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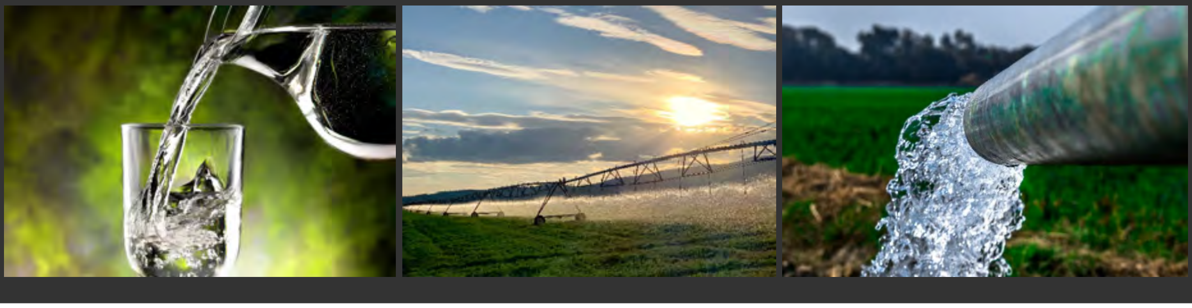

Report No: Z24002.m2

Post Closure Impacts of Bendigo Ophir Gold Deposit on the Ardgour Aquifer

07/02/2025
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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Our Vision

KSL delivers high quality science and research. We aspire to be at the forefront of creativity and innovation to address our increasingly complex water resource challenges; mō tatou, ā, mō kā uri ā muri ake nei (for us and our children after us).

Our mission

Our mission is to develop solutions to the increasingly challenging water resource management issues we now face by providing a clear vision of the pathway from problem to solution. We work closely with our partners, communities, and stakeholders, deploying state-of-the-art scientific methods and building trust through knowledge and honest science communication.

Limitations

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Key Findings

Key Findings

In this report we undertook an *a. priori.* modelling assessment of the potential impacts of contaminants in Sheperds Creek on the Ard. Aquifer (Ardgour Alluvial Aquifer). There is minimal information available to constrain the model, so the results are inherently uncertain and should be considered conservatively.

Our key findings are:

- There are multiple potential plumes of Sheperds Creek water in the Ard. Aquifer depending on the model parameterisation. Some parameterisations yield significant dilution of Sheperds Creek water, while others do not.
- Generally, Sheperds Creek water is likely to be more prevalent in the deeper parts of the aquifer, though given the limitations of the model we cannot confidently suggest that abstraction from the Ard. Aquifer will not be impacted by Sheperds Creek water.
- The model suggests that any contaminants will likely have a short residence time in the Ard. Aquifer. Model results suggest breakthrough times between 4 and 10 years and recovery times of 3 to 20 years at Ardgour Road, depending on the model parameterisation.
- Given the limitations of the model, we suggest that the only confident conclusion is that we cannot reject the hypothesis that Sheperds Creek water will not experience significant mixing in the Ard. Aquifer.
- We suggest maximum dilution factors from 0-5% for many wells. For more details see Section 4.3.
- The model results assume a constant concentration of contaminants in Sheperds Creek. If the concentration of contaminants in Sheperds Creek is variable (e.g., a various flow rates), then the models may over or under estimate the potential impacts of Sheperds Creek water on the Ard. Aquifer.
- We suggest that further investigation of the Ard. Aquifer may allow for low dilution parameterisations to be rejected, which would provide confidence that contaminants in Sheperds Creek may be mitigated by dilution in the Ard. Aquifer. We recommend that this work be undertaken before any mining activities commence.
- We suggest a range of further work options that may be undertaken to refine the model results. These options are described at a high level in Section 4.4.

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Definitions and Abbreviations

Ard. Aquifer	Ardgour Alluvial Aquifer

1 Scope of Work

The purpose of the work undertaken here is to support post-closure environmental assessments of a potential mining operation at the Rise and Shine resource in the Dunstan Mountains, Central Otago. The hard rock mining operation and engineered landforms will likely have impacts on the chemistry of Sheperds Creek. The exact chemical impacts depend on the intersection of the mining activities, plant design, and the hydrogeological environment and are not the focus of this report. At the time of this report the exact chemical impacts on Sheperds Creek are unknown, but a key contaminant of concern is high concentrations of sulphate. Sheperds Creek discharges into the Ard. Aquifer (Ardgour Alluvial Aquifer), so any potential contaminants in Sheperds Creek will likely impact the groundwater quality in the Ard. Aquifer aquifer.

The purpose of this work is:

1. To determine the likely areas of the Ard. Aquifer which source water from Sheperds Creek.
2. To quantify the potential for mixing in the Ard. Aquifer between the Sheperds Creek water and other sources of groundwater to estimate the potential effects of dilution on potential contaminants.
3. To provide an indicative assessment of the likely timescale for effects.
4. To identify further work that may be undertaken to refine these assessments.

2 Methods

2.1 Hydrogeological Setting and Conceptual Model

The Ard. Aquifer (Ardgour Alluvial Aquifer) is located in the Lindis River Valley between The Clutha River and the town of Tarras, Otago, New Zealand. The aquifer is bounded on the West by high glacial / post glacial terraces and on the East by the Dunstan Mountains. Figure 2.1 shows the hydrogeological setting of the Ard. Aquifer. Note that Otago Regional Council has also designated a portion of the Ard. Aquifer as the Lindis Alluvial Ribbon Aquifer. This designation is to support the management of abstraction rather than a demarcation of different hydrogeological units. Bores in the Lindis Alluvial Ribbon Aquifer are considered to be stream depleting and subject to the allocation associated with the Lindis River. For our purposes, this demarcation is not relevant and we consider both the Lindis Alluvial Ribbon Aquifer and the designated Ardgour Alluvial Aquifer to be the Ard. Aquifer. An additional unit, the Sheperds Creek Alluvium refers to the thin alluvial deposits in the Sheperds Creek Catchment, which sit on relatively impermeable schist bedrock. The terrace materials (tan in Figure 2.1) are glacial, periglacial, and post glacial deposits, which are considered to be relatively impermeable.

The Ard. Aquifer is considered a deep alluvial aquifer though the depth to hydrogeological basement is not constrained. There is minimal hydrogeological data available for the Ard. Aquifer, but a single bore log (G41/0150) (Figure 2.2) suggests the aquifer is composed of highly permeable gravels and sands with a high hydraulic conductivity. Figure 2.3 shows a conceptual cross-section of the interaction between the Sheperds Creek Alluvium and the Ard. Aquifer. As Sheperds Creek flows from the Dunstan Mountains to the end of the Sheperds Creek Alluvium, it loses most to all of its flow to the groundwater system. As the alluvium enters the Ard. Aquifer, the aquifer thickness increases dramatically and the depth to water increases signficantly. Despite minimal data, the water table in the Ard. Aquifer is considered to be relatively flat. Sheperds Creek water flows North to North-West, eventually discharging into the Lindis and/or Clutha Rivers.

Figure 2.4 shows the conceptual model of the Ard. Aquifer. Note that the elevation of the hydrogeological basement is indicative and the actual elevation is unknown. An estimated 522,000 m^3yr^{-1} of water enters the Ard. Aquifer from Sheperds Creek. This water then co-mingles with water from the Lindis River, and other Dunstan Mountain catchments, before discharging into the Lindis river and/or flowing parallel to the Lindis River and discharging into the Clutha River. The area is relatively dry and therefore land surface recharge is likely to be minimal except where augmented by irrigation.

Both the Lindis and Clutha rivers are large rivers with very high relative flows as compared to the Sheperds Creek. This work assumes that the Sheperds Creek water is a very minor component of the Lindis River and

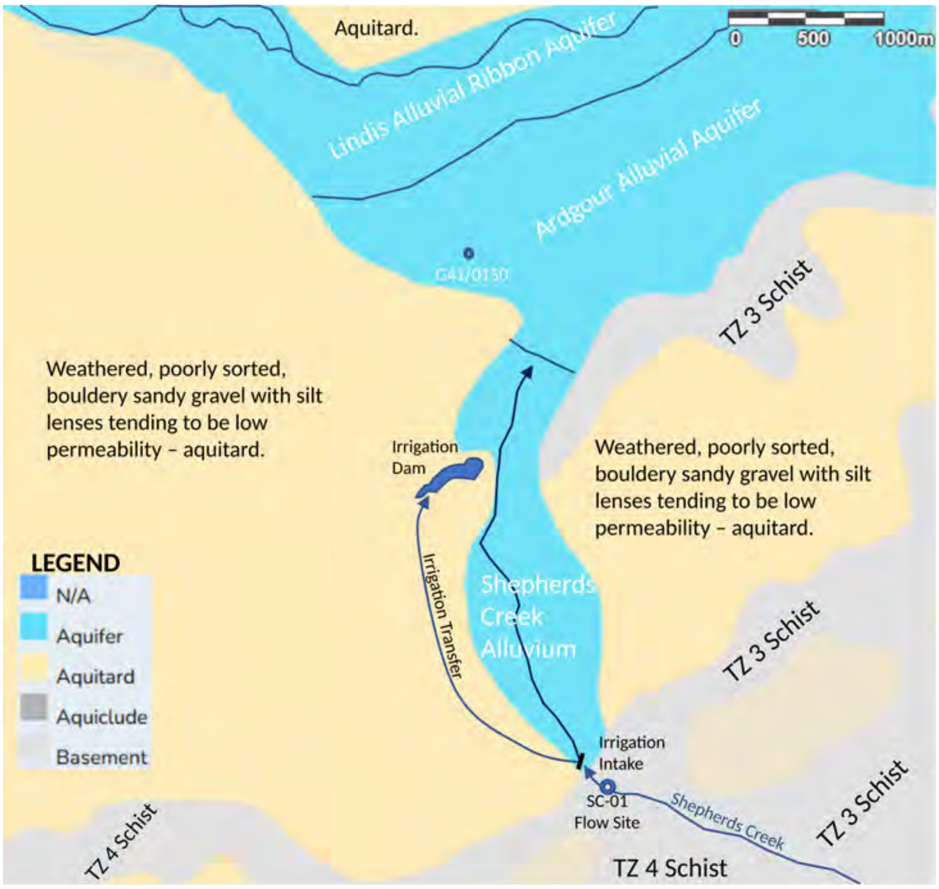

Figure 2.1: Hydrogeological Setting

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Clutha River flows and therefore activities are unlikely to influence the water quality of these rivers.

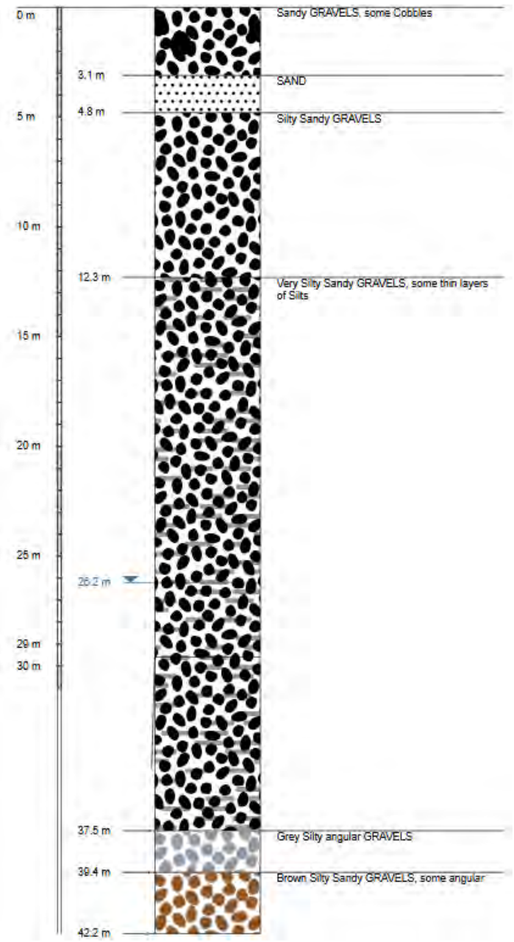

Figure 2.2: Bore log for G41/0150

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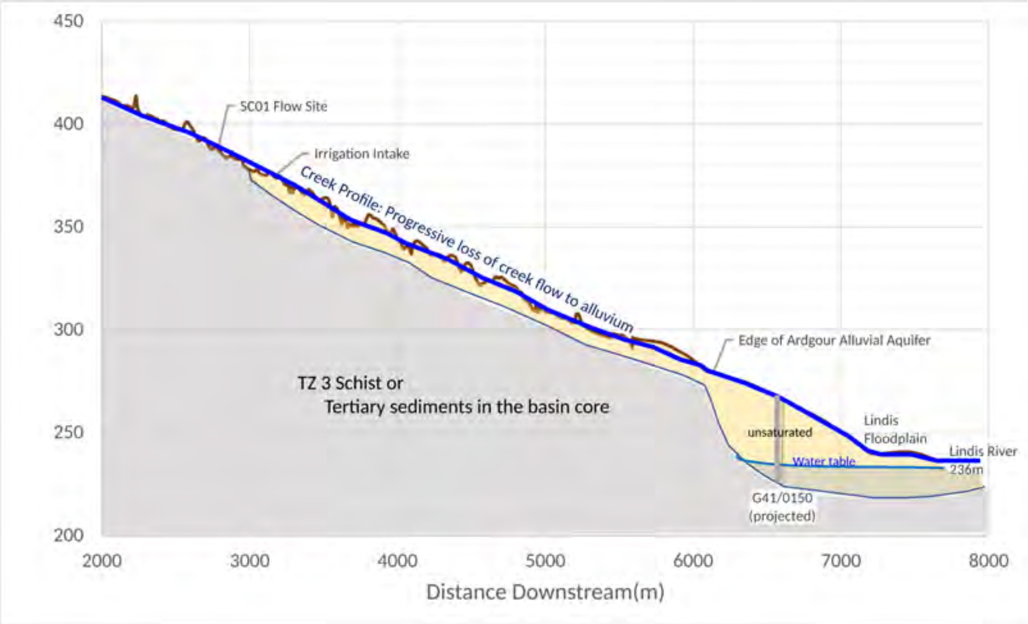

Figure 2.3: Conceptual Cross Section along Sheperds Creek into the Ard. Aquifer

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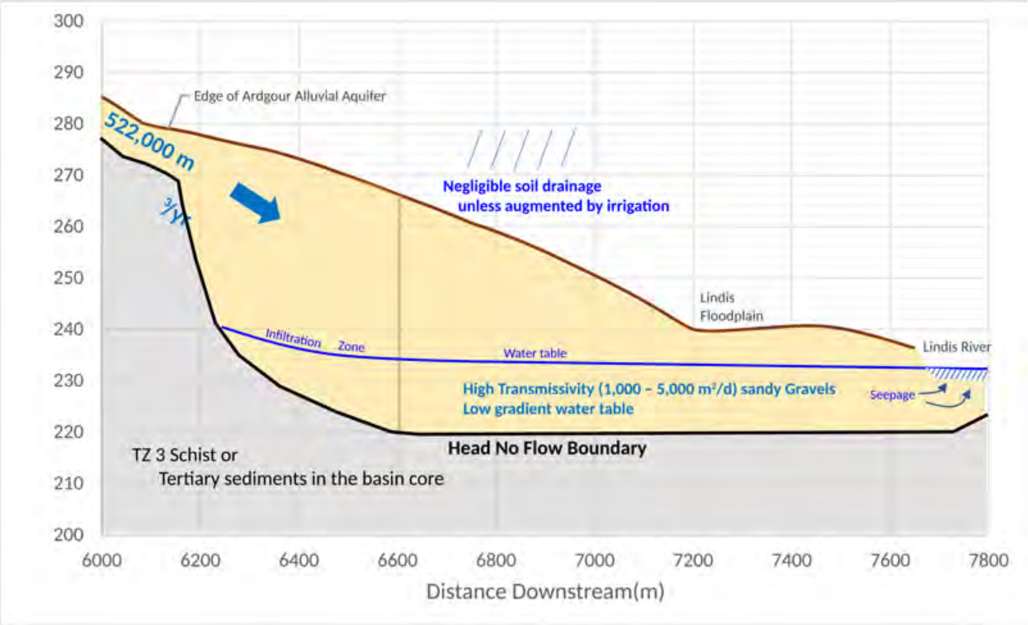

Figure 2.4: Conceptual Model

Note that the elevation of the hydrogeological basement is indicative and the actual elevation is unknown.

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2.2 Numerical Model Structure

We developed a numerical model for the Ard. Aquifer to simulate the relative attribution of groundwater to the Sheperds Creek Catchment. The model domain is shown in Figure 2.5 The model covers the Lindis River Valley from Cloudy Peak to the confluence of the Clutha River. The model is discretised into 4 layers with 50 m horizontal resolution with grid cells oriented North-South and East-West. The top of the model is set via the National 8-m Digital Elevation Model (DEM) and the bottom of the model is set at 50 m below the surface or 200 m mean sea level, whichever is lower. The base of the first model layer is set to 10 m below an indicative water table. The indicative water table was defined by the minimum of multiple steady-state single layer simulations of the model under all parametrisation sets. This single layer model was developed with the identical domain, boundary conditions, and parametrisation as the final model. The bottom of the second and third layers are set at 20 m and 30 m below the indicative water table respectively.

The model is run as both a steady-state and transient flow model with a subsequent transient transport model. All boundary conditions were developed for a 10-water-year period from 1 July 2013 to 30 June 2023, which is the period of the available data. The modelled transient period is 80 years with 31 years of “affected” Sheperds Creek water and 49 years of “unaffected” water. The flow boundary conditions are simply repeated 8 times for the transient flow simulation. The transient model dates are 1 July 2013 to 30 June 2093, with affected Sheperds Creek water from 1 July 2013 to 30 June 2044 and unaffected water from 1 July 2044 to 30 June 2093.

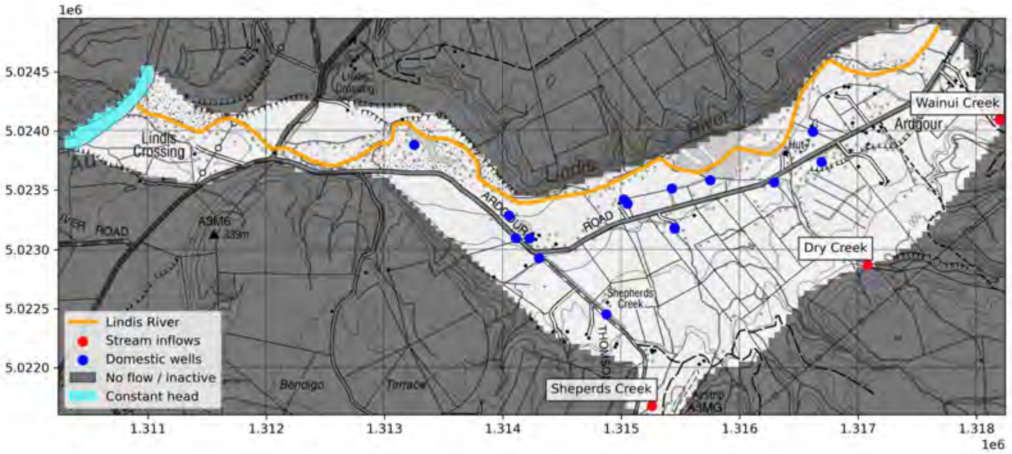

Figure 2.5: Model boundary conditions and domain

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2.3 Model Software

The model was developed in MODFLOW-NWT, which is an open source finite difference groundwater flow model, which is widely used in the groundwater modelling community and provides robust handling of wetting and drying conditions that can occur in transient unconfined aquifers. We chose MODFLOW-NWT over the more recently released MODFLOW-6 because it is more computationally efficient, and we did not require the additional features of MODFLOW-6. Note that MODFLOW-NWT and MODFLOW-6 will produce very similar results for the same model setup. We use MT3D-USGS to simulate the transport of Sheperds Creek water in the model domain.

We undertook model construction in Python using the FloPy library and other in house Python packages. Models developed in Python are more easily reproducible than Graphical User Interface modelling programs (e.g., GW Vistas, GMS, etc.) as the code can be shared and each modelling decision is explicitly coded, rather than relying on the modeller to keep an accurate log of their actions. Additionally, Python based model implementations allows for more flexibility and automation in model construction, optimisation, and analysis.

2.4 Numerical Model Boundary Conditions and Prediction Points

The numerical model has the following boundary conditions and prediction points. The location of these boundaries is shown in Figure 2.5.

1. Spatially distributed recharge via the RCH package, see Section 2.4.1.
2. Layer invariant no-flow boundaries as per Figure 2.5.
3. The Lindis River which is simulated using the STR package, see Section 2.4.2.
4. Existing groundwater bores are simulated using the WEL package, see Section 2.4.3. These bores are key prediction points for the model.
5. The Clutha River is simulated using a constant head boundary at 215 m msl.
6. Inflows from Wainui Creek, Dry Creek, and Sheperds Creek are simulated using the WEL package.
7. The other key prediction locations are indicative cross-sections (see Figure 2.6). These cross-sections are used to assess the maximum relative attribution of groundwater to the Sheperds Creek Catchment along the cross-section line for each layer.

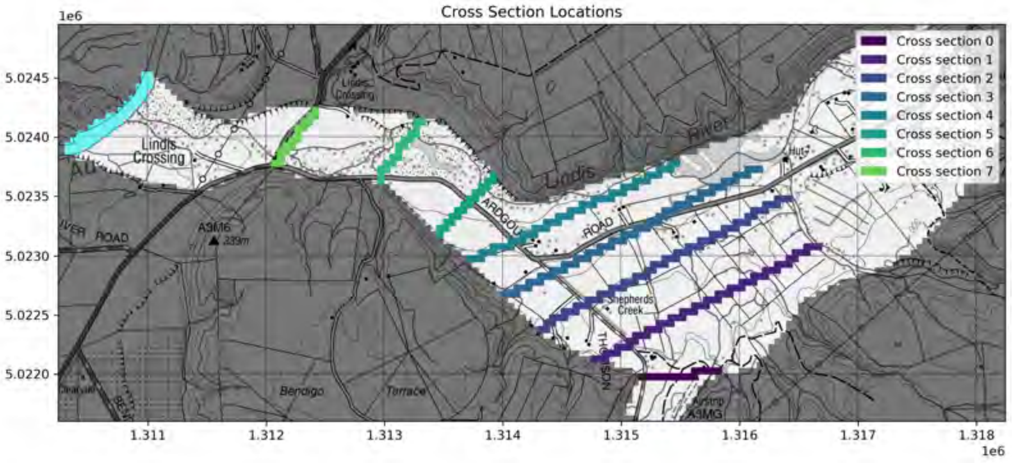

Figure 2.6: Prediction cross sections

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2.4.1 Recharge

Groundwater recharge was modelled using an in-house implementation of the Rushton Recharge model (Rushton et al., 2006). Briefly, the Rushton Recharge model is a transient soil moisture – water balance model. Rainfall and potential evapotranspiration was sourced from the ERA5-Land dataset (Muñoz-Sabater et al., 2021). Soil properties (profile available water and readily available water) were sourced from the New Zealand Fundamental Soil Layer. The Rushton model simulates the effects of irrigation via a trigger / target method, with parameters set in accordance with typical spray irrigation practices. Here a maximum of 5 mm of irrigation is applied when the soil moisture content drops below 75% of field capacity and applies irrigation up to 90% of field capacity with 90% efficiency (e.g., an additional 10% of water is applied beyond the amount required to reach the target). Irrigated area was defined as the 2020 irrigated area from Dark (2020) The average annual recharge is shown in Figure 2.7.

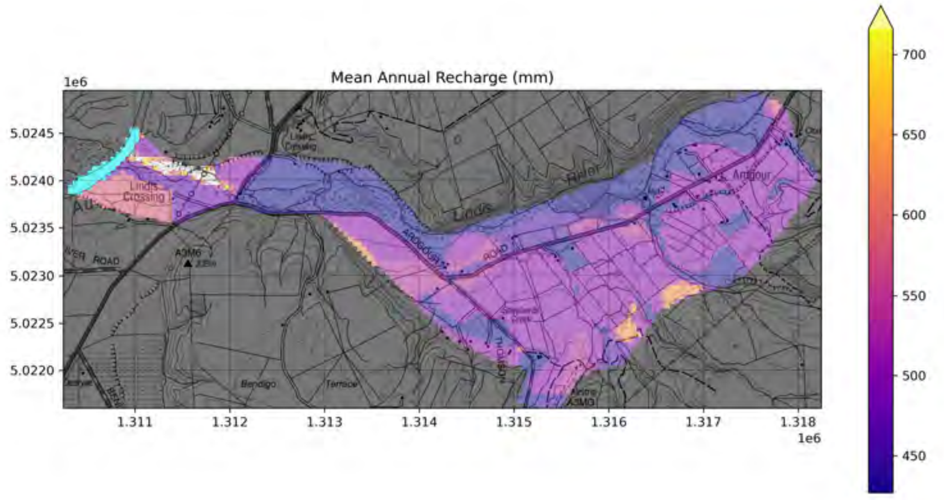

Figure 2.7: Mean annual land surface recharge

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2.4.2 Lindis River

We simulated the Lindis River using the STR package. The time invariant river stage was set at the minimum model cell elevation from the National 8-m DEM. We set the river bottom and top to 2 m below and 1 m above the river stage, respectively. The only time variant parameter was the river flow at the top of the model domain, which was defined based on the naturalised flow data provided by the Otago Regional Council. The time variant river flow is shown in Figure 2.8. The river conductance was parameterised, see Section 2.5.

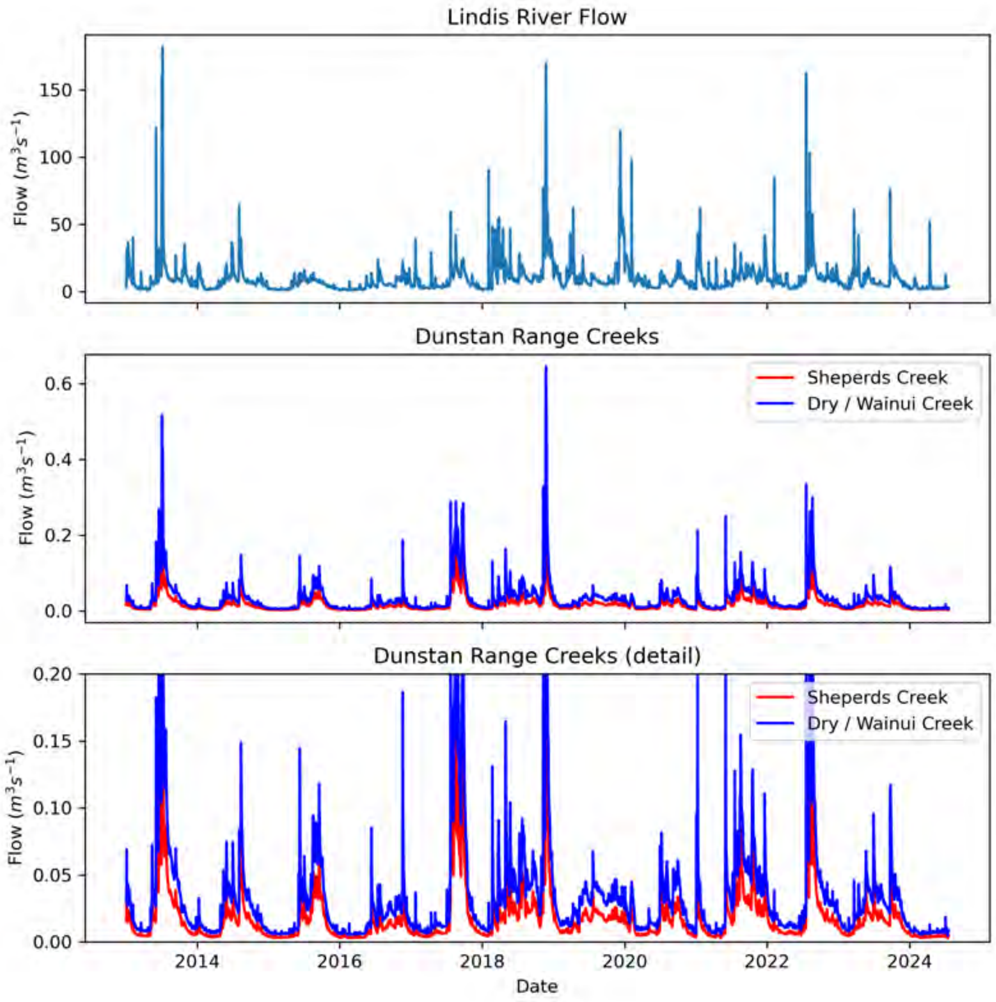

Figure 2.8: River and Dunstan creek flows

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2.4.3 Existing Groundwater Bores

There are 14 existing groundwater bores in the model domain, largely used for domestic and stock water supply. For the purpose of this model, these bores operate as potential receptors of Sheperds Creek water and any contamination that may be present. These wells are shallow with reported depths of 2-30 m. There is minimal abstraction data for these bores, and given the simplicity of the conceptual model we have chosen to simulate these bores in the top layer of the model with a prescribed abstraction rate of 10 m^3d^{-1}. This approach was chosen to allow for the potential of the bores to draw in water from the surrounding area. We report the concentration of Sheperds Creek water in these bores for all layers of the model.

2.4.4 Wainui Creek, Dry Creek, and Sheperds Creek

There are three catchments that drain the Dunstan Mountains into the Southeast portion of the model domain. These catchments, from North to South, are Wainui Creek, Dry Creek, and Sheperds Creek. Sheperds Creek is the primary interest of this model, however flows from Wainui Creek and Dry Creek likely impact the groundwater flow of Sheperds Creek water.

All three streams quickly lose all flow to the groundwater system as it intersects the alluvial basin. Apart from very peak flows, anecdotally only several times in a decade, the streambed from the terrace mouth to the confluence with the Lindis River is dry. Unfortunately there is no streamflow monitoring records for Wainui and Dry Creek and only 2 years of data for Sheperds Creek. To extend the Sheperds Creek record we conducted a cross correlation assessment and modelling of the Cluden Stream flow data, which has a longer 10-year record. Importantly, the Cluden Stream occurs in simliar geological and climatic conditions to Sheperds Creek and is in close proximity to Sheperds Creek (c. 25 km). The flows in Wainui Creek and Dry Creek are assumed to be proportional to the flows in Sheperds Creek by the ratio of the catchment areas. From this we would expect c. 180% of the flow in Sheperds Creek to be in both Wainui and Dry Creek. Figure 2.8 shows the flows in Sheperds Creek and the estimated flows in Wainui and Dry Creek.

2.4.5 Contaminant Sources

To ascertain the relative concentration of "affected" water derived from Sheperds Creek in the model domain, we simulate the concentration of the Sheperds Creek WEL feature with a concentration of 1 and all other water sources with a concentration of 0 for the "affected" period. The "unaffected" period is simulated with all water sources having a concentration of 0. Note this assumes that water from Sheperds Creek will no longer be used for irrigation and other "unaffected" water sources will be used instead.

We chose to simulate the concentration of Sheperds Creek water rather than a contaminant because at the time of modelling there were no set contaminant concentrations for Sheperds Creek water. Instead, this approach allows for the relative attribution of Sheperds Creek water to be assessed without the need for bespoke contaminant concentration data. However, this assumes that any contaminants in Sheperds Creek water will not vary in concentration over time or at different streamflow rates. This may lead to an under or over estimation of receptor concentrations and subsequent modelling should be conducted with more detailed contaminant loading data.

2.5 Numerical Model Parameterisation

Given the lack of observation data in the Ard. Aquifer, we used a range of plausible parameter values for the model. The model has the following variable parameters and values:

- Horizontal hydraulic conductivity (k_h): (50, 150, 210, 500, 1000) md^{-1}
- Vertical hydraulic conductivity ratio (vka): (1, 10) where $k_v = \frac{k_h}{vka}$
- Specific yield (s_y): (0.1, 0.2) dimensionless
- Stream conductance ($cond$): (50, 500, 5000) m^{2}d^{-1}
- Effective porosity (por): (0.20, .225, 0.25) dimensionless

In addition, the following parameters were set as constants:

- Specific storage (s_s): 1E-5 m^{-1}
- Longitudinal dispersivity (dsp_{lon}): 0.1 m
- Ratio of the horizontal transverse dispersivity to the longitudinal dispersivity (dsp_{trpt}): 0.1
- Ratio of the vertical transverse dispersivity to the longitudinal dispersivity(dsp_{trpv}): 0.01

2.6 Numerical Model simulations

The model was run for each unique combination of the model parameters for both the steady-state and transient flow models and the subsequent transient transport model. Given the uncertainty in the model parameters, the results are presented as a range of possible outcomes (the minium and maximum values) for each prediction point across all simulations.

3 Model Results

3.1 Steady State Flow

Figure 3.1 to Figure 3.4 show the mean steady state model heads across all simulations for each layer. The model results are consistent with the conceptual model of the hydrogeological environment and suggest relatively homogenous water table elevations across the model domain. In addition, these results suggests that the inflows from the Dunstan Mountains are not significant enough to create a significant hydraulic gradient across the model domain. Instead, the dominant gradient is likely to be generally down valley parallel to the Lindis River.

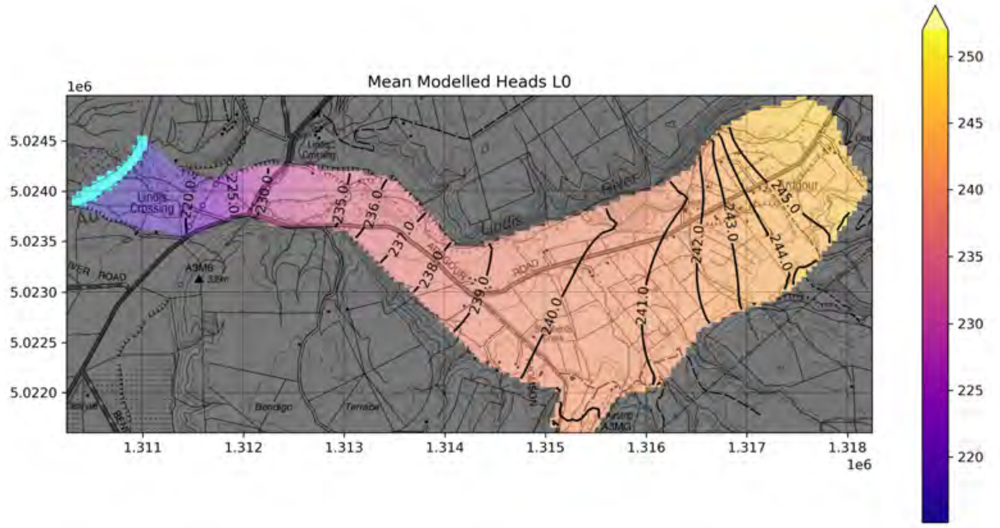

Figure 3.1: Mean steady state model heads across all simulations for layer 0

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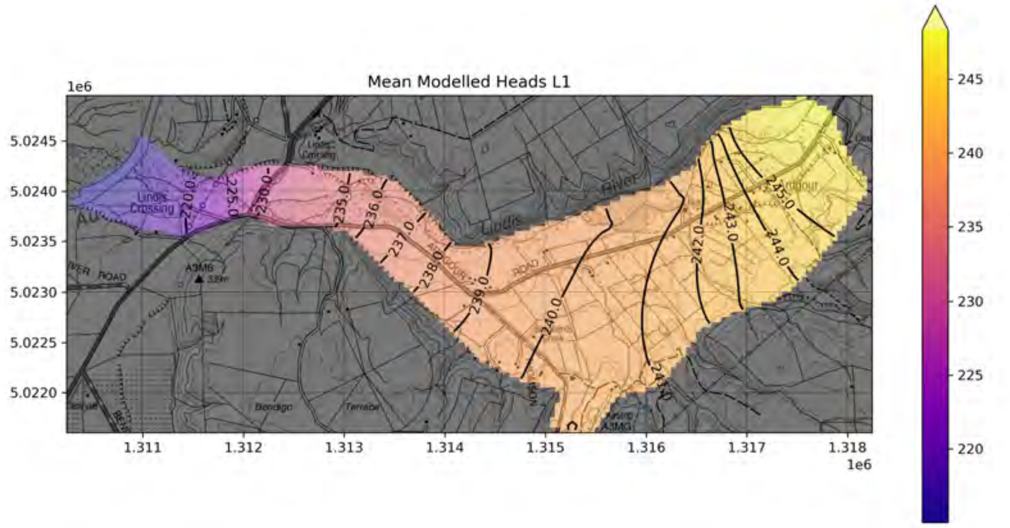

Figure 3.2: Mean steady state model heads across all simulations for layer 1

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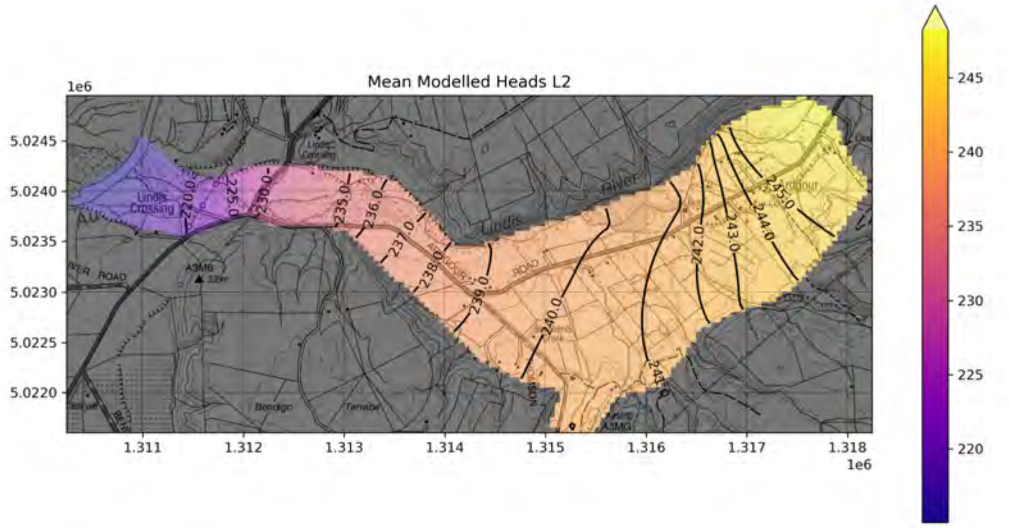

Figure 3.3: Mean steady state model heads across all simulations for layer 2

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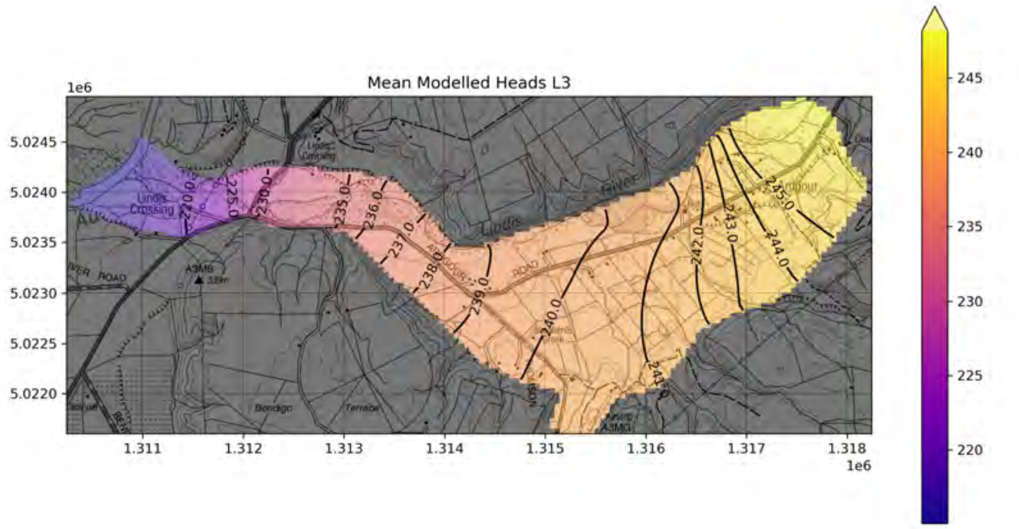

Figure 3.4: Mean steady state model heads across all simulations for layer 3

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3.2 Sheperds Creek Influence under Steady State Conditions

Figure 3.5 shows the maximum percentage of Sheperds Creek water across all layers at the end of the proposed activity time period for all simulations. Note this is a spatial cell by cell maximum percentage. The value reported is the maximum percentage of Sheperds Creek water in any layer and simulations for a given spatial cell. Figure 3.6 to Figure 3.9 similarly shows the maximum percentage of Sheperds Creek water for each layer at the end of the proposed activity time period for all simulations.

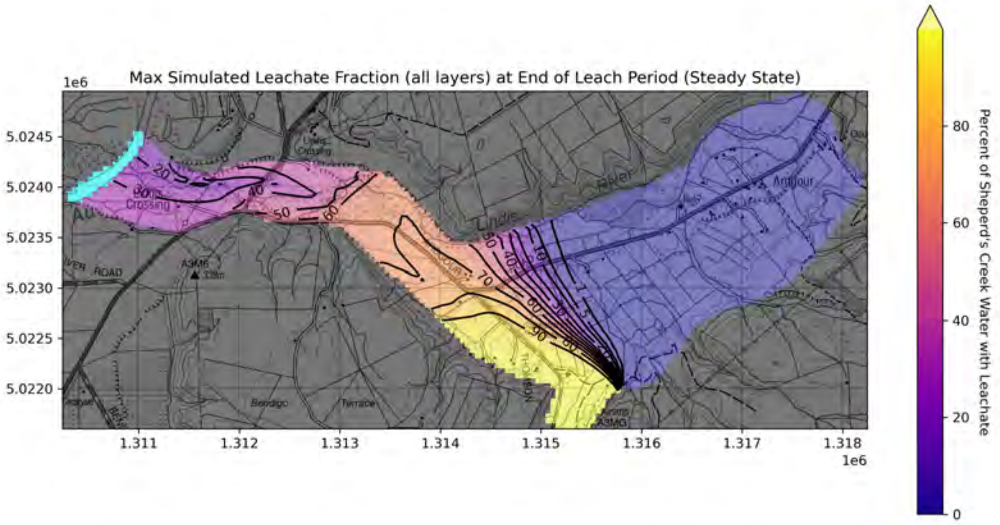

Figure 3.5: Maximum Percentage of Sheperds Creek water across all layers at the end of the proposed activity time period

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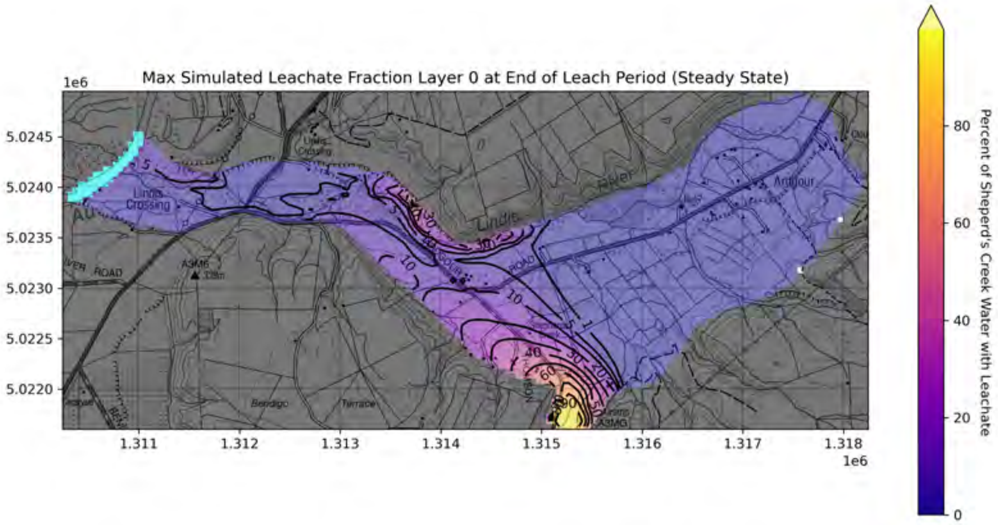

Figure 3.6: Maximum Percentage of Sheperds Creek water for layer 0 at the end of the proposed activity time period

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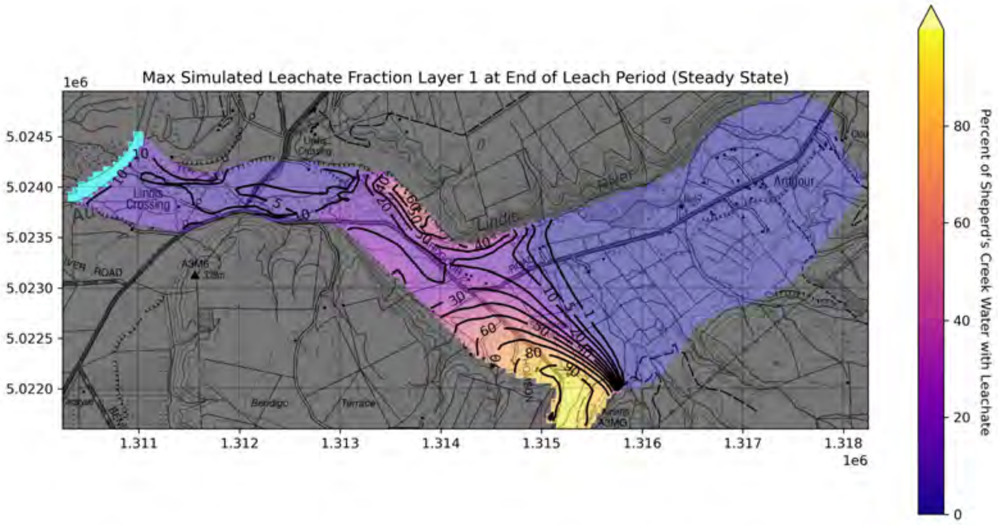

Figure 3.7: Maximum Percentage of Sheperds Creek water for layer 1 at the end of the proposed activity time period

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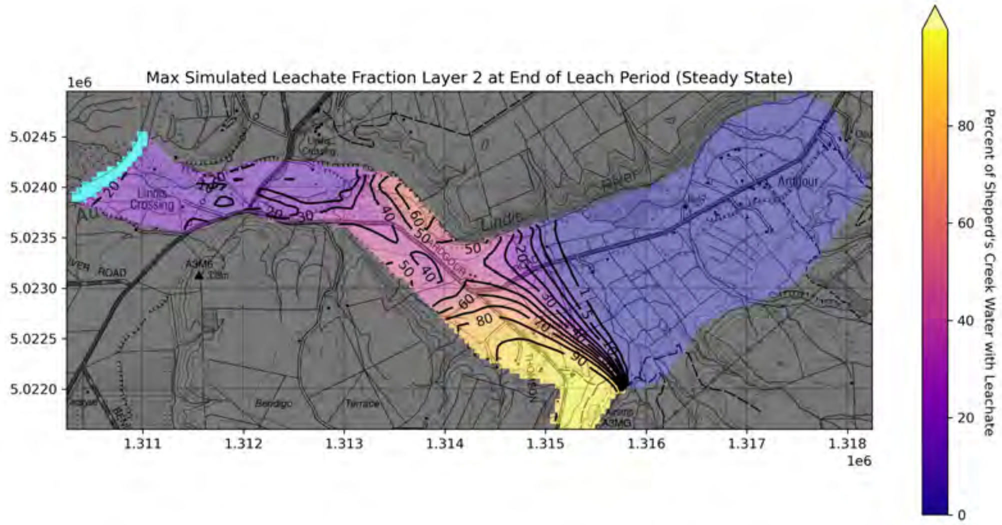

Figure 3.8: Maximum Percentage of Sheperds Creek water for layer 2 at the end of the proposed activity time period

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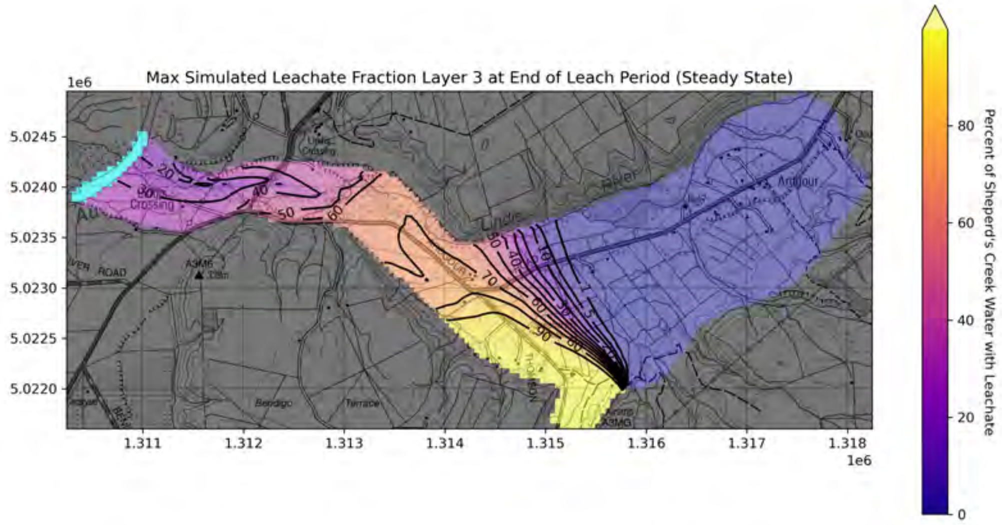

Figure 3.9: Maximum Percentage of Sheperds Creek water for layer 3 at the end of the proposed activity time period

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3.3 Sheperds Creek Influence under Transient Conditions

Figure 3.10 to Figure 3.17 show the range of maximum concentration along each cross section over the full transient simulation. Note that each line in the plot represents a single simulation (e.g., unique combination of parameters), but that there may be multiple simulations which yield similar results.

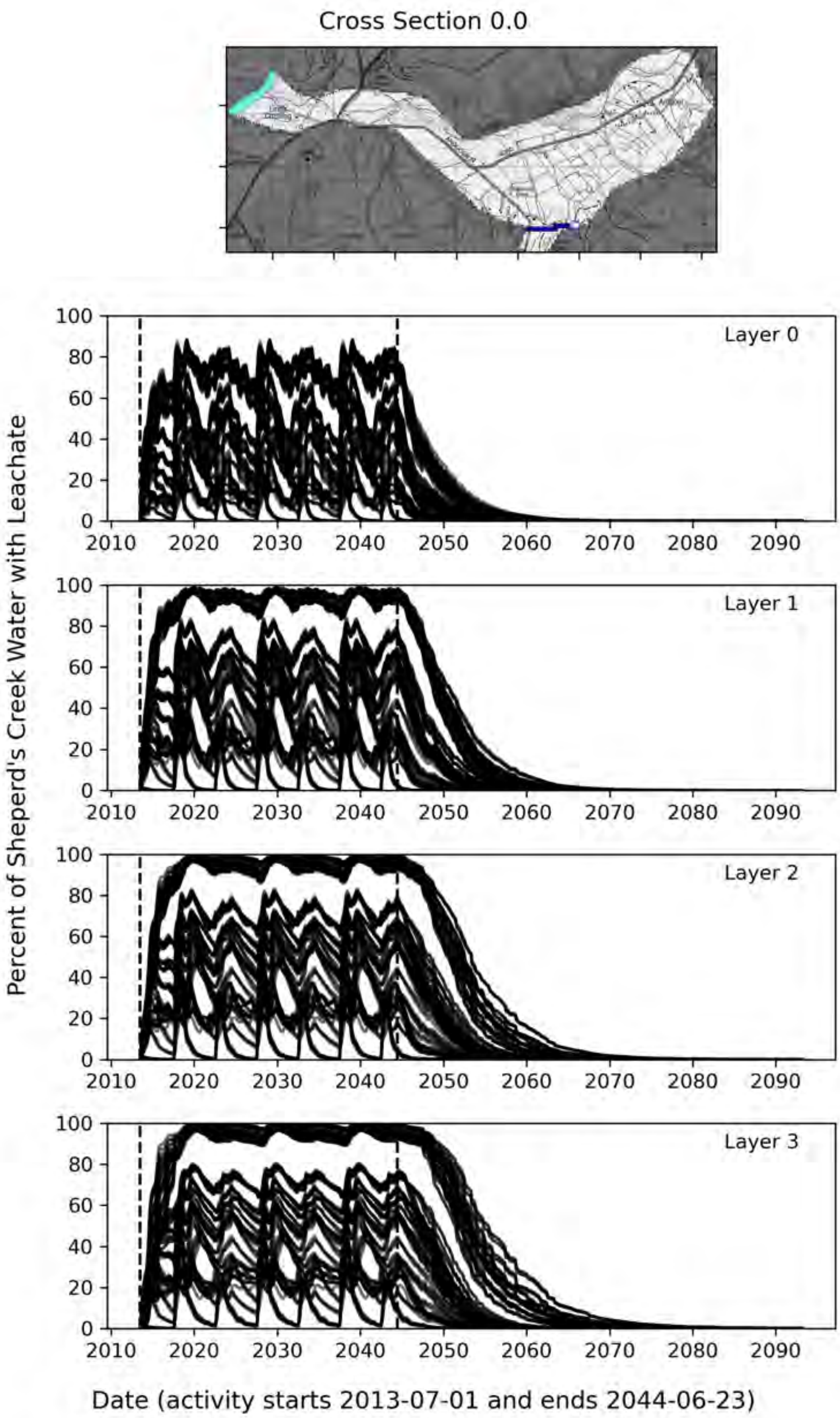

Figure 3.10: Range of maximum concentration along cross Section 0

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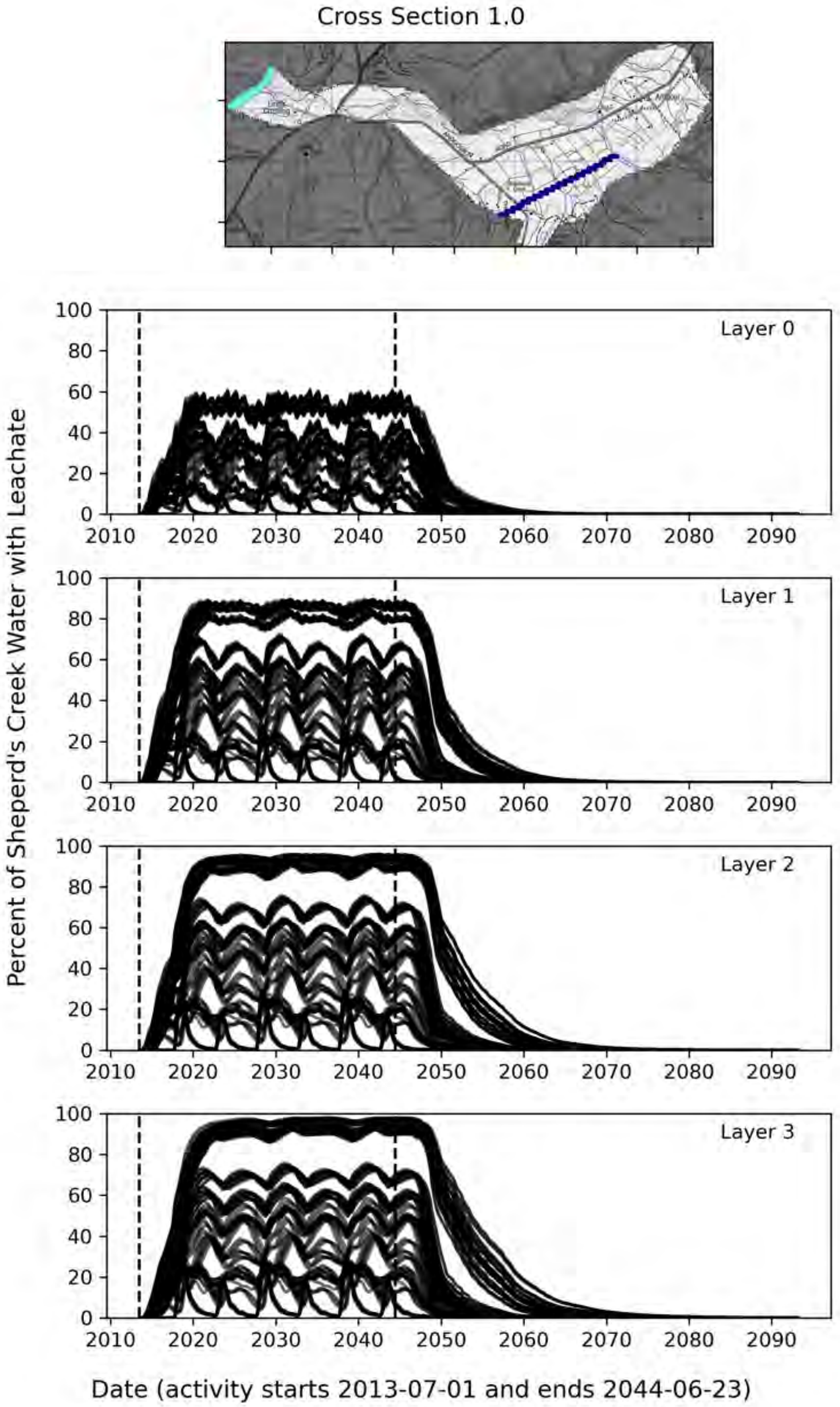

Figure 3.11: Range of maximum concentration along cross Section 1

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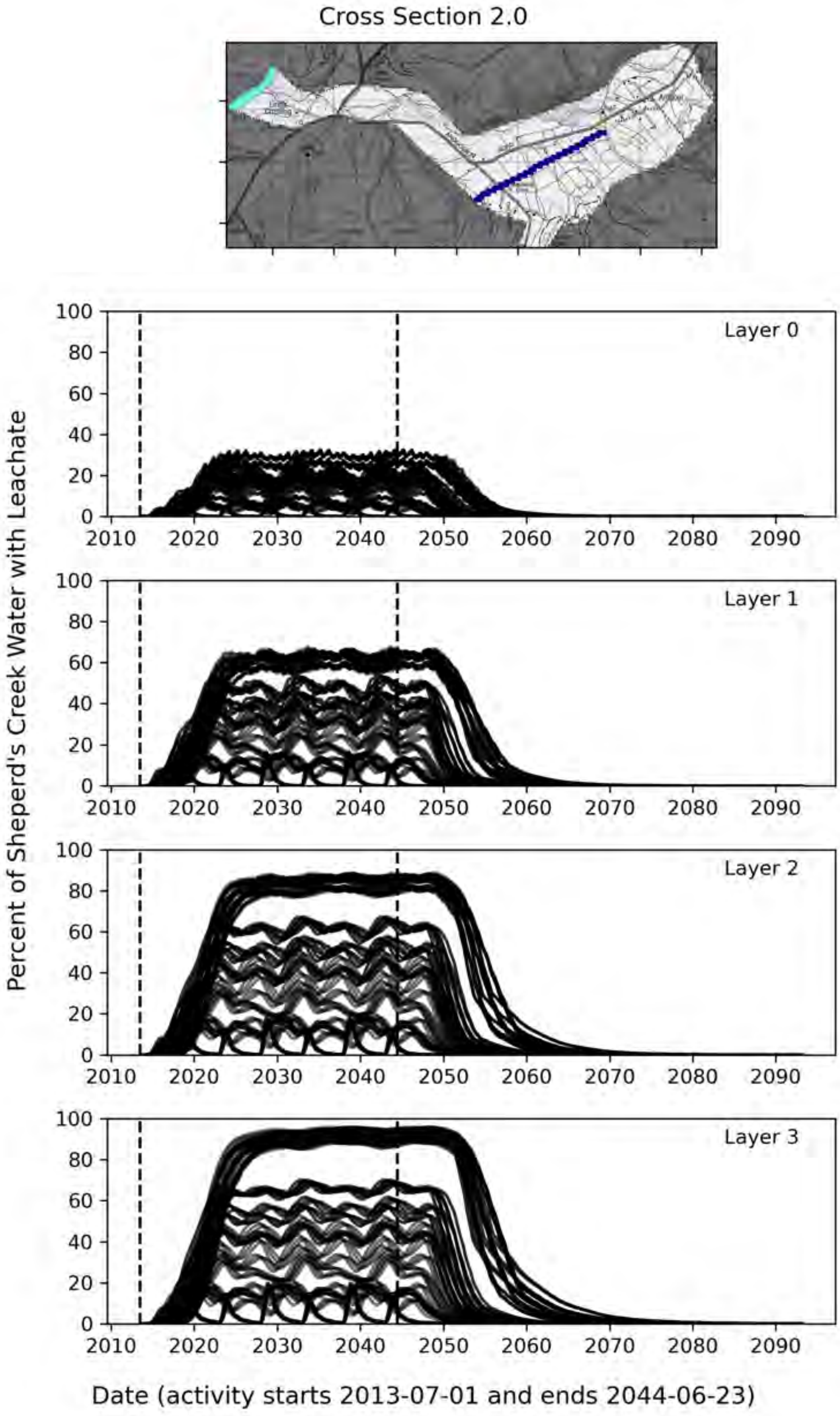

Figure 3.12: Range of maximum concentration along cross Section 2

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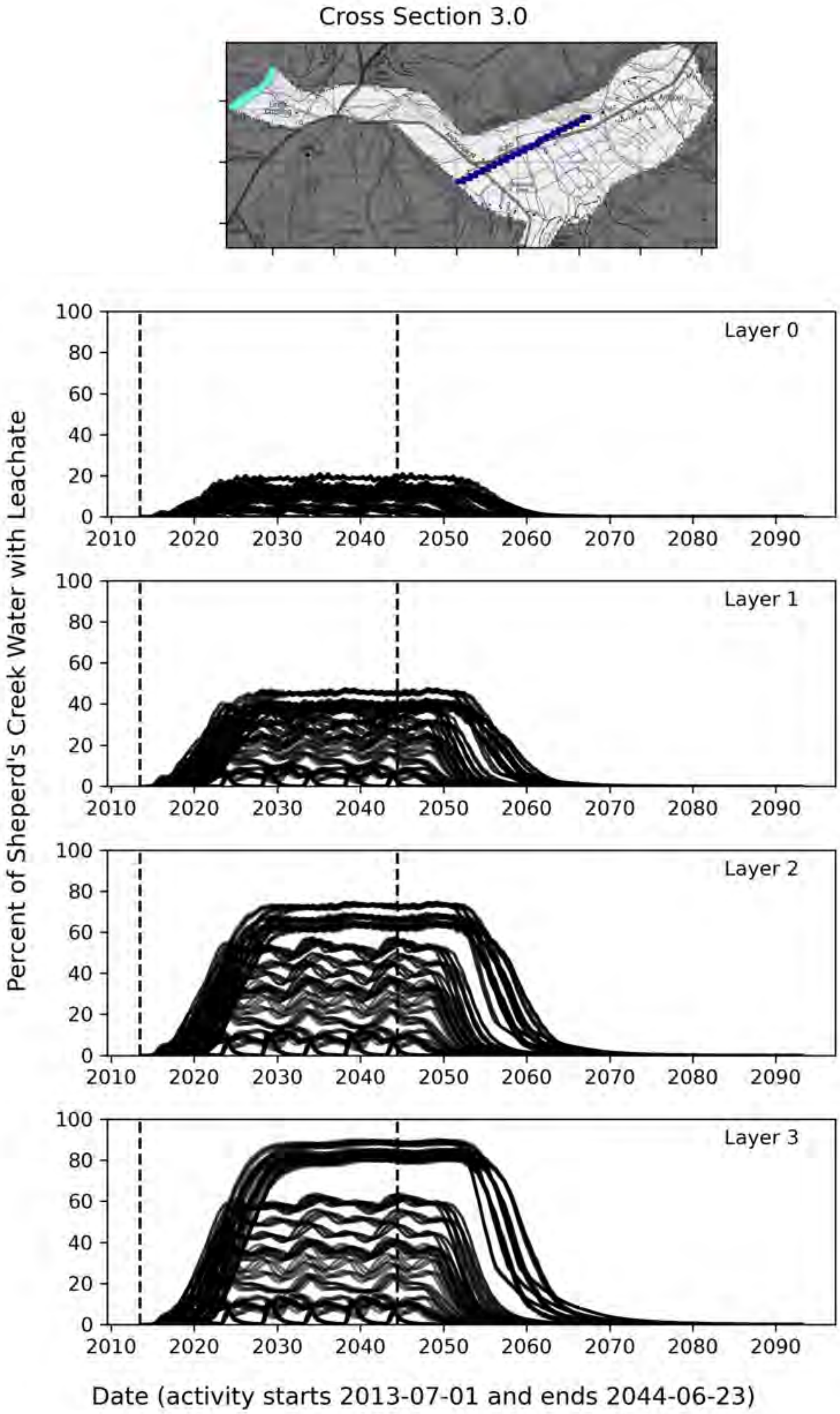

Figure 3.13: Range of maximum concentration along cross Section 3

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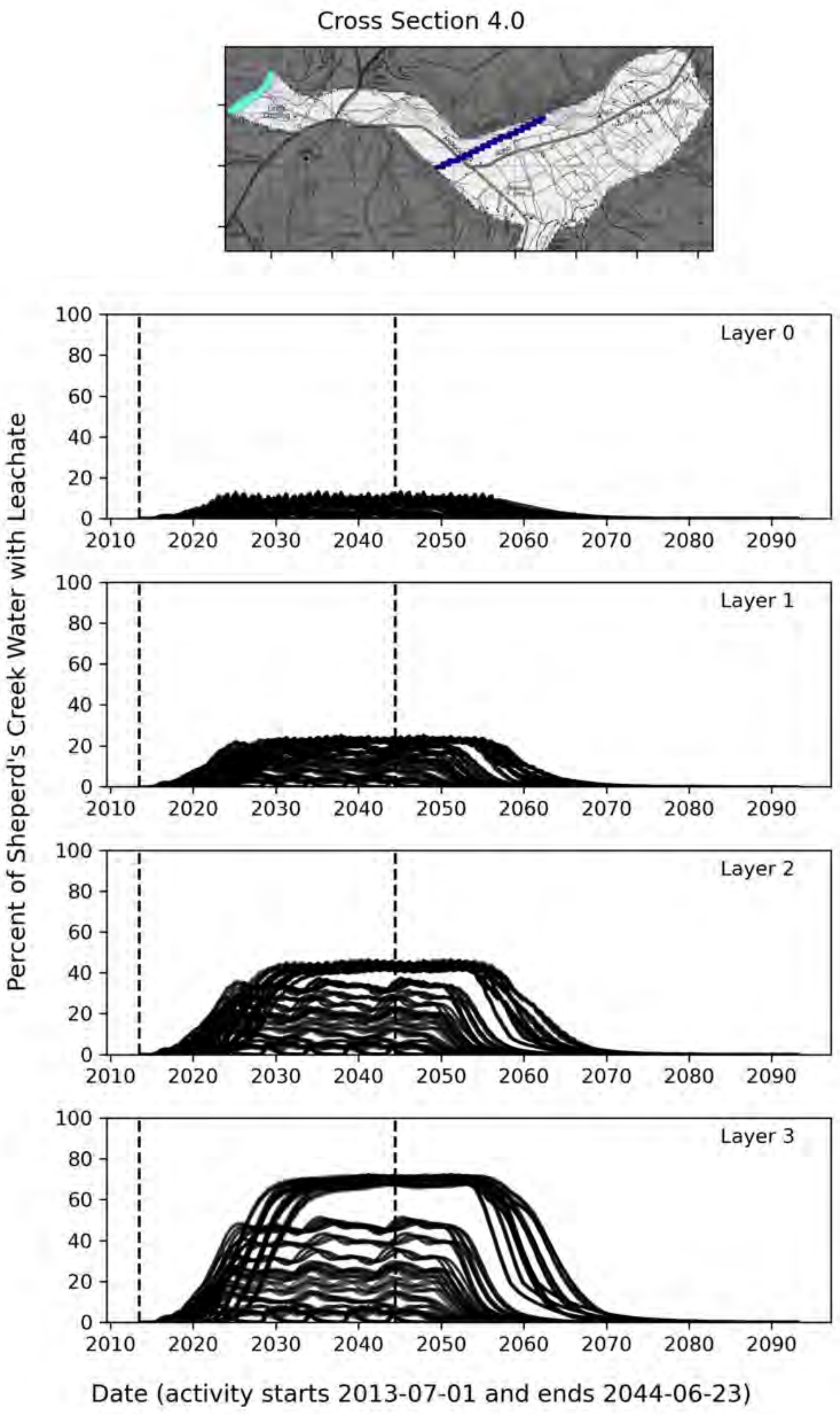

Figure 3.14: Range of maximum concentration along cross Section 4

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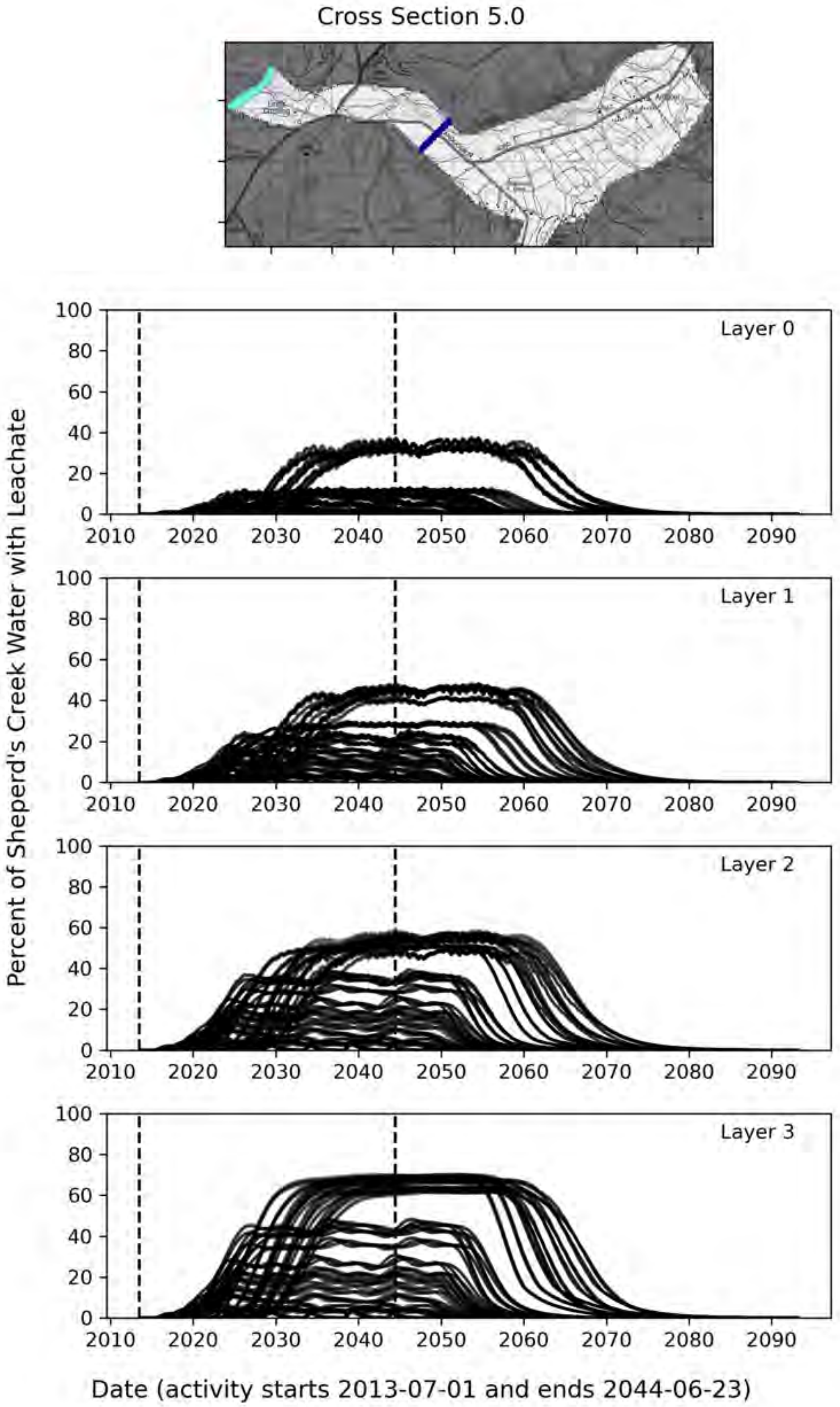

Figure 3.15: Range of maximum concentration along cross Section 5

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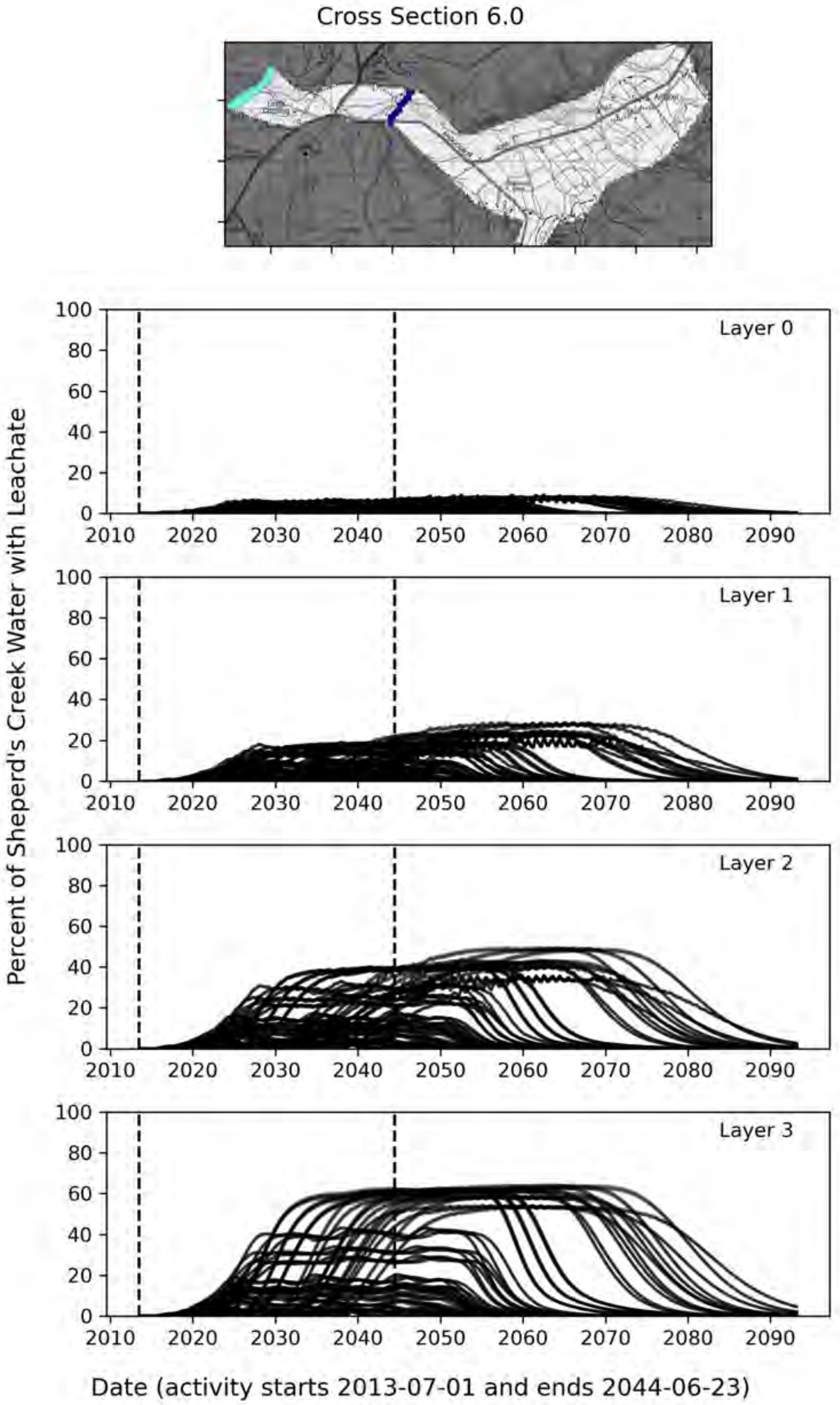

Figure 3.16: Range of maximum concentration along cross Section 6

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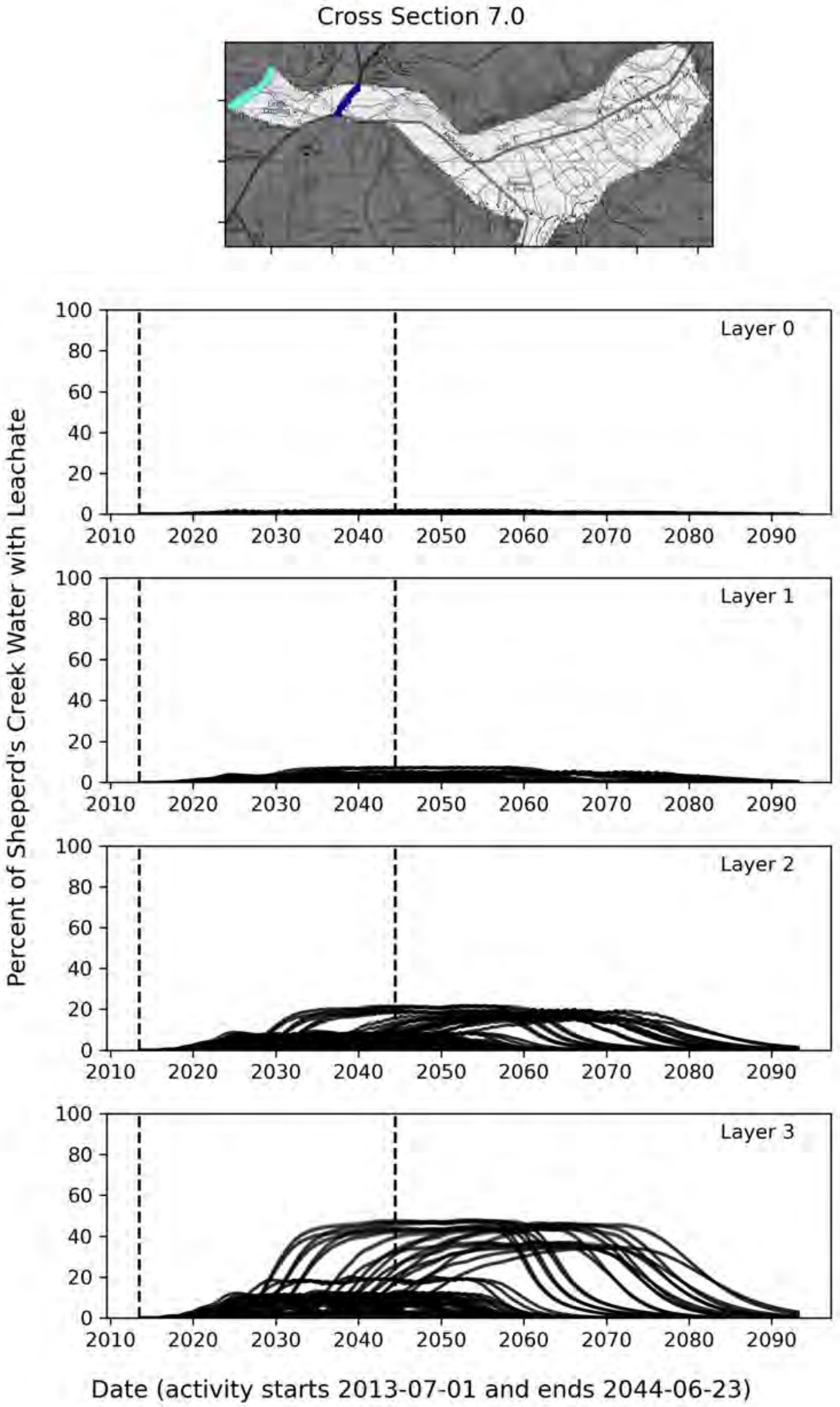

Figure 3.17: Range of maximum concentration along cross Section 7

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3.4 Transient Influence on Existing Bores

Figure 3.18 to Figure 3.25 show the range of maximum concentration at each bore over the full transient simulation. Note that we have excluded some bores as there was no or very minimal modelled influence of Sheperds Creek at any layer. These excluded bores are:

- Cb13_0170
- G41_0152
- G41_0249
- G41_0285
- G41_0369
- G41_0382

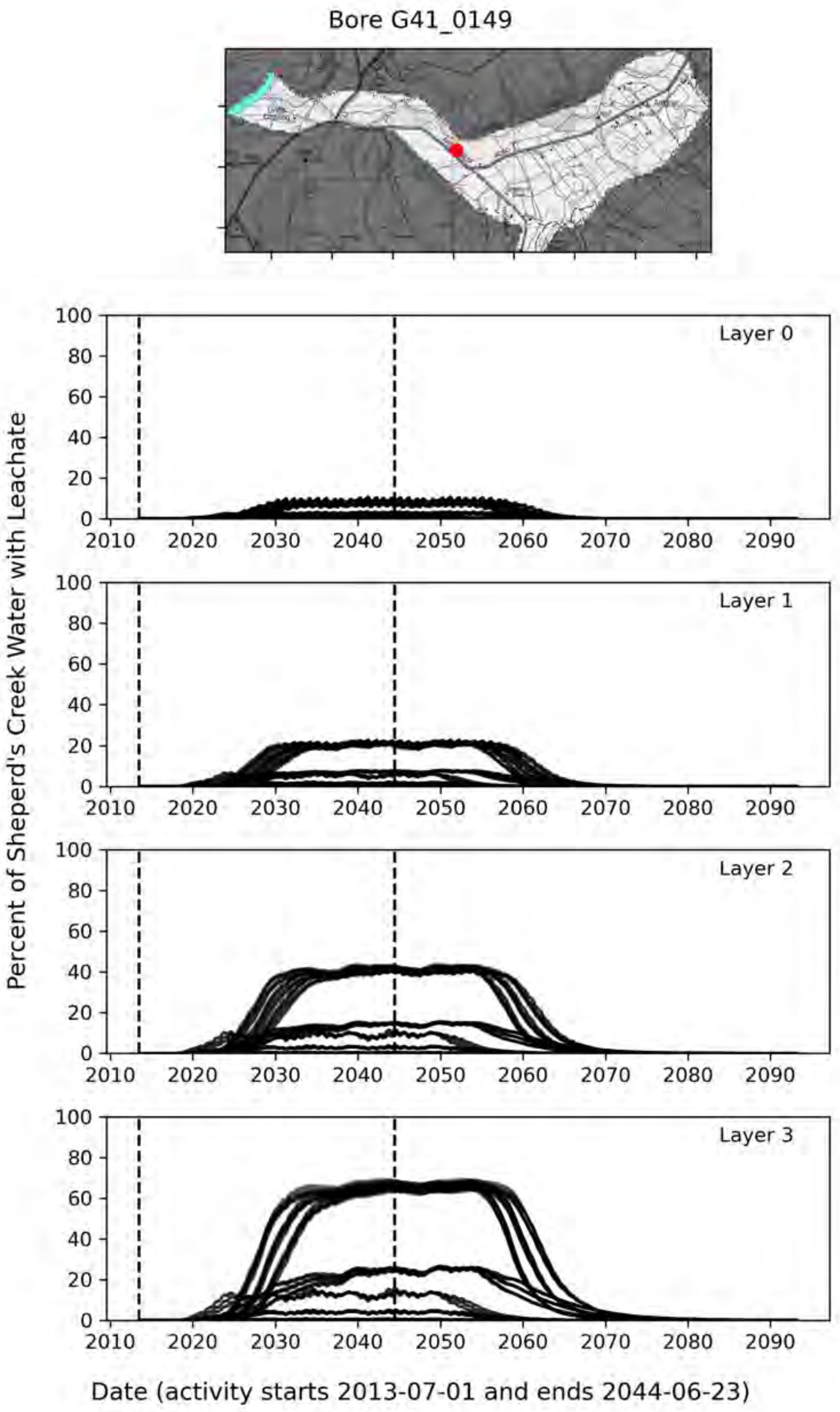

Figure 3.18: Transient Influence on Bore g41/0149

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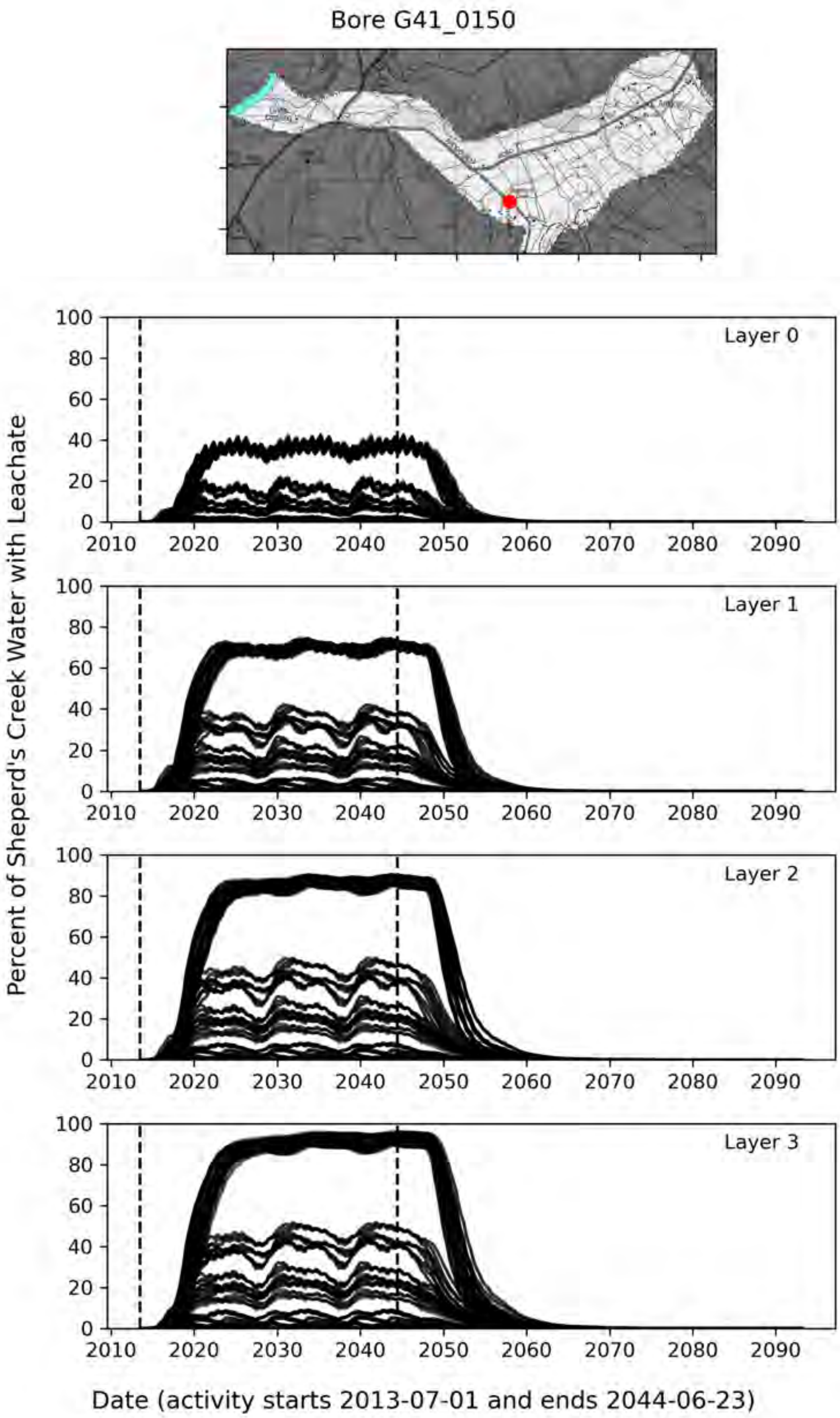

Figure 3.19: Transient Influence on Bore g41/0150

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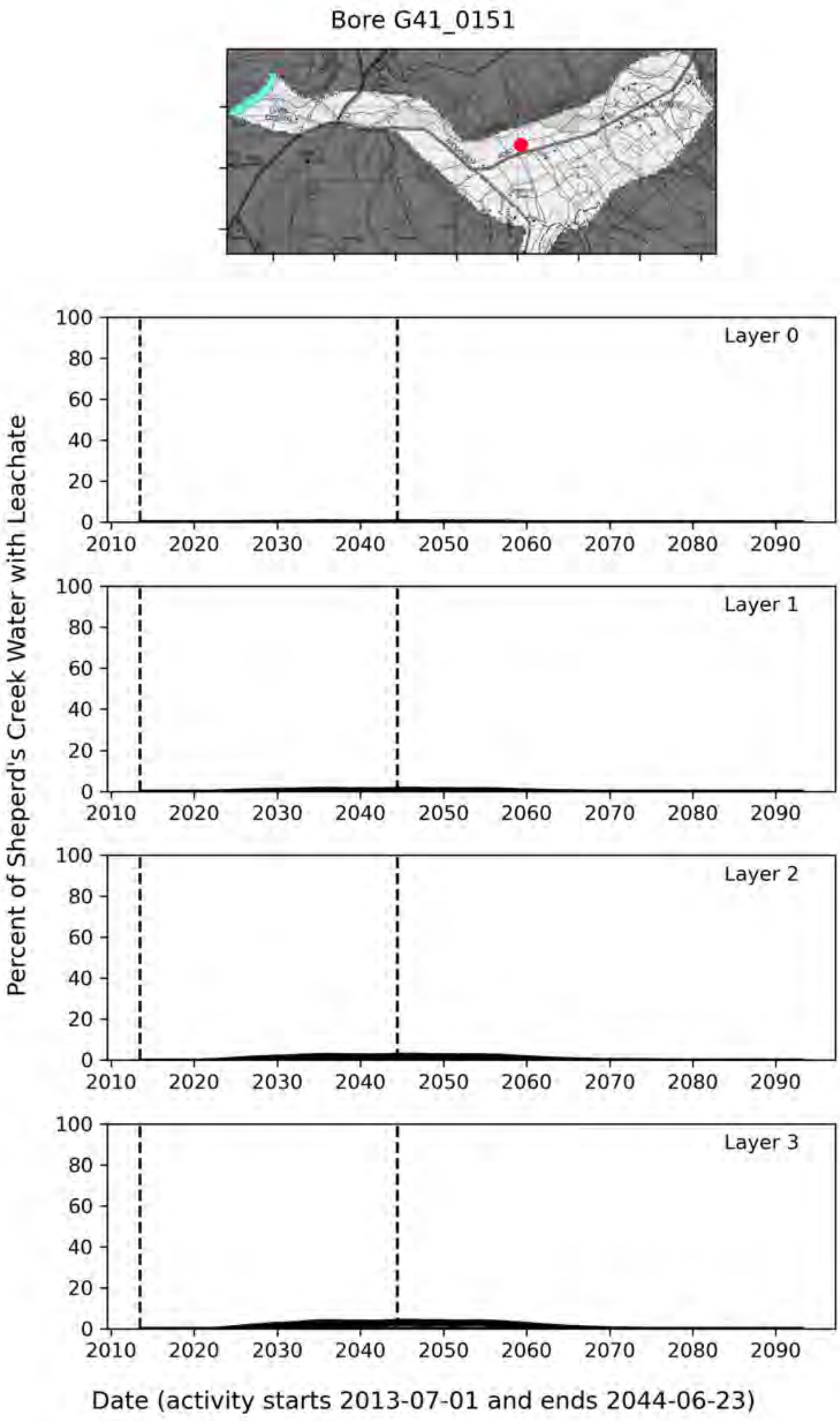

Figure 3.20: Transient Influence on Bore g41/0151

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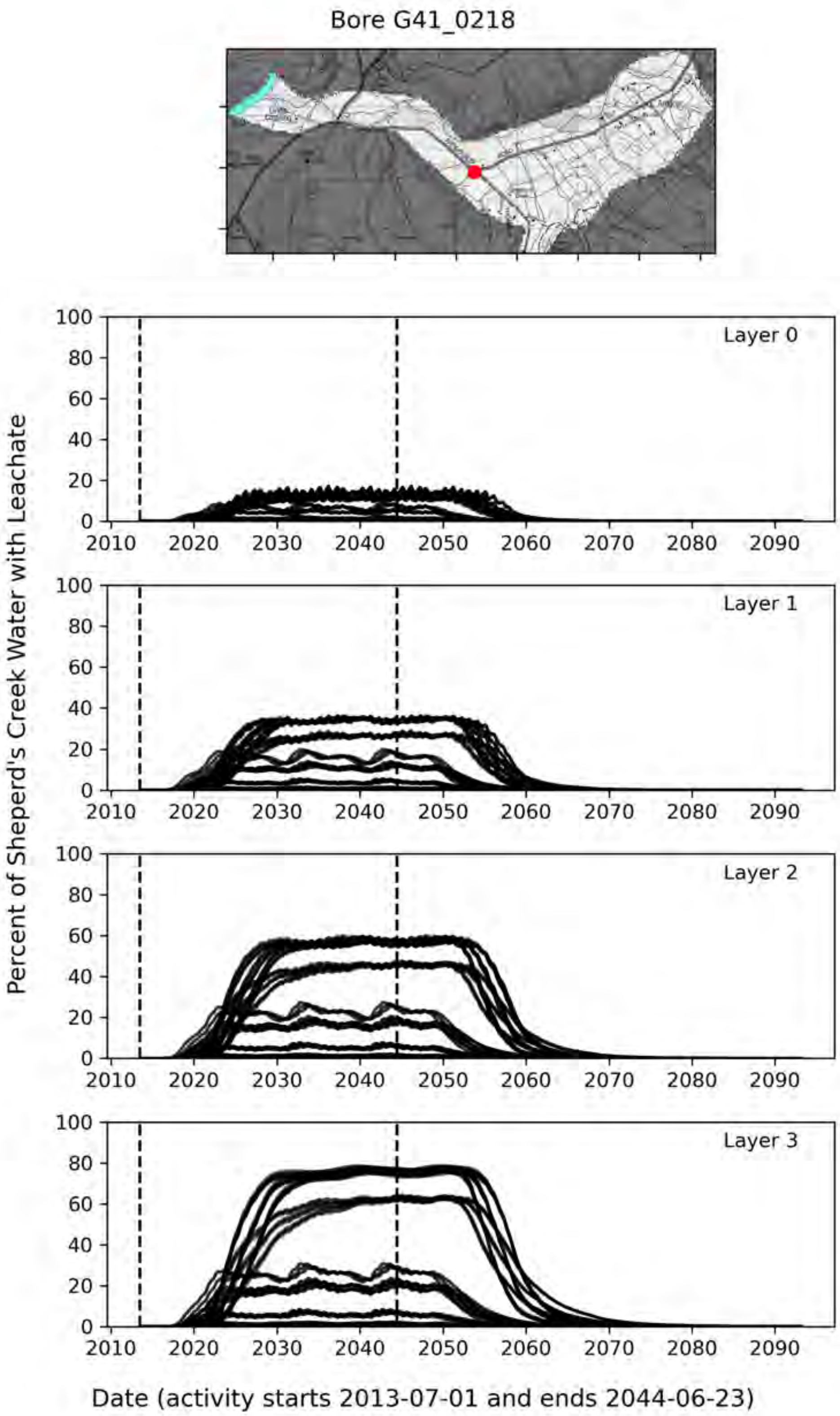

Figure 3.21: Transient Influence on Bore g41/0218

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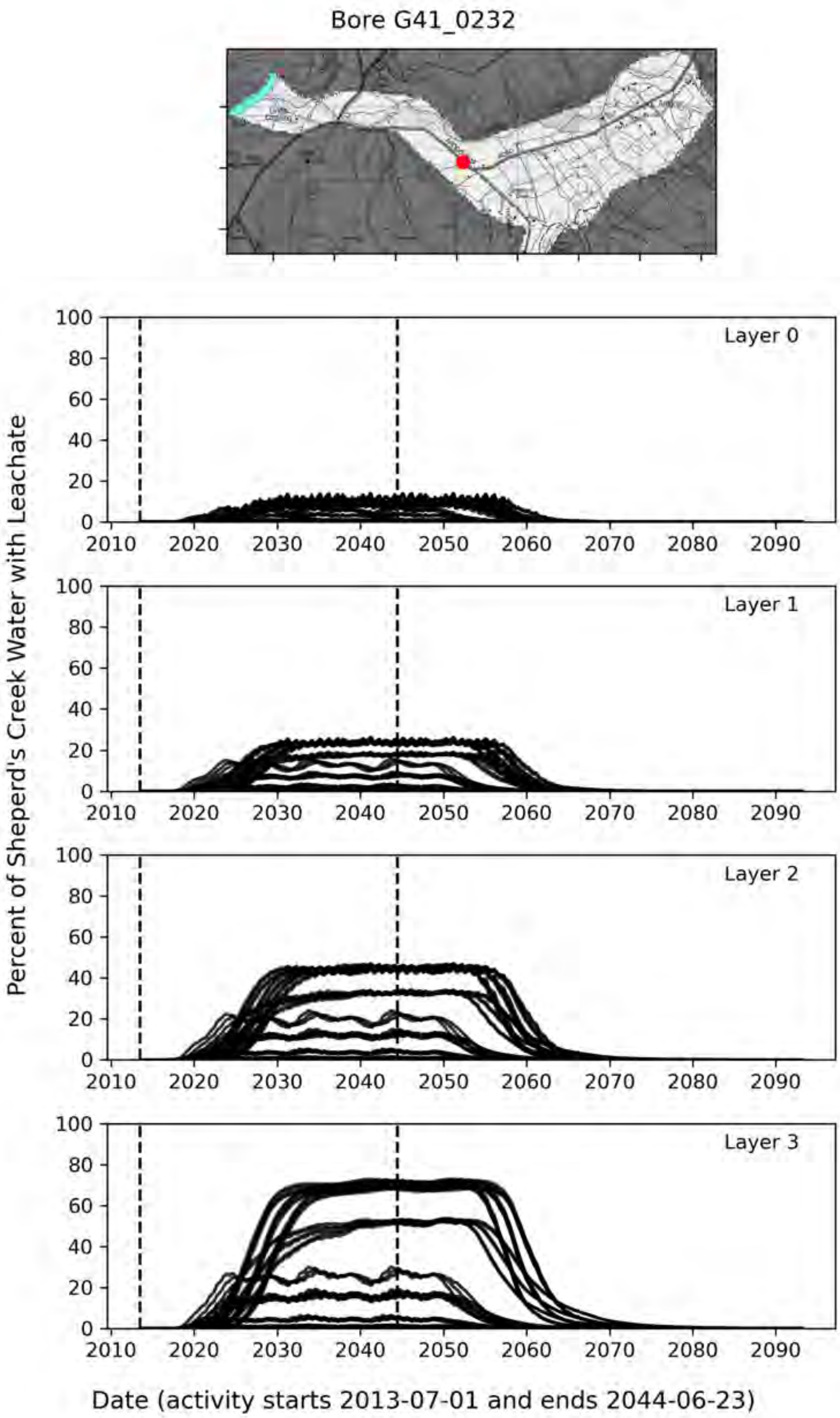

Figure 3.22: Transient Influence on Bore g41/0232

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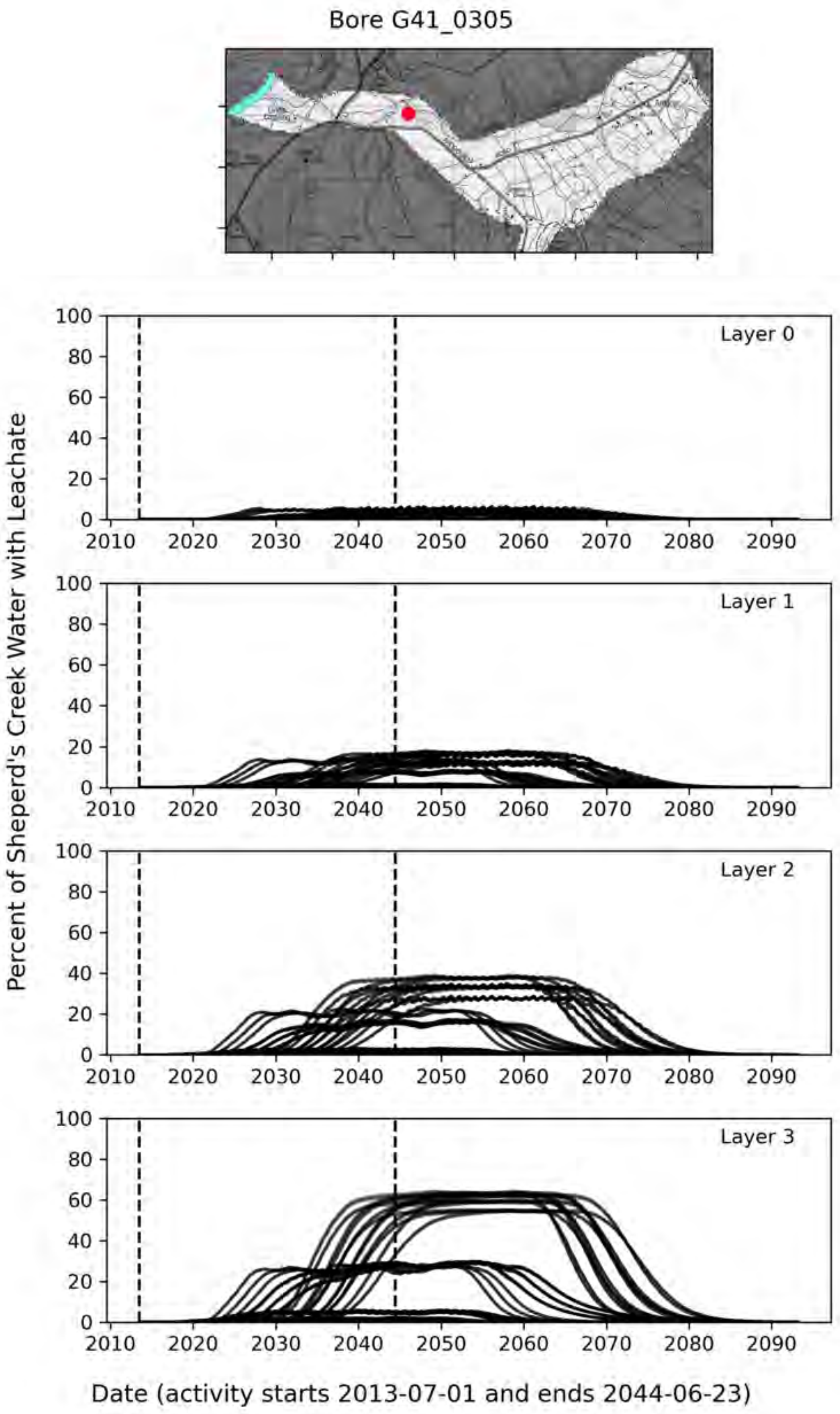

Figure 3.23: Transient Influence on Bore g41/0305

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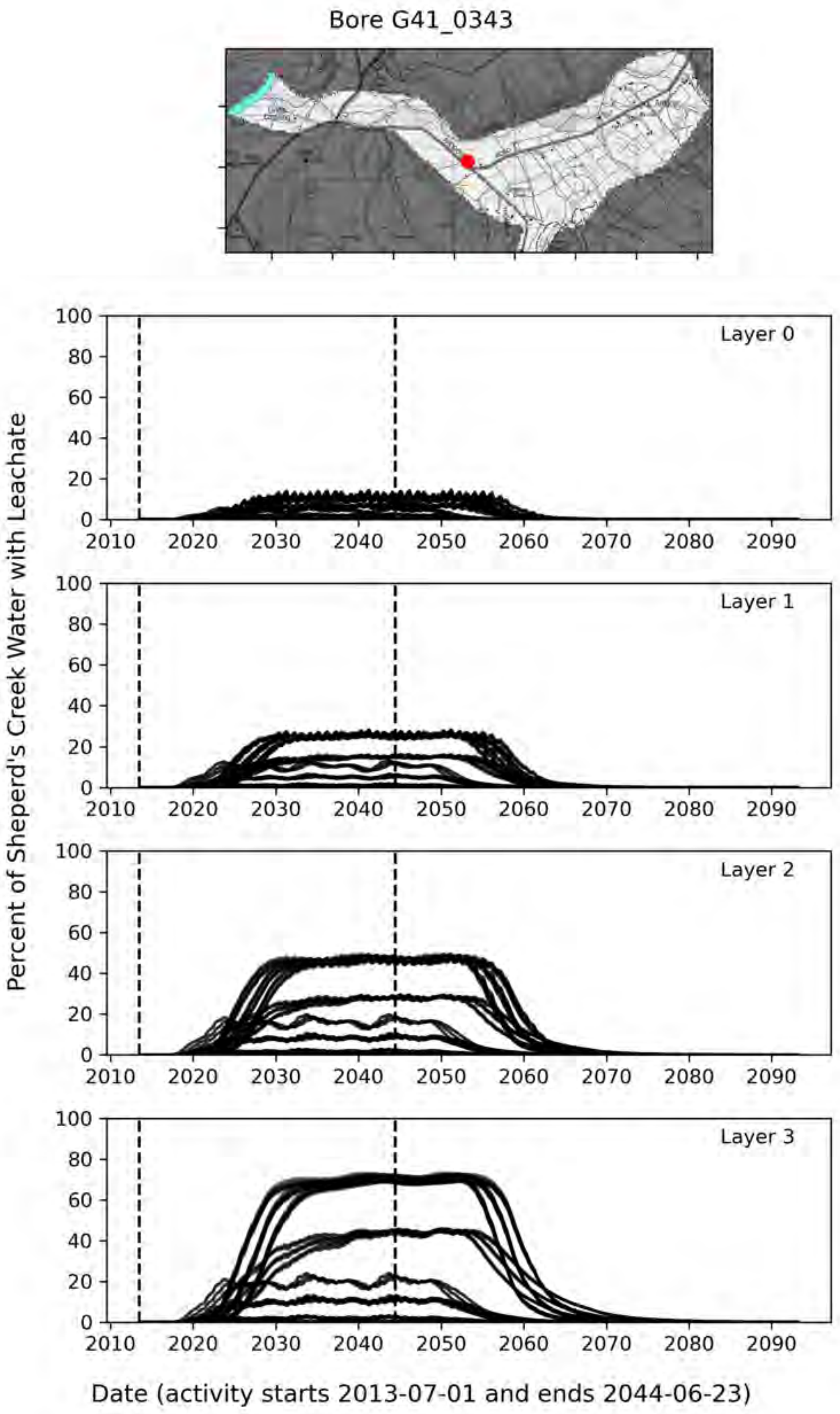

Figure 3.24: Transient Influence on Bore g41/0343

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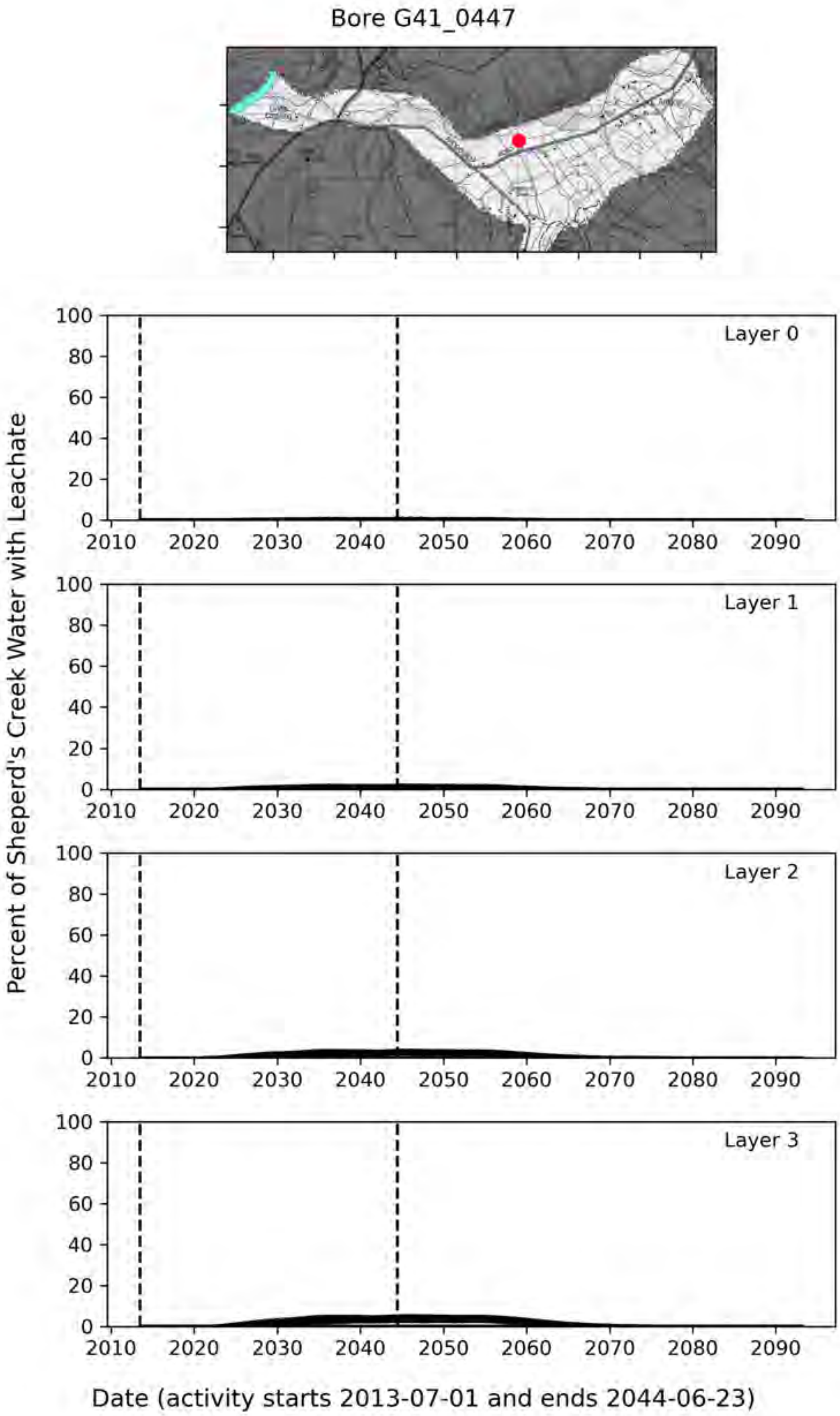

Figure 3.25: Transient Influence on Bore g41/0447

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4 Discussion

4.1 Model Limitations

The model is very limited by the minimal information available to constrain the model results. Typically, numerical groundwater models would undergo calibration and validation to ensure that the model is at least consistent with the observed data. Since there is no observed data, the model results are not validated. Instead, we have used a range of plausible parameter values to explore the potential range of model predictions. The range of these values are based on the available information and expert judgement. The parameter ranges have also been inflated (i.e., increasing the upper bound and decreasing the lower bound) to give higher confidence that the "true" value is within the range provided. Any interpretation of the model results should be done with caution and approached conservatively. It is possible that some processes are not represented in the model and therefore there is a risk that the true behaviour of the system is not captured by the model.

4.2 Discussion of Model Results

The model results must be considered in the context of the limitations of the model Section 4.1. Nevertheless, some general observations can be made based on the model results. First, as expected, the influence of Sheperds Creek decreases down gradient, as is expected for a typical contaminant plume. Second, the model results suggest that the lower sections of the aquifer are more likely to be influenced by Sheperds Creek than the upper sections, particularly as the contaminant plume moves down gradient. Third, any contaminant plume is likely to be transported relatively quickly through the aquifer. Table 4.1 summarises the cross-sections and the time to breakthrough and recovery. Figure 3.17, which is the furthest downstream cross-section, suggests that the breakthrough of a contaminant plume should be expected within 10-20 years after the start of the activity and that the contaminant plume should largely be dissipated within 50 years after the cessation of the activity.

Table 4.1: Breakthrough (>10%) and Recovery (<10%) times (years) for each cross section. Note that simulations that do not exceed 10% concentration are excluded.

	Breakthrough (yr)	Recovery (yr)
Cross Section 0.0	0.57 - 3.41	0.87 - 25.48
Cross Section 1.0	1.42 - 12.99	0.87 - 18.73
Cross Section 2.0	2.80 - 6.63	2.48 - 20.11
Cross Section 3.0	3.95 - 9.69	2.63 - 20.50
Cross Section 4.0	5.86 - 21.96	2.10 - 23.03
Cross Section 5.0	6.78 - 17.82	6.70 - 26.63
Cross Section 6.0	8.39 - 26.87	6.93 - 44.80
Cross Section 7.0	12.84 - 34.07	0.03 - 38.05

The spatial location of the contaminant plume is also highly variable, with different parameter sets yielding different results. Figure 4.1 shows two examples of the range of contaminant plume spatial distributions. The maximum percentage Sheperds Creek water in the plumes pictured varies from 90% to just over 40%. Given the minimal information available to constrain the model, it is difficult to say which of these is more likely, however more information could be used to reduce this uncertainty, see Section 4.4.

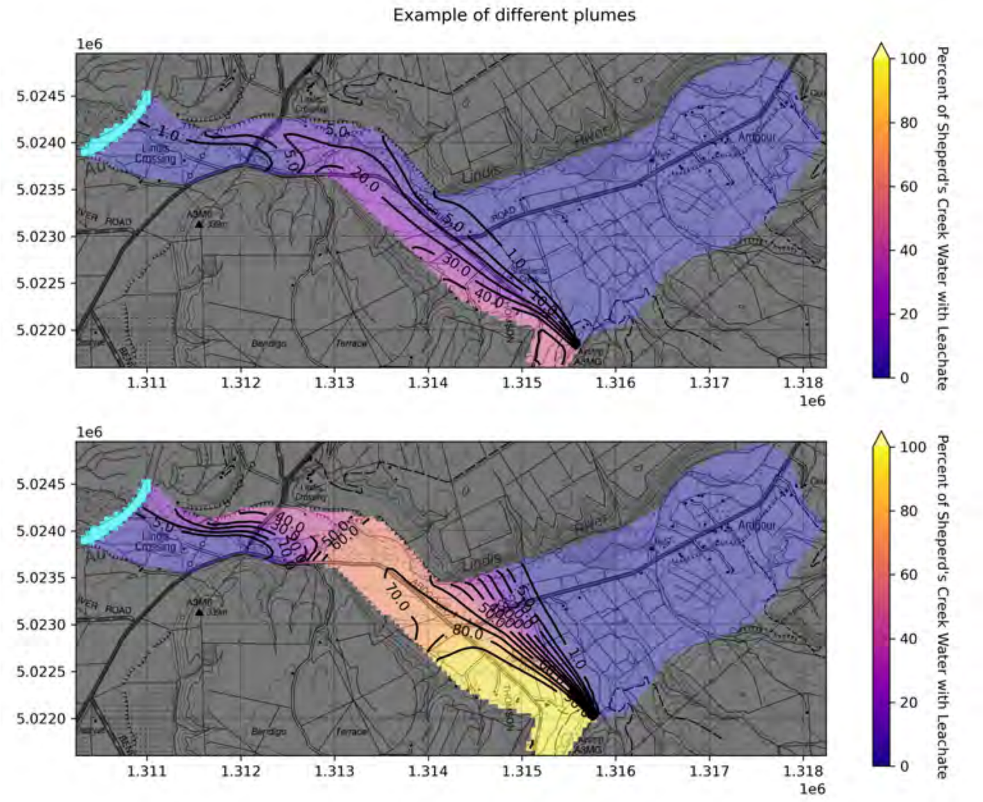

Figure 4.1: Examples of the range of contaminant plume spatial distributions

Note the concentration is the maximum of all layers

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4.3 Maximum Dilution Factors

The key prediction of interest is the maximum dilution factor of the contaminant plume spatially and at existing groundwater bores. As discussed in Section 4.1, no one model realisation is more likely than any other and the realisations cannot be viewed as a probability distribution. Therefore, we have interpreted the results in a conservative manner. Additionally, although all model realisations suggest that concentrations are likely to be higher in the lower sections of the aquifer, the layer structure here is poorly defined and constrained. Groundwater bores may be present in any layer and abstraction could draw up contaminants from deeper in the system. The specifics of these interactions are poorly constrained, so we have taken the maximum concentration across all layers at each bore location as the most conservative estimate of the maximum dilution factor at each bore.

Figure 4.2 shows the conservative estimate of the maximum dilution factor that should be assumed spatially across the aquifer. Table 4.2 applies the same conservative approach to the bore locations for existing wells. The maximum dilution factor for many bores is less than or equal to 5%, which suggests that based on the current knowledge of the system, the risk of contamination of the groundwater cannot be significantly mitigated by dilution within the aquifer. Note that as per Section 4.1 and Section 4.2, these results could change dramatically with more information. Additional information could confidently reject the parameterisations that

Table 4.2: Maximum dilution at bore locations

Bore Name	Max Dilution
cb13_0170	Unlikely to be significantly impacted
g41_0149	Up to 5%
g41_0150	Assume no dilution
g41_0151	Unlikely to be significantly impacted
g41_0152	Unlikely to be significantly impacted
g41_0218	Up to 5%
g41_0232	Up to 5%
g41_0249	Unlikely to be significantly impacted
g41_0285	Unlikely to be significantly impacted
g41_0305	Up to 25%
g41_0343	Up to 5%
g41_0369	Unlikely to be significantly impacted
g41_0382	Unlikely to be significantly impacted
g41_0447	Up to 65%

yield minimal dilution of contaminants in the aquifer and thus allow for a more confident assessment for the potential for dilution to mitigate the risk of contamination. Section 4.4 discusses some options to reduce this uncertainty.

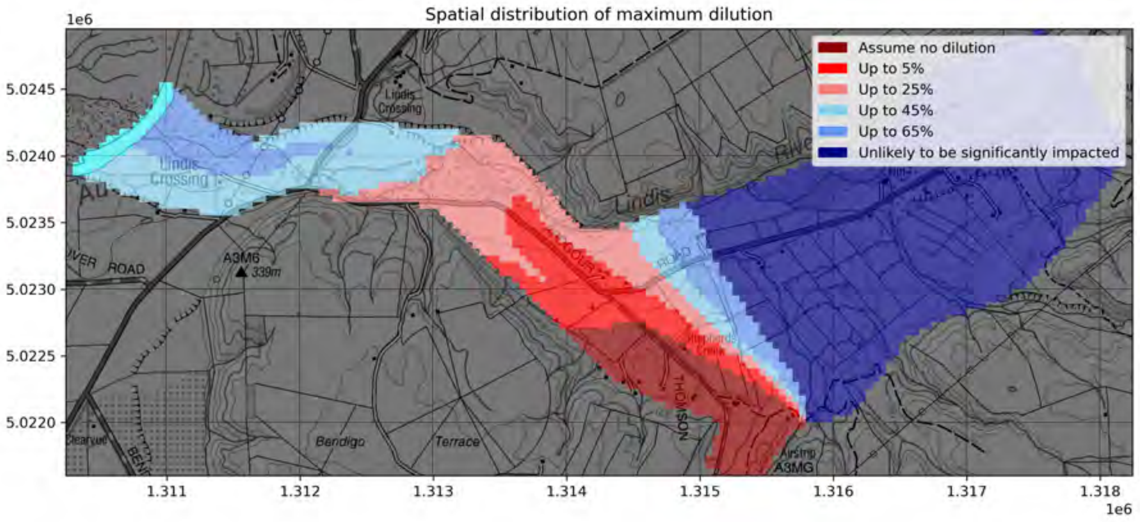

Figure 4.2: Maximum dilution factor to assume across the aquifer

Note the dilution factor has been reduced by 5% as a conservative estimate

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4.4 Options to Reduce Uncertainty

The current model results cannot preclude minimal dilution of contaminants in the aquifer, however the model is highly uncertain. Further investigation could be undertaken to reduce this uncertainty. It is beyond the scope of this report to provide detailed proposals for further investigation, however we suggest the following as potential options to reduce uncertainty:

1. Piezometric survey
2. Pumping tests
3. Injection tests
4. Push-pull tests
5. Water Chemistry Survey
6. Numerical experiments

We provide a brief discussion of each of these options in the sections below.

4.4.1 Piezometric Survey

A piezometric survey could be undertaken to provide a snapshot of the piezometric surface. Figure 4.3 shows the range of steady state model heads across all simulations. There would likely be significant co-variance between the input uncertainties and the piezometric surface. Of particular difficulty would be the interaction of the aquifer with the Lindis River. The Lindis River is likely to be a significant driver of the hydraulic gradient and transmissivity of the aquifer. Direct measurements of the river-aquifer interaction are likely to be difficult as the Lindis River is a braided river. Braided rivers typically have a surface flow and a subsurface "braid plain" flow. Therefore, gauging the river flow is unlikely to provide a good estimate of the river-aquifer interaction as the river-braid plain interaction would confound the results. Instead, multiple piezometric surveys could be undertaken to characterise the reaction of the piezometric surface to different Dunstan Mountain inflows, which would provide a much better understanding of the aquifer properties.

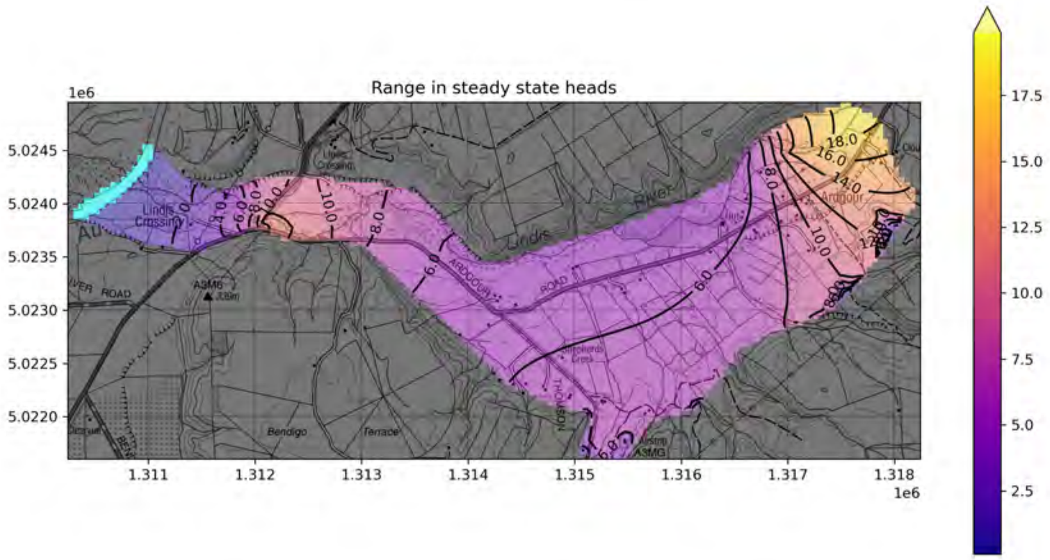

Figure 4.3: Range of steady state model heads across all simulations

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4.4.2 Pumping Tests, Injection Tests, and Push-Pull Tests

Pumping tests could be undertaken at many, or all of, the existing groundwater bores to better understand the hydraulic properties of the aquifer. Note it would likely be beneficial to undertake pumping tests outside the potential plume to better characterise the aquifer and potential flow effects. Pumping tests measure the local scale transmissivity and storativity of the aquifer, but may not provide a good estimate of the properties on the scale of the model. Given the location of the existing bores, one or more long duration constant rate tests could be undertaken with many observation wells to characterise the aquifer properties. This pumping test could then be used to significantly constrain the model with a stochastic inversion approach.

Injection tests could also be undertaken to characterise the aquifer properties, here a known volume of water is injected into the aquifer and the response is measured. This approach could be particularly useful to characterise the impacts of inflows adjacent to Sheperds Creek. Tracers could also be introduced to the injection test to further characterise the aquifer properties and flow paths. A variety of tracers could be used including dyes (e.g., fluorescein), salts (e.g., chloride, sulphate, or bromide), or alternative tracers (e.g., synthetic DNA). These tracers could be used solely in an injection test, or could be used in a push-pull test, where a down gradient bore is pumped to increase the flow rate and draw the tracer through the aquifer. Additional monitoring locations may be necessary to support the tracer test.

4.4.3 Water Chemistry Survey

A water chemistry survey could be undertaken to characterise the current plume associated with Sheperds Creek. This could provide a direct measurement of the projected future contaminant plume, and significantly reduce the uncertainty in the model. A water chemistry survey would only provide useful information if there is currently a significant difference between the various water sources. It is possible that the exposure of the Rise and Shine Shear Zone within the Sheperds Creek Catchment could provide a unique chemical signature that could be used to trace the Sheperds Creek water. Figure 4.4 shows the relative water chemistry of Sheperds Creek and Rise & Shine Creek. Sheperds Creek has much higher concentrations of sulphate and chloride, and also has higher alkalinity than Rise and Shine Creek.

Chemistry samples would also need to be taken for the other water sources including the Lindis River, Dry Creek, and Wainui Creek to ensure that the chemical signature of Sheperds Creek is unique enough to be traced.

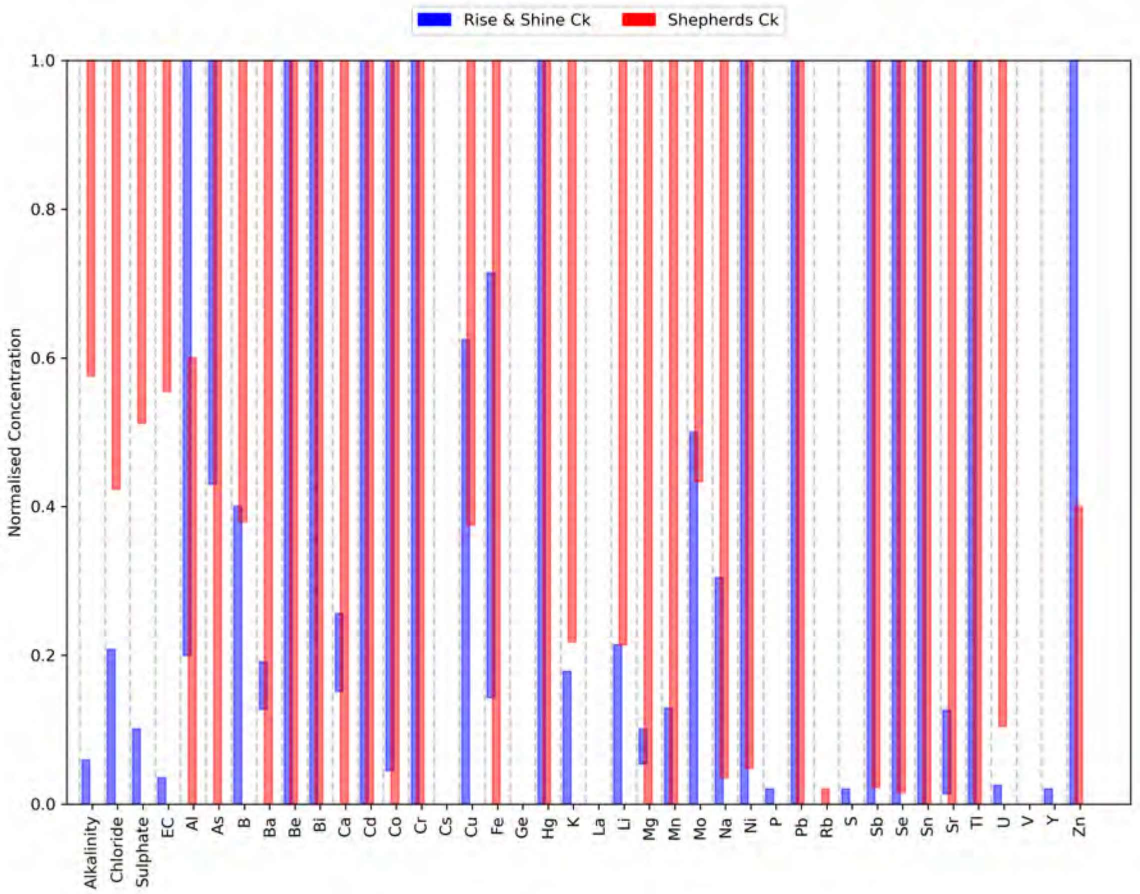

Figure 4.4: Relative water chemistry of Sheperds Creek, Lindis River (where avalible), and Rise & Shine Creek

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Ideally samples would be taken under multiple flow conditions (e.g., high vs low flows), though a single sample would still provide valuable information. In addition, it would be valuable to sample the chemistry of the nearby Cluden Stream across multiple flow conditions as there is a longer duration flow record for this stream. A direct comparison of the water chemistry and flow conditions of Cluden Stream could be used to better assess the variability of the water chemistry of Dry and Wainui Creeks, assuming that the water chemistry between these water bodies is similar.

A further potential challenge is that Sheperds Creek is used for irrigation, which may disperse the chemical signature of Sheperds Creek water depending on the range of irrigation practices. If the irrigation practices and irrigation areas which use Sheperds Creek water are known, this could be partially addressed through coupled hydrological, recharge, and contaminant transport modelling. Figure 4.5 shows the comparison of the absolute water chemistry of Sheperds Creek and Rise & Shine Creek. If we assume that the Lindis River, Dry Creek, and Wainui Creek have similar water chemistry to Rise & Shine Creek, then the water chemistry survey could be used to trace the Sheperds Creek water and significantly reduce the uncertainty in the model. In this instance Sheperds creek water would only become indistinguishable from the other water sources at a 70% dilution factor with pristine water. Sampling of the Lindis River, Dry Creek, and Wainui Creek would be the next step to assess the feasibility of this approach and samples may be necessary at different flow rates to account for the potential for different flow regimes to have different chemical signatures. This approach may also benefit from additional groundwater sampling locations.

Historical water chemistry for bores in the area was found for site G41_0285 (see Figure 4.6). The location

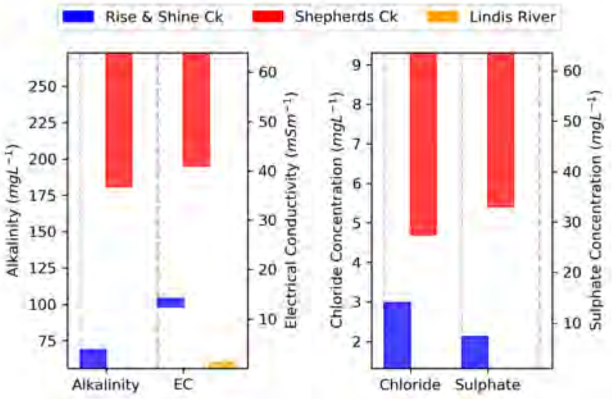

Figure 4.5: Detailed comparison of water chemistry of Sheperds Creek, Lindis River (where avalible), and Rise & Shine Creek

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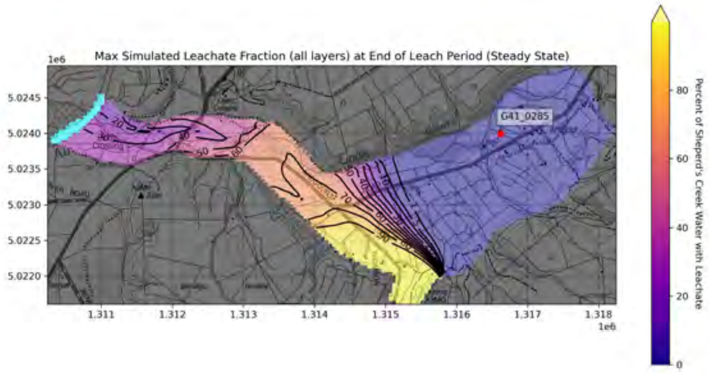

Figure 4.6: Overview of the location of sulphate samples

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of this bore suggests that it is largely influenced by the Lindis River, and no model realisations suggest that it is influenced by Sheperds Creek. The sulphate concentration in this bore is relatively low (9.4 mgL^{-1}). If this concentration is indicative of the "normal" groundwater chemistry then the Sheperds Creek water would have to be diluted by approximately 60% with pristine water to reach this concentration. This result is consistent with the low electrical conductivity reported for the Lindis River. Unfortunately bore G41_0285 is very distant from both Dry and Wainui Creeks, so it does not preclude the possibility that the water chemistry of these creeks is similar to Sheperds Creek.

4.4.4 Numerical Experiments

Numerical experiments could be undertaken to explore the potential for deep water to be drawn up to bores. This would involve running the model with a range of different pumping rates at exising bores to characterise a "safe" abstraction rate to preclude the risk of drawing up contaminants from deeper in the system. This work is not worth undertaking until the aquifer properties are better understood, as the results could be so highly uncertain as to be meaningless under the current constraints.

In addition, numerical experiments could be preformed to better understand the consequences of potentially adverse outcomes. Here the model would be run with a higher than expected contaminant concentration in Sheperds Creek and then the contamination would be reduced or stopped. This simulates a response to an undesirable monitoring result. The model results would give and indication of the duration and extent of impacts from a short term higher contaminant source. This could be used to inform monitoring and response plans. Note that this approach would only be useful if additional work is undertaken to reduce the uncertainty in the model.

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