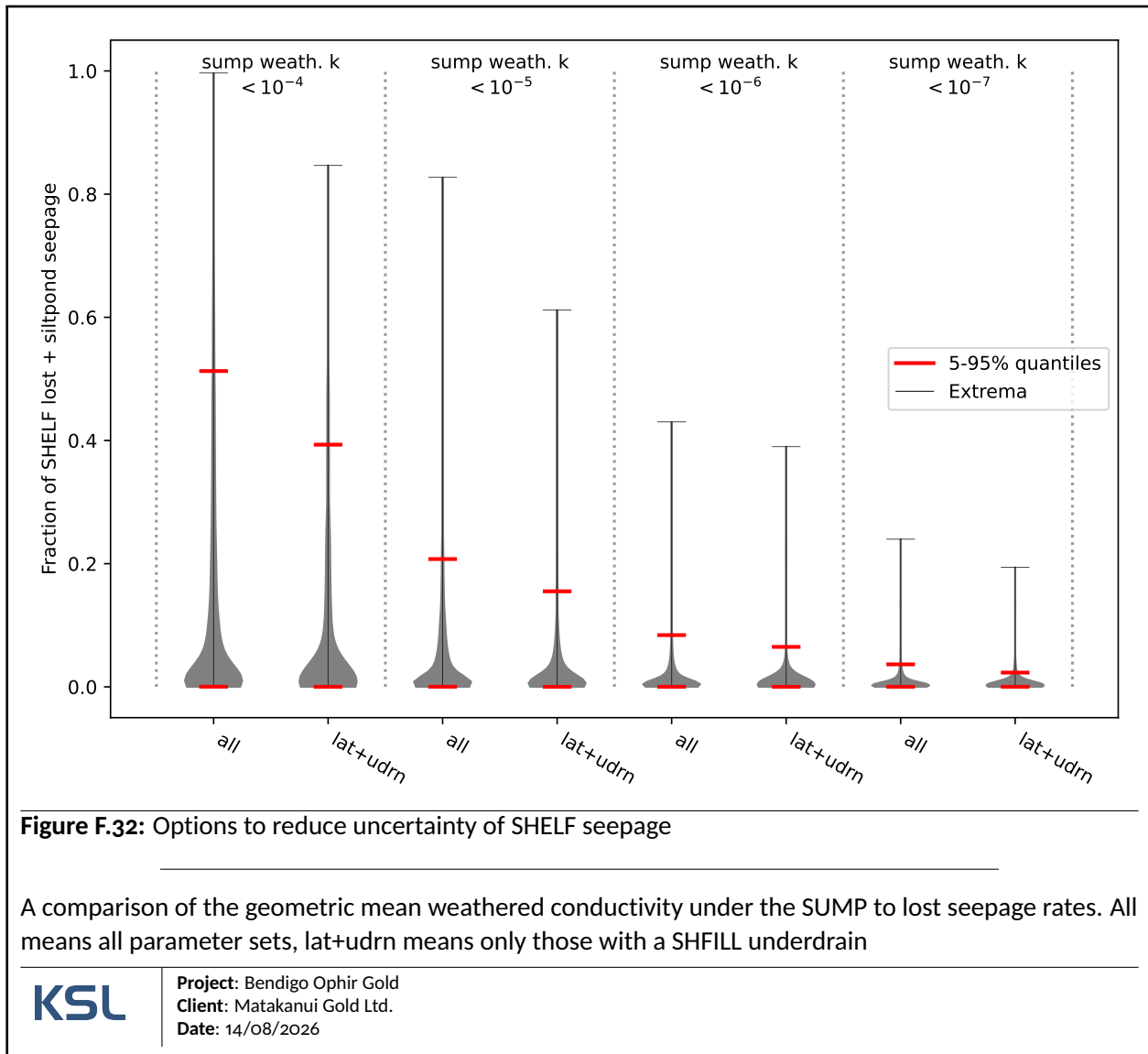
The raw and biased suite of TSF seepage cannot exclude the possibility of very high lost seepage (up to 30% for the biased 95th percentile). However, further investigation suggests that these high values are likely to be physically unrealistic and a much lower range of lost seepage is likely. Figure F.31 has 4 sub-figures showing the modelled heads at synthetic monitoring points in the QALCL (top left), a locator map for the synthetic monitoring points (bottom left), A comparison of the lost seepage for the raw suite and a revised suite (top right), and a comparison of the lost seepage for the raw suite and the effects of extending the underdrainage in the TSF (bottom right). In the raw suite there are many parameter sets that yield very high heads in the TSF (up to 900 m). These heads would produce extreme artesian pressures as the top of the TSF material is likely to be at or near the top of the TSF-D (approximately 690 m). The correlation between the lost seepage and TSF recharge (see Section F.2.1) suggests that these high heads are likely due to a paring high recharge with a low conductivity of the TSF material. In reality, such low-conductivity material would refuse recharge and the water would discharge to the surface ponds of the TSF (Hope and Torvelainen, 2025). If we filter the raw suite to only include parameter sets that yield heads less than 700 m (10 m above the top of the TSF) in the synthetic observation points 30–32, we find a significant reduction in lost seepage. Some of this “reduced” seepage is caused by a reduction in the driving pressure into the deeper system, while other “reduced” seepage is due to the model no longer discharging seepage to the Shepherds Creek bypass. This latter pathway is upgradient and is physically impossible. It only occurs in our model because water can only discharge to specified boundary conditions. We did not include surface drains in the model (e.g., replicating surface runoff) as we wanted to carefully capture all potential lost seepage at the precise water features.

Excluding the simulations with unrealistic heads reduces the 95th percentile of lost seepage from 29% to 12%. Inclusion of under drainage within SHFILL re-captures some of this lost seepage, further reducing the 95th percentile of lost seepage to 8%. The lateral drains in the SHFILL region exist to allow discharge of near-surface flow along the steep slopes of the SHFILL area. This water would, in reality, likely enter the SHFILL as either surface runoff or infiltrate into the SHFILL. Our model does not include this potential pathway, but if we exclude the SHFILL surface drains from the model, then the 95th percentile of lost seepage is further reduced to 4%. Assuming the inclusion of underdrainage in the SHFILL, We suggest that the 8% lost seepage is a very conservative upper estimate, likely higher than is realistic. A more realistic conservative upper estimate is <8% but >4% lost seepage, or slightly above the 95th percentile of the revised suite with only underdrains in the SHFILL region. The most likely figure for lost seepage from the TSF is < 3% with many realisations showing < 2% lost seepage.

Initial modelling suggested that extending the underdrainage in the TSF would provide a similar effect to filtering the heads to 700 m. The model suggests that the area in the lower TSF is a more likely discharge area for the deep schist system than the upper reaches of the TSF (Figure B.38). Extension of the underdrainage in the TSF to roughly the first extension detailed in Figure C.6 would ensure the full discharge area of the deep schist system is captured by the underdrainage system. Conceptually, this would significantly reduce the potential for higher heads in the upper TSF. However, extending the underdrainage in the TSF after the filtering to 700 m yields very little effect on the percentage of lost seepage, so such extension may not be required.



F.3.2 Revised SHELF Seepage Partitioning



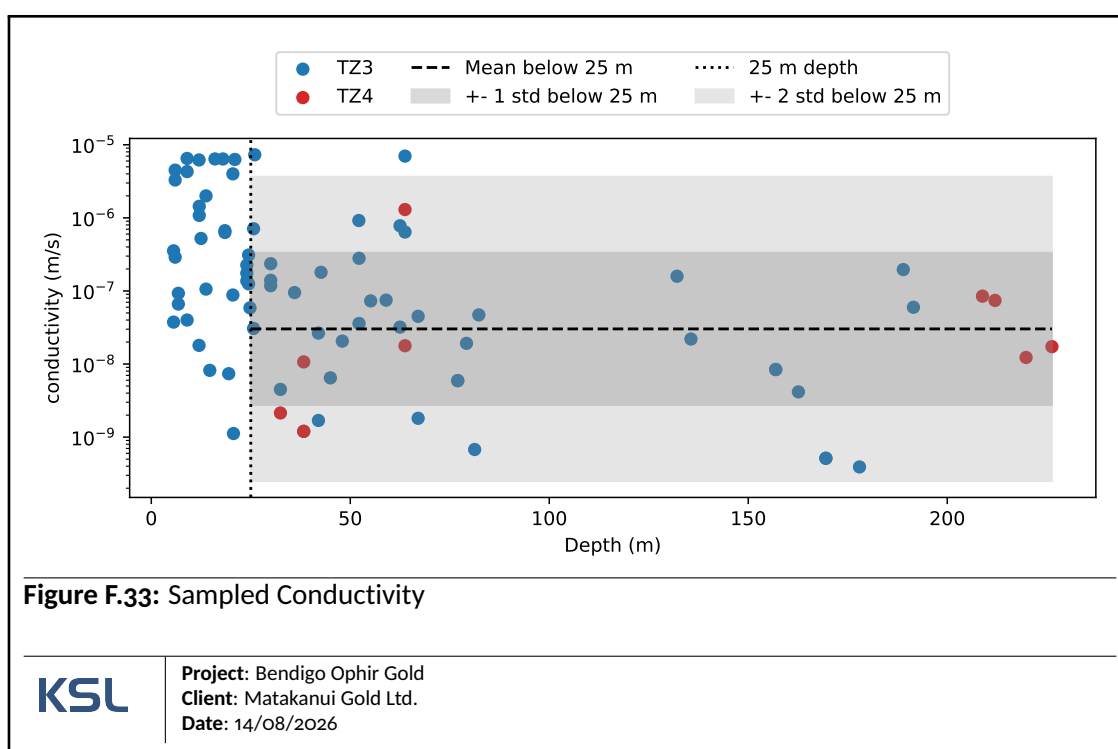
The raw distribution suggests 95th percentile seepage rates of up to 55%. The most sensitive parameter for predicting lost seepage from the SHELF is the weathered schist conductivity in the area. The model does preferentially select more conductive weathered schist in the area at and below the transition from the SHELF to SHFILL (see Figure B.19). There is relatively low variability for the pilot points at and below point 705 on the northern ridge of Shepherds Creek. This causes a transition to the higher variability and lower conductivity area upstream of the SUMP. The median (in $\log_{10}$ space) of the posterior geometric mean conductivity for the area under the SUMP is $10^{-6.1}$ m/s with an IQR of $10^{-4.2}$ to 10^{-8} m/s. Clearly, the conductivity here is not well-informed by the water level observations in the inversion. The prediction of lost seepage from the SHELF is very sensitive to the weathered schist conductivity (Figure F.32). Filtering the stochastic suite to only those modes with lower conductivity yields a marked reduction in the predicted 95th. Additionally, the inclusion of an underdrain in SHFILL further reduces the estimate of lost seepage. These values are shown in Figure F.32 and Table F.1

The full set of conductivity data recorded for tests in Shepherds Creek is shown in Figure F.33. There is no evidence of the upper end of the distribution being as high as 10^{-4} m/s, suggesting that the parameter may be compensatory for model structural errors. These errors could include too high recharge, insufficient thickness of the QALCL or weathered schist, or other structural errors in the model. Values between 10^{-5} and 10^{-6} m/s are more consistent with the shallow measured data. Additionally, the area under the SUMP will be modified to remove the QALCL and much of the weathered schist. This was parameterised in the model, but the reduction

Table F.1: 95th percentile seepage rate limits for the SHELF

k_{weath} limit	No U. drain	U. drain
$<10^{-5}$	21%	16%
$<10^{-6}$	9%	7%
$<10^{-7}$	4%	3%

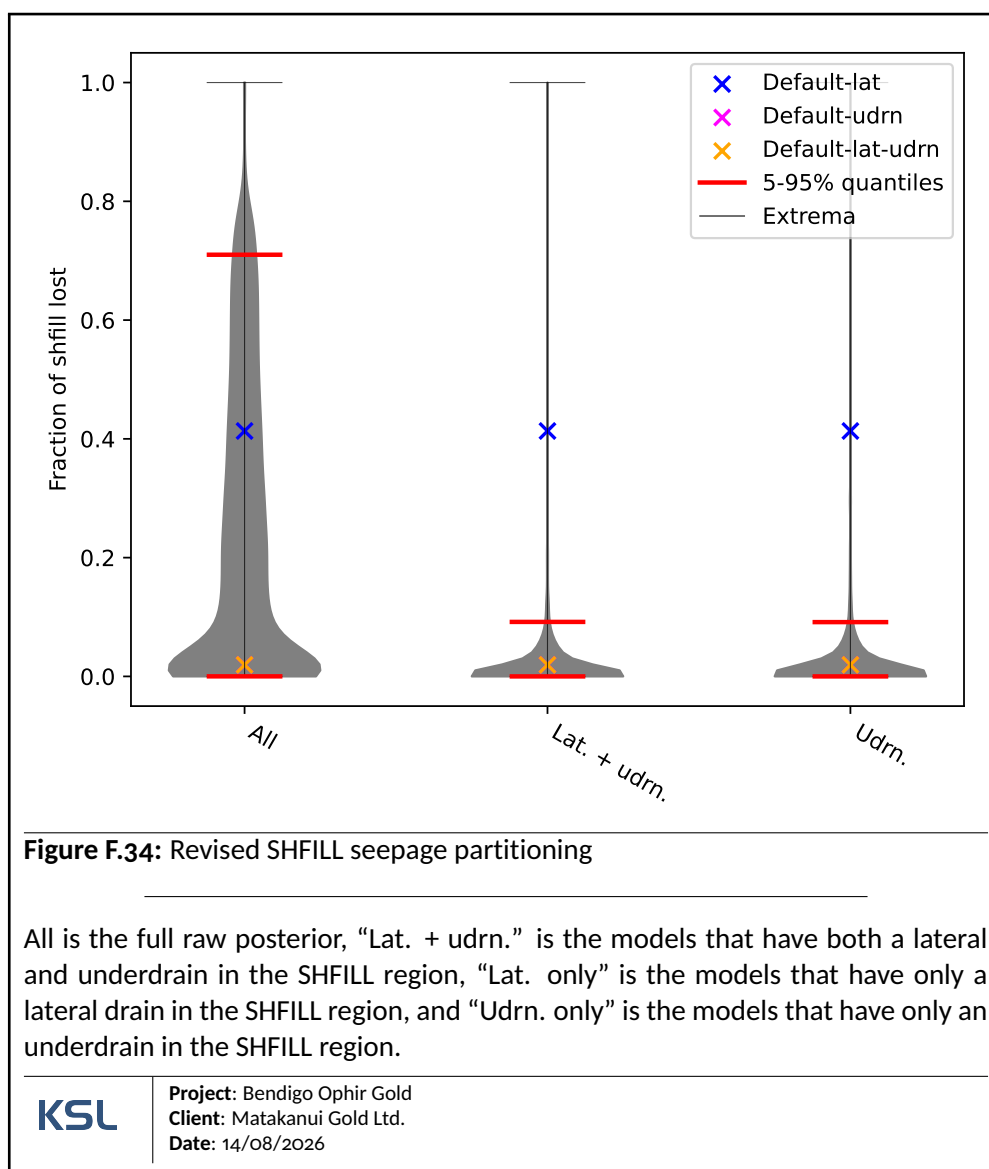
in conductivity parameter was not sufficient to address these very high compensatory values. Unmodified weathered schist could realistically yield a loss rate of 16% (assuming a SHFILL underdrain), but the modified weathered schist is likely to be significantly less conductive, suggesting that the 95th percentile of lost seepage is likely to be less than 10%. The weathered schist in the model has a uniform conductivity and a uniform thickness (20 m). As long as modified schist can ensure a transmissivity of less than $2 \times 10^{-5} \text{ m}^2/\text{s}$, then the lost seepage from the SHELF is likely to be less than 9% (95th percentile). The most likely scenario under these assumptions would be to have lost seepage rates from the SHELF of less than 5%.



F.3.3 Revised SHFILL Seepage Partitioning

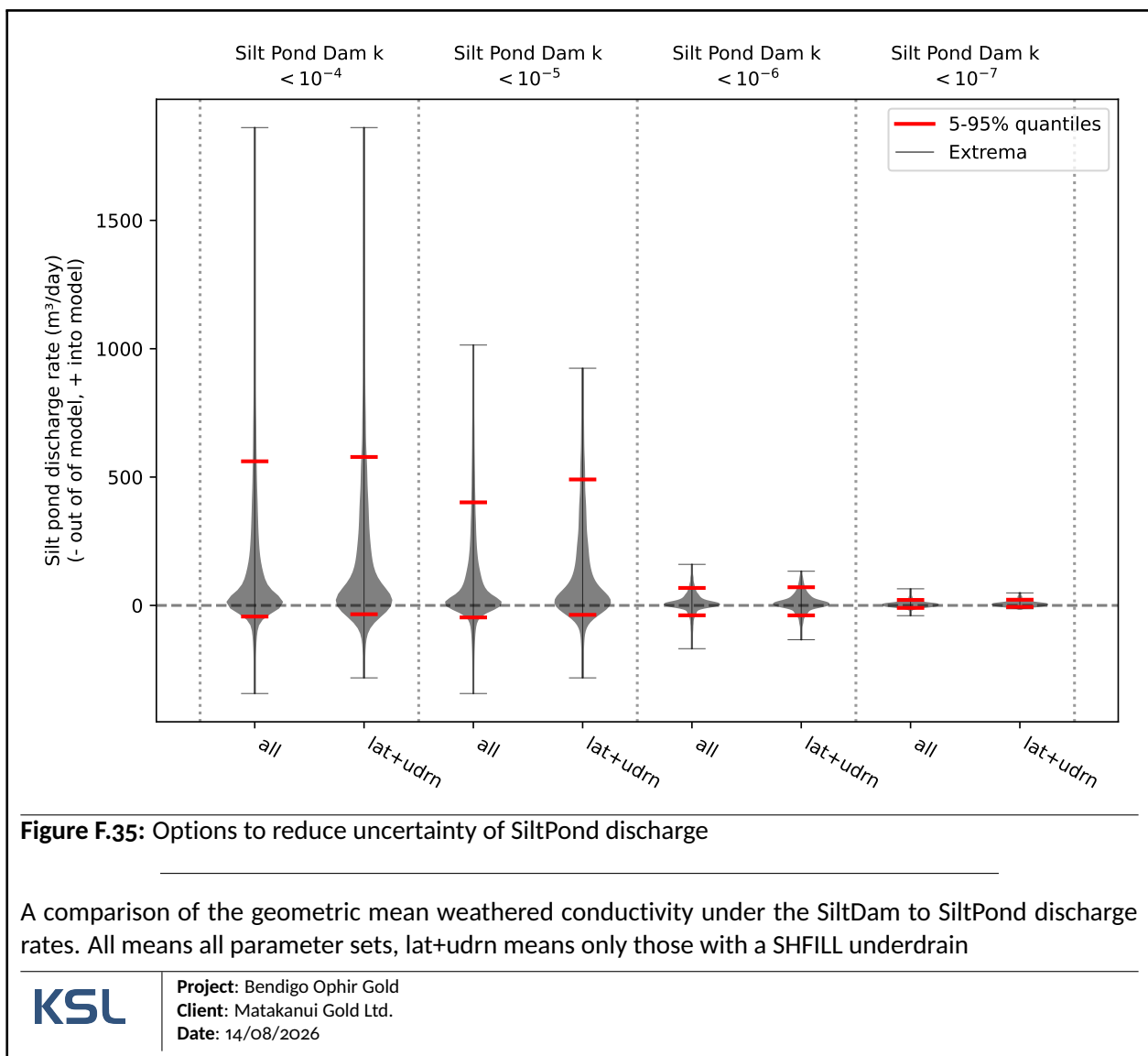
Figure F.34 shows the predicted lost seepage from the SHFILL depending on the lateral and underdrain configuration in the SHFILL region. With only the lateral drains, the lost seepage is significant, with most of the seepage discharging to the lateral drains (>70%). Inclusion of an underdrain in the SHFILL with or without the lateral drains significantly reduces the lost seepage to the quaternary and weathered drains in the seepage model. This yields a 95th percentile of lost seepage of approximately 9% for the SHFILL seepage.

Seepage lost to the lateral drains is a function of heads where these exceed the top of the SHFILL. While this may seem unrealistic, unlike the TSF the high heads are not driven by a misfit of recharge and conductivity, but rather by the deep schist system. In a previous iteration of the seepage model, we did not include lateral or underdrains in the SHFILL region. This yielded very high (artesian) heads in the SHFILL, with significant lost seepage to the quaternary and weathered drains and the upstream SiltPond. This was not considered a realistic outcome, which is why we implemented the lateral and underdrains in the SHFILL region. The deep model predicts that the SHFILL area is a major discharge area for the deep schist system, and therefore the SHFILL will be a net sink of water [Figure B.38](#). Without a discharge point in the SHFILL region, the model was unable



to route this water quickly enough to the downward SHFILL drains or upward to the SiltPond without creating very high heads in the SHFILL. In reality this discharge would have seeped out of the SHFILL as surface seepage, runoff, or other localised surface discharges. Such seepage would likely be difficult to capture and would likely be lost to the environment. It is worth noting that while the underdrains in the SHFILL region were explicitly implemented as drain boundary conditions, this is not necessarily a required component of the underdrainage system. There is a strong parameter sensitivity to the SHFILL conductivity and the underlying alluvial conductivity. Further modelling could be undertaken to constrain the required design of the underdrainage system, but provided the drainage system is effective, the lost seepage from the SHFILL is likely to be low. We suggest that a conservative upper estimate of lost seepage from the SHFILL is 10% of the seepage, noting that many model realisations suggest far lower lost seepage. The most likely scenario based on our model suite is lost seepage from the SHFILL of less than 5% of the total mass load. Further analysis of the model suite may provide a lower upper bound on the likely lost seepage from the SHFILL.

F.3.4 Revised SiltPond Losses



The raw distribution suggests very high discharge rates from the SiltPond, which are generally unrealistic. Similar to the SHELF seepage, the weathered schist conductivity in the area under the SiltDam is a key driver of the lost seepage to the SiltPond. Again, this area of the deep model selected relatively high conductivity with median (in log₁₀ space) of the posterior geometric mean conductivity for the area under the SiltPond is 10^{-6.0} m/s with an IQR of 10^{-5.0} to 10^{-7.0} m/s. Figure F.35 shows the relationship between the geometric mean conductivity under the SiltDam and the lost seepage to the SiltPond. Assuming values less than 10⁻⁶ m/s, the discharge

from the SiltPond is much more reasonable, with a 95th percentile of approximately 75 m³/day. The discharge from the SiltPond is not considered a problem per se, but this serves to explain the anomalous behaviour of the SiltPond in the raw suite.