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Cc	
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Subject:	Macquarie Point Conceptual Hydrogeological Model and Numerical Model Memo

1 Introduction

Hydro Earth Consulting (Hydro Earth) was commissioned by Macquarie Point Development Corporation (MPDC) to construct a simple groundwater model to support the development of the Mac Point Multipurpose Stadium. This memorandum (memo) outlines the conceptual hydrogeological model used by Chris Nicole of Groundwater Logic, for the generation of the numerical groundwater model for the area surrounding the Macquarie Point Stadium. This memo supports the modelling report submitted by Groundwater Logic (Groundwater Logic, 2024; Appendix A) and it includes an outline of the key findings of the numerical model in relation to flow paths.

1.1 Scope of work

This memo includes a succinct summary of conceptual hydrogeological model and data collection used in the groundwater flow model developed by Groundwater Logic (2024). It also includes modelled P10, P50, and P90 groundwater elevations, which will be used to assess modelled groundwater flow paths. Please refer to the modelling report (Groundwater Logic, 2024; Appendix A) for other model results and water table mapping, together with:

- Model design and construction
- Model history-matching to available observation data.

This assessment does not include an assessment of site contamination, which could also be used to better define groundwater flow directions. The basic conceptual hydrogeological model and modelling approach herein are suitable for a simple, class 1 model, as defined by the Australian

Groundwater Modelling Guidelines (Barnett et al, 2012). An in-depth assessment of underground services and their impact on groundwater flows is beyond the scope of this project.

1.2 Data sources

This assessment is mostly based on data sources provided by MPDC. The data were provided expressly for the purpose of conceptualising the numerical model. Hydro Earth take no responsibility for information that is incorrect or inaccurate. Hydro Earth have not interrogated the data's accuracy. Where Hydro Earth have made interpretations, they have been made based on the information that was analysed, noting that due to time restrictions, not all the available data was assessed.

Key datasets and documents are as follows:

- GIS Master File (file name: 01_01_Mac_Point_Master_v3.gdb).
    - This is a geodatabase file, which was provided by the MPDC, included attribute tables showing borehole details (depths, lithology, water levels) and other site-specific information.
- 3D geology model: the model was sent to Hydro Earth as dwg files. Hydro Earth opened the model using Leapfrog and transformed the layers into ASC files, which were transformed into raster files in QGIS, ready for use in the numerical model.
- AECOM (2015a) Groundwater Assessment, August 2015, Macquarie Point Development Project, Job No.: 60321835, DRAFT, 21 January 2016.
- Austral Tasmania (2016) Macquarie Point Seawall and Archaeological Refuse Deposit Investigation, Final Report prepared for the Macquarie Point Development Corporation, AT0197, 23 May 2016.
- GHD (2014a) Macquarie Point Site Investigation, Ground Penetrating Radar Surveys, 24 February 2014.
    - Note: Hydro Earth Consulting have not reviewed the GHD (2014a) report, but it was referenced a separate report.
- GHD (2015a) Macquarie Point Groundwater Model Development Report, Macquarie Point Development Project, September 2015.

- GHD (2015b) Hydraulic conductivity interpretations, Macquarie Point Development Project, Job no. 32/16838, 16 December 2015.
- SKM (2001) AN Hobart Macquarie Point groundwater transport, solute and monitored natural attenuation evaluation study, Indec Consulting, Quarterly Summary Report QR_02, Period May to July 2001, Update Number 02, August 2001.

1.3 The study area

The area overseen by the MPDC is referred to as the Mac Point Site herein. A larger area was investigated in this memo to contextualise and assess groundwater systems at the Mac Point Site, this larger area, which is shown in Figure 1, is referred to as the Study Site herein.

1.4 Key questions for the model

A simple, class 1 model was created to answer the following questions:

- What are the average/typical groundwater levels in the sediments across the Mac Point Site?
- What are the typical groundwater flow directions?
- Initially, the model was to assess the impacts of tidal fluctuations, particularly their impact on Groundwater flow directions (i.e. does tidal action change/reverse groundwater flow directions?).
    - However, data collected using level loggers at the Mac Point Site (documented in this report) suggest tidal influences are minor and not of concern. Further monitoring is recommended to confirm this finding, but current data are not sufficient to model this.
- Therefore, rainfall responses were used to calibrate the model.
    - Two scenarios are modelled, wet conditions and dry conditions.

2 Background

2.1 Geology

The 1:25,000 map scale surface geology (The LIST, downloaded on 12 September 2022) is shown in Figure 1 and descriptions are provided in Table 1. There is Jurassic dolerite (map symbol *Jd* on Figure 1) cropping out in the northern part of the Mac Point Site, and its surface expression continues up the slope. There are Quaternary deposits of alluvial (map symbol *Qa*) and estuarine (map symbol *Qi*) origins to the west of the Mac Point Site. These alluvial and estuarine deposits likely underlie the man-made deposits (map symbol Qhmm; referred to as fill herein), which overlie most of the Study Site and extend to the Derwent River to the east and south.

The client provided a 3D geology model for the Study Site, and this was used in the numerical model (Figure 2). There is Jurassic dolerite cropping out to the north of the Mac Point Site and this dolerite underlies fill and silty sand in the south and east. Hydrogeological units are described in more detail in subsequent sections.

Table 1 – Geological descriptions of units cropping out near the Study Site

Symbol	Period	Formation	MIN AGE (Mya)	MAX AGE (Mya)	Description
Qhmm	Quaternary	NULL	0	0.0117	Man-made deposits.**
Qa	Quaternary	NULL	0	2.58	Alluvial gravel, sand and clay.
Qi	Quaternary	NULL	0	2.58	Undifferentiated bay, estuarine, deltaic and alluvial deposits of sand, shelly sand, pebbly sand, pebble to boulder size gravels, clayey sand, silt and clay.
Jd	Jurassic	Tasmanian Dolerite	182.7	183.1	Dolerite and related rocks.

***Note**: MIN AGE and MAX AGE mean minimum age and maximum age respectively.*
Mya means million years ago.
Descriptions are from 1:25,000 map scale geology map, sourced from the LIST on 12 September 2022.
*** The man-made deposits are referred to as fill herein.*

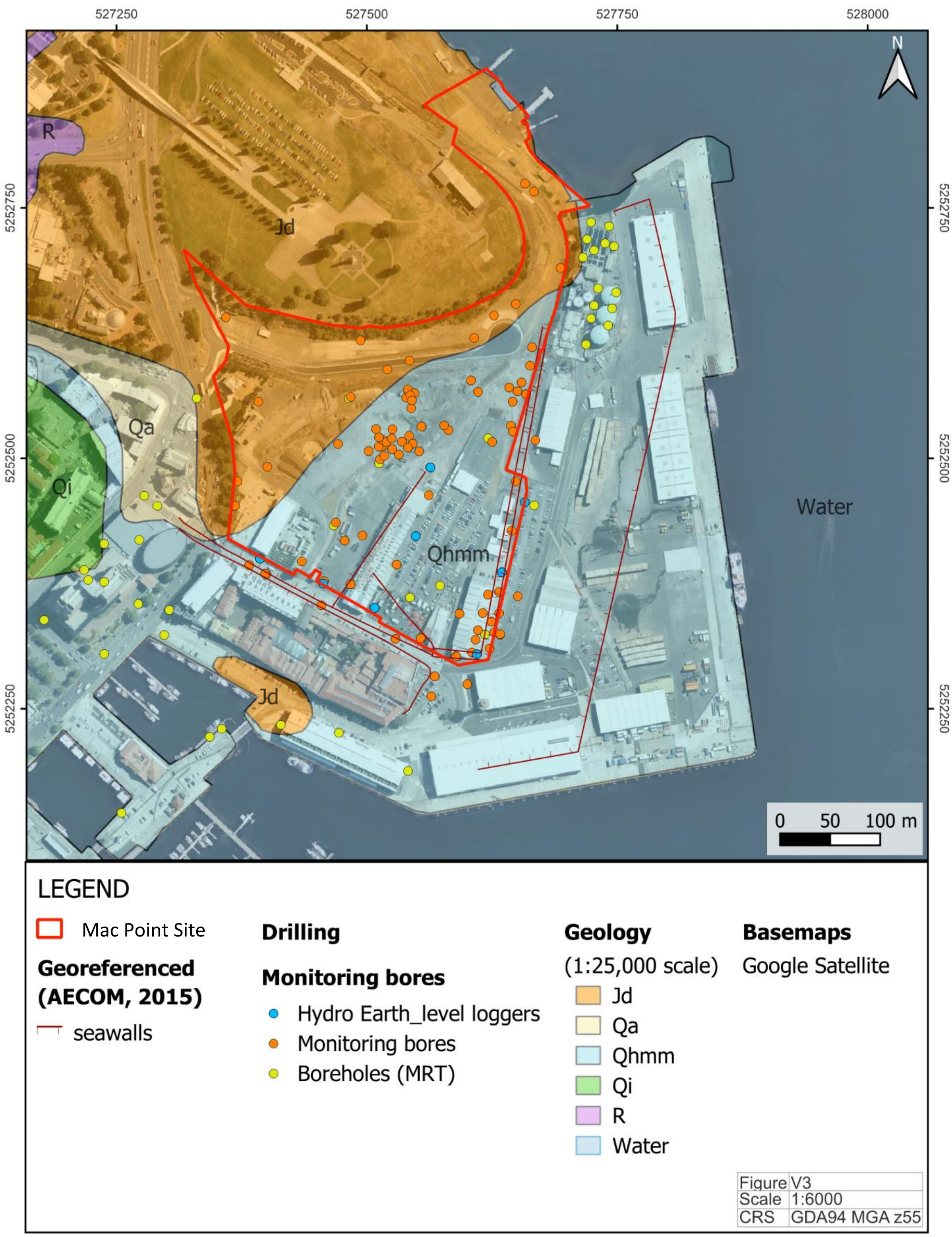
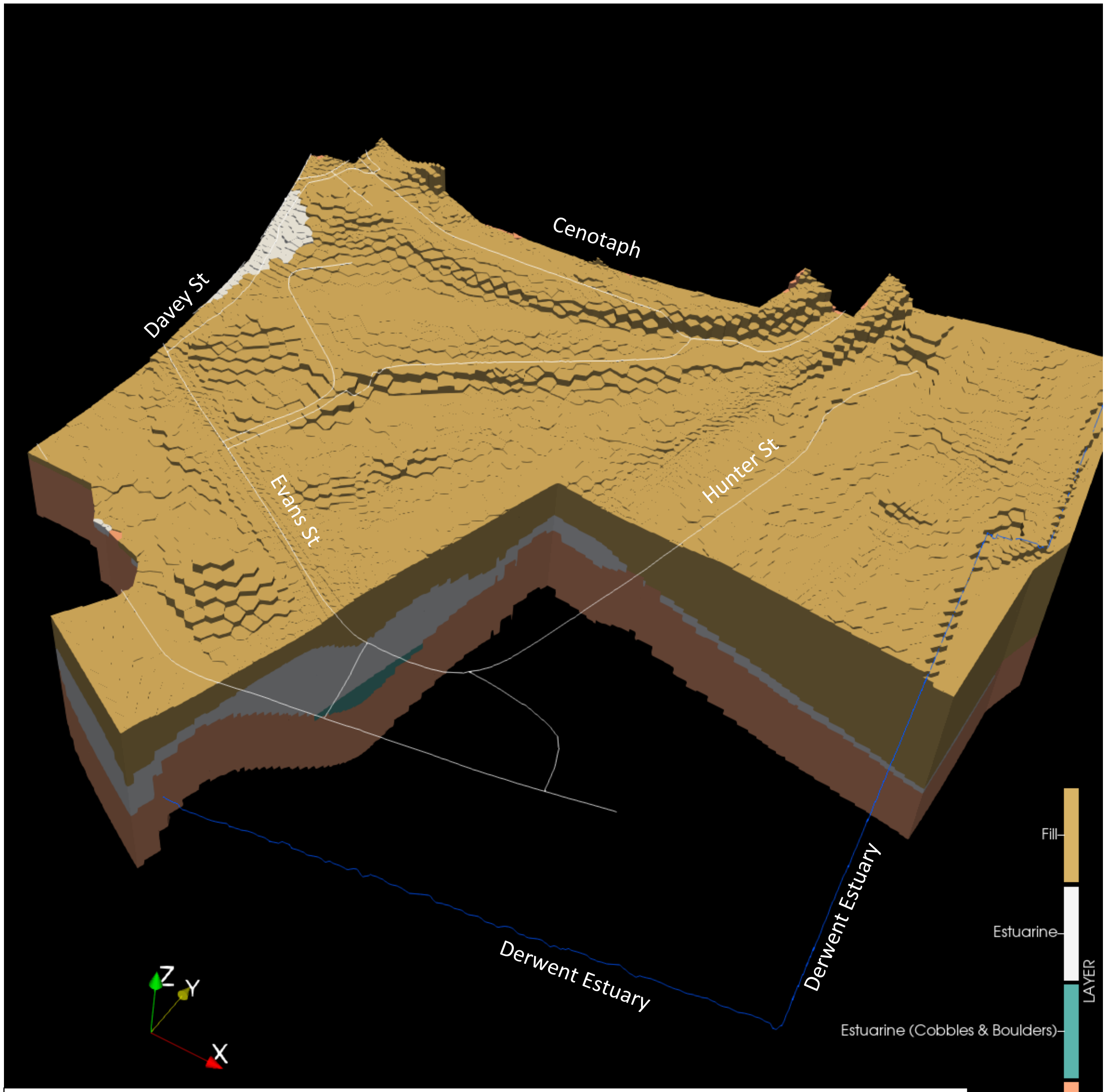


Figure 1 – The Study Site, surface geology, topography, and monitoring bore locations



The numerical model mesh was created using the 3D geological model provided by MPDC. The model was box cut into the southeast corner to show the model layering at the Site.

Figure 2 – Numerical model mesh and layering

2.1.1 Man-made deposits (fill)

The man-made deposits, referred to as fill herein, have been placed at the Study Site since the 1800s. Dolerite rubble seawalls were built and the area behind them was progressively backfilled to create land for new development areas. The area was used as a rubbish dump until early in the 20th century (Austral Tasmania, 2016).

The thickness of the fill varies between 0.2-12.0 m. The fill material has been described as a combination of clays, sands, gravels, cobbles and bricks. The deeper fill generally consists of silty sands, like the underlying sediments, and it is interpreted to be reworked natural material (AECOM, 2015a).

2.1.2 Estuarine sediments (silty sands)

Fill material is generally underlain by estuarine sediments in the 3D model, likely in reference to sediments defined as map symbol *Qi* Figure 1 and Table 1. However, this unit may include alluvial material in some areas (map symbol *Qa* in Figure 1 and Table 1). These estuarine sediments were referred to as silty sands and marine sediments by AECOM (2015a). The sediments are generally found at depths of about 3.7-15 m below ground level. The estuarine sediments are generally not present in the northern part of the Mac Point Site (AECOM, 2015a).

2.1.3 Slope deposits and weathered dolerite

Slope deposits, which include weathered dolerite comprise clays, gravels and cobbles. The slope deposits underlie the fill in the north of the Mac Point Site where the silty sand is absent, and they underlie the silty sand elsewhere (AECOM,2015a). The 3D geology model does not appear to include this layer, although it may correlate with the unit referred to as *Estuarine (Cobbles & Boulders)*.

2.1.4 Dolerite

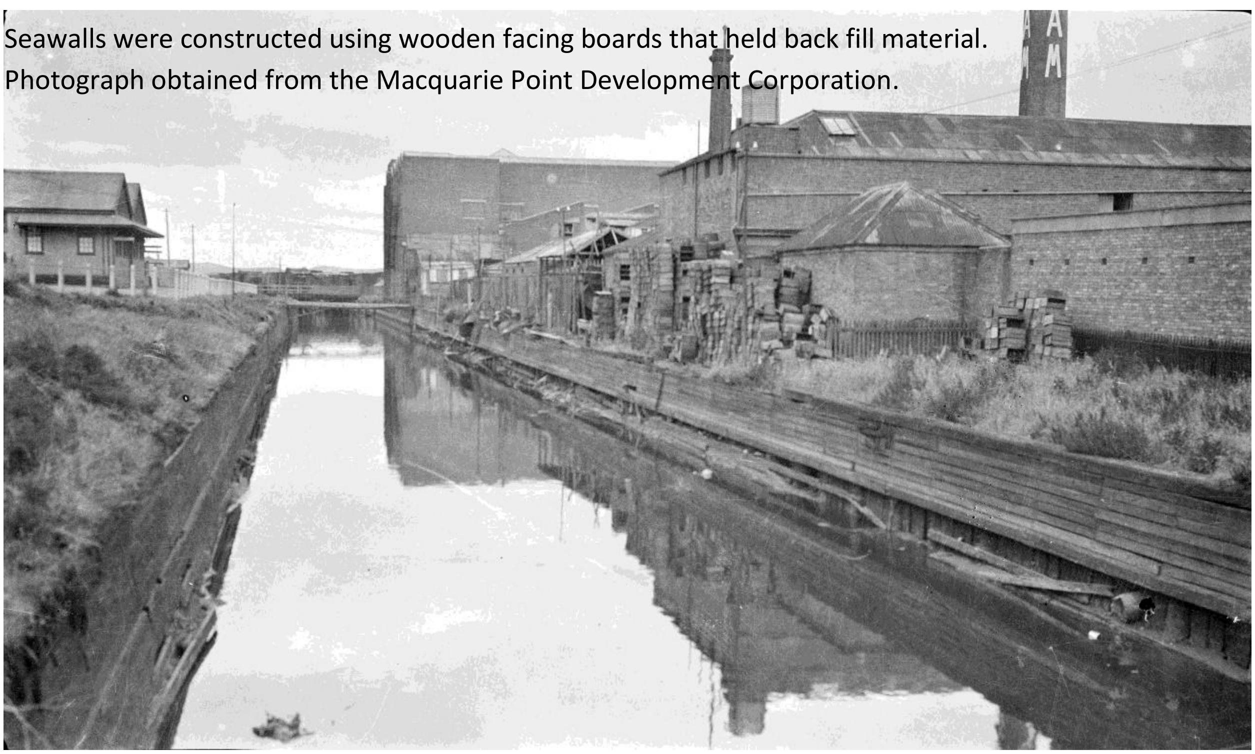
Dolerite crops out to the north of the Study Site and it generally underlies the sediments at depths of about 25 m on the Study Site (AECOM,2015a). Dolerite sheets intruded layered Permian and Triassic bedrock (mostly within the Parmeener Supergroup) and it normally forms extensive flat or gently sloping sheets up to 500 m thick. Dolerite is similar in composition to basaltic andesite, it is hard, and it forms the resistant caps to many of Tasmania's peaks (Corbett et al., 2014).

Jurassic dolerite generally contains well developed joints, most notably, sub-vertical columnar jointing (e.g. the organ pipes on Mount Wellington), which are typically 2-6 m across. Smaller fractures are present within each column, and these generally open as weathering progresses (Corbett et al., 2014). Groundwater flows occur through the columnar jointing systems, and to a lesser extent, through the smaller fractures within each column. Joints are likely more open towards the surface as the columns break and weather.

2.2 Hydrology

The main hydrological features near the Study Site are the Derwent River and the Hobart Rivulet. The Derwent River is tidal in the area surrounding the Study Site. Initially, the groundwater response to this tidal action was to be assessed in this project using level logger data collected from eight monitoring bores over two days. However, no tidal response could be identified in the eight monitoring bores. Historical data shows there is tidal response at PC8 (GHD, 2015a), located to the southeast of the Mac Point Site, close to the Derwent Estuary. More information on the tidal response in presented in Section 3.4.

The Hobart Rivulet originally discharged at Evans Street, as shown in the photograph in Figure 3. However, in recent times, including the timescales covered by the groundwater level data used in this investigation, the rivulet was re-directed to the north near the cenotaph. The rivulet is contained by tunnels to the north and west of the Mac Point Site, and there is an outlet allowing discharge into the Derwent River.



Seawalls were constructed using wooden facing boards that held back fill material. Photograph obtained from the Macquarie Point Development Corporation.

Figure 3 – Hobart Rivulet at Evans Street in 1910

2.3 Monitoring bore network

The monitoring bore network is shown in Figure 4, noting that not all bore names are shown because of the close spacing. Bores that were mentioned in-text are labelled in the figure.

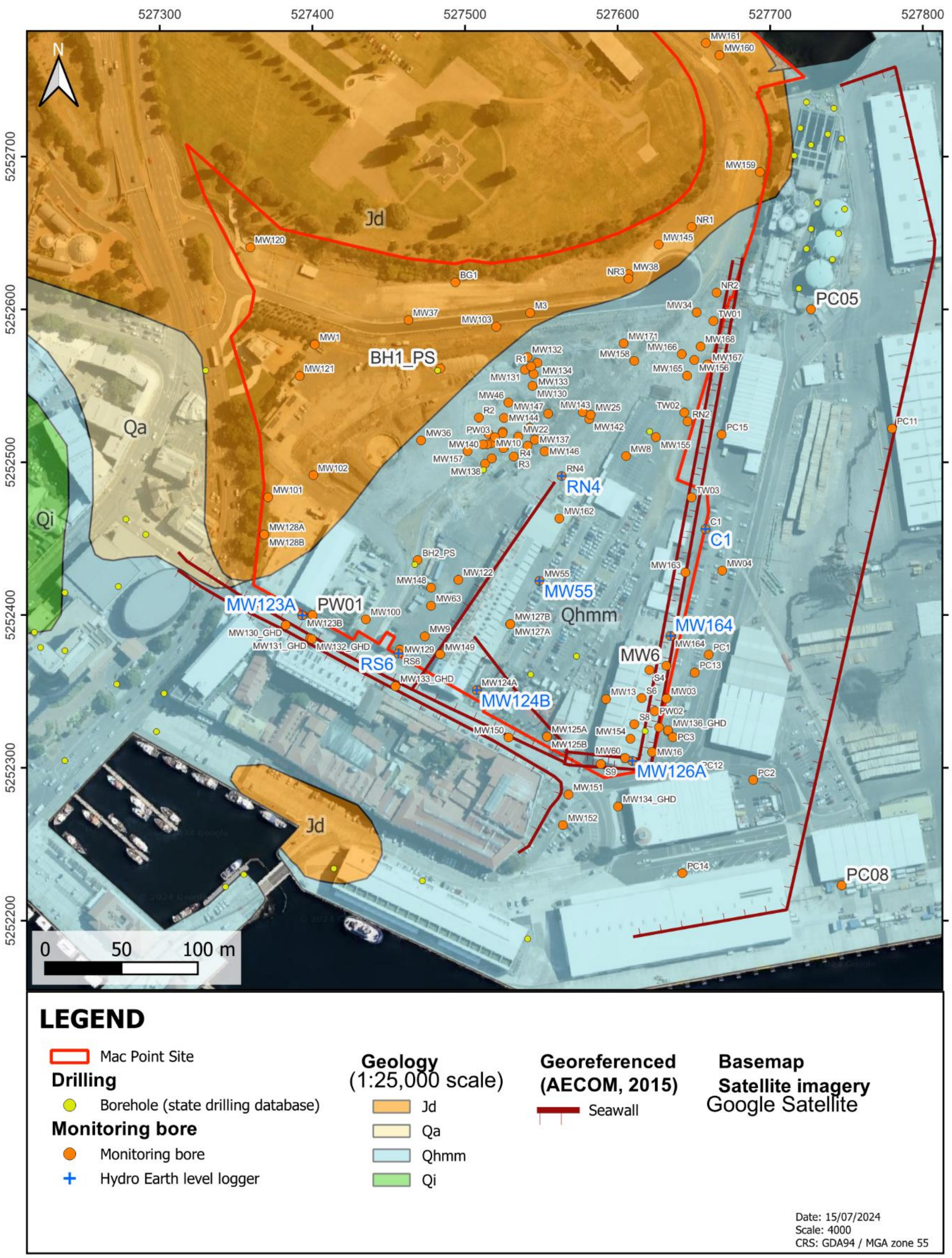


Figure 4 – Monitoring bore network

3 Conceptual hydrogeological model

3.1 Groundwater flow systems

Groundwater levels in nested bores (i.e. two or more monitoring bores at the same location but screened in different units and/or depths) are generally the same or very similar, suggesting the units are hydraulically interconnected. This conceptualisation was used by AECOM (2015a) and GHD (2015a), and it was also used in the Groundwater Logic (2024) model.

Previous reports show that groundwater generally flows to the south-southeast. Groundwater in the Jurassic dolerite would flow through fractures and joints. In contrast, the slope deposits, silty sand, and fill are porous units.

3.2 Flow barriers and preferential flow

There are several seawalls located on the Study Site which could act as barriers to groundwater flows, and they have therefore been included in the model. The seawalls have been described as follows:

- Eight trenches were excavated to expose the seawalls, as reported in Austral Tasmania's (2016) report. Evidence of the seawalls did not appear above a depth of 1.5-2 m from the present surface, but seawalls of at least **3 m in width** were exposed below this point.
- Earliest (1890s) seawalls were dolerite rubble structures with the resulting basin infilled (Austral Tasmania, 2016).
- The walls lining the rivulet (now Evans Street; Figure 3), which are interpreted to be Sections 101.0, 103.0 and possibly 102.0 in Figure 5, were a mixture of stone, concrete, timber piles and boards.

Underground services may also act as either a barrier or a preferential flow system. Concrete, poly, and PVC pipes will act as flow barriers, but reworked sediments and infill may be more permeable. However, the sewerage line is largely located in the middle of the Mac Point Site where the depth to groundwater is around 3-5 m (pre-excavation). The sewer mains is-understood to be at a depth of 4 m (AECOM, 2015a; pre-excavation). Therefore, these services may impact on groundwater flows. However, they are not included in the groundwater model, because:

- Their impacts would be difficult to quantify and understand, especially given the short time provided to conceptualise and complete this model.
- They would likely only interfere with flows in the top 1-2 m of the water table, unlike the seawalls, which extend to much greater depths. If they act as barriers, flows could go beneath the services, minimising their impacts. We note that have no substantiated this this assumption with any field testing/observations.

Figure 5 – Modelled seawalls (GHD, 2015a)

3.3 Hydraulic parameters

Hydraulic parameters applied to the steady state model (some transient logger data was used for calibration) developed by GHD (2015a), are shown in Table 2. Hydraulic conductivity data from various reports was collated in GHD (2015b), as presented in Table 3. The data are presented graphically Figure 6 and Figure 7 and a statistical breakdown of the data is provided in Table 4. Noteworthy observations include:

- The elevated hydraulic conductivity in fill near the eastern shores of the Study Site, from the eastern seawall to the coast.
  - The void material modelled in GHD (2015a), which presumably would have been required to calibrate the model, appears related to the high permeability zone on the eastern shores of the Study Site.
  - Hydraulic conductivities may be elevated in some areas where beach and rivulet sands are present, or where they have been re-worked into the overlying fill. This simplistic assessment is confounded by the introduction of fill to the area, which is difficult to characterise and may vary spatially.
  - The lower permeability materials may contain estuarine clays (re-worked or in their native state). We also note the impact of various fill materials.

Documented values for generic materials are provided in Table 5. A reasonable estimate of the specific yield of fine grained and coarse grained material is 0.1 and 0.2 respectively, and a reasonable hydraulic conductivity estimate for fine sand is 2-4 m/day (Kasenow, 2006).

Table 2 – Model parameters form GHD (2015a)

Material	Horizontal Hydraulic Conductivity “Kh” (m/day)	Vertical anisotropy “Kh/Kv”	Specific Storage “Ss” (1/m)	Specific Yield “Sy”	Porosity
Fill	50	3	0.00001	0.15	0.3
Silty sand	0.1	3	0.00001	0.1	0.3
Weathered dolerite	0.1	3	0.00001	0.1	0.3
Transitional Dolerite	0.05	3	0.00001	0.1	0.3
Fractured Dolerite	0.033	3	0.00001	0.1	0.3
Void * (area/material in direct interaction with the coast)	100	3	0.00001	0.5	0.3
Note: * The “concept of a high permeability ‘void’ was introduced to handle the areas envisaged to be in direct/uninhibited contact with the Derwent” (GHD, 2015a).					

Table 3 – Hydraulic conductivity interpretations from previous reports as documented in GHD (2015b)

Bore_ID	Easting (mMGA)	Northing (mMGA)	Elevation ## (mAHD)	Primary screened unit	Bouwer & Rice (m/day)	Dagan (m/day)	Hvorslev (m/day)	Adopted K (m/day)	Interpreted#
BG1	527493.6	5252618	7.492	Fill	6.051	6.971	8.201	7.1	GHD, 2015b
BH1_PS	527483.8	5252561	6.038	Weathered Dolerite	0.096	0.081	0.311	0.16	GHD, 2015b
BH2_PS	527468.9	5252436	5.286	Fill	0.317	0.294	0.421	0.34	GHD, 2015b
C1	527657.5	5252456	3.142	Fill	50	50	50	50	GHD, 2015b
MW1	527401.5	5252577	7.69	Dolerite	0.37	NA	NA	0.37	SKM, 1998
MW100	527434.9	5252397	4.006	Fill	8.403	8.59	11.34	9.4	GHD, 2015b
MW101	527370.9	5252477	5.317	Fill	50	50	50	50	GHD, 2015b
MW102	527400.6	5252491	5.778	Fill	0.112	0.168	0.166	0.15	GHD, 2015b
MW103	527520.4	5252589	7.412	Fill	1.313	1.58	1.756	1.6	GHD, 2015b
MW123A	527393.3	5252400	3.223	Fill	0.322	0.381	0.524	0.45	AECOM, 2015
MW123B	527393.2	5252400	3.278	Sand	0.578	NA	NA	0.27	AECOM, 2015
MW124A	527507.7	5252351	3.767	Fill	50	50	50	50	GHD, 2015b
MW124B	527507.7	5252351	3.738	Sand	0.82	NA	0.99	0.59	AECOM, 2015
MW126A	527609.6	5252304	2.857	Fill	NA	NA	NA	0.59	AECOM, 2015
MW126B	527609.7	5252304	2.831	Weathered Dolerite	0.28	NA	0.399	0.26	AECOM, 2015
MW128B	527368.4	5252453	5.209	Dolerite	0.0053	NA	NA	0.0053	AECOM, 2015
MW13	527592.4	5252345	3.159	Fill	1.961	2.221	2.967	2.4	GHD, 2015b
MW16	527622.6	5252310	2.63	Fill	0.745	0.805	1.174	0.91	GHD, 2015b
MW21	527517.5	5252502	5.584	Fill	50	50	50	50	GHD, 2015b
MW23	527542.1	5252522	5.571	Fill	3.544	5.181	6.117	4.9	GHD, 2015b
MW25	527582.3	5252531	4.262	Dolerite	NA	NA	NA	0.4	SKM, 1998
MW34	527651.8	5252598	4.562	Silty sand	NA	NA	NA	3.5	SKM, 1998
MW36	527471.125	5252514	6.109	Dolerite	NA	NA	NA	1.4	SKM, 1998
MW37	527462.9	5252593	0	Dolerite	NA	NA	NA	0.17	SKM, 1998
MW38	527607.2	5252623	7.714	Dolerite	NA	NA	NA	1.4	SKM, 1998
MW46	527528.4	5252539	5.676	Silty sand	NA	NA	NA	2.0	SKM, 1998
MW55	527548.7	5252422	3.789	Silty sand	9.579	2.591	3.128	5.1	GHD, 2015b

Bore_ID	Easting (mMGA)	Northing (mMGA)	Elevation ## (mAHD)	Primary screened unit	Bouwer & Rice (m/day)	Dagan (m/day)	Hvorslev (m/day)	Adopted K (m/day)	Interpreted#
MW6	527631.9	5252367	2.896	Fill	9.053	9.434	10.15	9.5	GHD, 2015b
MW60	527604.8	5252306	2.864	Fill	3.14	3.344	4.526	3.7	GHD, 2015b
MW9	527473.6	5252386	4.01	Fill	NA	NA	NA	35	SKM, 1998
NR1	527648.6	5252654	8.295	Weathered Dolerite	0.636	0.636	0.417	0.56	GHD, 2015b
NR2	527664.8	5252611	4.559	Fill	0.791	0.929	1.004	0.91	GHD, 2015b
NR3	527607.8	5252620	7.807	Fill	7.035	9.877	9.469	8.8	GHD, 2015b
PC1	527661	5252375	2.85	Fill	NA	NA	NA	17	SKM, 1998
PC2	527688.8	5252292	2.78	Fill	NA	NA	NA	2.2	SKM, 1998
PC05	527726.7	5252600	2.947	Fill	22	NA	NA	22	GHD, 2014
PC08	527746.8	5252223	2.836	Fill	NA	NA	NA	50	GHD, 2014
PC09	527817.7	5252353	2.804	Fill	NA	NA	NA	50	GHD, 2014
PC10	527817.9	5252666	2.507	Fill	NA	NA	NA	50	GHD, 2014
PC11	527779.8	5252522	2.725	Fill	NA	NA	NA	50	GHD, 2014
PC12	527651.7	5252297	2.845	Fill	2.5	NA	NA	2.5	GHD, 2014
PC13	527650.5	5252362	2.636	Fill	6.3	NA	NA	6.3	GHD, 2014
PC14	527642.4	5252231	2.431	Fill	10.5	NA	NA	11	GHD, 2014
PC15	527668.1	5252518	3.489	Fill	NA	NA	NA	50	GHD, 2014
RN2	527645.8	5252527	4.182	Fill	0.127	0.138	0.152	0.14	GHD, 2015b
RN4	527563.3	5252491	4.045	Fill	1.11	1.307	1.524	1.3	GHD, 2015b
RS6	527456.3	5252375	3.792	Fill	0.299	0.394	0.383	0.36	GHD, 2015b
S4	527620.8	5252364	2.842	Fill	10.79	10.98	20.29	14	GHD, 2015b
S6	527615.7	5252346	2.895	Fill	0.34	0.379	NA	0.36	GHD, 2015b
S8	527610.9	5252328	2.83	Fill	1.431	2.223	2.223	2.0	GHD, 2015b

Notes: The original table had many values as 0 m/day under the various testing methods, with an adopted K >0. We have assumed an error here and the 0 value was replaced with NA. It is unclear how the Adopted K was determined in cases where no test data is provided (these details were not provided in GHD (2015b).
The groundwater response was too rapid to be measured by the sensor in some tests – from the report "Where the response is too rapid to be measured, this is interpreted as a very high hydraulic conductivity and is included in the dataset as the value 50 m/day. This is applicable for a total of 9 bores in the current dataset of 50" (GHD, 2015b).
mMGA means metres Map Grid of Australian, mAHD means metres Australian height datum, m/day means metres per day, K means hydraulic conductivity.
GHD (2015b) appear to have collated data from SKM (1998), SKM (2001), GHD (2014), and AECOM (2015), but the full citation for these reports was not provided and Hydro Earth have not viewed these reports.
The elevation refers to the elevation of the monitoring point.

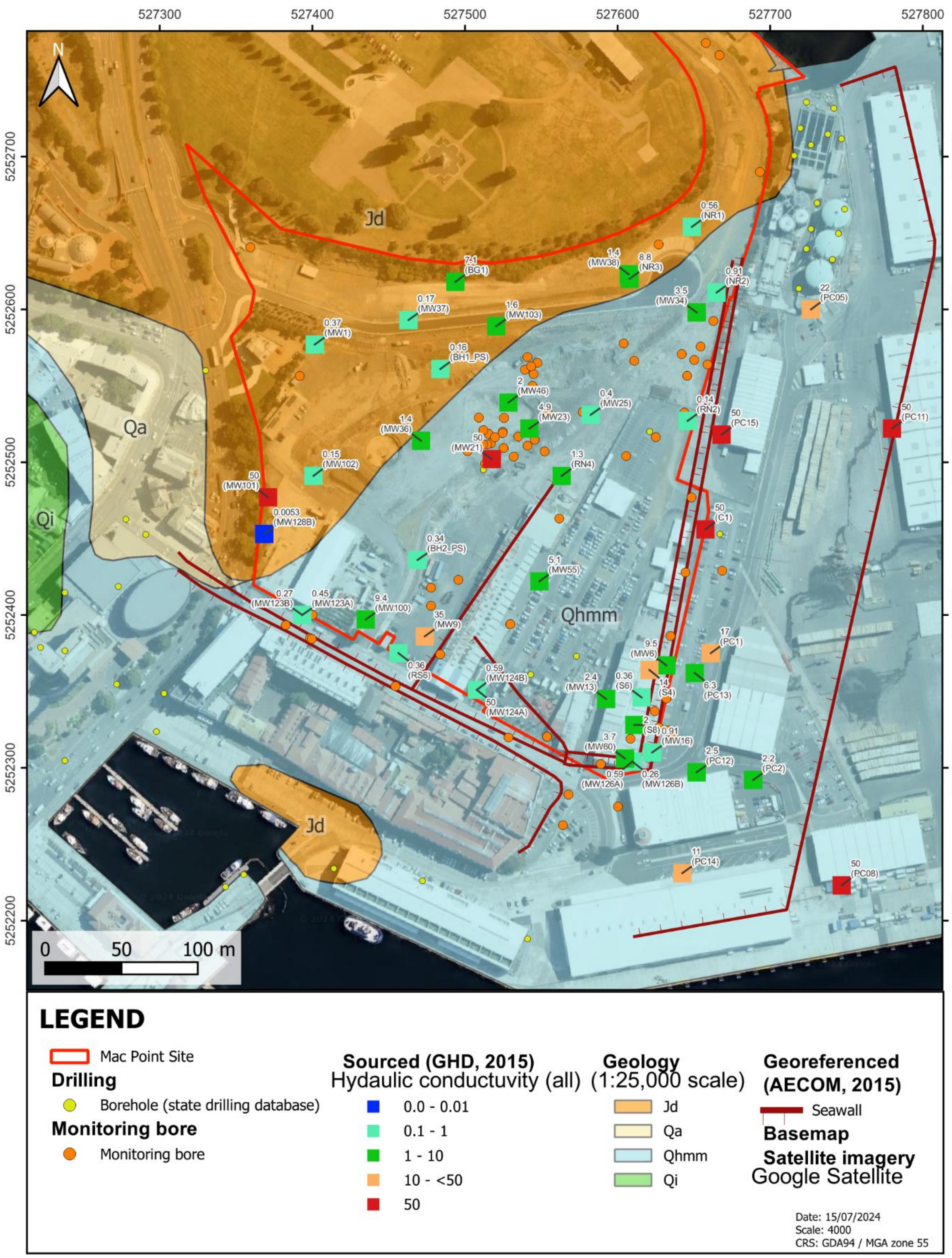


Figure 6 – Adopted hydraulic conductivity values from bores screened in all lithologies (data from GHD, 2015b)

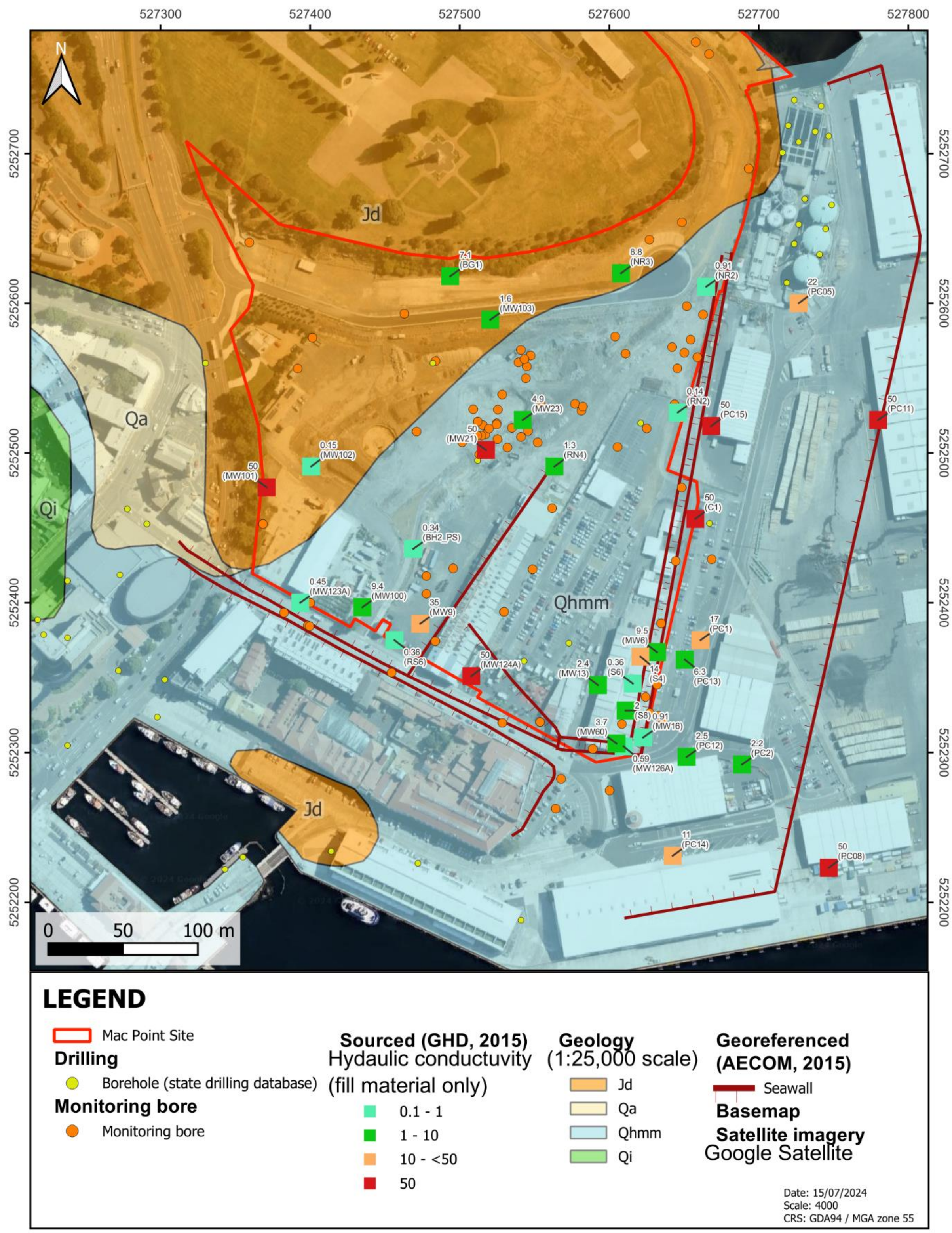


Figure 7 – Adopted hydraulic conductivity values from bores screened in the fill (data from GHD, 2015b)

Table 4 – Statistical summary of hydraulic conductivity data

Material	Min	10%tile	mean	median	90%tile	Max	Count
Fill	0.1	0.35	17	6.7	50	50	36
Sand / silty sand	0.3	NA	2.3	2.0	NA	5	5
Weathered Dolerite	0.2	NA	0.33	0.26	NA	0.6	3
Dolerite	0.005	NA	0.62	0.39	NA	1	6
Notes: Raw data obtained from GHD (2015b)							

Table 5 – Documented values for porosity and specific storage for generic materials

	compressibility of a porous medium α (m2/Newton)		Porosity		Ss	
Material	lower	Upper	lower	upper	lower	Upper
clay	1.00E-08	1.00E-06	40.00%	70.00%	1.0E-04	9.8E-03
sand	1.00E-09	1.00E-07	25%	50%	1.1E-05	9.8E-04
gravel	1.00E-10	1.00E-08	25%	40%	2.2E-06	1.0E-04
jointed rock	1.00E-10	1.00E-08	0%	10%	9.8E-07	9.9E-05
sound rock	1.00E-11	1.00E-09	0%	5%	9.8E-08	1.0E-05
Reference	Freeze and Cherry (1979)		Kruseman & deRidder (1994)		Ss = specific storage = $\rho w g(\alpha + n\beta)$	

3.3.1 Hydraulic parameters for the seawalls

Table 6 shows the hydraulic conductivity values that GHD assigned to the seawalls. The permeability of 105.0 and 106.0 are significantly lower than the other walls, possibly due to the presence of compacted clays (noted at 105.0 by Austral Tasmania, 2016).

Table 6 – Modelled seawall hydraulic conductivity values (GHD, 2015a)

Horizontal flow barriers	Model parameter	Package	Hydraulic characteristic (m/day/m)**	Hydro Earth Comments
HFB_1	101.0	HFB	0.6	
HFB_2	102.0	HFB	0.8	Figure 3 suggests 102.0, 103.0 and 104.0 were lined with wooden boards, but the boards were not found during excavation of a pit in the area. Austral Tasmania (2016) concluded that the boards were removed from the upper parts of the seawall (mostly above the water table). Excavations did not extend far below the water table. Compact clay was underlain by sandstone boulders and "beach **sand**" was identified just below the water table.
HFB_3	103.0	HFB	1	
HFB_4	104.0	HFB	1	
HFB_5	105.0	HFB	0.001	Austral Tasmania (2016) excavated three trenches in this feature. Near the seawalls northern extent, the seawall appeared to contain clay, but the descriptions were not clear. To the south, wooden facing boards were exposed, together with loose dolerite fill at shallow depths, with **compacted clay** underneath. We note that there are two parallel seawalls presented by AECOM (2015a), but only one seawall was modelled by GHD (2015a).
HFB_6	106.0	HFB	0.001	
HFB_7	107.0	HFB	1	Excavated – horizontal wooden facing boards uncovered to ~3.8 m below ground level, with dolerite boulders and brick fill (circa 1889; Austral Tasmania, 2016)
HFB_8	108.0	HFB	20	Not on GHD plans so the location is unknown

* HFB means horizontal flow barriers package in MODFLOW
** In the GHD table, it said "Conductivity m2/day/m" We assume this was meant to be the hydraulic characteristic (m/day/m), which is the hydraulic conductivity divided by the width of the horizontal-flow barrier (a value specific to MODFLOW).

3.4 Groundwater levels

3.4.1 Recent data

Water level loggers were installed in eight monitoring bores on Tuesday 22 May 2024 and the data were downloaded on Thursday 24 May 2024, providing two days of water level data. Water levels do not appear to fluctuate in response to tidal forces, but there is a rainfall response, especially at MW164 and to a lesser extent MW123A.

This data is insufficient for an in-depth assessment, but it was all that could be collected in the short timeframe available for this project. The loggers have been left in place to collect more data for future modelling projects, should they be required. Observations from this data are sufficient for a simple, class 1 numerical model.

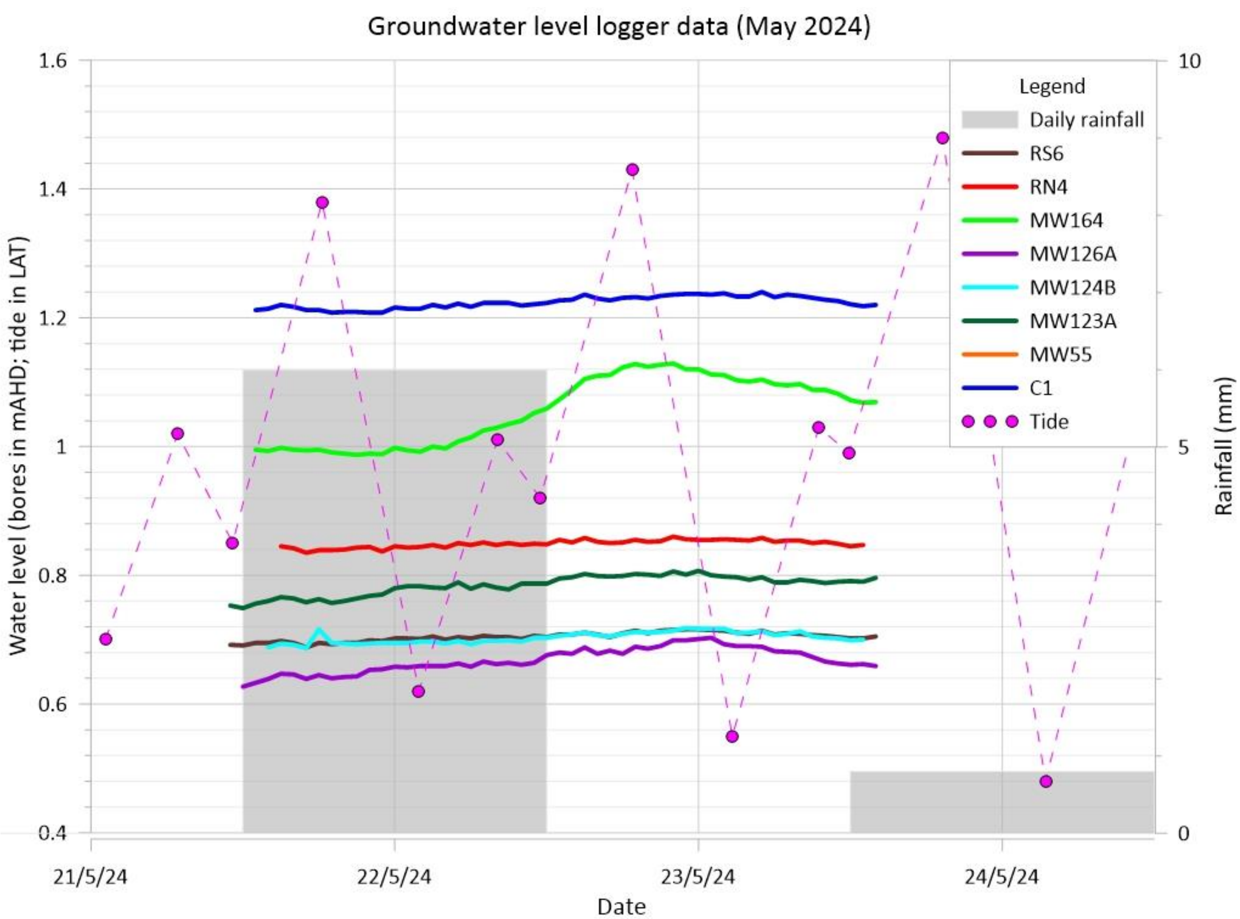


Figure 8 – Water level data collected by Hydro Earth in May 2024

3.4.2 Historic data - 2001

Water levels were collected over a tidal cycle on 23 March 2001. Resultant data is provided in Table 7. The data shows a small response at most bores, especially near the river (<0.03 m near the river), but the results are likely confounded by rainfalls that occurred on and before the 23 March 2001, as follows:

- 22 March 2001: 1.8 mm
- 23 March 2001: 10.4 mm (BoM, Station No 94029, accessed on 27 May 2024).

We note that the high tide measurement appears to have been collected on 24 March 2001 (it is presented after the low tide measurement even though it was reported to be taken at an earlier time), after 10.4 mm of rain was recorded on the previous day, but we can’t be certain of this. This may explain why the largest response was noted at MW21, which is distal to the shoreline (location shown on Figure 4). Therefore, this data is of limited use with regards to assessing tidal-induced groundwater fluctuations. However, it does support the view that the tidal response at the Mac Point Site is minimal, and it probably has no measurable impact on groundwater flow directions. More data is required to confirm this. Due to the ambiguity of the timing of the high tide result, this data has not been used to assess the rainfall response.

Table 7 – Water level fluctuations on 23 March 2001

Location	Distance to River	Mid tide SWL (mbTOC) 9:30-10:40 am	Low tide SWL (mbTOC) 1:15 pm	High tide SWL (mbTOC) 6:40 am#	Diff between High & low tides	Diff between High & mid tides	Diff between low & mid tides	Easting *	Northing*	Elevation **	Mid tide SWL (mAHD) 9:30-10:40 am	Low tide SWL (mAHD) 1:15 pm	High tide SWL (mAHD) 6:40 am
River 2	ND	3.53	3.97	3.26	0.71	0.27	0.44	ND	ND	ND	ND	ND	ND
River 1	ND	2.39	2.7	2.02	0.68	0.37	0.31	ND	ND	ND	ND	ND	ND
PC3	245.5	2.36	2.37	2.34	0.029	0.012	0.017	527636.1	5252320	2.783	0.423	0.413	0.443
PC1	212.4	2.41	2.43	2.39	0.032	0.014	0.018	527659.6	5252374	2.703	0.293	0.273	0.313
MW16	259	2.3	2.29	2.28	0.014	0.024	0.01	527622.6	5252310	2.957	0.657	0.667	0.677
MW60	416.1	2.47	2.51	2.47	0.04	-0.007	0.047	527604.8	5252306	2.884	0.414	0.374	0.414
MW13	283.9	2.65	2.74	ND	ND	ND	0.087	527592.4	5252345	3.193	0.543	0.453	3.193
MW55	315.8	3.27	3.27	3.27	0.003	0	0.003	527548.7	5252422	3.962	0.692	0.692	0.692
MW8	239.9	3.58	3.6	3.56	0.039	0.025	0.014	527605.5	5252504	4.313	0.733	0.713	0.753
MW01	434.9	3.87	3.88	3.88	0.004	-0.004	0.008	527404	5252576	7.279	3.409	3.399	3.399
MW17	319.7	4.8	4.8	4.61	0.19	0.19	0	527524.6	5252519	5.6	0.8	0.8	0.99
MW21	330	4.85	4.85	4.29	0.562	0.563	0.001	527517.5	5252502	5.673	0.823	0.823	1.383
MW22	310.7	4.71	4.7	4.7	0.005	0.011	0.006	527534.9	5252517	5.6	0.89	0.9	0.9
MW23	303	4.86	4.85	4.81	0.044	0.048	-0.004	527542.1	5252522	5.582	0.722	0.732	0.772
MW6	240.1	2.49	2.49	2.48	0.008	0.01	-0.002	527631.9	5252367	3.004	0.514	0.514	0.524
MW03	244.7	2.28	2.27	ND	ND	ND	-0.01	527631.9	5252345	2.905	0.625	0.635	ND
MW05	250.5	2.4	2.38	ND	ND	ND	-0.011	527627.1	5252326	2.972	0.572	0.592	ND
MW04	192.5	ND	2.64	2.58	0.054	ND	ND	527668.5	5252429	3.136	ND	0.496	0.556
MW36	375	ND	4.13	4.13	-0.004	ND	ND	527471.1	5252514	6.125	ND	1.995	1.995
MW19	335.5	ND	5.05	5.04	0.009	ND	ND	527512	5252521	5.95	ND	0.9	0.91
MW10	328.6	ND	4.93	4.83	0.103	ND	ND	527517	5252512	5.68	ND	0.75	0.85
MW63	314.8	ND	3.49	3.59	-0.102	ND	ND	527477.7	5252406	4.118	ND	0.628	0.528
MW25	262.6	3.61	3.62	3.6	0.025	0.019	0.006	527582.3	5252529	4.262	0.652	0.642	0.662

Notes:
This data was collated from SKM (2001).
ND means no data provided/available.
mbTOC means metres below top of PVC casing, mAHD means metres Australian height datum, SWL means standing water level.
*Eastings and northings were obtained from the GIS master file for bores where possible. Some monitoring bores from in the SKM (2001) report were not in the GIS Master file, the eastings and northings for these bores were collected from the SKM (2001) report and the eastings were corrected by adding 112 m and the northings were corrected by adding 182 m (old datum used in the SKM report).
**Elevation data was collated from SKM (2001), and they generally corresponded with those in the GIS Master file. Some differences were noted, and these are attributed to recent adjustments (i.e. cutting off the top of the casing due to earthworks).
High tide is assumed to have been collected on 24 March 2001, based on the times and the order of the columns, but this was not stated in the SKM (2001) report.

3.4.3 Historic data – 2015-2019

Point measurements were collected from 106 bores located in the Study Site (Figure 4) from 2015-2019 (GIS Master File), as summarised in Table 8.

Table 8 – Standing water level measurement statistics (mAHD) collected between 2015-2019

Bore ID	Easting	Northing	Main Screen Lithology	HGU	Count	Min	10th%tile	median	Mean	Geometric mean	90th%tile	Max
C1	527657.503	5252456.17	Fill	Fill only	5	1.11	1.11	1.12	1.14	1.14	1.20	1.21
MW03	527631.947	5252345.277	Fill	Fill only	10	0.64	0.65	0.69	0.71	0.71	0.77	0.85
MW05	527627.117	5252326.438	Fill	Fill only	10	0.59	0.61	0.68	0.67	0.67	0.74	0.74
MW123A	527393.27	5252399.74	Fill	Fill only	9	0.62	0.65	0.77	0.83	0.81	1.09	1.12
MW125A	527553.73	5252320.26	Fill	Fill only	7	0.60	0.62	0.66	0.68	0.68	0.78	0.81
MW126A	527609.6	5252304.45	Fill	Fill only	8	0.53	0.53	0.60	0.62	0.62	0.72	0.77
MW127A	527529.64	5252393.95	Fill	Fill only	4	0.64	0.66	0.70	0.72	0.72	0.80	0.84
MW13	527592.406	5252344.885	Fill	Fill only	8	0.73	0.77	0.81	0.90	0.89	1.11	1.16
MW133_GHD	527454.4	5252353.36	Fill	Fill only	8	0.54	0.55	0.60	0.63	0.62	0.73	0.75
MW135_GHD	527632.94	5252323.79	Fill	Fill only	4	0.60	0.62	0.67	0.68	0.68	0.76	0.80
MW137	527545.66	5252514.71	Fill	Fill only	7	0.97	0.98	1.03	1.03	1.02	1.07	1.08
MW142	527581.36	5252528.23	Fill	Fill only	8	0.97	0.99	1.04	1.06	1.06	1.14	1.24
MW143	527577.06	5252532.82	Fill	Fill only	7	0.98	1.00	1.06	1.09	1.09	1.24	1.28
MW147	527554.46	5252531.72	Fill	Fill only	6	0.99	1.00	1.01	1.07	1.06	1.21	1.33
MW148	527477.706	5252417.844	Fill	Fill only	5	0.69	0.69	0.71	0.74	0.73	0.79	0.81
MW149	527483.676	5252374.243	Fill	Fill only	5	0.57	0.57	0.61	0.62	0.62	0.67	0.68
MW154	ND	ND	Fill	Fill only	5	0.74	0.77	0.82	0.81	0.81	0.84	0.85
MW157	527501.635	5252507.233	Fill	Fill only	4	0.87	0.87	0.93	0.93	0.93	0.98	0.98
MW158	527610.893	5252566.316	Fill	Fill only	2	1.04	1.04	1.07	1.07	1.07	1.10	1.11
MW16	527622.576	5252310.246	Fill	Fill only	10	0.59	0.60	0.65	0.66	0.66	0.74	0.84
MW163	527644.415	5252427.853	Fill	Fill only	4	1.07	1.07	1.09	1.09	1.09	1.12	1.12
MW164	527634.673	5252386.218	Fill	Fill only	4	0.96	1.01	1.44	1.47	1.40	1.94	2.02
MW165	527645.479	5252556.553	Fill	Fill only	2	1.20	1.20	1.21	1.21	1.21	1.22	1.22
MW166	527641.992	5252570.733	Fill	Fill only	2	1.10	1.11	1.13	1.13	1.12	1.14	1.15
MW167	527658.873	5252563.922	Fill	Fill only	2	1.53	1.53	1.54	1.54	1.54	1.56	1.56
MW168	527654.34	5252575.677	Fill	Fill only	2	1.14	1.14	1.15	1.15	1.15	1.16	1.16
MW171	527603.899	5252577.785	Fill	Fill only	2	1.08	1.08	1.10	1.10	1.10	1.13	1.13
MW19	527511.986	5252520.981	Fill	Fill only	8	0.73	0.82	0.91	0.92	0.91	1.03	1.17
MW22	527534.87	5252516.694	Fill	Fill only	7	0.99	0.99	1.07	1.09	1.08	1.19	1.37
MW6	527631.882	5252366.709	Fill	Fill only	10	0.77	0.77	0.83	0.83	0.83	0.90	0.96
PW02	527624.264	5252337.008	Fill	Fill only	12	0.46	0.55	0.66	0.66	0.65	0.78	0.79
RN2	527645.786	5252526.638	Fill	Fill only	7	1.28	1.29	1.30	1.32	1.32	1.37	1.41
S4	527620.807	5252363.953	Fill	Fill only	10	0.82	0.82	0.90	0.89	0.89	0.96	0.98
S6	527615.679	5252345.586	Fill	Fill only	8	0.73	0.75	0.80	0.82	0.82	0.91	0.96
S8	527610.904	5252328.497	Fill	Fill only	8	0.66	0.69	0.74	0.77	0.77	0.87	0.91
MW124A	527507.73	5252350.79	Fill	Silty sand & or Fill	4	0.58	0.59	0.64	0.66	0.66	0.75	0.79
MW130_GHD	527382.45	5252393.37	Marine Deposits	Silty sand & or Fill	8	0.54	0.57	0.61	0.64	0.64	0.74	0.76
MW131	527539.23	5252560.53	Fill/ Estuarine/ Marine Deposits	Silty sand & or Fill	7	1.02	1.04	1.13	1.17	1.16	1.31	1.51
MW131_GHD	527398.42	5252384.86	Marine Deposits	Silty sand & or Fill	8	0.48	0.49	0.54	0.56	0.56	0.65	0.69
MW132_GHD	527399.6	5252384.26	Fill/Marine Deposits	Silty sand & or Fill	8	0.55	0.58	0.61	0.65	0.65	0.75	0.76
MW133	527544.91	5252557.78	Fill	Silty sand & or Fill	7	1.06	1.07	1.17	1.17	1.17	1.29	1.44

Bore ID	Easting	Northing	Main Screen Lithology	HGU	Count	Min	10th%tile	median	Mean	Geometric mean	90th%tile	Max
MW134	527547.39	5252565.03	Fill/ Weathered Dolerite	Silty sand & or Fill	6	1.03	1.04	1.17	1.19	1.18	1.37	1.50
MW134_GHD	527600.19	5252274.58	Fill	Silty sand & or Fill	5	0.26	0.27	0.29	0.32	0.31	0.41	0.50
MW135	527524.69	5252519.85	Fill	Silty sand & or Fill	7	0.95	0.96	1.01	1.06	1.05	1.20	1.35
MW136	527525.25	5252509.22	Fill	Silty sand & or Fill	7	0.87	0.87	0.90	0.93	0.93	1.03	1.10
MW136_GHD	527633.06	5252324.5	Fill	Silty sand & or Fill	3	0.50	0.52	0.59	0.56	0.56	0.59	0.59
MW146	527552.11	5252507.05	Fill	Silty sand & or Fill	8	0.95	0.95	1.00	1.03	1.03	1.12	1.23
MW150	527528.454	5252319.791	Fill / Marine Deposits	Silty sand & or Fill	2	0.64	0.64	0.64	0.64	0.64	0.64	0.64
MW151	527567.7196	5252282.382	Fill / Marine Deposits	Silty sand & or Fill	2	0.30	0.30	0.31	0.31	0.31	0.32	0.32
MW155	ND	ND	Fill	Silty sand & or Fill	6	1.15	1.15	1.19	1.18	1.18	1.21	1.21
MW156	ND	ND	Fill	Silty sand & or Fill	4	1.17	1.18	1.20	1.20	1.20	1.21	1.21
MW55	527548.733	5252422.331	Fill	Silty sand & or Fill	2	0.77	0.77	0.79	0.79	0.78	0.80	0.80
NR2	527664.812	5252610.953	Marine Deposits	Silty sand & or Fill	7	0.97	0.97	0.99	1.03	1.03	1.14	1.24
R1	527543.288	5252562.731	Fill	Silty sand & or Fill	8	0.93	1.00	1.06	1.09	1.08	1.21	1.32
R2	527509.005	5252529.146	Fill	Silty sand & or Fill	8	0.93	0.98	1.15	1.29	1.22	1.67	2.62
R3	527531.849	5252503.629	Fill	Silty sand & or Fill	9	0.87	0.87	0.91	0.94	0.93	1.03	1.05
R4	527540.965	5252510.749	Fill	Silty sand & or Fill	8	0.97	1.00	1.05	1.08	1.07	1.18	1.27
RN4	527563.308	5252490.93	Fill/Marine Deposits	Silty sand & or Fill	7	0.88	0.89	0.91	0.93	0.93	1.00	1.03
RS6	527456.344	5252374.791	Fill	Silty sand & or Fill	11	0.50	0.57	0.65	0.68	0.67	0.80	0.84
S9	527588.943	5252302.383	Fill	Silty sand & or Fill	10	0.74	0.77	0.81	0.81	0.81	0.87	0.93
BG1	527493.615	5252617.707	Bedrock	some Jd	5	6.20	6.21	6.32	6.37	6.37	6.59	6.69
BH1_PS	527483.786	5252561.39	Weathered Dolerite/ Bedrock	some Jd	6	2.30	2.41	2.63	2.87	2.81	3.57	4.34
BH2_PS	527468.859	5252435.884	Fill/Marine Deposits	some Jd	8	0.70	0.72	0.79	0.82	0.81	0.95	1.09
M3	527542.598	5252597.729	Bedrock	some Jd	6	2.61	2.99	3.92	3.90	3.80	4.78	5.42
MW10	527517.013	5252512.4	Fill/Bedrock	some Jd	8	0.66	0.67	0.91	0.88	0.87	1.03	1.07
MW120	527359.28	5252640.61	Fill	some Jd	5	5.75	5.76	6.07	6.22	6.20	6.78	6.86
MW121	527391.61	5252556.42	Weathered Dolerite	some Jd	6	2.91	2.94	3.18	3.24	3.22	3.60	3.93
MW122	527495.56	5252422.98	Fill	some Jd	10	0.70	0.71	0.78	0.80	0.80	0.91	0.96
MW123B	527393.23	5252399.73	Slope Deposits/Bedrock	some Jd	9	0.29	0.33	0.35	0.37	0.37	0.44	0.46
MW124B	527507.67	5252350.79	Alluvial/ Marine Deposits	some Jd	4	0.56	0.58	0.62	0.64	0.64	0.73	0.77
MW125B	527553.71	5252320.34	Marine Deposits	some Jd	6	0.59	0.60	0.63	0.65	0.64	0.72	0.80
MW126B	527609.66	5252304.43	Slope Deposits	some Jd	6	0.44	0.47	0.55	0.59	0.58	0.75	0.76
MW127B	527529.68	5252393.99	Slope Deposits	some Jd	4	0.56	0.58	0.63	0.66	0.65	0.76	0.81
MW129	527457.19	5252377.34	Slope Deposits	some Jd	7	0.44	0.46	0.50	0.55	0.54	0.67	0.70
MW130	527544.21	5252549.92	Fill	some Jd	6	1.04	1.06	1.12	1.16	1.15	1.28	1.41
MW132	527540.88	5252568.83	Fill	some Jd	4	1.30	1.30	1.45	1.58	1.55	1.97	2.14
MW138	527513.08	5252499.01	Fill	some Jd	6	0.84	0.84	0.85	0.88	0.88	0.95	1.01
MW139	527514.45	5252511.63	Fill	some Jd	7	0.69	0.79	0.86	0.89	0.88	1.01	1.07
MW140	527511.76	5252511.63	Fill	some Jd	7	0.31	0.39	0.85	0.74	0.69	0.95	1.06
MW141	527515.39	5252518.55	Fill	some Jd	7	0.88	0.89	0.94	0.96	0.96	1.07	1.11
MW144	527525.48	5252528.97	Fill/Bedrock	some Jd	7	1.02	1.03	1.11	1.14	1.13	1.30	1.48
MW145	527626.85	5252642.48	Bedrock	some Jd	4	1.28	1.50	2.19	2.37	2.20	3.39	3.83
MW159	527693.238	5252689.962	Bedrock	some Jd	2	1.18	1.19	1.24	1.24	1.24	1.30	1.31
MW160	527666.699	5252766.39	?	some Jd	2	2.62	2.63	2.67	2.67	2.67	2.72	2.73

Bore ID	Easting	Northing	Main Screen Lithology	HGU	Count	Min	10th%tile	median	Mean	Geometric mean	90th%tile	Max
MW161	527657.8	5252774.319	?	some Jd	2	3.42	3.43	3.45	3.45	3.45	3.47	3.47
MW173	ND	ND	Fill/Marine Deposits	some Jd	1	2.17	2.17	2.17	2.17	2.17	2.17	2.17
MW174	ND	ND	Fill/Marine Deposits	some Jd	1	1.03	1.03	1.03	1.03	1.03	1.03	1.03
NR1	527648.559	5252654.045	Bedrock	some Jd	5	2.31	2.36	2.92	3.11	3.01	4.09	4.63
NR3	527607	5252620.121	Slope Deposits / Bedrock	some Jd	4	1.58	1.62	1.89	2.00	1.96	2.47	2.65
PW03	527519.542	5252516.317	Fill/Bedrock	some Jd	7	0.89	0.90	0.96	1.04	1.03	1.27	1.28
TW01	527662.7147	5252592.413	Fill	some Jd	4	1.38	1.40	1.43	1.44	1.44	1.50	1.53
TW02	527643.6646	5252532.485	Fill	some Jd	4	1.09	1.09	1.10	1.14	1.14	1.23	1.28
TW03	527648.4272	5252476.922	Fill	some Jd	6	1.16	1.17	1.17	1.19	1.19	1.23	1.25
MW100	527434.926	5252397.121	Fill	Unsure	9	0.58	0.62	0.66	0.70	0.69	0.81	0.89
MW101	527370.927	5252477.012	Fill	Unsure	7	2.54	2.69	3.11	3.07	3.06	3.34	3.43
MW102	527400.582	5252491.493	Fill/Weathered Dolerite/Slope Deposits	Unsure	10	2.52	2.62	2.93	2.91	2.90	3.21	3.44
MW103	527520.429	5252588.668	Fill/ Slope Deposits	Unsure	6	3.53	3.77	4.30	4.43	4.38	5.22	5.79
MW128A	527368.37	5252452.59	Slope Deposits/Bedrock	Unsure	5	2.53	2.72	3.07	3.18	3.15	3.67	3.70
MW128B	527368.39	5252452.59	Bedrock	Unsure	5	2.51	2.69	3.06	3.15	3.12	3.62	3.68
MW162	527561.725	5252463.136	Fill	Unsure	3	0.88	0.88	0.89	0.91	0.91	0.96	0.98
MW21	527517.477	5252502.427	Fill	Unsure	7	0.83	0.84	0.85	0.88	0.88	0.95	1.01
MW23	527542.123	5252522.481	Fill	Unsure	7	0.95	0.98	1.06	1.09	1.08	1.22	1.38
MW36	527471.125	5252514.268	Fill/Bedrock	Unsure	7	1.94	1.94	1.96	1.96	1.96	1.99	1.99
MW60	527604.842	5252306.32	Fill	Unsure	8	0.61	0.64	0.71	0.78	0.76	0.97	1.13
PC13	527650.528	5252362.247	Fill	Unsure	2	0.92	0.92	0.92	0.92	0.92	0.92	0.92
PC15	527668.146	5252518.054	Fill	Unsure	3	1.60	1.60	1.60	1.61	1.61	1.63	1.64

Notes:
HGU means hydrogeological unit.
The main screen lithology was assigned in the GIS database. The HGU was determined by interrogating the construction and lithology database (also in the main GIS database).
Jd means Jurassic dolerite.
Data collected from GIS Master File.

3.4.4 Historic data from level loggers – 2013-2015

GHD (2015a) placed level loggers in six monitoring bores between December 2013 and January 2015. The measurement interval was not stated in the report, but it was at least daily, judging by the figures they presented. Three of the bores were located within the Mac Point Site (BH1_PS, MW21 and MW6), and three were located outside the Mac Point Site (PC5, PW01 and PC8; locations shown in Figure 4).

None of the bores within the Mac Point Site showed a tidal response, and PC8 was the only bore that showed a tidal response, suggesting that the tidal response does not propagate far from the shoreline (PC8 is located about 150 m southeast of the Mac Point Site and about 30-40 m from the shoreline; Figure 4), and it possibly doesn't reach past the seawalls.

3.5 Groundwater recharge

Of the groundwater level data presented in Section 3.4, only the 2024 data provide a reliable snapshot of recharge processes. The 2024 data is the best dataset for calculating recharge rates, as presented in Table 9. The results are summarised below:

- The total range for recharge assuming porosity ranges from 1%-30% is 0.003%-5.65% of rainfall, with a mean of 0.59% and a median of 0.19%.

- The fill and silty sand likely have a porosity of between 5%-25%; therefore, the following recharge rates are likely based on this assessment: Range: 0.02%-4.71% of rainfall, with a mean of 0.54% and a median of 0.20%.

- If the results from MW164 are ignored, and we assume porosity of between 5%-25%, **recharge rates ranged between 0.02%-1.04% of rainfall**, **with a mean of 0.25% and a median of 0.17%**. This compares favourably with the recharge rates used by GHD (2015a) for paved areas (0.00000274m/day, which equates to 0.18% of total rainfall assuming a median annual rainfall of 569.2 mm; median Rainfall from BoM, accessed on 29 May 2024, Station 094030 Hobart Botanical Gardens), and it is a good starting point for paved areas in our model.

- The recharge rate at MW164 suggest a small area of higher recharge is nearby. At MW164, if we assume porosity of between 5%-25%, recharge rates ranged between 0.94%-4.71% of rainfall, with a mean and median of 2.83%. A recharge rate of between 1-5% is a good starting point for a small high recharge zone near MW164.
    - Note that a small high recharge zone was not included in the model (Groundwater Logic, 2024). More data is required to confirm this observation and more time is required to adequately model it.

Notably, most of these monitoring bores are in areas where the surface has pavement/concrete/bitumen. Monitoring bores RN4 and MW123A are close to the excavated zones, but no additional recharge was recorded at these bores (Table 9). Recharge rates are expected to be higher in the excavated areas. We note that in 2015-2019, this area was not excavated, so recharge zones would be different. Recharge zones for 2016 - 2019 are presented in Figure 9 and the recharge areas for 2024 are presented in Figure 10.

Table 9 – Calculated recharge rates based on groundwater level logger data collected in 2024 over a two-day period

	22/05/2024 0:00	22/05/2024 17:00		Percent rainfall to recharge groundwater for a range of assumed porosity values					
	Pre-rain SWL (mAHD)	Post-rain SWL (mAHD)	Increase SWL (m)	1%	5%	10%	20%	25%	30%
C1	1.216	1.227	0.011	0.02	0.09	0.18	0.37	0.46	0.55
MW55	0.817	0.821	0.004	0.01	0.03	0.07	0.13	0.17	0.20
MW123A	0.78	0.798	0.018	0.03	0.15	0.30	0.60	0.75	0.90
MW124B	0.695	0.705	0.01	0.02	0.08	0.17	0.33	0.42	0.50
MW126A	0.658	0.683	0.025	0.04	0.21	0.42	0.83	1.04	1.25
MW164	0.998	1.111	0.113	0.19	0.94	1.88	3.77	4.71	5.65
RN4	0.845	0.85	0.005	0.01	0.04	0.08	0.17	0.21	0.25
RS6	0.702	0.704	0.002	0.003	0.02	0.03	0.07	0.08	0.10

Note: mAHD means metres Australian Height Datum, SWL means standing water level, m means metres.

Figure 9 – Recharge zones using Google Earth images from 2016 (top) and 2019 (bottom)

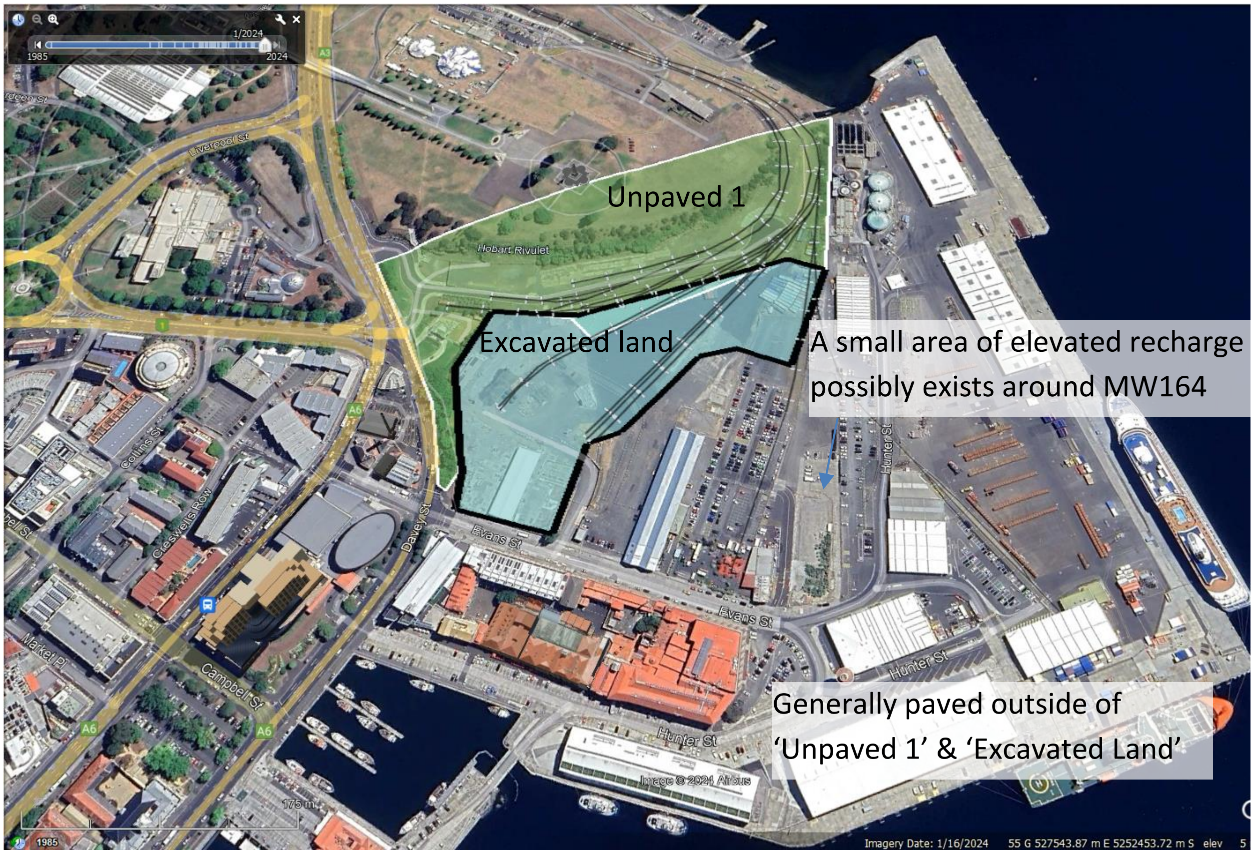


Figure 10 – Recharge zones in 2024, based on an assessment of Google Earth imagery

3.5.1 Chloride mass balance

Groundwater recharge rates for the unpaved area in the north of the Mac Point Site have been estimated using the chloride mass balance (CMB) method, described by many authors including Wood and Sanford (1995), and Crosbie and Rachakonda (2021). Unfortunately, this method is not suitable for the other regions, because the overlying pavement/concrete/bitumen would reduce recharge and groundwater chloride concentrations are likely influenced by groundwater recharging from the north. The unpaved areas are assumed to be recharged by direct infiltration of rainfall, which may only be partially true. Therefore, recharge rates obtained from this method are considered indicative, and a good starting point for the model.

The CMB method assumes that chloride is conservative, and that some precipitation and the associated chloride is lost to runoff, while the remaining precipitation is evapotranspired. Chloride is excluded from evapotranspired water and the remaining chloride leaches downwards into groundwater. The CMB method assumes that the chloride concentration of groundwater is related to the initial volume of precipitation and the concentration of chloride in precipitation and dry deposition. The following equation is used to calculate groundwater recharge rates (R), after Crosbie and Rachakonda (2021):

Equation 6: $R = (100 \times D(1-RC))/Clgw$

where R is average annual net recharge (mm/year), D is the annual chloride deposition (kg/ha/year), RC is the runoff coefficient, Clgw is the chloride concentration of the groundwater (mg/L) and the multiplier of 100 is a unit conversion factor. Annual chloride deposition rates are estimated by the CSIRO with a grid spacing of 0.05° x 0.05° across Australia (Wilkins et al., 2022; 5th percentile, mean, and 95th percentile), as follows:

- The 5th percentile of the modelled chloride deposition is 49.79 kg/hectare/year.
- The mean of the modelled chloride deposition is 57.56 kg/hectare/year.
- The 95th percentile of the modelled chloride deposition is 67.27 kg/hectare/year.

An RC of 0.8 was estimated by dividing the approximate mean annual runoff by the mean precipitation. Mean annual runoff was estimated at 456 mm after Viney et al. (2009; Table 3 – climate scenario A – Derwent – South East) and mean annual precipitation was estimated at 569.2 mm (BoM, http://www.bom.gov.au/climate/data/, Station No. 094030 Hobart Botanical Gardens, accessed on 29 May 2024).

Groundwater chloride concentrations are documented in AECOM (2015a) at two monitoring bores located in the north of the Mac Point Site. Chloride concentrations were reported as 66 mg/L at BG1 after sampling on 13 January 2015, and 34 mg/L at MW101 after sampling on 14 January 2015.

Recharge rates were calculated as follows:

- BG1
    - Using 5th percentile modelled chloride deposition rates: 15 mm per year.
    - Using mean modelled chloride deposition rates: 17 mm per year.
    - Using 95th percentile modelled chloride deposition rates: 20 mm per year.
- MW101

- Using 5th percentile modelled chloride deposition rates: 13 mm per year.
- Using mean modelled chloride deposition rates: 15 mm per year.
- Using 95th percentile modelled chloride deposition rates: 17 mm per year.

Therefore, we can say a range of 13-20 mm per year is a good starting point for recharge rates in the unpaved area to the north of the Study Site. **This equates to a recharge rate for the unpaved area in the north of the Study Site of about 2-4% of total rainfall** assuming a median annual rainfall of 569.2 mm; median Rainfall from BoM, accessed on 29 May 2024, Station 094030 Hobart Botanical Gardens). GHD (2015) had a much higher recharge rate for unpaved areas (0.000548 m/day, which equates to 35.1% of total rainfall assuming a median annual rainfall of 569.2 mm; median Rainfall from BoM, accessed on 29 May 2024, Station 094030 Hobart Botanical Gardens), but nonetheless, a recharge rate of between 2-4% is a good starting point for the unpaved areas of the Study Site.

4 Summary of the model and indicative model parameters

Groundwater recharge rates are likely higher in the north where the ground surface is mostly unpaved. Indicative recharge rates in this unpaved area are estimated at about 2-4% of rainfall based on an assessment using the CMB method. Recharge rates in the paved areas likely range from about 0.02%-1.04% of rainfall (calculated mean was 0.25% and the median was 0.17% of rainfall). There may be a small area of elevated recharge near MW164 (and possibly other unidentified areas on Study Site), where recharge may range from about 1-5% of total rainfall. These recharge rates are considered good starting points for the model, but they are not definitive estimates.

Indicative model parameters for the fill and the silty sand are presented in Table 10.

A 3D model of the geology is provided for the construction of the model framework, and groundwater level data are also provided in the body of this report (Table 8).

Table 10 – Indicative model parameters

Hydrogeological units	Lower K (m/day)	Upper K (m/day)	Lower porosity	Upper porosity	Lower Sy	Upper Sy	Lower Ss	Upper Ss	Comments
Fill	0.1	50	5%	25%	0.05	0.2	1.1E-05	9.8E-04	
Silty sand	0.3	10	5%	25%	0.05	0.2	1.1E-05	9.8E-04	

Notes:

K means hydraulic conductivity; Sy means specific yield; Ss means specific storage; m/day means metres per day.

K estimates based largely on hydraulic testing results presented in GHD (2015b), as presented in Table 3 and Table 4.

Porosity estimates are based loosely on values for sand presented in Kruseman and deRidder (1994) presented in Table 5, but values were reduced to account for the silt component.

Specific yield estimates are based on estimates for fine and coarse sand in Kasenow (2006), as discussed in Section 3.3, but the lower estimate is reduced to account for the silt component.

Specific storage estimates based on estimates calculated in Table 5.

5 Modelled groundwater flow paths

This section contains groundwater flow path interpretations based on modelling conducted by Groundwater Logic (Groundwater Logic, 2024). Please refer to Section 5 of the Groundwater Logic report (2024), which outlines the limitations of the modelling approach, noting that all groundwater models are simplifications of more complex systems.

Note that this investigation did not include an in-depth assessment of groundwater contamination. Therefore, interpreted flow paths around mapped contamination should be used with caution. Further investigations are required to assess the potential for contaminant transport, including, but not limited to the assessment of current contaminant concentrations, and contaminant transport modelling.

Groundwater flow path interpretations based on modelled levels for high water table conditions and low water table conditions respectively are presented in Figure 11 and Figure 12 using the median (P50) uncertainty estimates, in Figure 13 and Figure 14 using the lower (P10) uncertainty estimates, and in Figure 15 and Figure 16 using the upper uncertainty estimates (P90). Groundwater generally flows to the southeast, as predicted in the conceptual hydrogeological model (Section 3). Figure 11 through to Figure 16 are collectively referred to as the *modelled groundwater flow direction figures* herein.

Most of the *modelled groundwater flow direction figures* show a mound located near the southeast of the Mac Point Site between the two seawalls. A more detailed look at this area shows that the mound is present in five of the six *modelled groundwater flow direction figures* (Figure 17), meaning that according to the model, groundwater near the seawall may move westward back towards the Mac Point Site.

5.1 Model history matching notes

Section 3.3 of the modelling report (Groundwater Logic, 2024) contains a more complete summary of the history matching results. Two important notes from this section are discussed briefly below:

- The rainfall response at MW164 on 22 May 2024 (logger data; refer to Section 3.4.1) was not replicated in the model. This rainfall response requires more investigation to determine if it impacts groundwater flow paths.

- A tidal response is modelled at MW124B, but none were observed in the data. This discrepancy probably won't affect the model findings in relation to generalised groundwater flow directions in this area but more work is required to confirm this.

Follow-up modelling using more logger data, and providing more time for modelling, data assessments, and conceptualisation are required to assess the implications of these history matching results.

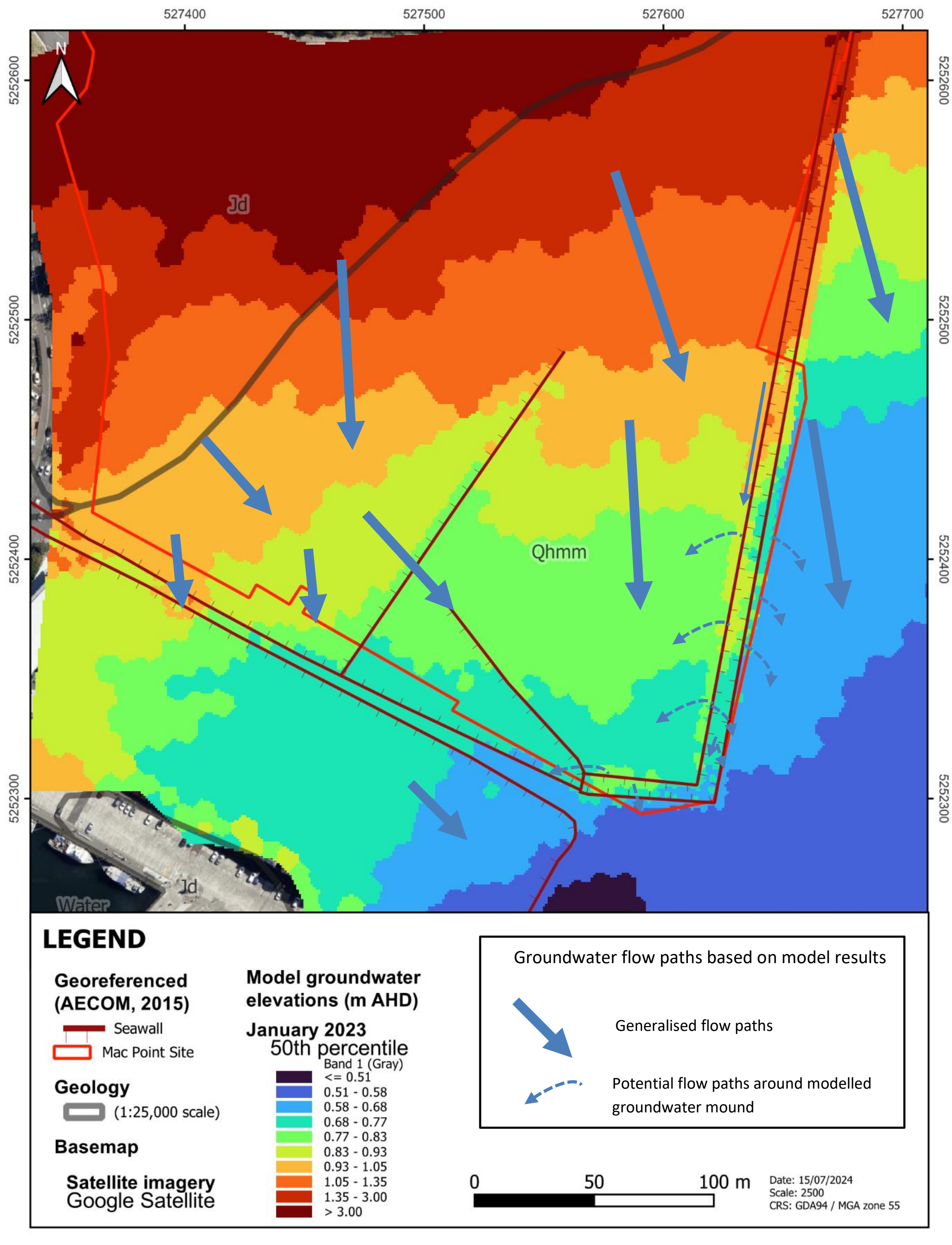


Figure 11 – Modelled groundwater levels for the median (P50) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during high water table conditions

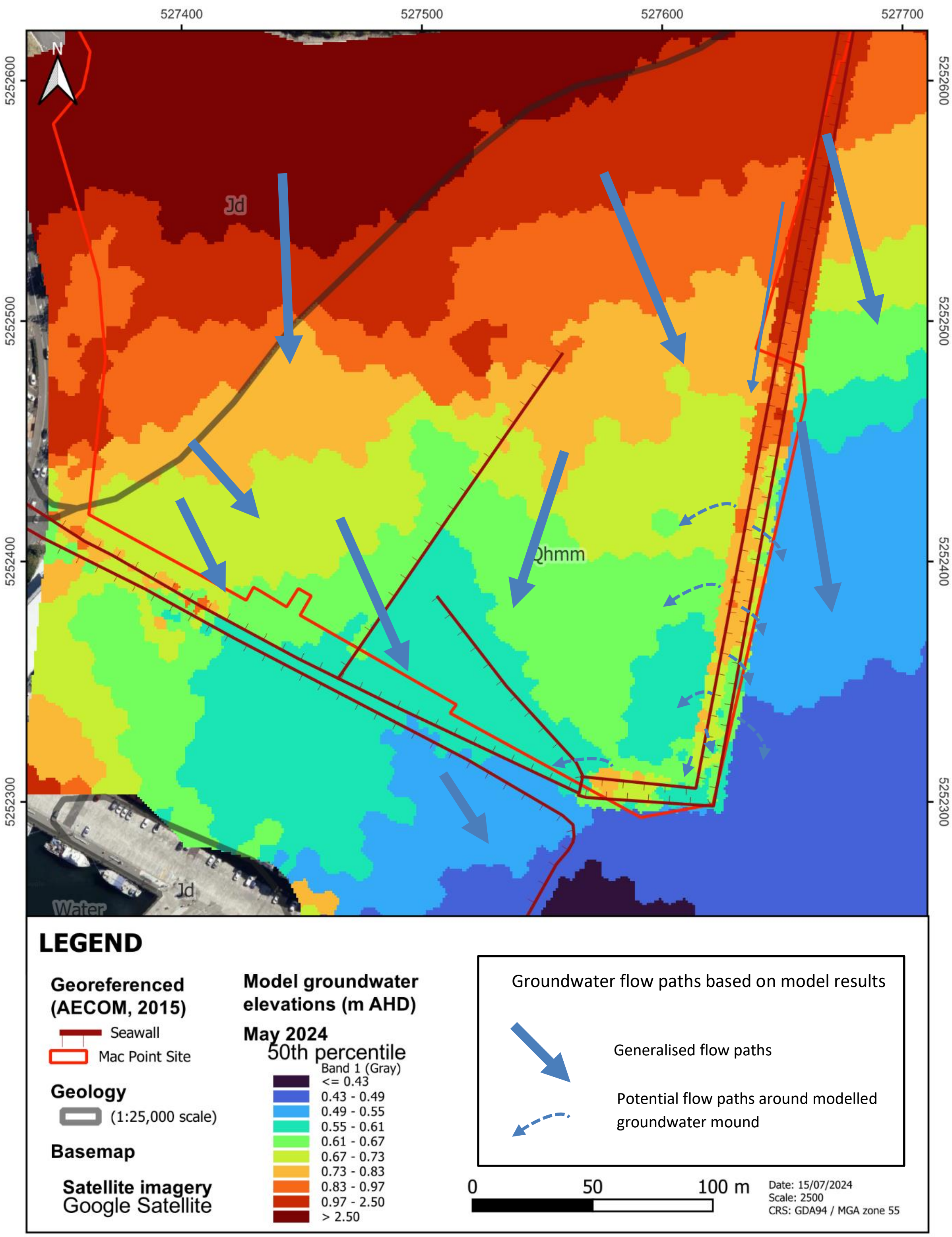


Figure 12 – Modelled groundwater levels for the median (P50) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during low water table conditions

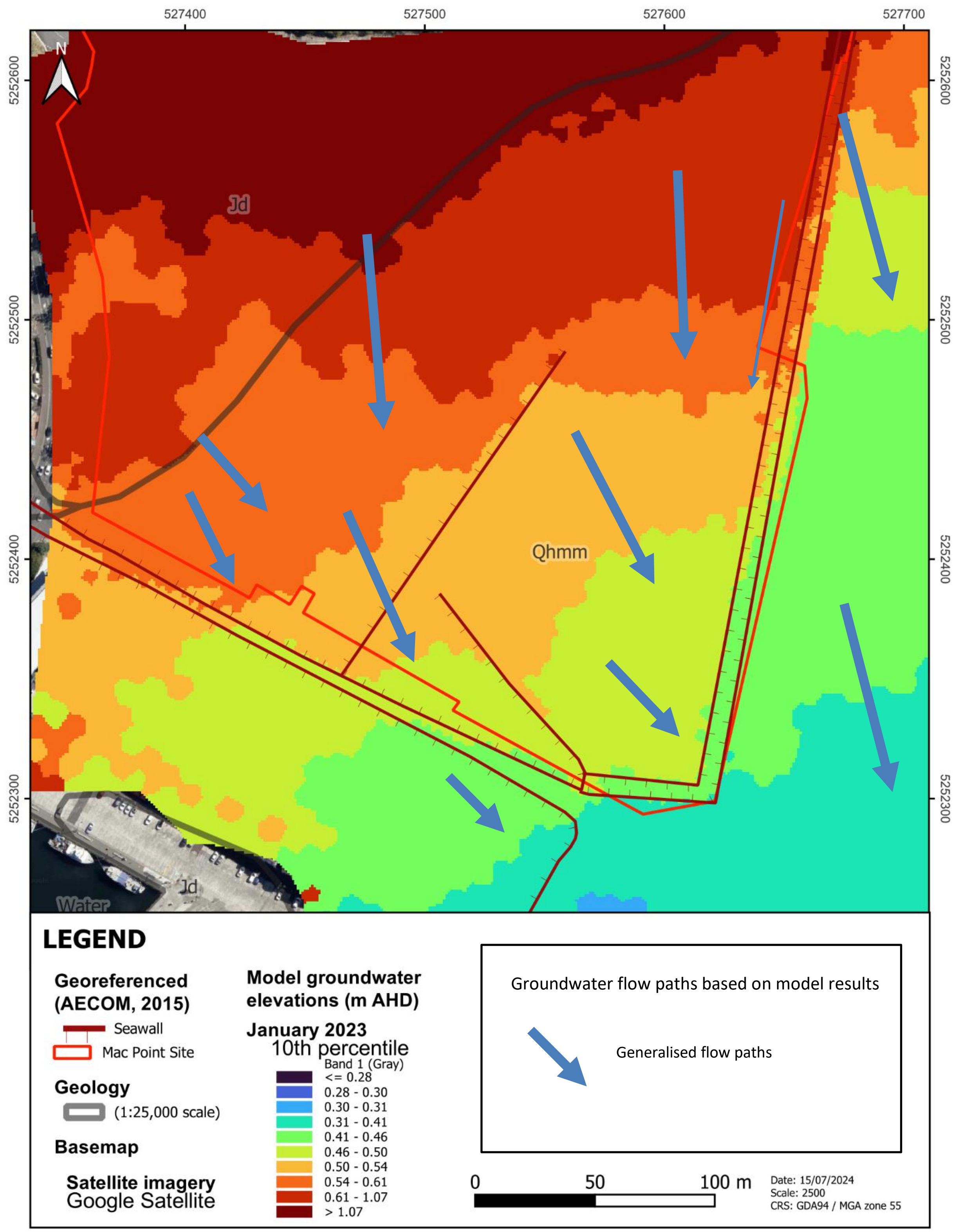


Figure 13 – Modelled groundwater levels for the lower (P10) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during high water table conditions

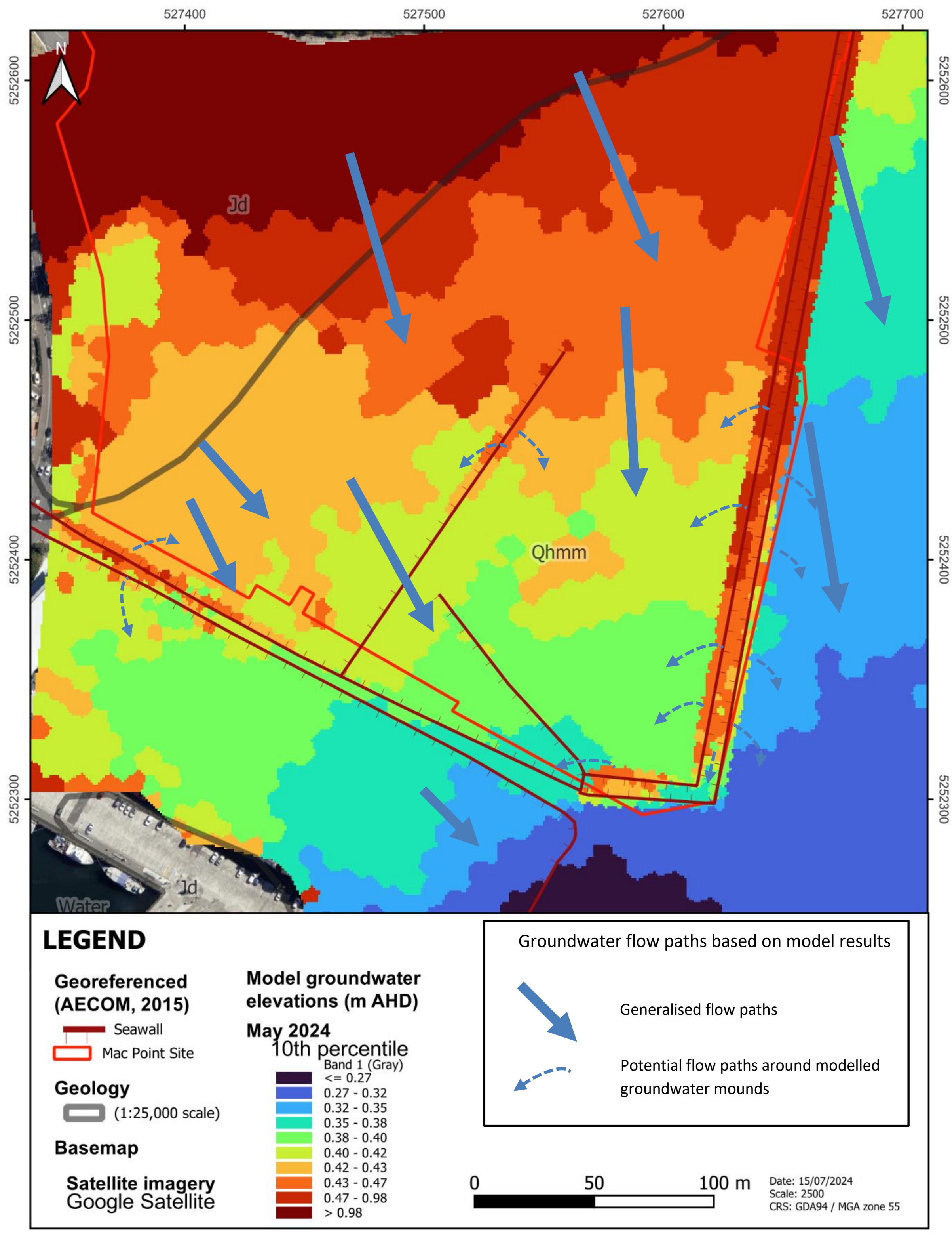


Figure 14 – Modelled groundwater levels for the lower (P10) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during low water table conditions

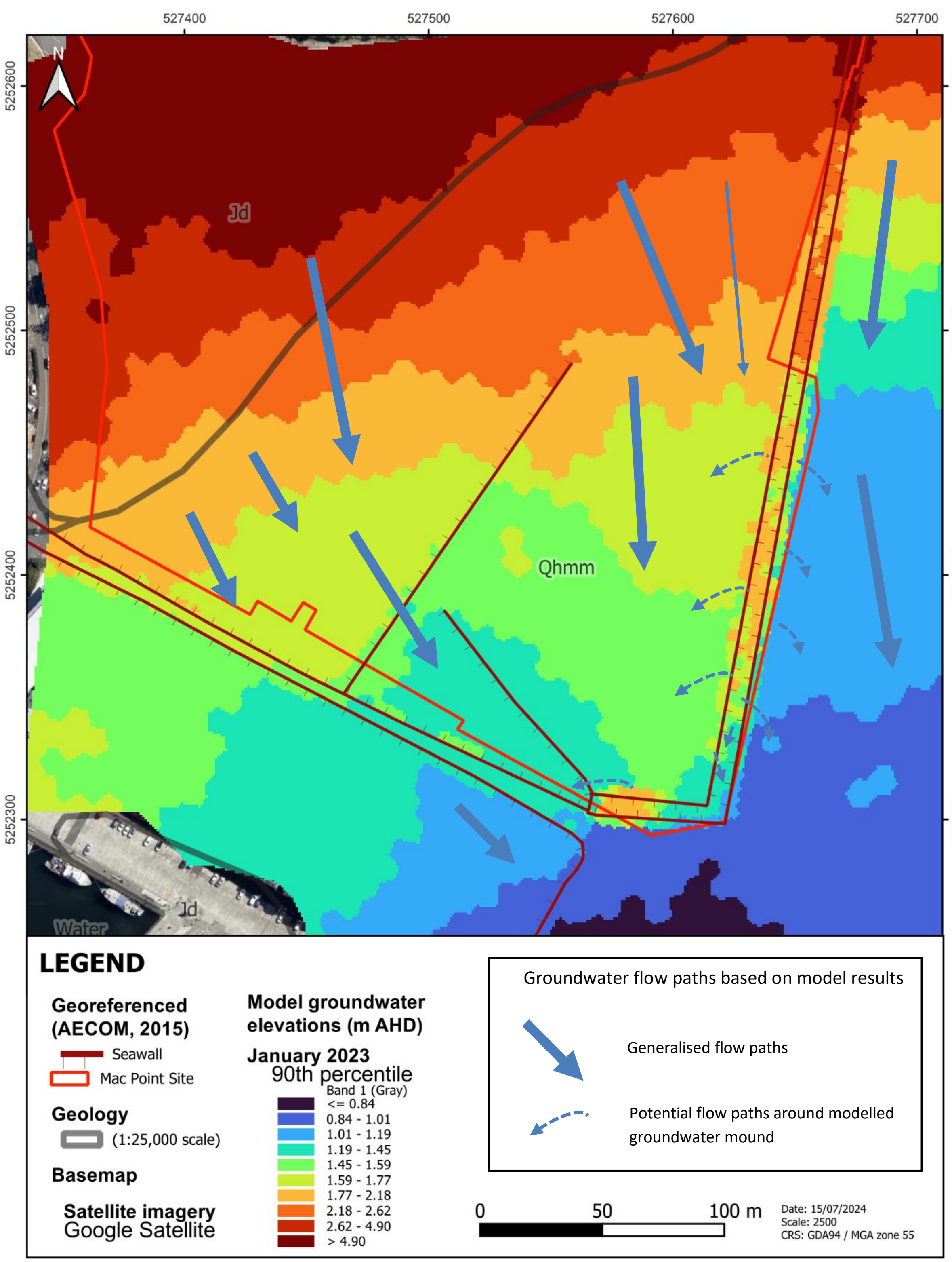


Figure 15 – Modelled groundwater levels for the upper (P90) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during high water table conditions

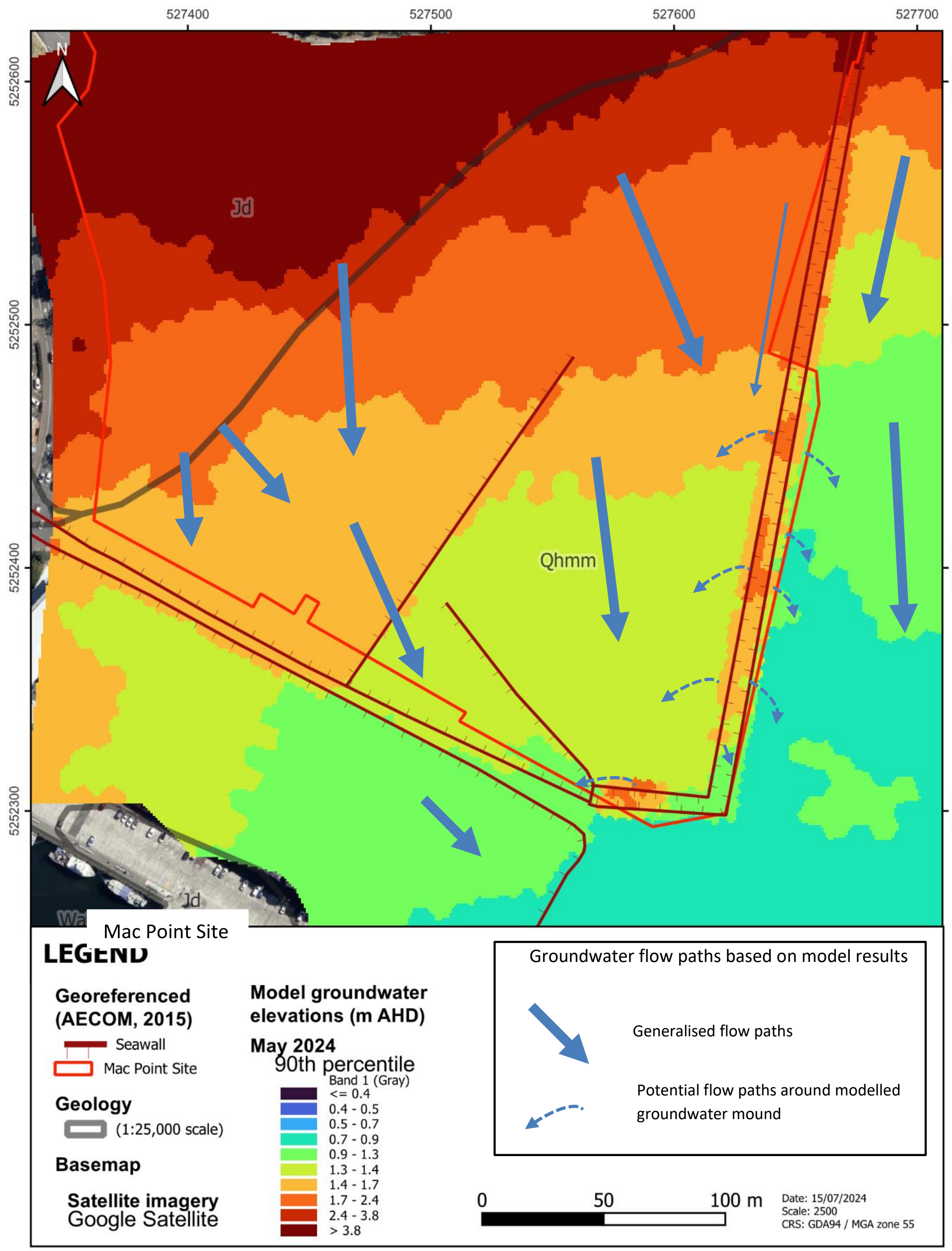


Figure 16 – Modelled groundwater levels for the upper (P90) uncertainty estimate (Groundwater Logic 2024) and associated flow paths during low water table conditions

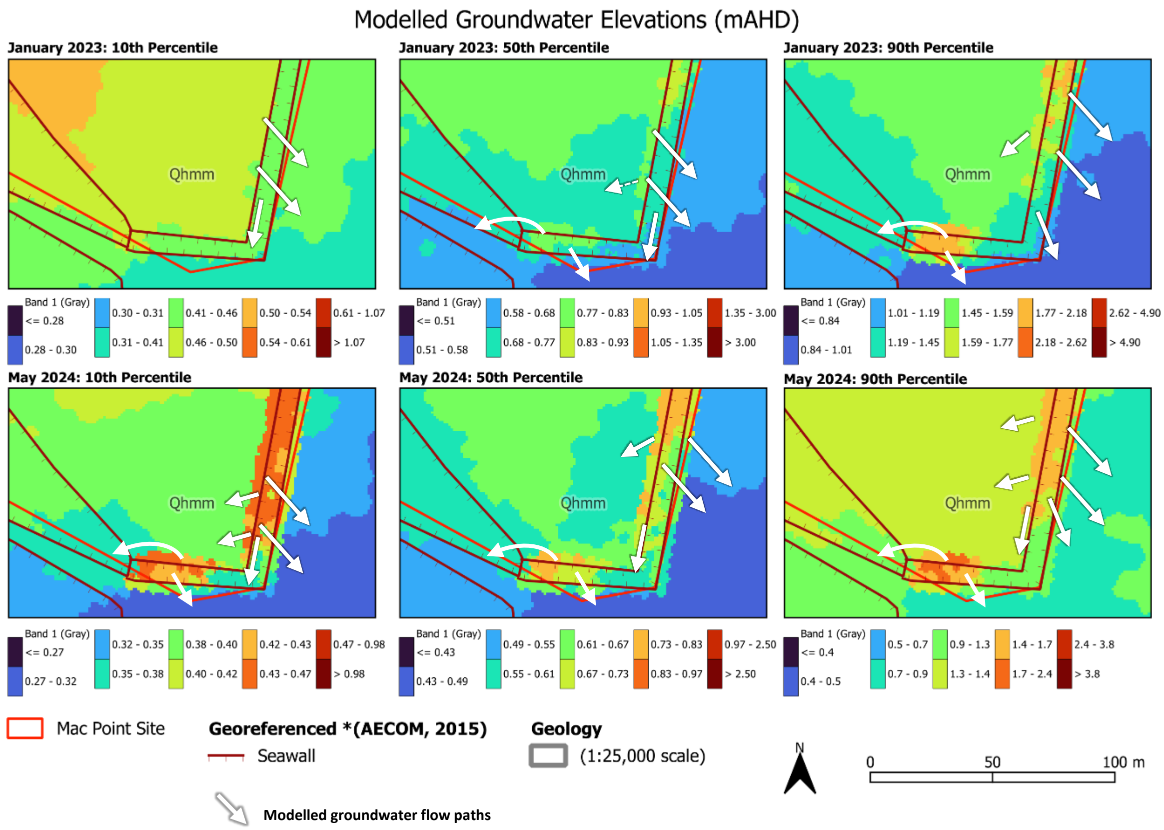


Figure 17 – Modelled groundwater levels and associated flow paths near the southeast of the Mac Point Site

6 References

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7 Limitations

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Appendices

Appendix A – Groundwater Logic modelling report

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DATE:	9th July 2024
TO:	Adam King, Hydro Earth Consulting
FROM:	Chris Nicol, Hydrogeologist
RE:	Macquarie Point Stadium Watertable Modelling
OUR REF:	HE001/c001 rev1

1. Introduction

Hydro Earth Consulting (HEC) commissioned Groundwater Logic to develop a simple numerical groundwater (watertable) flow model of the Macquarie Point Stadium site (termed "the Site" herein).

This modelling and its outcomes were requested by the Macquarie Point Development Corporation (MPDC), and hence the information in this report is for sole use by MPDC, for the sole purpose described below, whilst acknowledging the limitations and assumptions underpinning the assessment that are outlined in Section 5 and as detailed throughout this memo.

As defined by HEC (2024), the modelling described in this memo is designed to answer the following questions (and nothing more than this):

- What are the average/typical groundwater levels in the sediments across the Site?
- What are the typical groundwater flow directions?
- Initially, the model was to assess the impacts of tidal fluctuations, particularly their impact on groundwater flow directions (i.e. does tidal action change/reverse groundwater flow directions?).
  - However, data collected using level loggers at the Site (collected and documented by HEC, 2024) suggest tidal influences are minor and not of concern. Further monitoring is recommended to confirm this finding, but current data are not sufficient to model this.
  - The model should now focus on using rainfall response to calibrate the model.

The modelling and assessment of this report can be defined as simple, or class 1, as defined by the Australian Groundwater Modelling Guidelines (Barnett et al, 2012). Reasons for this include limited allocated project time, limited data available with which to history-match the model, and the varied third-party sources of data. These data sources have had to be directly relied upon as supplied, with neither mechanism nor scope for verification. Having said that, a simple class 1 model is suitable for the broad and relatively simple modelling objectives. An approach that attempts to incorporate model uncertainty has been applied to convey the uncertainty in key model outputs arising from the limited available data.

This memo very briefly describes:

- Model design and construction.
- Model history-matching to available observation data.
- Modelled watertable mapping.

2. Model Design and Construction

Hydrogeological conceptualisation and data collation and provision for use in model development were conducted by HEC, as documented by Hydro Earth Consulting (2024). The reader is referred to that document for conceptualisation information. This conceptualisation and underlying data were used to design and construct a numerical groundwater flow model for the objectives described in Section 1.

2.1 Code Selection

The numerical groundwater flow model described in this report utilises MODFLOW-USG-Transport (version 2.3.0; Panday and others (2013) and Panday (2023)). This is a MODFLOW version that uses the Control Volume Finite Difference method, which allows for an unstructured model grid (and hence computationally efficient local refinement), as opposed to structured regular or irregular grids. It also possesses the necessary capabilities to meet the model objectives.

2.2 Mesh and Layering

Model layering is defined directly using a geological model provided by MPDC to HEC, and subsequently to Groundwater Logic. Four layers are applied. These, along with the model mesh are shown in Figure 2-1. The Dolerite (layer 4; representing the upper weather 10m / slope deposits) was ultimately included because some bores with the most transient observation data screen this unit.

The model mesh (comprising Voronoi polygons) and boundary conditions are shown in Figure 2-2. Selective areas of mesh refinement and alignment are included along the mapped locations of buried seawalls (provided and described by HEC, 2024), at observation bores, and along Hobart Rivulet. Areas away from these features become coarser.

2.3 Initial Heads and Temporal Discretisation

The model uses stress periods of variable duration. Initial heads are defined by an initial steady state stress period. This is followed by 24 monthly stress periods from 2013 to 2015, 9 annual periods from 2015 to January 2024, 4 monthly periods from January to May 2024, 3 weekly stress periods and then 24 3-hourly stress periods from the 21st to the 24th of May 2024.

This discretisation is dictated by the density and availability of groundwater level observation data; the last sub-daily stress periods are designed to capture potential tidal influence in the logger data collected over this period by HEC (2024), whereas the monthly periods over 2013-14 are capture the GHD (2015) observation data (which were digitised for this modelling).

Given this discretisation, tidal influence is only tested at the sub-daily (tidally influenced) scale in late May 2024, when we have logger data.

2.4 Boundary Conditions

Model boundary conditions were defined based on the conceptualisation and groundwater level mapping of HEC (2024); these comprise the following:

- A General Head Boundary along the Derwent Estuary.
    - Heads are defined as freshwater heads (i.e., accounting for sweater density).

- Transient (tidal) heads are included, based on a simple tidal prediction model developed using the Utide Python package[1], with the Utide model trained to the nearest available sub-daily tidal level data (Spring Bay, east coast of Tasmania). The absolute levels are shifted vertically by the recorded mean sea level difference between Spring Bay and Hobart. Figure 2-3 shows modelled versus observed tide heights.
- Conductance is defined using cell geometries (cross sectional areas) hydraulic conductivities of the relevant model layer at each cell; the latter is updated as these hydraulic properties are optimised during model history-matching. The length term is assumed to be 1 m. Spatially variable and adjustable multiplier parameters (pilot points; Doherty 2003) are used to scale these conductances during history-matching.

- A Specified Gradient Boundary (SGB) is applied to the (inflowing) northern model boundary along Hobart Rivulet / the Cenotaph area. The initial (inflowing) gradient was defined based on HEC (2024), at 0.08 m/m, but this was adjusted during history-matching using pilot points.
- All other boundaries, such as along the western model margin, are designated no flow boundaries; hence, groundwater flow tends to be parallel to these at the boundary. These were assigned based on the mapped groundwater levels in HEC (2024).
- Recharge (RCH) boundary applied universally across the modelled ground surface.
  - Recharge rates were estimated using the soil moisture balance model PERFECT (Littleboy et al., 1989).
    - Three models were applied – one for each of the mapped land cover types identified by HEC (2024): grass (to the north, around Hobart Rivulet and the Cenotaph), paved (concrete), and previously paved / excavated in 2024 (at the Macquarie Point Stadium development site).
    - Selected input parameters for each of these three soil moisture models were made adjustable during model history-matching (saturated hydraulic conductivity, saturation, wilting point, residual saturation). Initial saturated hydraulic conductivity values were initially set very low for paved areas.
    - The excavated land cover model was simulated using the paved area model until excavation took place (2024), at which point it switched to a bare (excavated) land cover model (with no / little vegetation cover, and more permeable soils).
  - Spatially variable multiplier (pilot point) parameters were scattered across the model domain for adjustment during history matching. These serve to adjust the recharge rates from the relevant PERFECT land cover model at a scale finer than the mapped land uses, as informed by groundwater level observation data.
  - Initial recharge rates were well aligned with the estimates of HEC (2024), at 0-2 mm/year for paved areas, and 20-30mm/year for unpaved areas.
  - Figure 2-4 shows the modelled base realisation recharge.

[1] https://github.com/wesleybowman/UTide; UTide v1p0 9/2011 d.codiga@gso.uri.edu. http://www.po.gso.uri.edu/~codiga/utide/utide.htm; and Codiga (2011).

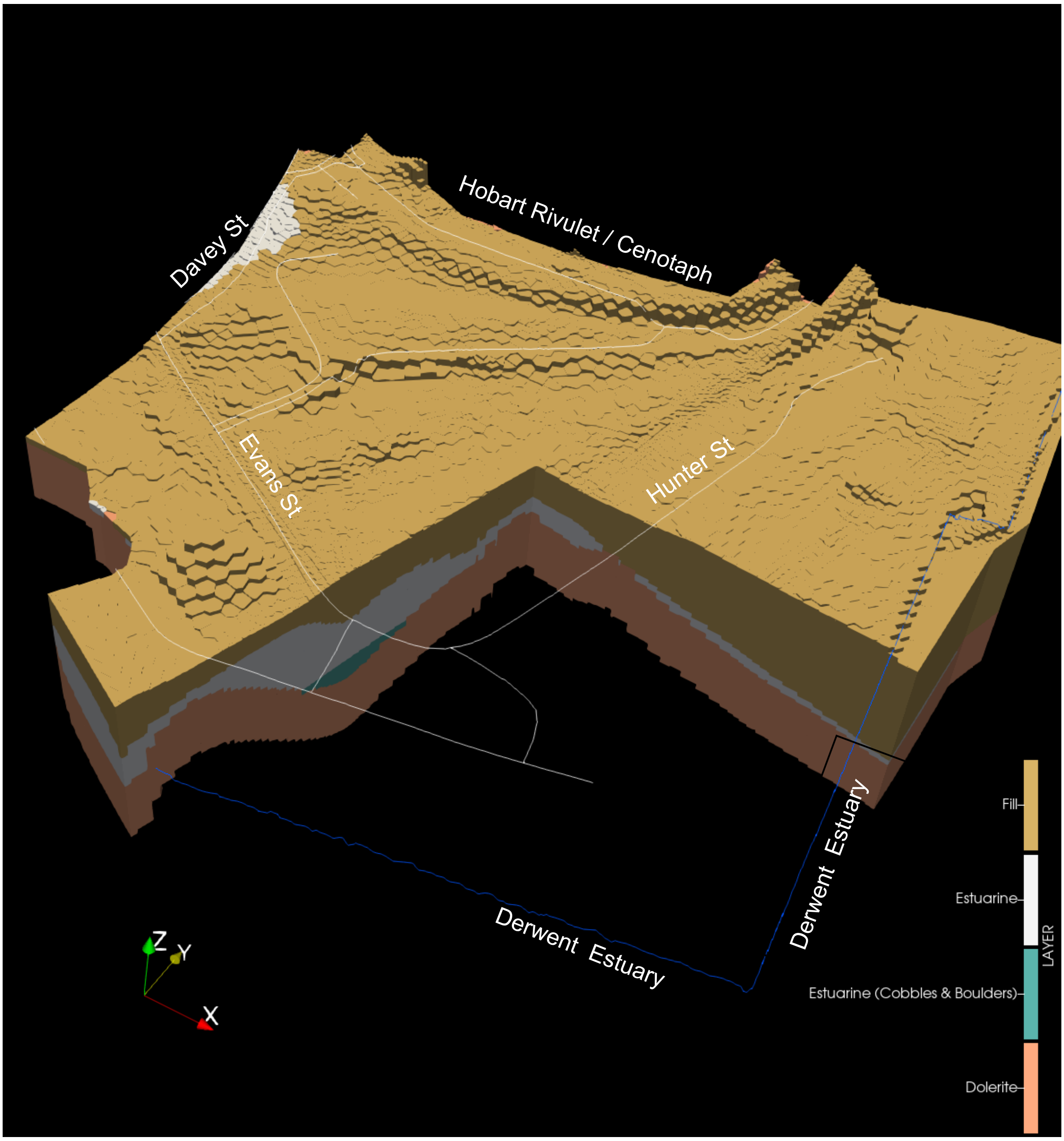


Figure 2-1 **Model mesh and layering. View from southeast towards the northwest. Box cut into the southeastern corner of the model to show layering beneath the site. Roads shown in white; land/water margin shown in blue.**

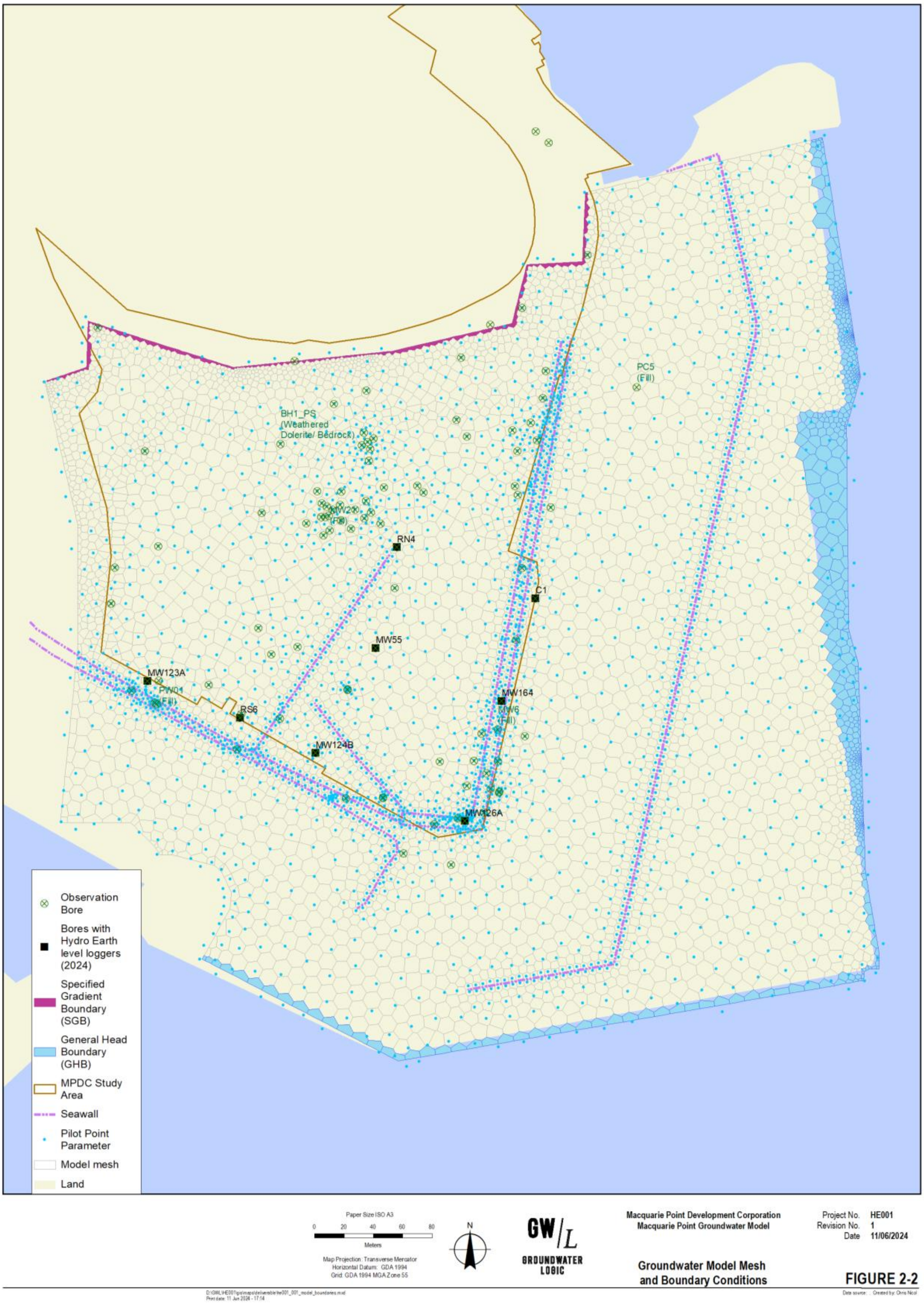


Figure 2-2 Groundwater Model Mesh and Boundary Conditions

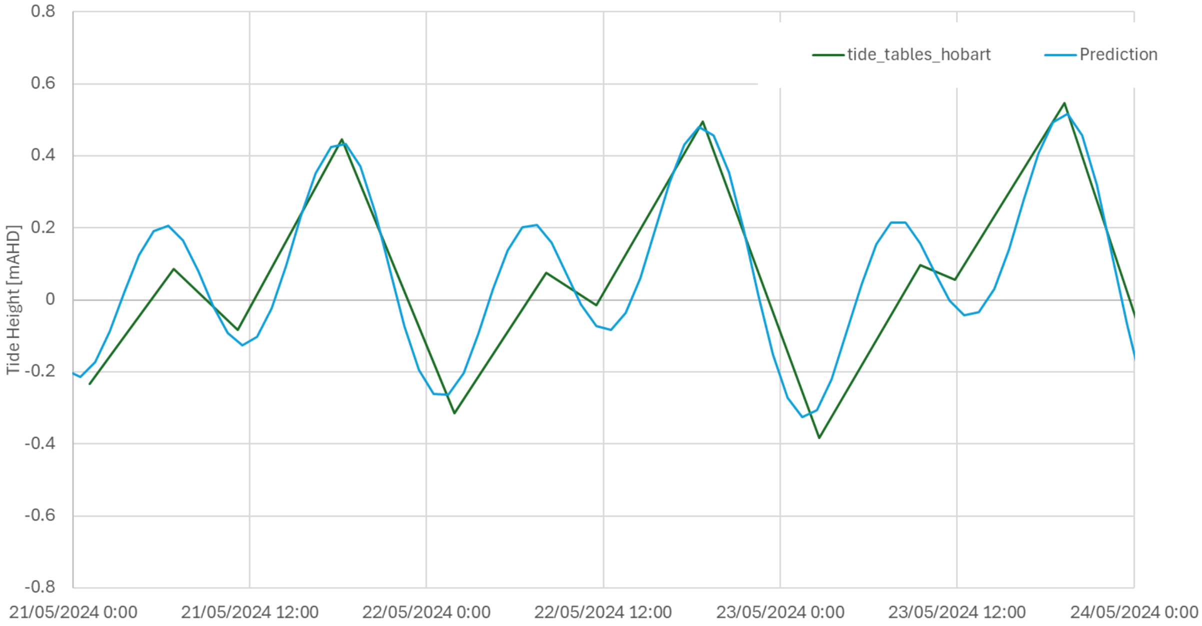


Figure 2-3 Modelled tide height predictions versus Hobart tide tables for the time of HEC logger data collection in May 2024.

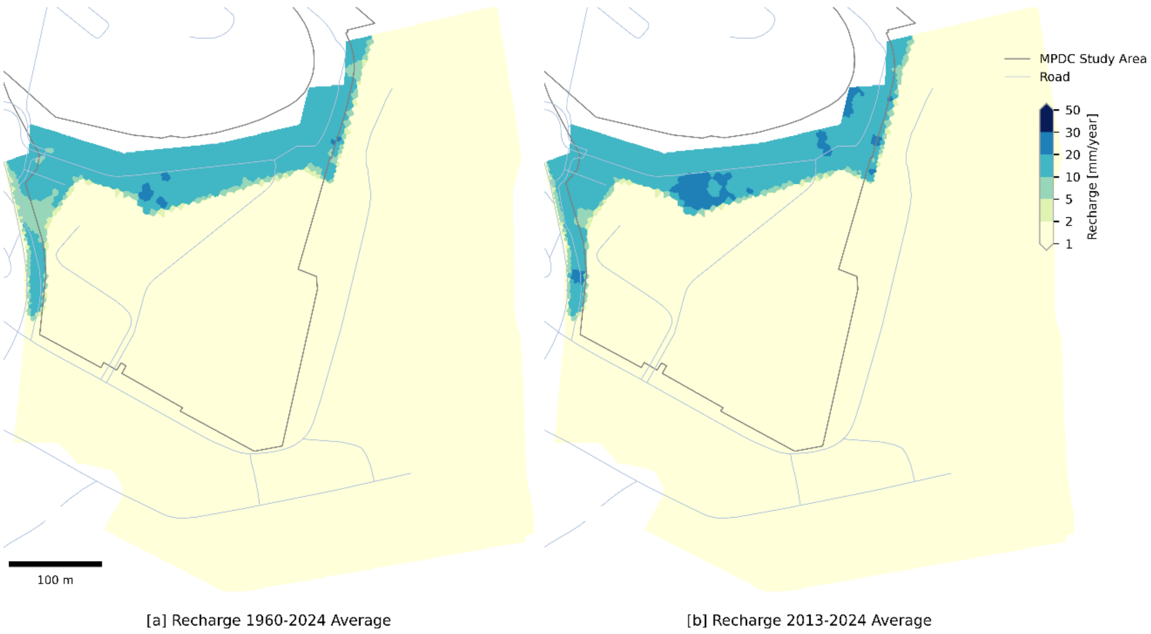


Figure 2-4 Modelled annual average recharge [optimised base model realisation]

2.5 Hydraulic Properties

Spatially variable pilot point parameters are assigned to each model layer, for adjustment during history matching. These are shown as blue dots across the model domain in Figure 2-2. These are included for all hydraulic properties (horizontal and vertical hydraulic conductivity, specific yield, and specific storage). Initial hydraulic properties and their allowable ranges during history matching were defined on a basis of the information presented by HEC (2024).

Allowable hydraulic property ranges in the model were in fact set wider than those suggested by HEC (2024), as recommended for best practice modern modelling approaches (see Doherty, 2015). This recognises that model parameters should not be restricted to field-obtained values because the model is an abstract numerical representation of an infinitely complex reality, and bore data is often affected by sampling bias (e.g., bores tend to screen more permeable intervals in which water is intersected).

In model layer 1 (anthropogenic fill material), additional property zones were included for each of the mapped seawalls (see Figure 2-2). These zones were assigned relatively lower initial hydraulic conductivities than the surrounding host material (as reference by HEC (2024) from GHD (2015)). This is a different approach to that taken by GHD (2015) for modelling the seawalls; they used discrete Horizontal Flow Barriers (i.e., the MODFLOW HFB package), which are at a finer scale than the model cells.

HEC (2024) notes that these seawalls, constructed at different times in the past, are made from variable materials ranging from rubble to cement, and are often approximately 3 m wide. Hence, given the model uses a more modern code capable of local refinement to that scale, and the documented construction of the seawalls, a zone-based approach was considered both possible and more suitable. This is primarily because the HFB package is designed to simulate flow barriers at a scale finer than the model mesh – but the conceptualisation is that these seawalls are about as wide as the model mesh along these features, and they comprise outer walls with inner fill material of varying types.

Therefore, it seems a reasonable approach to allow the model history-matching (i.e., the data) to decide not only whether these seawalls should act as horizontal flow barriers, but also whether they potentially act as lateral migration pathways within the materials such as rubble that were used to build some of them. Allowing this flexibility is the approach taken.

Appendix A presents maps of the optimised base model realisation hydraulic properties for all model layers. It is worth noting that optimisation preferred lower values of specific yield in most units, and to some degree hydraulic conductivity in the Fill (model layer 1), compared with the mean values estimated by HEC (2024). This may be an outcome of the conceptualisation (and starting parameter values) of such low recharge rates, particularly beneath the paved areas; it may be worth exploring recharge in the paved areas from sources such as leaking sewer and stormwater, and/or compromised areas of paving. That is however beyond the scope of this simple modelling.

3. Model History Matching

3.1 Approach

This section details the philosophy behind the model history-matching (previously referred to as “calibration”) and uncertainty analysis approaches applied with the numerical groundwater flow model described in earlier sections of this report, aimed at meeting the model objectives outlined in Section 1.

In this study, “history-matching” refers to the process of assimilating observed groundwater level data into the models. The purpose of history-matching in this context is to constrain model parameters and allowable ranges, based on what is known from field data, conceptual ideas and observed system behaviour - ideally that of direct relevance to the model forecasts of interest (in this case watertable elevations and flow directions).

This in turn constrains the suite of parameter sets that can be used to make model forecasts and to assess their uncertainty. Such an approach provides a good basis for enhanced use and understanding of model outputs, including their limitations, in model-dependent decision-making.

It should be noted that the term “calibration”, as described in the Australian Groundwater Modelling Guidelines, is intentionally avoided in this report. The traditional approach of developing a single calibrated model can give a false expectation that there is a single deterministic set of best parameters. The approach adopted and described in this report derives a suite of plausible parameters that reflects the uncertain nature of the model, its input data, and its history-matching process, which can be extended to predictive uncertainty analysis in an efficient manner. This probabilistic approach has become more widely applied in groundwater modelling since the publication of the guidelines in 2012.

PEST (Doherty, 2015 and 2016a), the software platform related to much of the work presented in this report, represents a family of code and workflows for highly parameterised environmental model optimisation (inversion), uncertainty analysis and associated tasks. In addition, a large set of support utilities have been developed, primarily by John Doherty of Watermark Numerical Computing.

A code that is derived from PEST is applied in the history-matching and uncertainty analysis processes applied in this study: PESTPP-IES, an Iterative Ensemble Smoother (IES; White, 2018). This code optimises an ensemble of random model parameter realisations on an iterative basis. It makes an estimate of the Jacobian (observation-to-parameter sensitivity) matrix, which is used by the traditional PEST code. It does this using the ensemble of parameters and observations, and the modelled equivalents thereof, for each parameter upgrade iteration.

3.2 Implementation

PEST's role in model inversion is to minimise its objective function (phi) by adjusting model parameters in an iterative fashion (Doherty, 2015 and 2016a). Phi is calculated internally by PEST as the sum of squared weighted residuals between observations and their modelled counterparts. Observations used in this case comprise:

- Groundwater level times series (and single point in time) data from MPDC, GHD (2015), and HEC (2024). These are of varying temporal resolution, as described in Section 2.3.
- Groundwater level change from the first observed value for each bore. This is aimed at making temporal variability "visible" to PESTPP-IES – whether that is from tidal or rainfall-recharge influence.
- Derived groundwater level statistics, including the recorded minimum, mean and maximum at each observation bore. This is specifically aimed at informing the model history matching process in terms of one of MPDC's objectives around "average groundwater levels" (Section 1).
- Contrived "penalty function" observations, including:
    - That the initial steady state stress period head shall preferably be less than 1 m above the historical average, to avoid unrealistic initial heads in this stress period, for which there are otherwise no observation data.
    - Standard deviation of tidal fluctuations in bore PC08 shall preferably be at least 0.2 m. This bore is located along the southern model margin and recorded as being the only heavily tidally influenced bore (in GHD, 2015). The GHD (2015) data for this bore could not be successfully digitised because the image is too noisy, and so in response to this, a contrived observation as described was included for the 3-hourly model stress periods of late May 2024.
    - Recharge rates shall be less than 30 mm/year in the northern unpaved area, and less than 5 mm/year in the paved areas.

PESTPP-IES was implemented with the described model using an initial ensemble of 300 stochastic parameter sets. A relatively new approach call "prior mean shifting" was implemented at iteration 3 – at which point the optimised ensemble parameter ranges are reinflated back to their original range but centred on the updated (optimised) mean from the first two iterations. This was followed by a single "polish" iteration to improve history-match quality, whilst trying to not over-fit the data, and minimising the potential for parameter bias.

During model optimisation, 61 realisations were lost to non-convergence or other issues. From the remaining 239 realisations, a selection of 87 of the best quality models was made. These are what is used and discussed for the remainder of this report, to estimate model output uncertainty.

This approach yielded reasonable parameter sets and a reasonable history-match quality across the ensemble.

3.3 Model History Matching Results

Summary groundwater level history-match statistics are presented in Figure 3-1; this include uncertainty across the 87 history-matched model realisations as both statistics and repeated grey chart series; statistics and series for the base realisation are also presented. The figure shows normalised root mean square (nRMS) and absolute mean errors are reasonable for groundwater levels (7-24% with a mean of 13.6%, and 0.31-1.38 m respectively), which is reasonable given the very limited temporal data set with which to work and the extremely limited time and budget allowed to undertake the modelling. The 'base' model realisation – that derived from the initial central parameter set, as defined based on the recommendations of HEC (2024) exhibits an nRMS error of 8.6%, and a mean absolute error of 0.38 m.

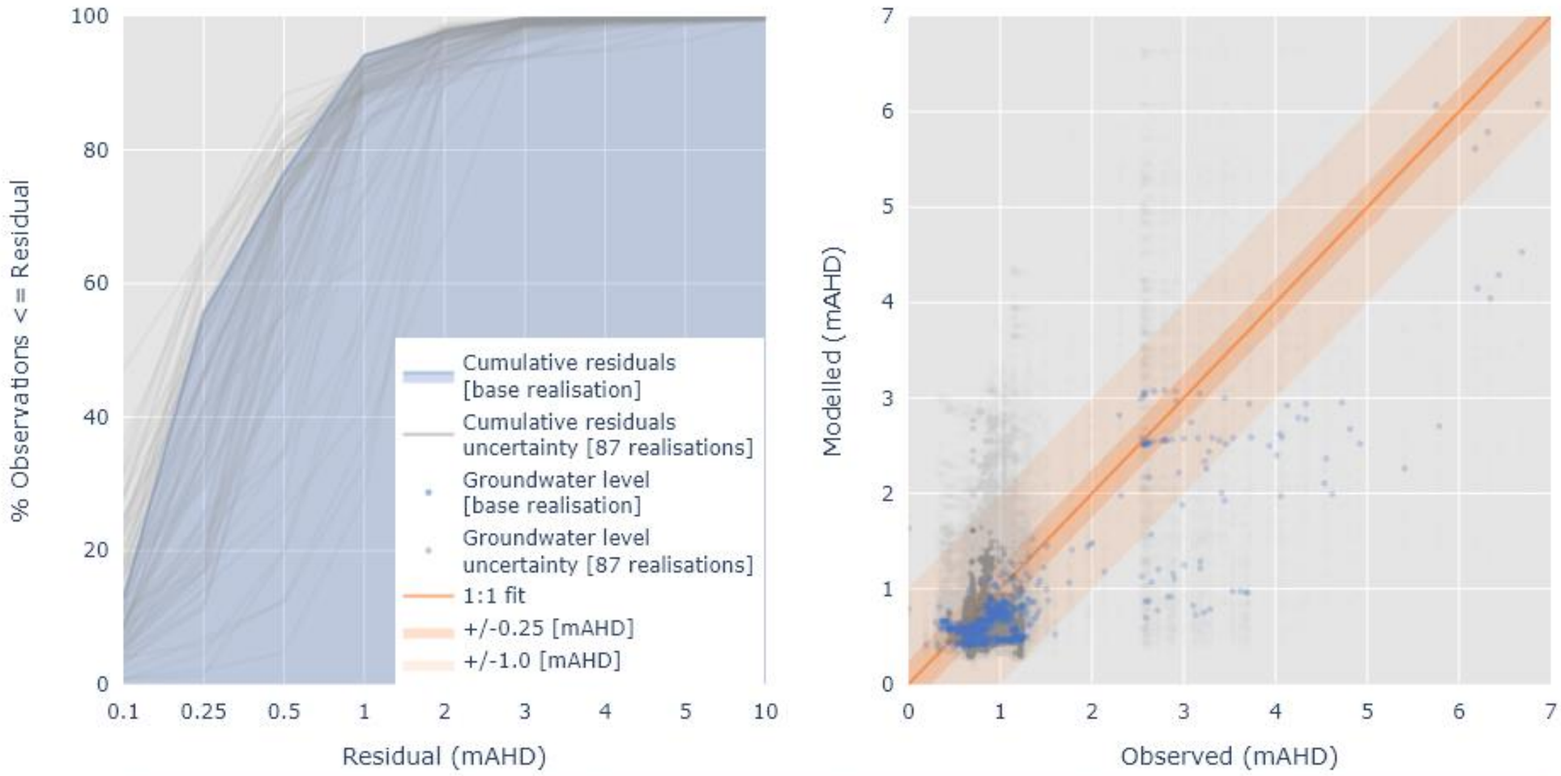
The cumulative residual plot on the left side of Figure 3-1 shows that approximately 90-95% of groundwater level observations are within 1 m error (against observation data spanning a 7 m range). 70-80% of observations are within 0.5 m of their observed counterparts. This is considered a good outcome given the model objectives.

Appendix B, Figure 3-2 and Figure 3-3 provide modelled and observed groundwater level hydrographs. Further, a selection of hydrographs is presented in Figure 3-2 (HEC, 2024 logger data) and Figure 3-3 (GHD, 2015 data); these bore are labelled on the map in Figure 2-2.

The hydrographs exhibit significant uncertainty range around the observation data, which is a positive feature and to be expected given the limited observation data set, and the approach taken of not overfitting the data with this very simple model. Most hydrographs cover the observation data range, and the minimal observed temporal variability is often (but not in all cases) mimicked by the models (see particularly Appendix B). Simulation of temporal variability is of variable quality; regardless - most bores show very little.

Two more detailed points regarding simulated temporal variability follow:

- The apparent recharge response to rainfall on May 22nd, 2024, in bore MW164 (Figure 3-2) is not replicated by any models. This could potentially be addressed by introducing local flexibility in the recharge models at this location; however, this is considered over-reach given that the longer-term hydrograph for bore MW164 shown in Figure 3-2 exhibits significant recharge responses to larger earlier rainfall events dating back to 2013. Put simply, it is unclear why bore MW164 exhibited that recharge response in May 2024 to such a small rainfall event (6 mm), and it is probably immaterial to model end use anyway.
- Bore MW124B (Figure 3-2) exhibits excessive tidal response across many model realisations. This is not considered to compromise the utility of the required model outputs in a broad sense, however. But it is suggested that any model outputs relied upon in around this bore take note of this overestimation and assess any implications on a case-by-case basis. If there are implications, a selection of model realisations that do not suffer from this issue could be extracted for the required purpose.



Model / Statistic of 87 realisations:	Number of Observations:	Sum of Squared Residuals:	Root Mean Square (RMS) Residual (mAHD):	Normalised RMS (nRMS) residual:	Mean Absolute Residual (mAHD):
Base realisation:	861	301	0.59	8.6%	0.38
Minimum:	861	202	0.48	7.1%	0.31
Mean:	861	822	0.93	13.6%	0.58
Maximum:	861	2301	1.63	23.8%	1.38

Figure 3-1 Summary Model History-Matching Statistics

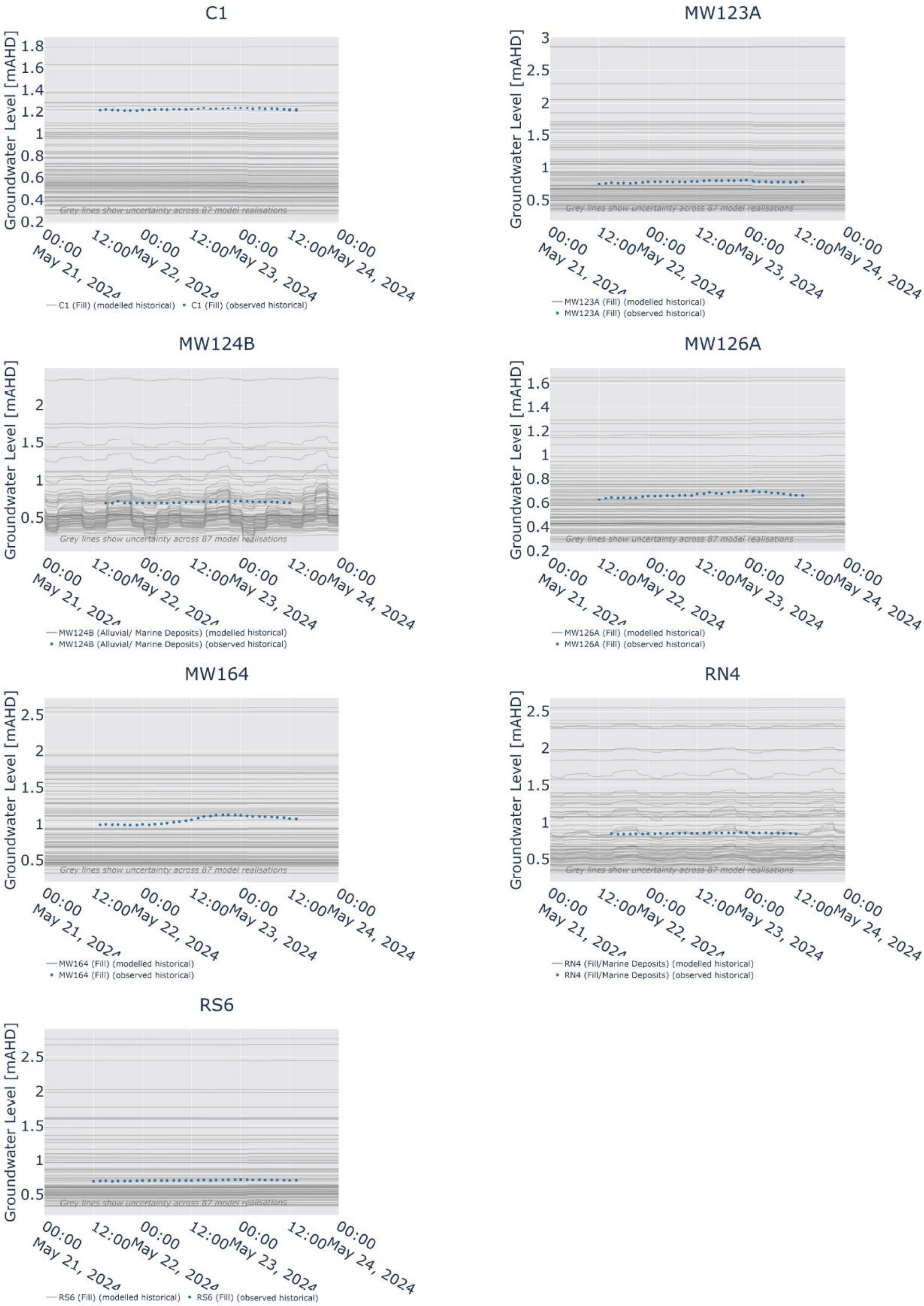


Figure 3-2 Selected History Matching Hydrographs: HEC (2024) Bore Logger Data

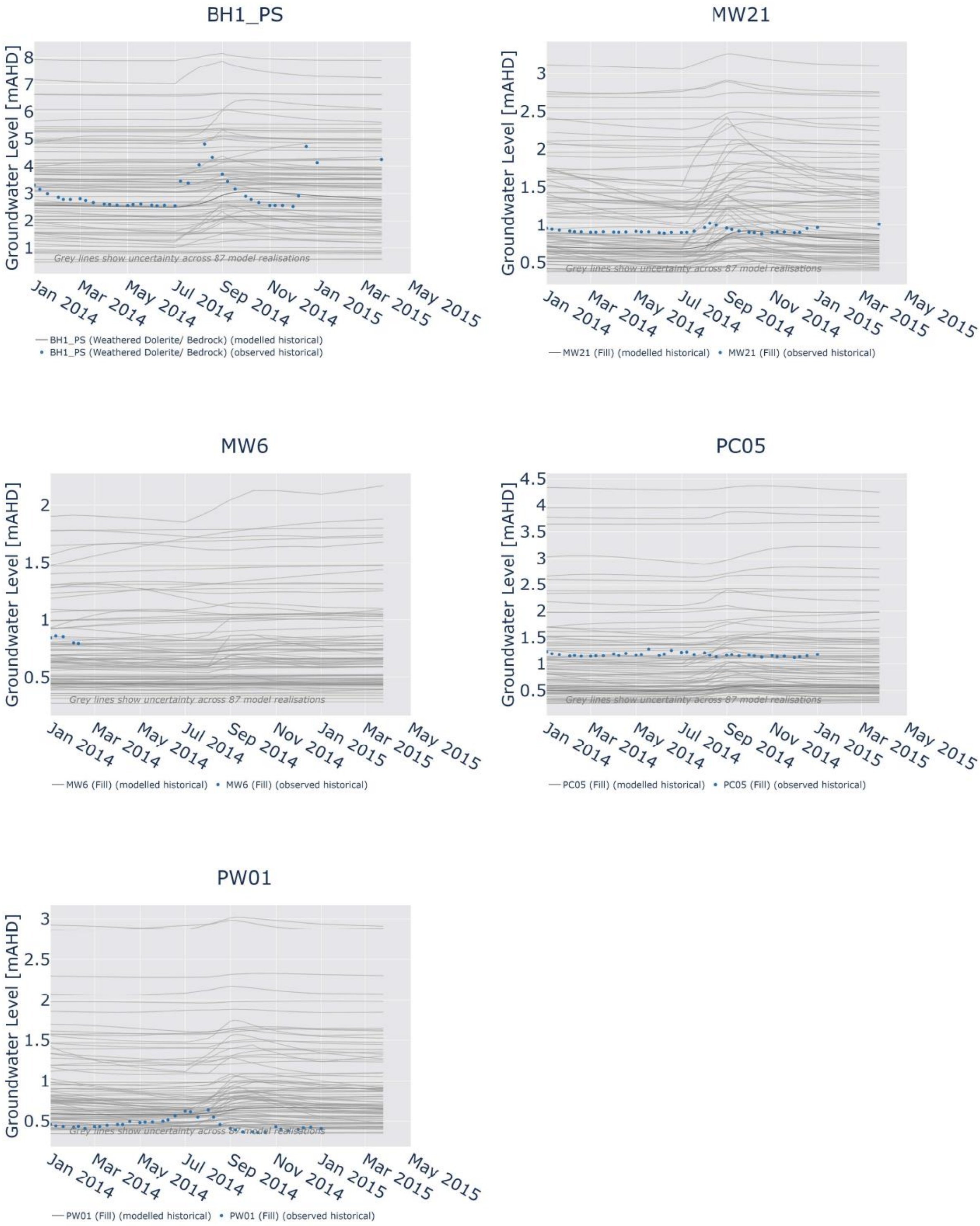


Figure 3-3 Selected History Matching Hydrographs: GHD (2015) Bore Data

4. Modelled Watertable Mapping

Figure 4-1 through Figure 4-4 present modelled estimates of ***watertable depth*** across the site. Figure 4-1 presents that of the “base” model realisation; this is the history-matched model realisation that is directly derived from the recommended initial parameter values of HEC (2024), whilst the other model 86 realisations represent models that use (history-matched) random samples from the defined prior parameter uncertainty distributions. Figure 4-2, Figure 4-3 and Figure 4-4 present the median (P50), lower (P10), and upper (P90) uncertainty estimates of watertable depths across the site.

Each of these figures presents three maps in a row, from left to right: for wetter, more typical, and drier climatic periods. These “periods” are defined as the lower 5^{th} (wet), median (typical), and upper 95^{th} (dry) percentile watertable depth below ground, as ***calculated over time*** within each model realisation. As such they are composite (or aggregate) statistical maps, representing different portions of the modelled hydrograph (lows versus highs) for each model cell.

Inspecting the P50 uncertainty estimate watertable depth maps for example (Figure 4-2), the reader can see by comparing the left and right map panes that most of the seasonal variability is in / towards the unpaved northern portion of the model domain, towards the cenotaph and to the east and southeast of Davey St. In contrast, there is very little seasonal variability to the south, southeast and east – i.e., beneath the paved areas.

Figure 4-5 through Figure 4-8 present ***watertable elevations*** (i.e., absolute elevations above Australian Height Datum (mAHD)). These can be used by dependent studies to assess potential flow directions across the site at different times; each figure shows two maps: that for January 2023 on the left (one of the wettest periods in the simulation and observed hydrographs), and for the end of May 2024 (a drier / more typical climatic period). Figure 4-5 presents that of the base model realisation (described above), whilst Figure 4-6, Figure 4-7, and Figure 4-8 present the median (P50), lower (P10) and upper (P90) uncertainty estimates.

It is worth noting the significant range of uncertainty in places in these maps. In the central portion of the site, the P10 to P90 uncertainty range is typically around 1 m (approximately 0.5 m either side of the median shown in Figure 4-6). This is an artefact of the limited temporal data set with which to work, and possibly limitations on budget and time allowed for the assessment – it may be that with more effort spent parameterising the model in different ways, re-formulating history-matching objectives differently, and re-running the optimisation, that this uncertainty range *may* be able to be reduced; but this is not a given because ultimately data limitations will control the residual uncertainty range. Longer-term targeted data collection would be more likely to improve the chances of reducing the uncertainty.

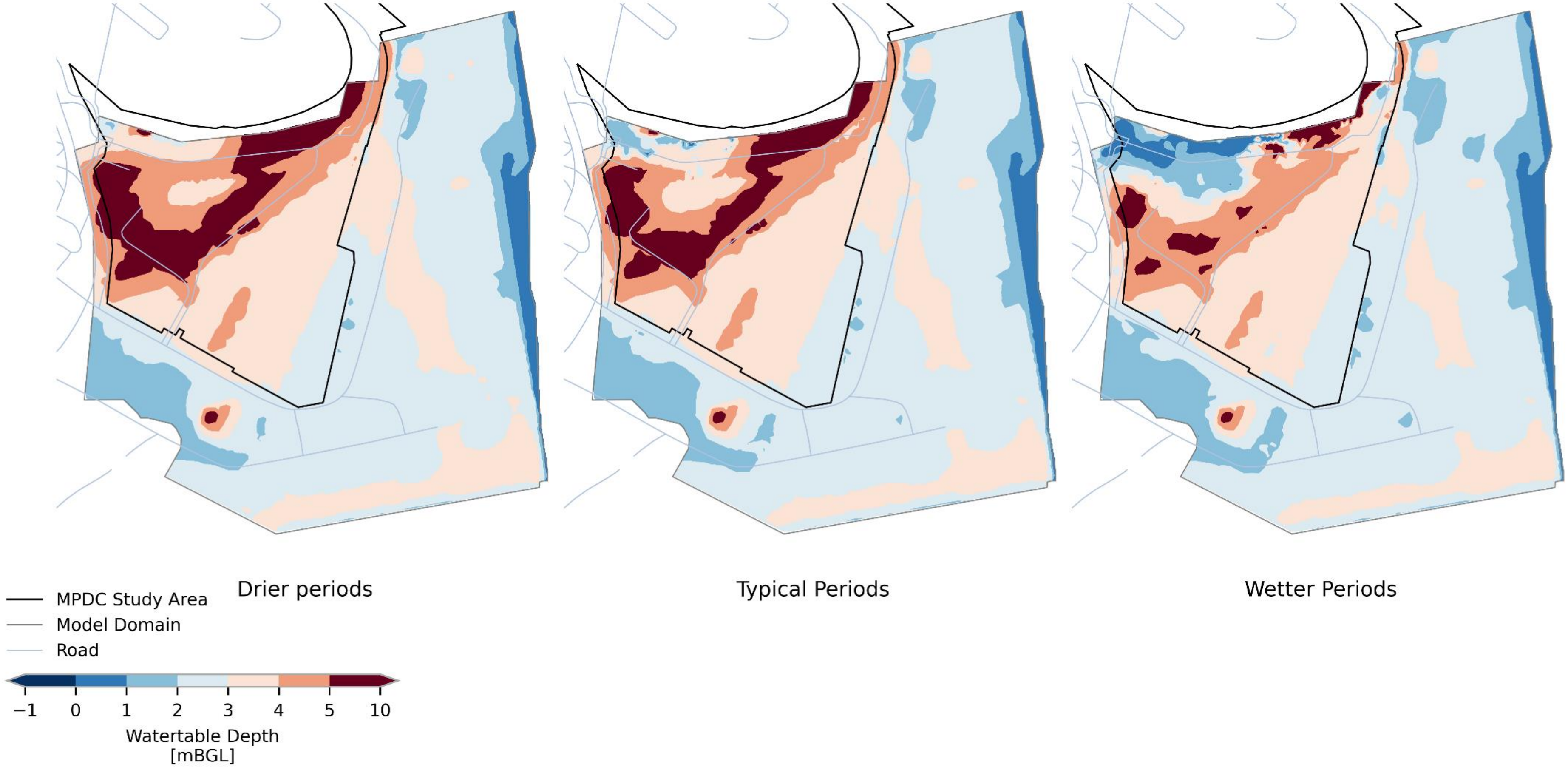


Figure 4-1 Modelled Watertable Depth Seasonality [Base Model Realisation]

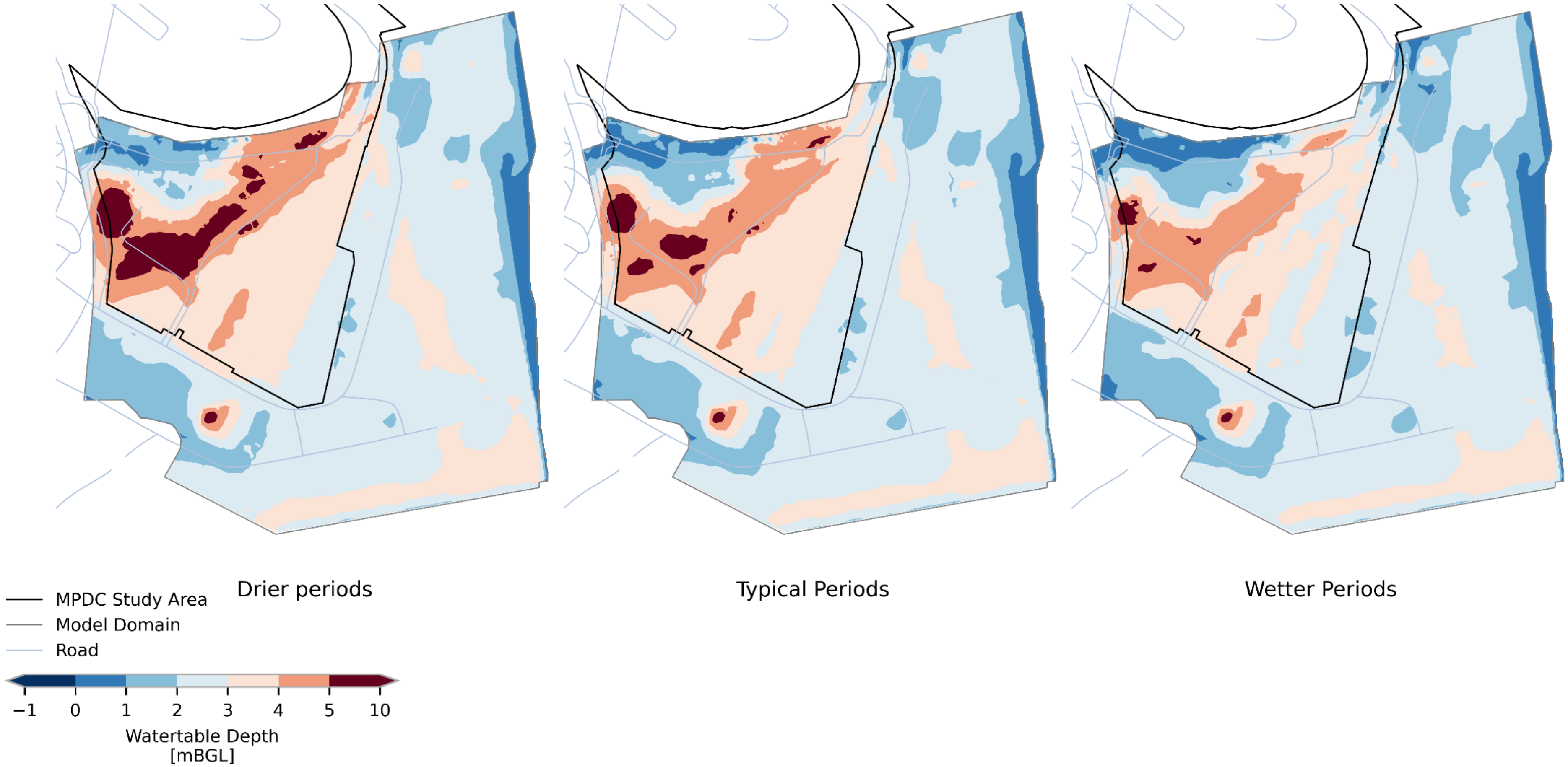


Figure 4-2 Modelled Watertable Depth Seasonality [Median (P50) Uncertainty Estimate]

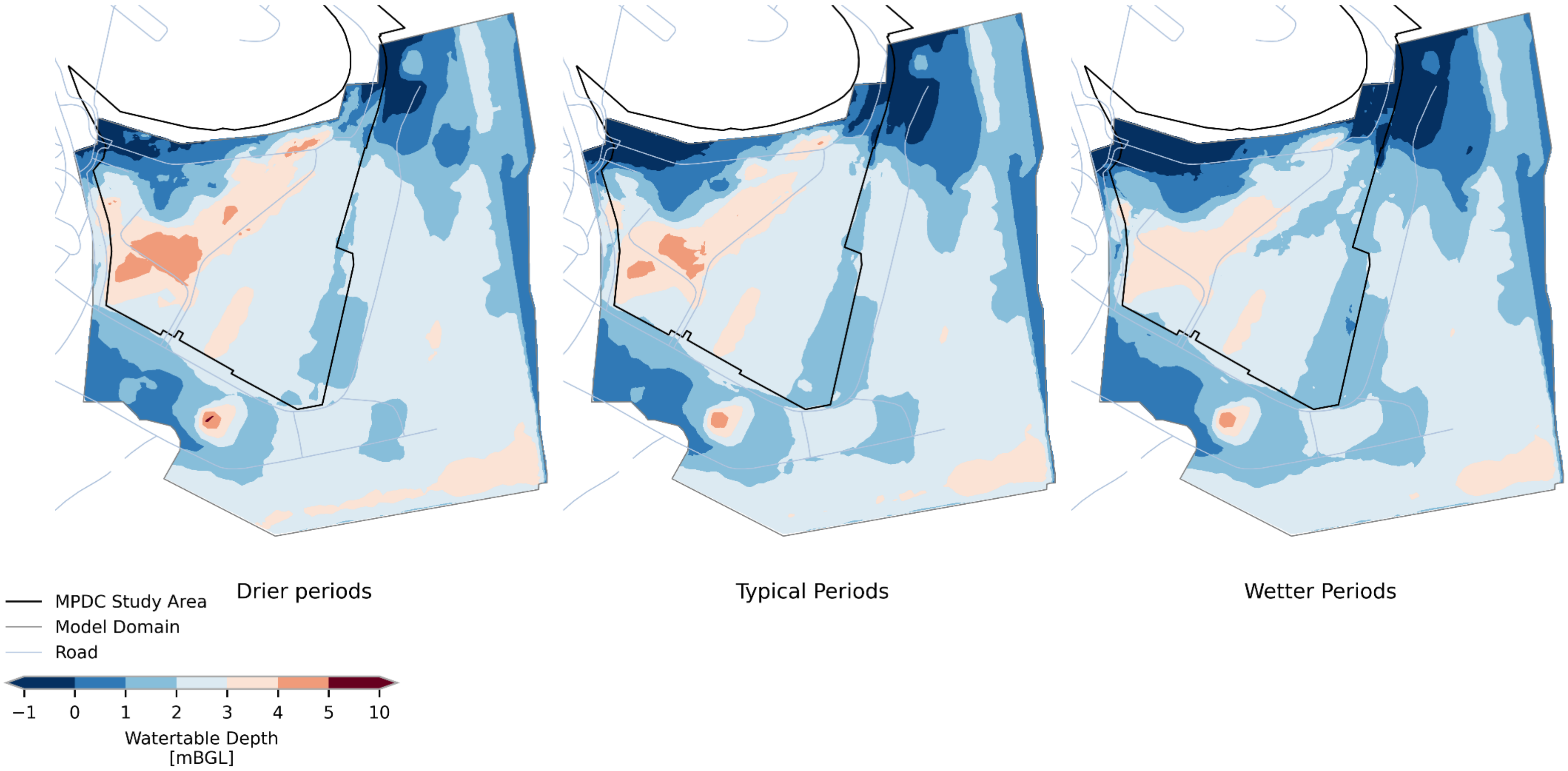


Figure 4-3 Modelled Watertable Depth Seasonality [Lower P10 Uncertainty Limit]

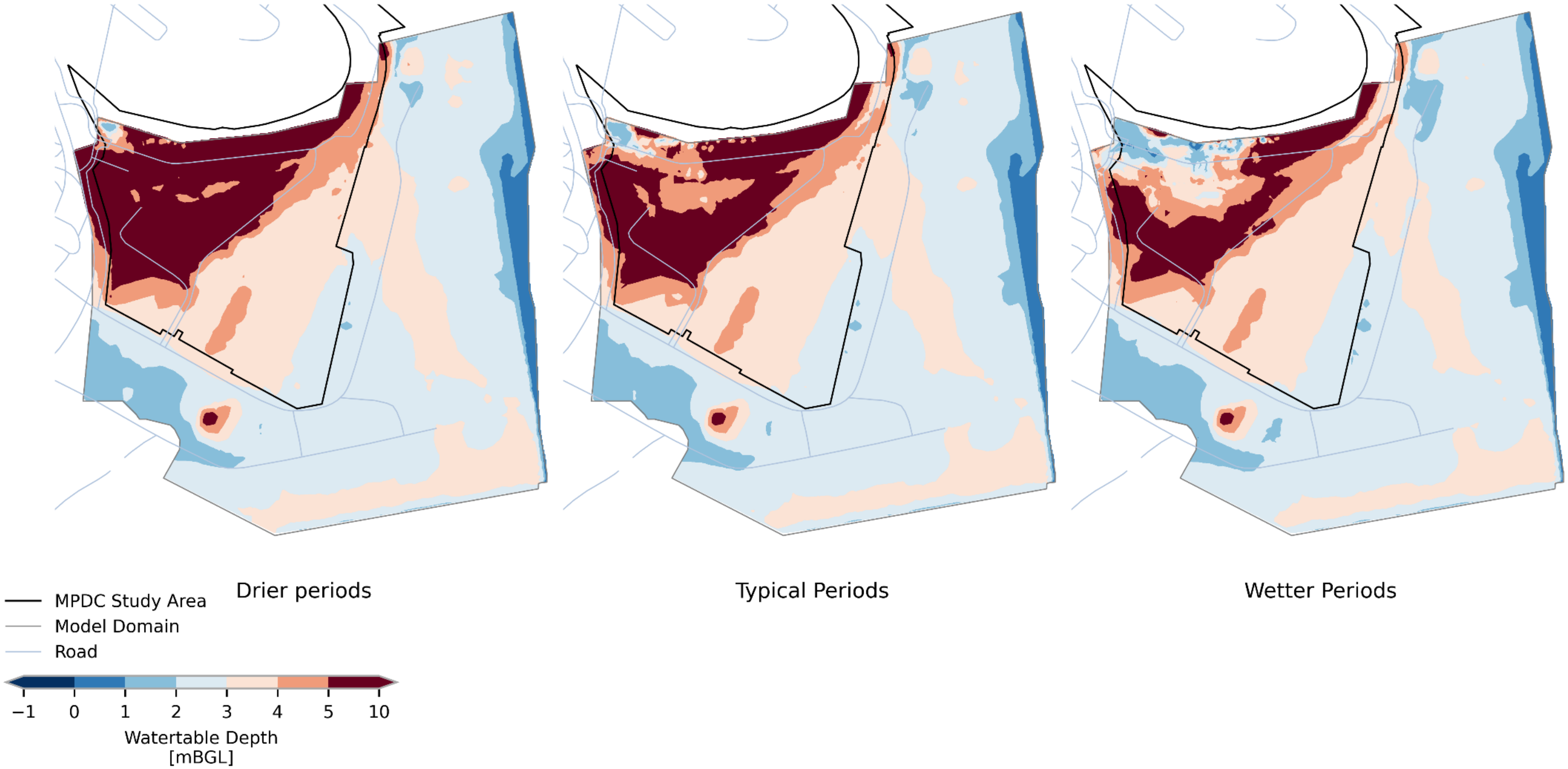


Figure 4-4 Modelled Watertable Depth Seasonality [Upper P90 Uncertainty Limit]

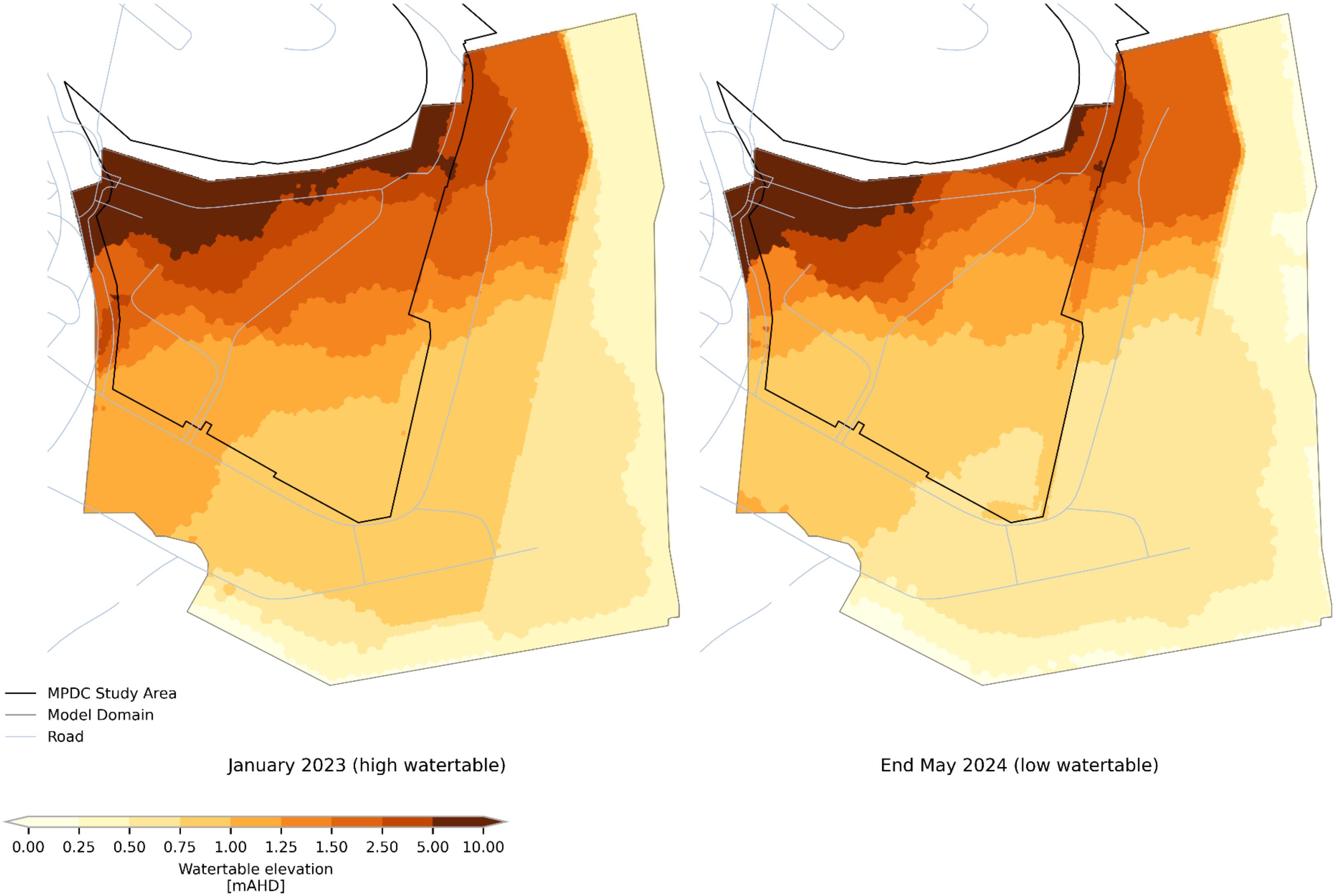


Figure 4-5 Modelled Watertable Elevation Wet and Dry Periods [base realisation]

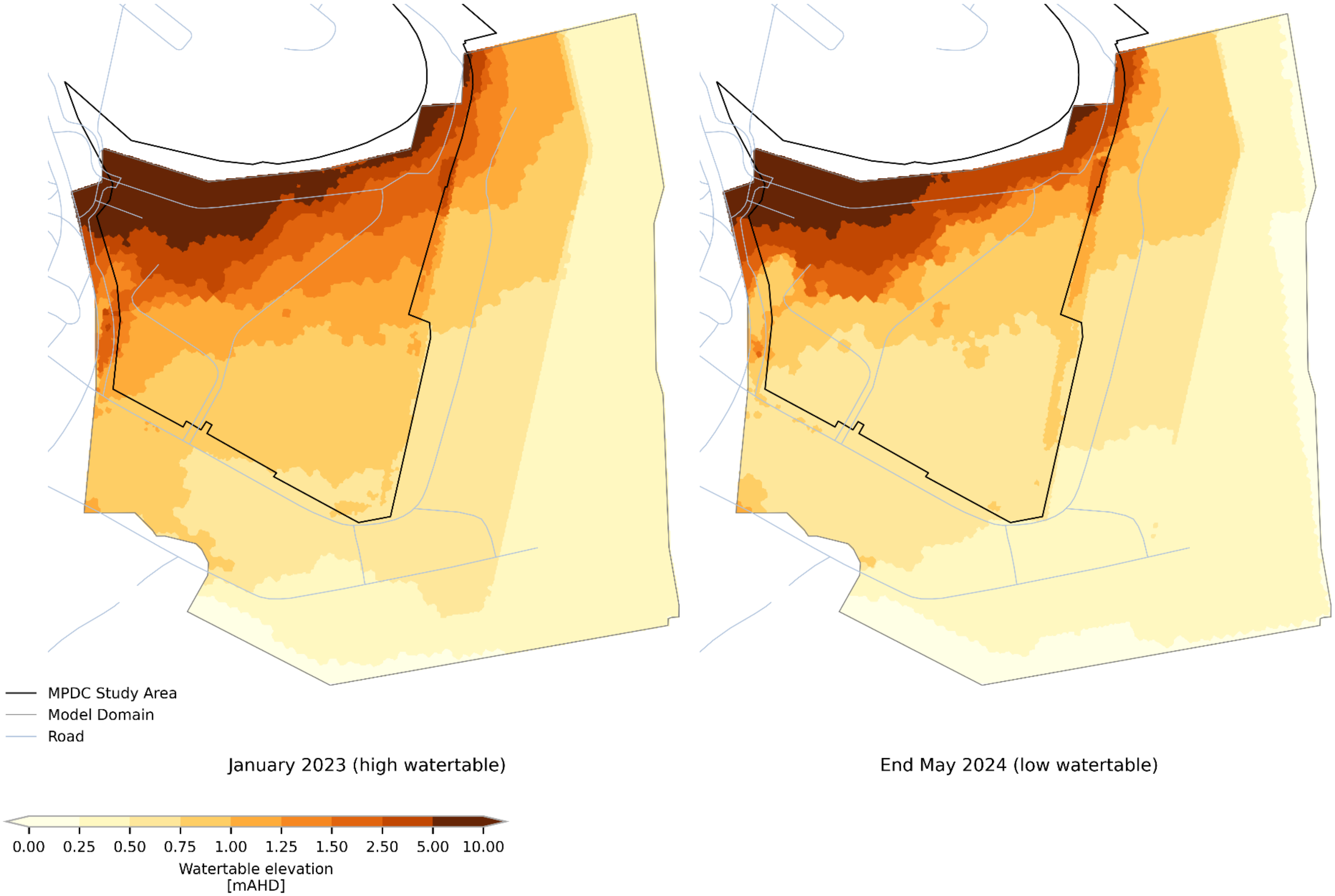


Figure 4-6 Modelled Watertable Elevation Wet and Dry Periods [Median (P50) Uncertainty Estimate]

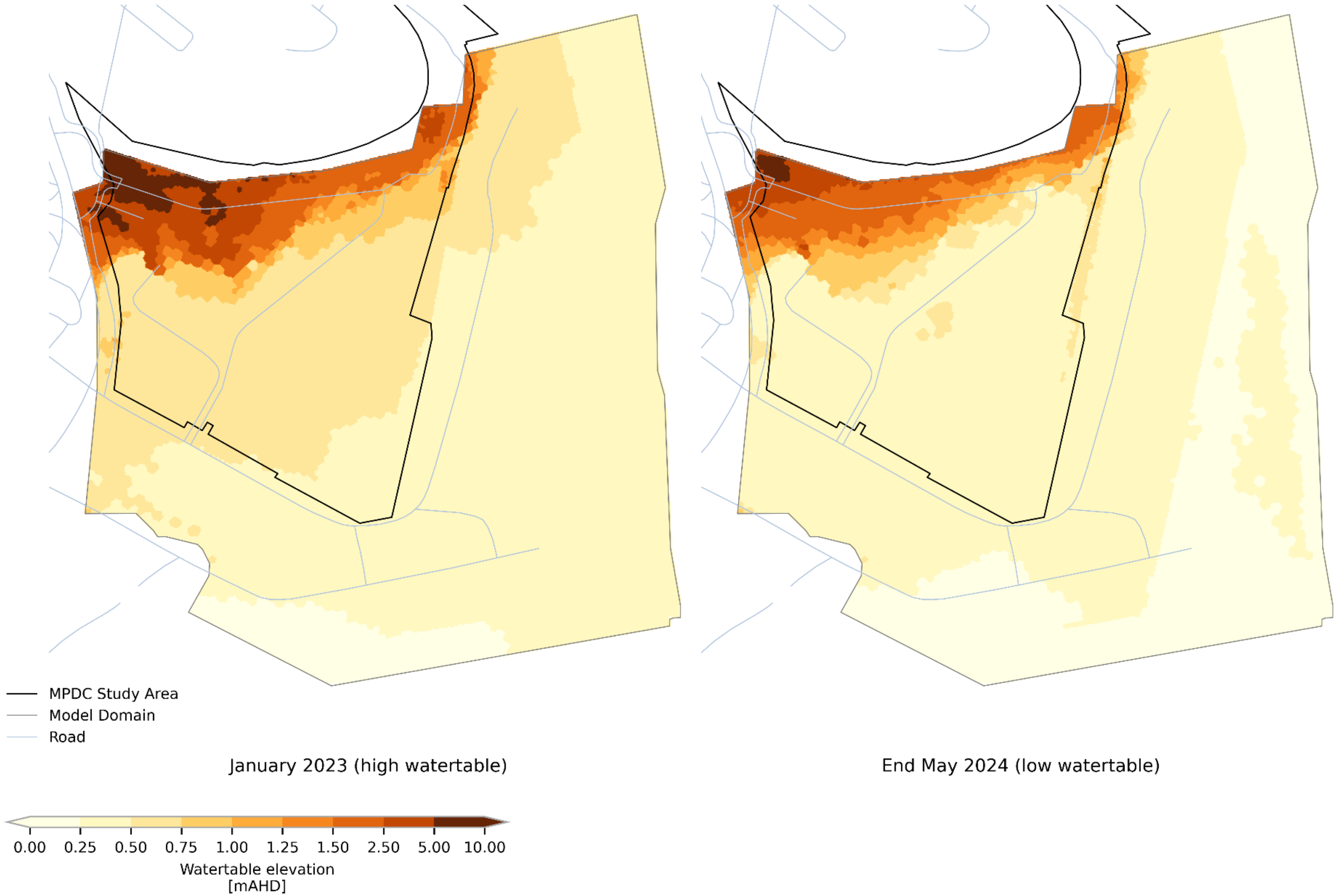


Figure 4-7 Modelled Watertable Elevation Wet and Dry Periods [Lower P10 Uncertainty Estimate]

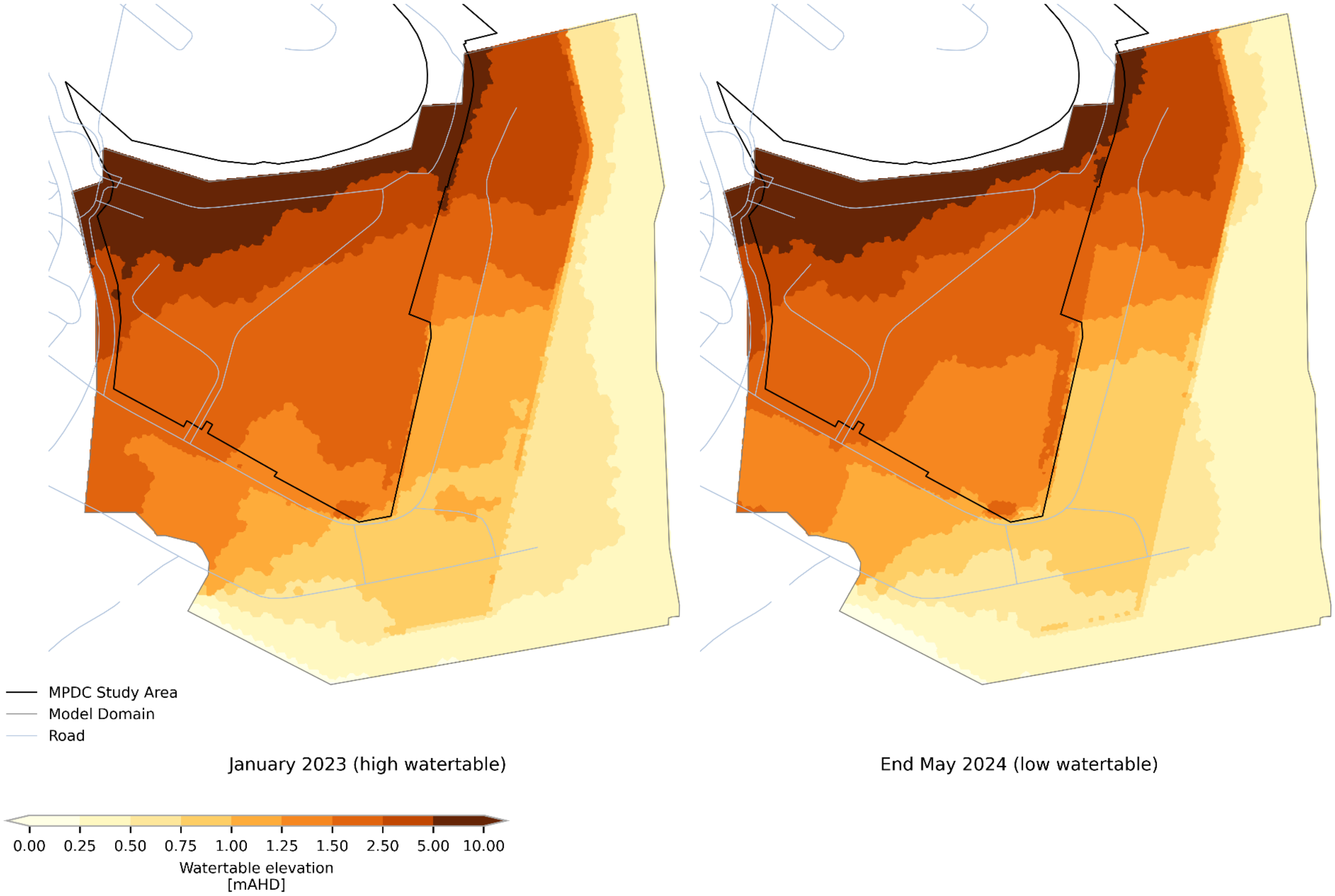


Figure 4-8 Modelled Watertable Elevation Wet and Dry Periods [Upper P90 Uncertainty Estimate]

5. Limitations

- Watertable elevation estimation in space and its variability in time within the sedimentary deposits are the focus of this modelling and report. Model design is specifically targeted at these objectives, and nothing more.
- Watertable mapping does not account for long-term exposure of the recently excavated area in the north of the site, and the potential for focussed recharge to it to alter watertable elevations and flow directions significantly from those shown. This would depend on the time that the area is left exposed (excavated / unsealed), and rainfall in the future.
- Due to client-dictated time and budget constraints, blind reliance has had to be placed on the integrity of the data provided and used to build and history-match the model. There was no time for data reviews, for example bore survey elevations and screen intervals.
- It is worth noting that model optimisation preferred lower values of specific yield in most units, and to some degree hydraulic conductivity in the Fill (model layer 1), compared with the mean values estimated by HEC (2024). This may be an outcome of the conceptualisation (and starting parameter values) of such low recharge rates, particularly beneath the paved areas; it may be worth exploring recharge in the paved areas from sources such as leaking sewer and stormwater, and/or compromised areas of paving. That is however beyond the scope of this simple modelling.
- The complex structure and stratigraphy of the groundwater system is necessarily simplified and idealised in the numerical model, because our geological understanding is based on bore hole data collected at a scale coarser than that of geological variability. The model described in this report utilises a geological model and conceptualisation provided by MPDC and HEC (2024).

  Much about the groundwater system's hydraulic properties and behaviour can only be inferred from the available groundwater data, which in this case is very limited and derived from a range of sources. Hence, the modelling outcomes are heavily dependent on the input data limitations, and the limitations of the applied modelling methods.

  As a result, potentially large uncertainties in some hydrologic behaviours are likely to be encountered. This is not to devalue the utility of modelling; to the contrary, recognition of and accounting for these uncertainties ensures that their potential or actual existence is carried through to their potential implications for model end use - i.e., forecasts of potential aquifer behaviour, and how widely that might range based on what we do and do not know. The approach taken to the modelling must therefore account for these uncertainties, and end users are requested to use the modelling outcomes of this memo in recognition of this.
- The reader is also directed to the limitations and simplifying assumptions identified throughout this memo.

6. Conclusions

A simple numerical groundwater flow model of the watertable aquifers at the Macquarie Point Stadium site has been developed. The conceptual basis for the model was provided by HEC (2024), and the geological basis by MPDC.

87 models that are history-matched (or "trained") to the available observed groundwater level data, as provided by MPDC and HEC (2024). Each of these model realisations (of "the ensemble") represents a different but plausible parameter set that can simulate the observed groundwater data to within certain levels of accuracy. This accuracy varies from location to location. The quality of the history match is spatially variable but generally reasonable, with mean absolute groundwater level errors ranging from 0.31 to 1.38 m across the 87 model realisations, and an ensemble mean of 0.58 m. the

mean residual for the “base” model realisation – that most reflective of the conceptualisation of HEC (2024) is 0.38 m.

The model history match to temporal watertable trends (i.e., seasonality) is generally fair. The majority of observed temporal variability appear to be due to rainfall recharge in the northern unpaved area of the site. There is no evidence of significant tidal influence in the available observation data across the site, nor in the modelled equivalents of those data; there is one exception to this in bore PC08 (GHD, 2015), and this observed tidal behaviour has been qualitatively incorporated into the model because it was not possible to obtain or digitise those data. The tidal response does not appear to extend far inland from the estuary however, in either available observation data, or their modelled equivalents.

A range of modelled watertable depth and elevation maps, including uncertainty estimates, are provided in this memo, and as a digital data package alongside it. These can be used by MPDC and HEC (2024) to assess potential watertable flow directions, and how these may have changed over time between 2013 and 2024. End users of these data are however directed to the limitations outlined throughout this memo, but particularly in Section 5.

7. References

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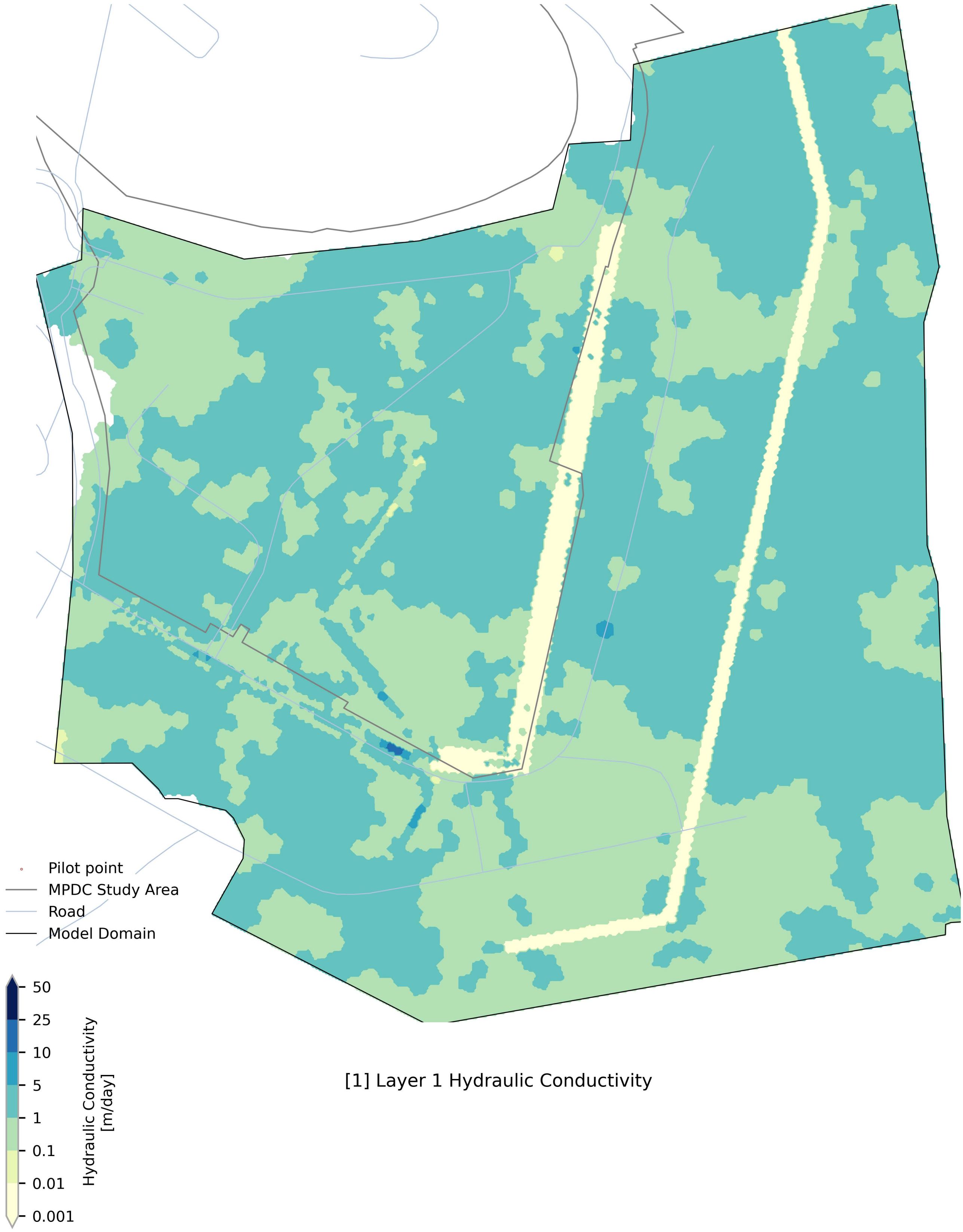
8. Closing

Please email (chris.nicol@groundwaterlogic.com) or call (0419 615 683) if you have any questions or issues.

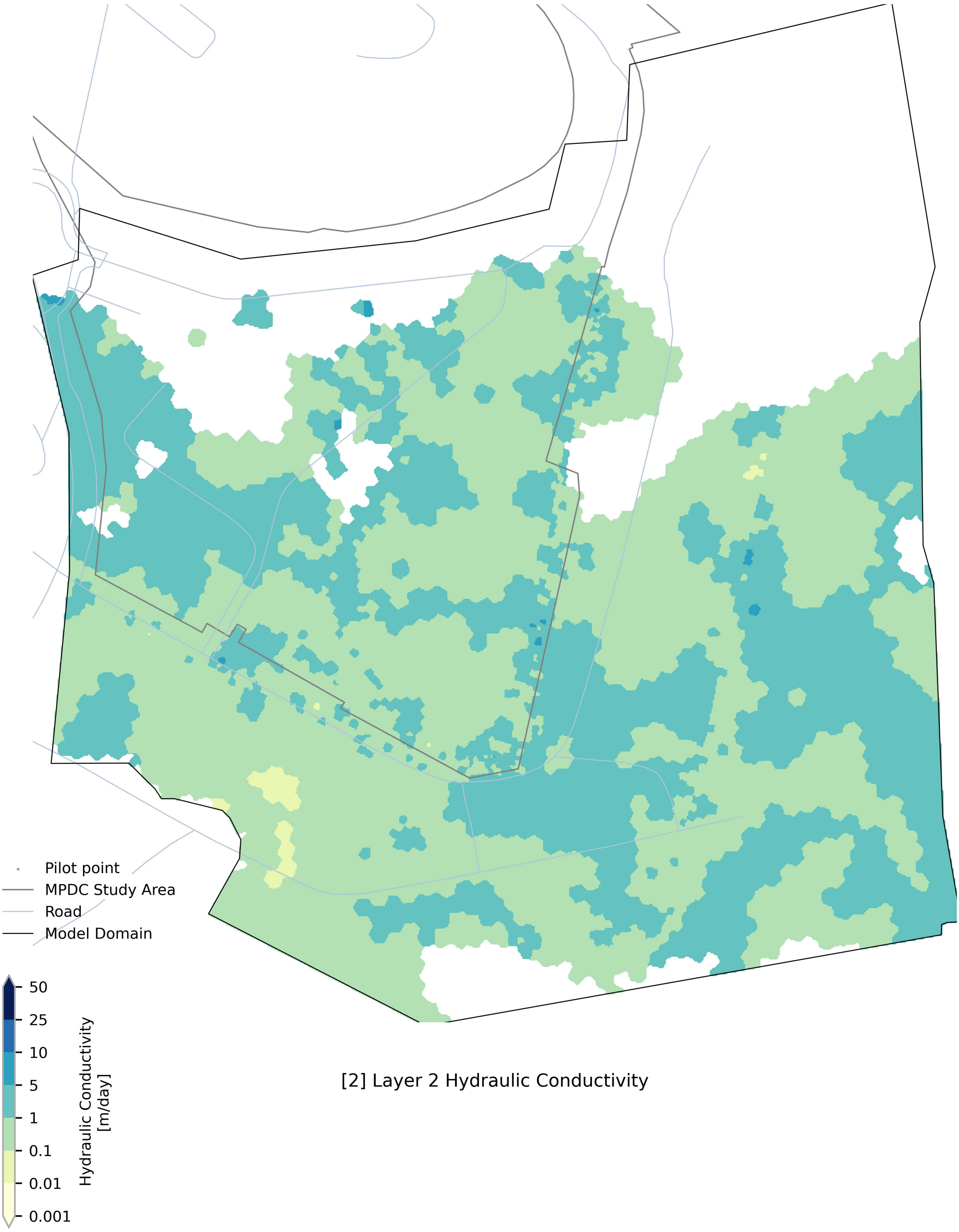
Chris Nicol | Director

Groundwater Logic

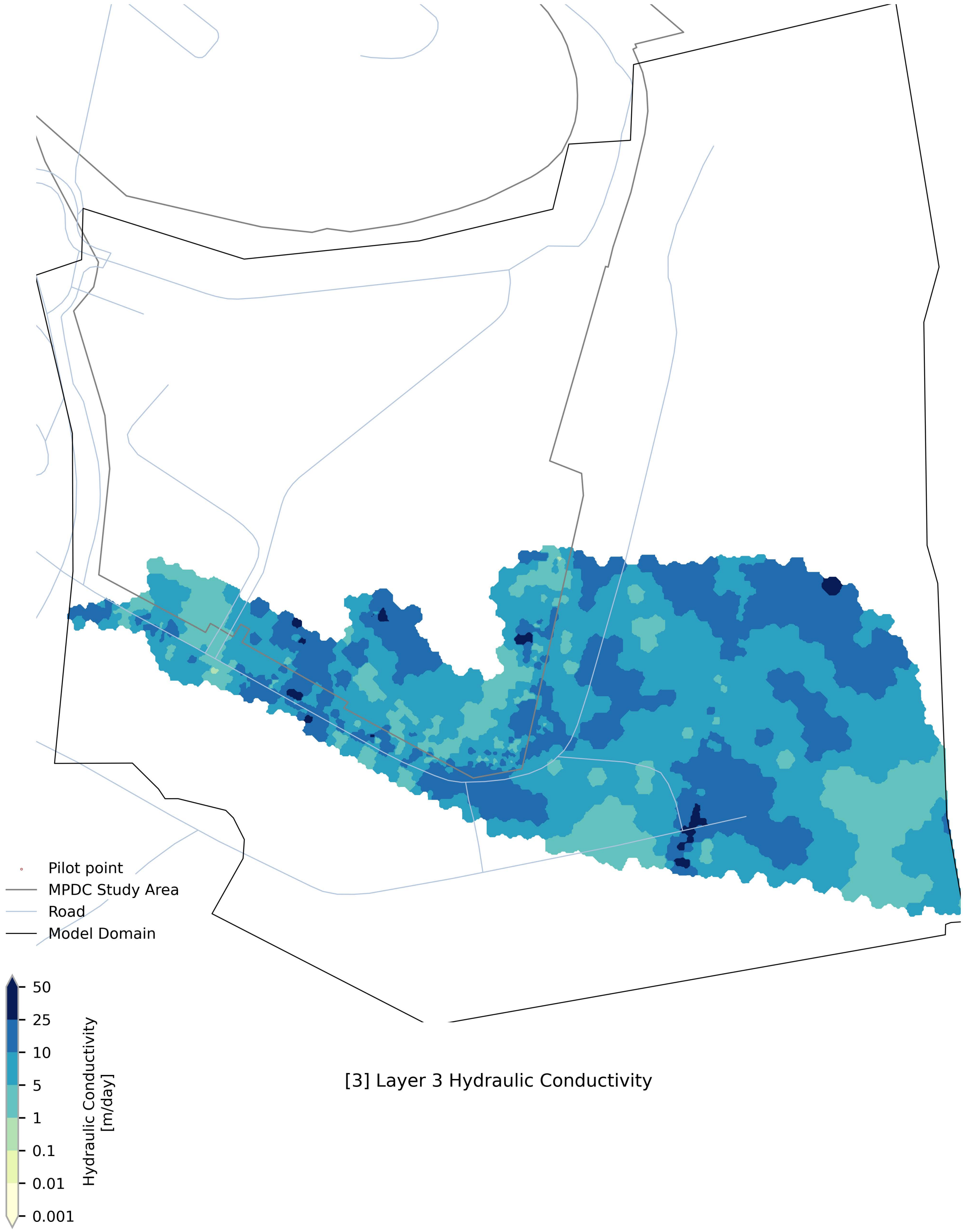
Appendix A Optimised base model realisation hydraulic properties for all model layers



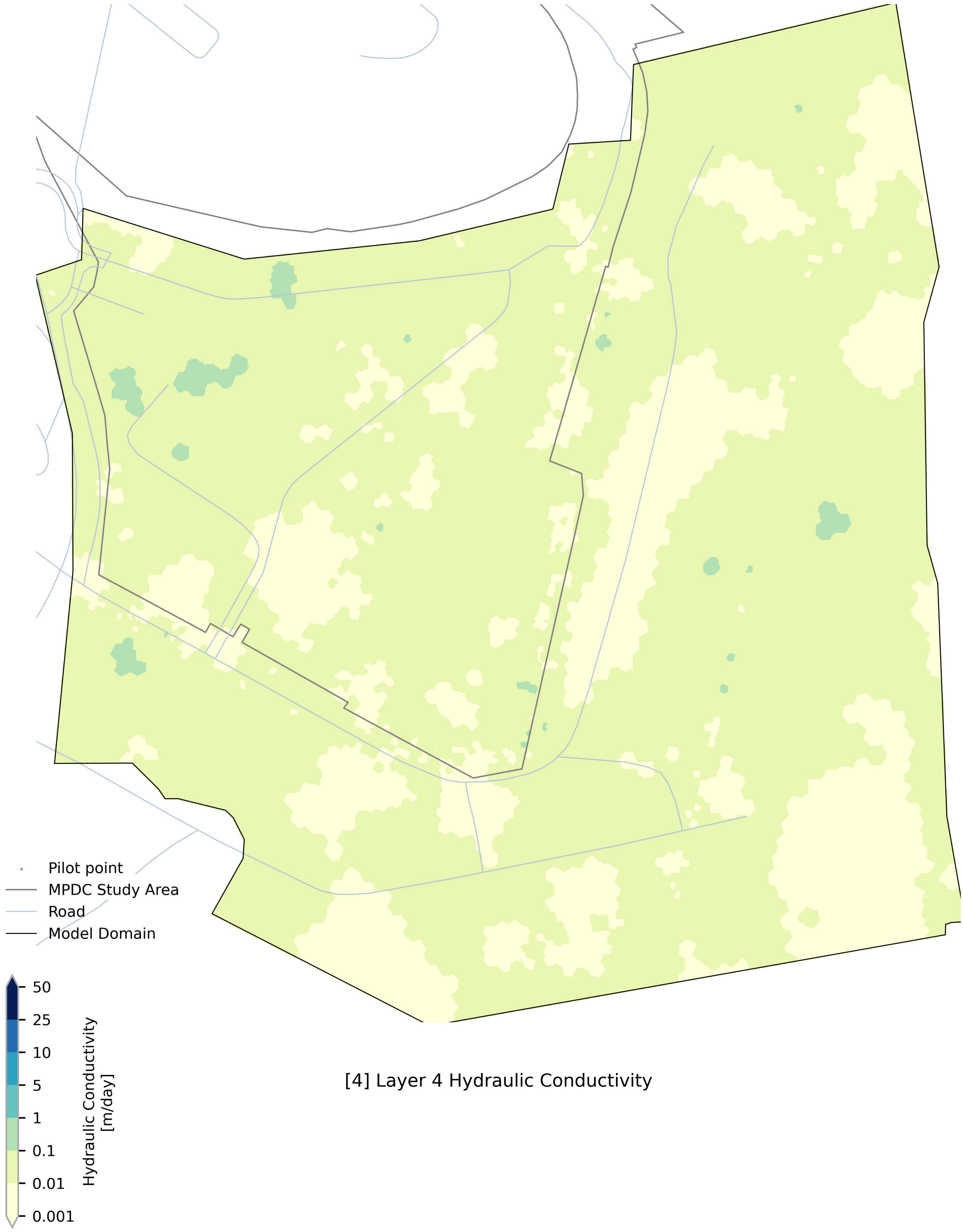
[1] Layer 1 Hydraulic Conductivity



[2] Layer 2 Hydraulic Conductivity

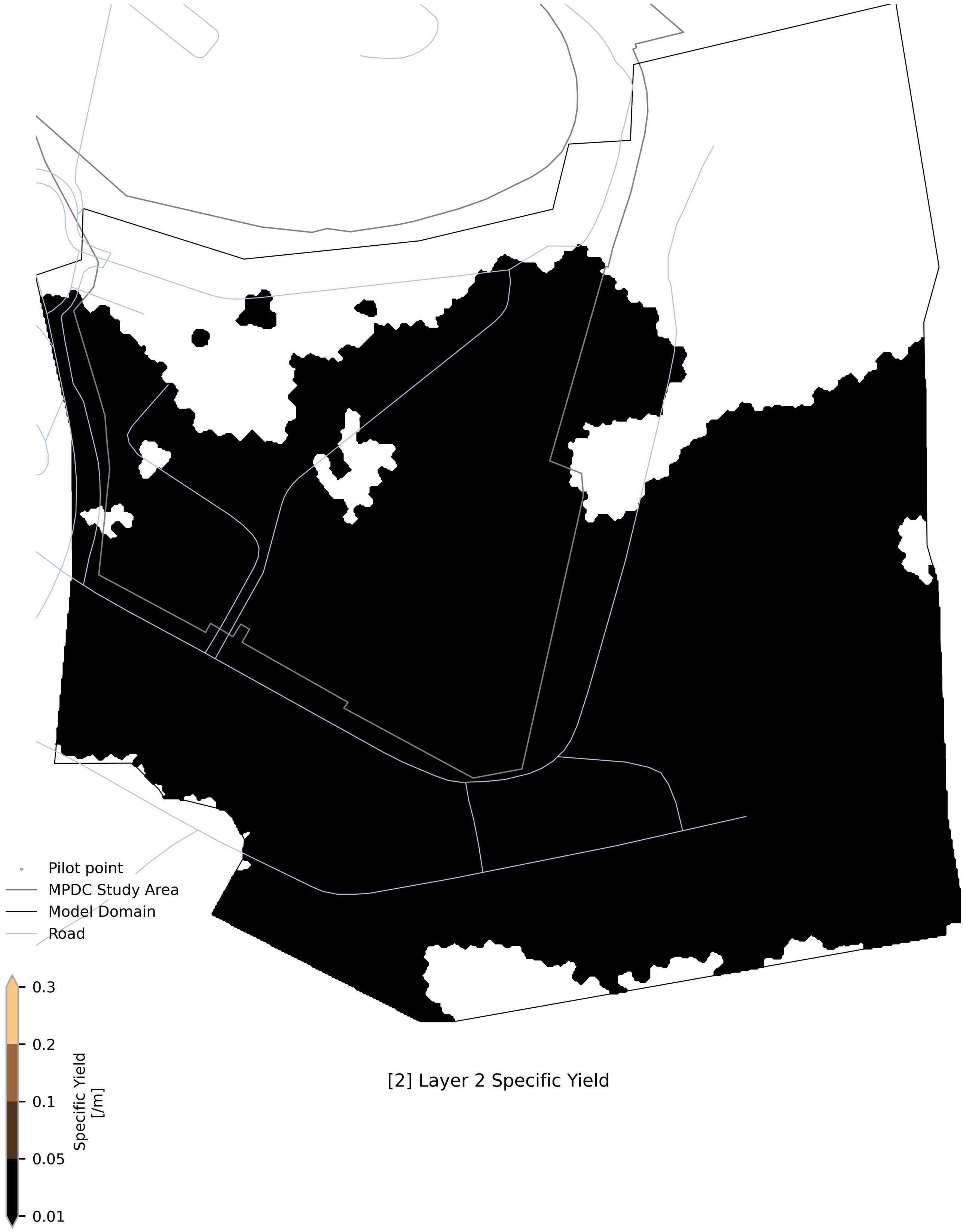


[3] Layer 3 Hydraulic Conductivity

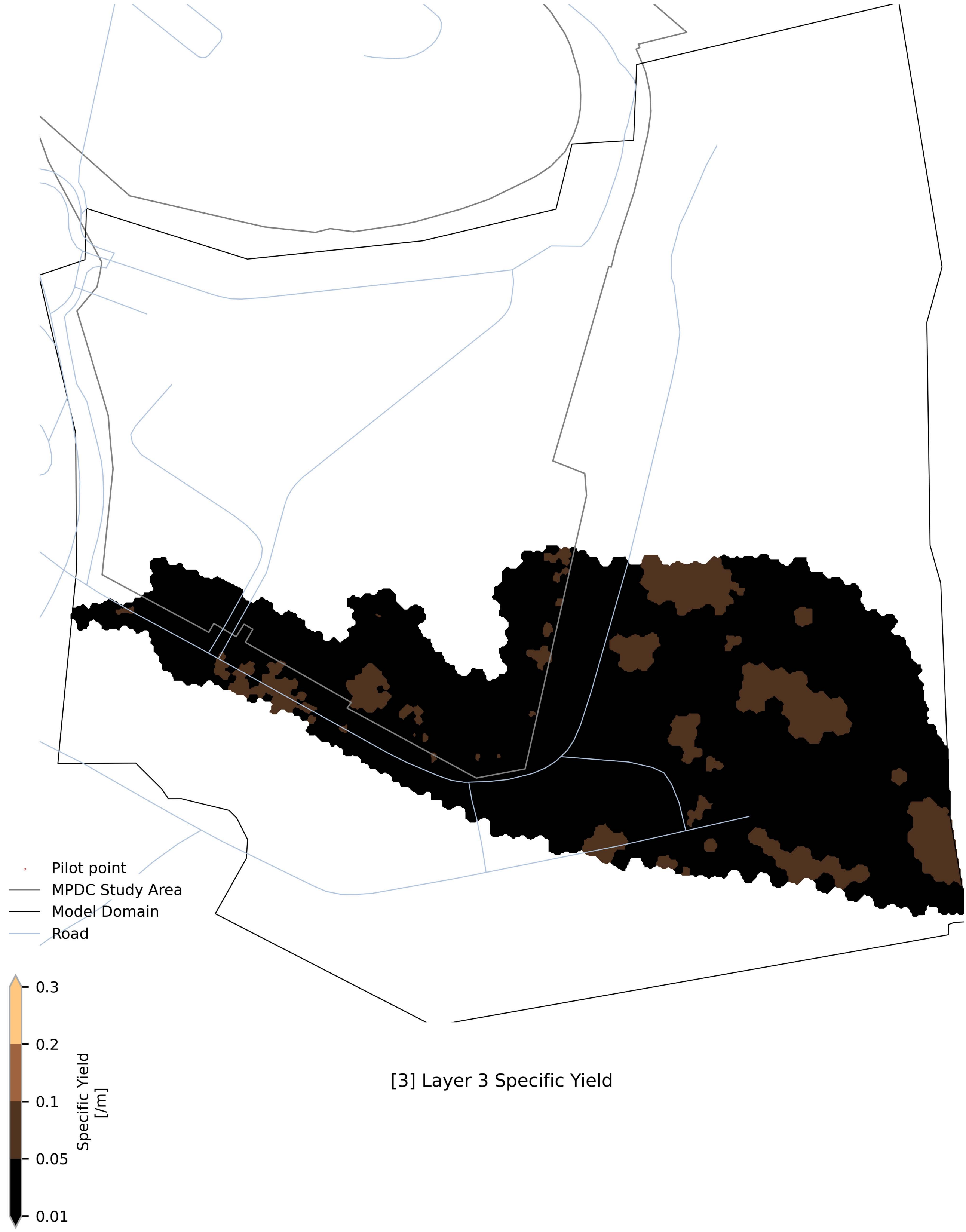


[4] Layer 4 Hydraulic Conductivity

[1] Layer 1 Specific Yield

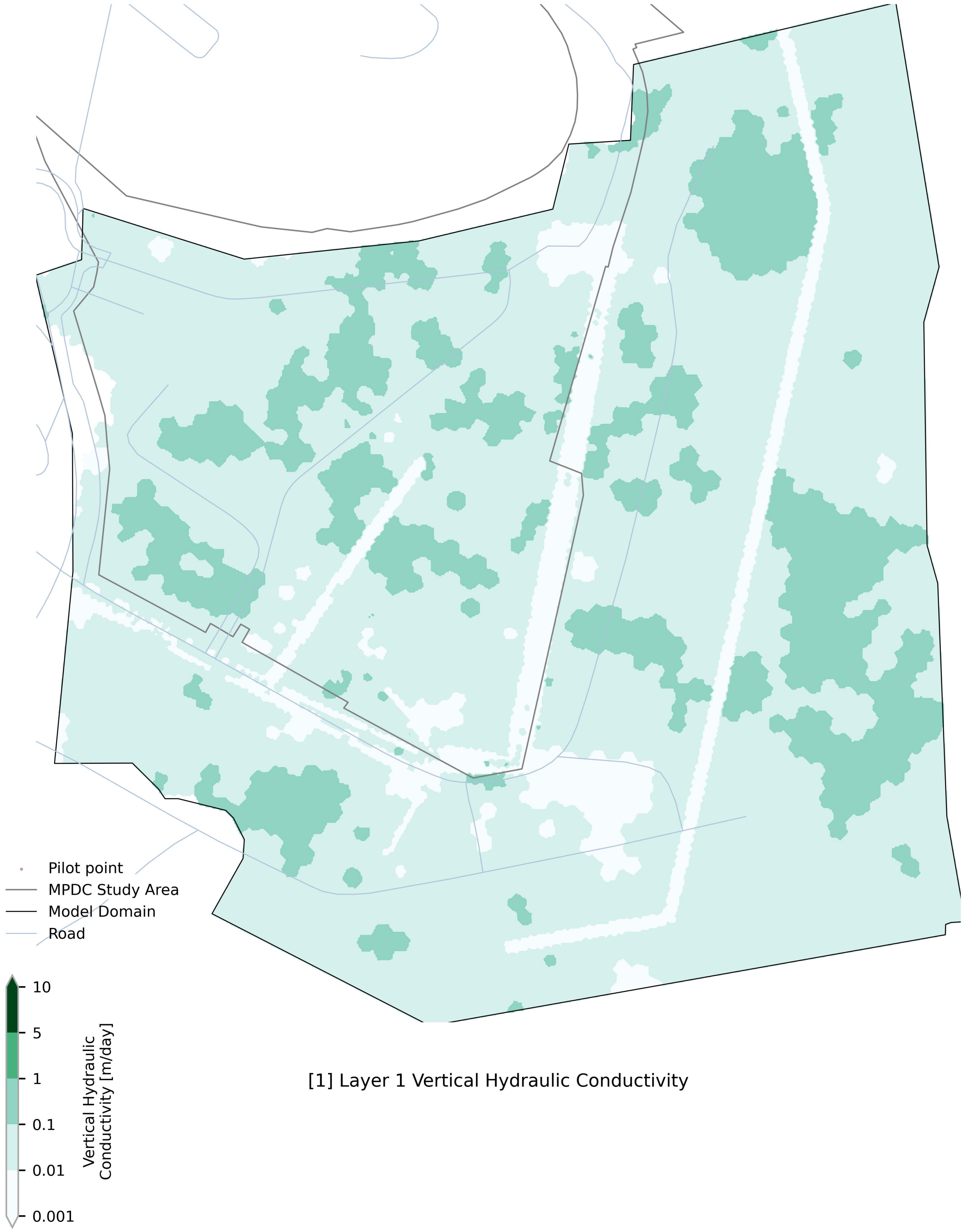


[2] Layer 2 Specific Yield

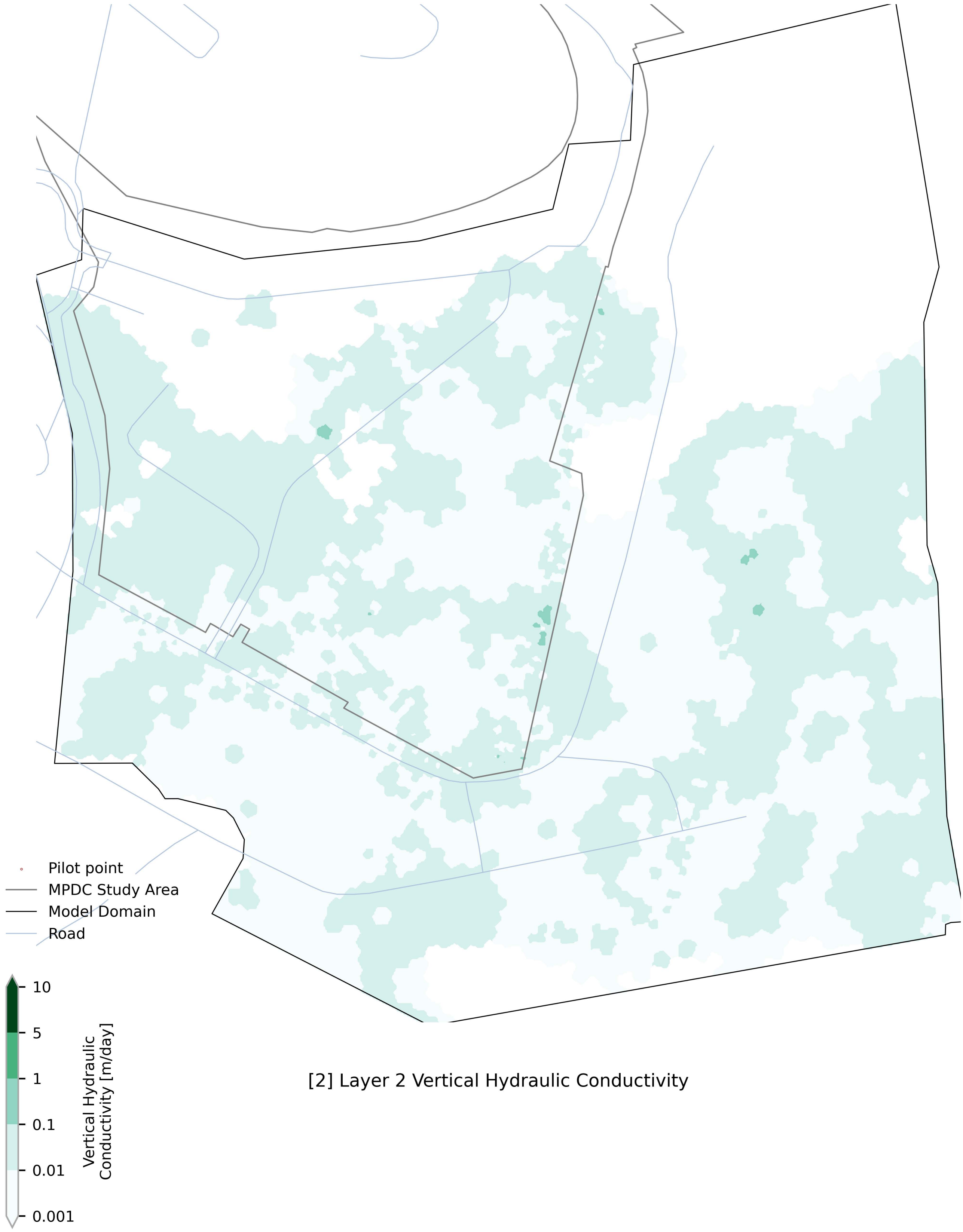


[3] Layer 3 Specific Yield

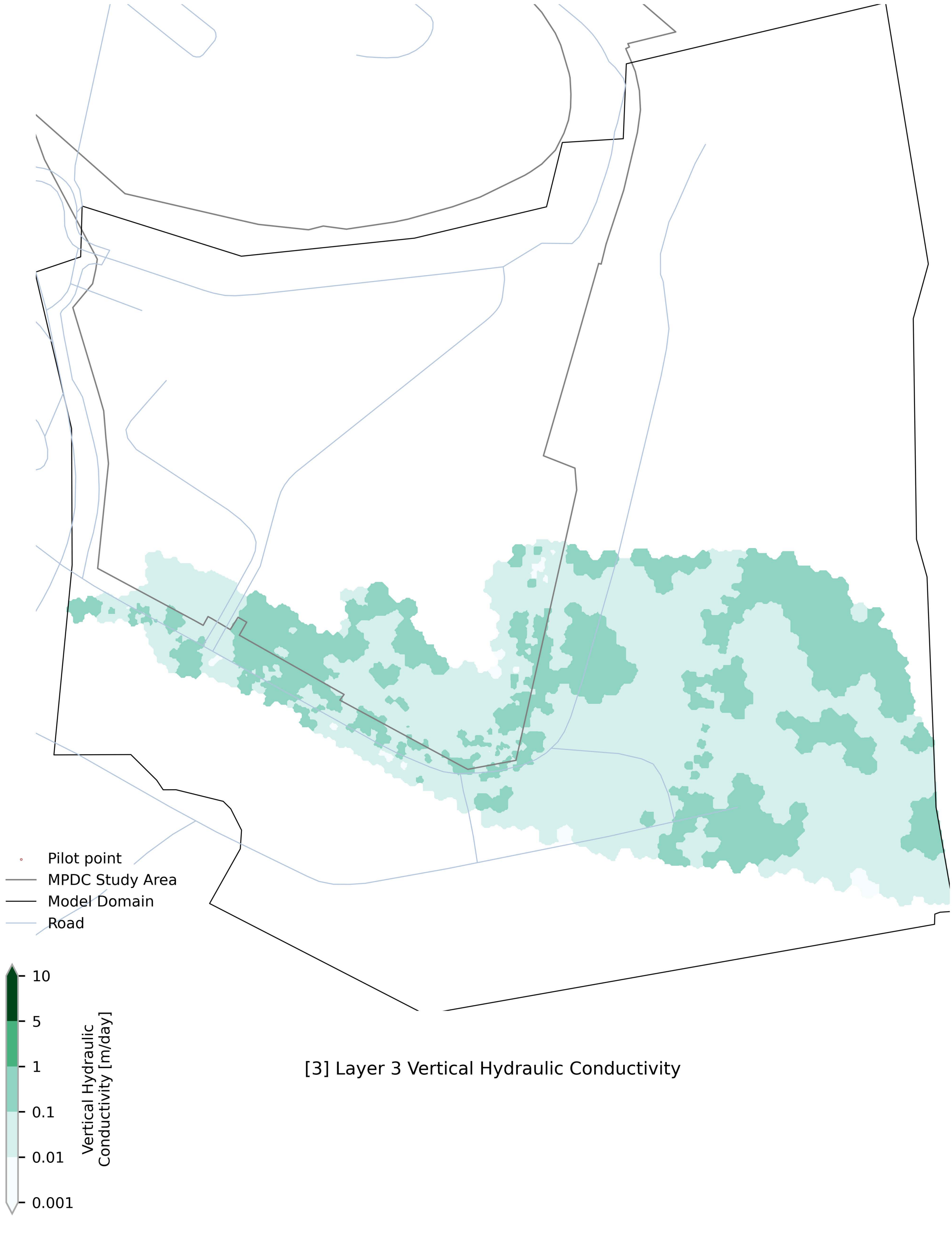
[4] Layer 4 Specific Yield



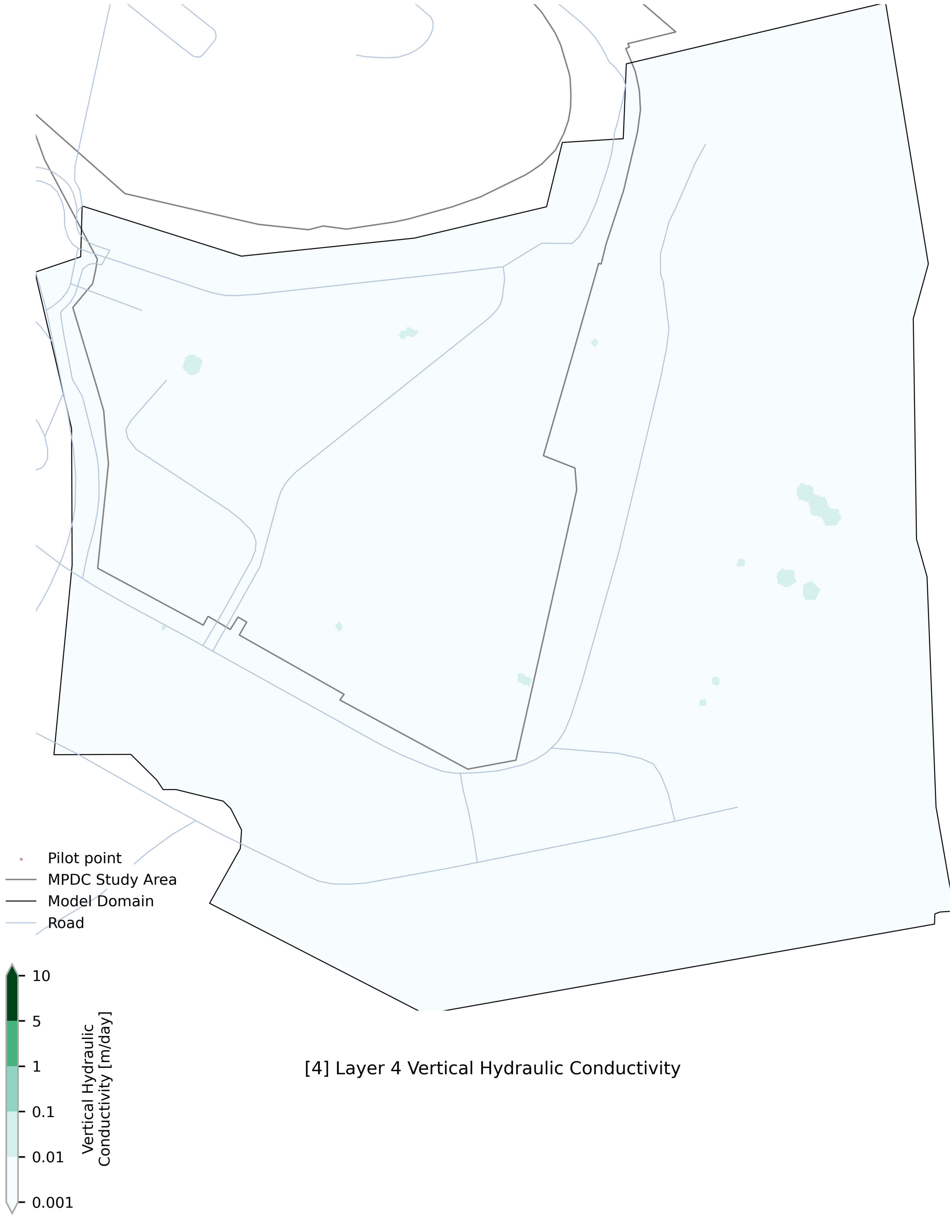
[1] Layer 1 Vertical Hydraulic Conductivity



[2] Layer 2 Vertical Hydraulic Conductivity

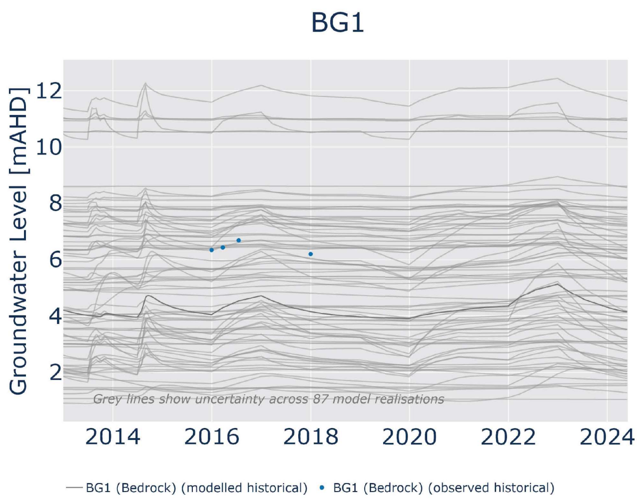


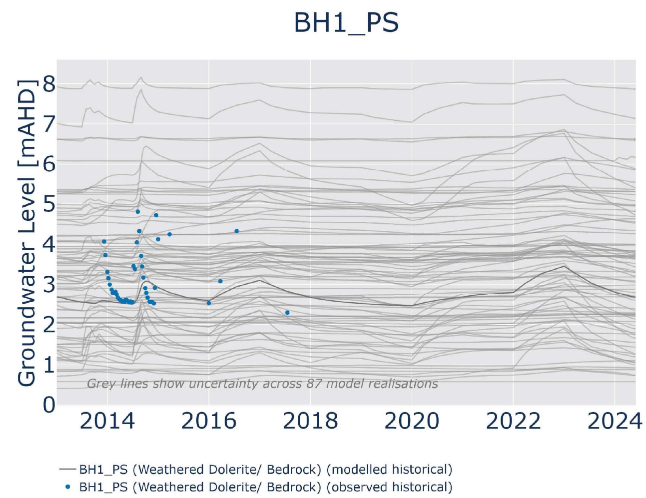
[3] Layer 3 Vertical Hydraulic Conductivity

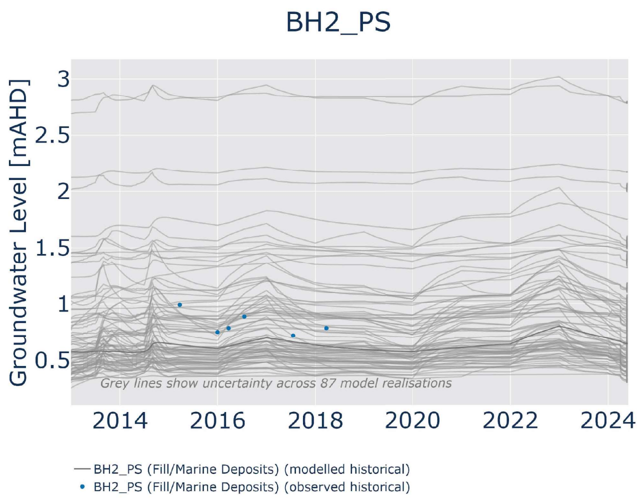


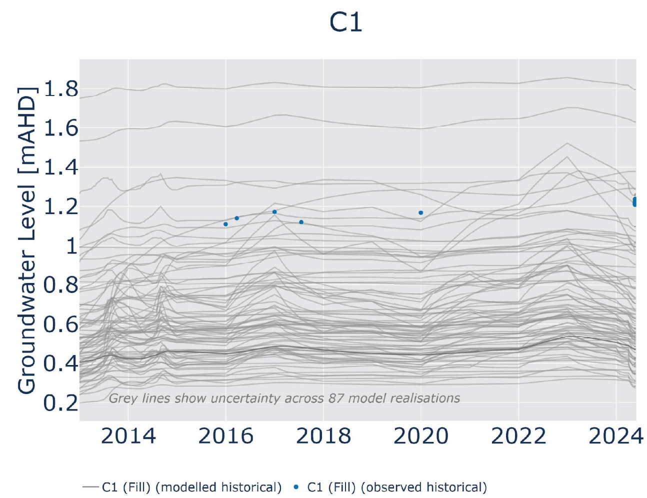
[4] Layer 4 Vertical Hydraulic Conductivity

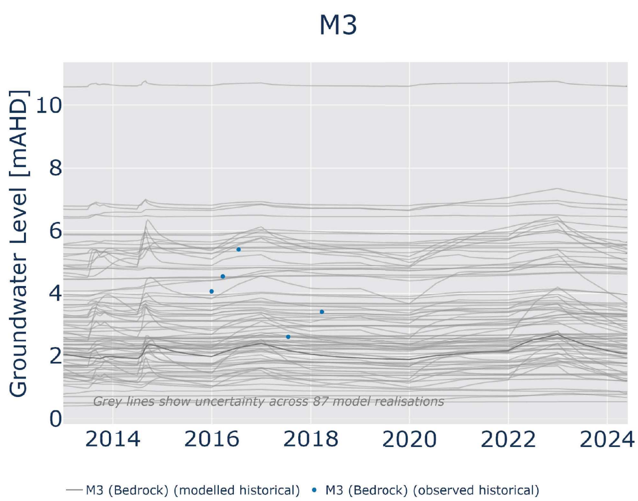
Appendix B Model History Match Hydrographs

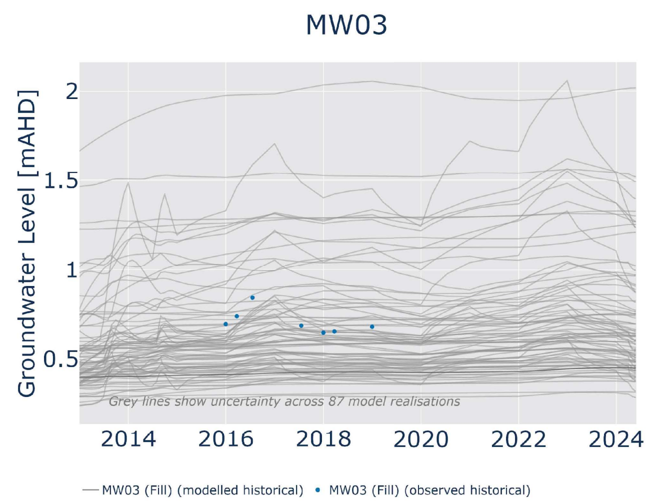

BG1
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
BG1 (Bedrock) (modelled historical)
BG1 (Bedrock) (observed historical)

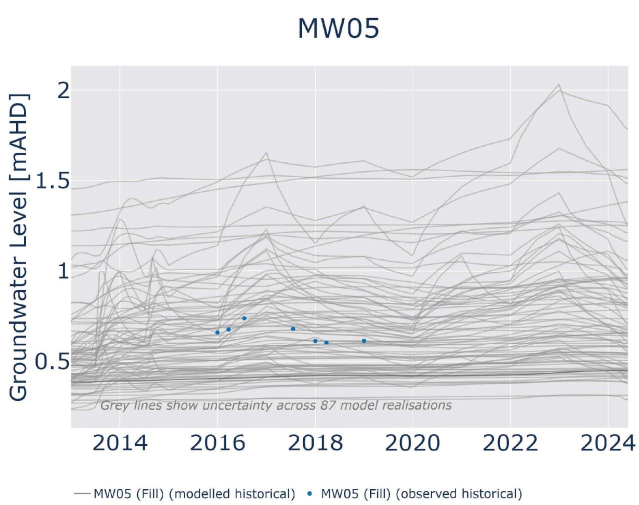

BH1_PS
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
BH1_PS (Weathered Dolerite/ Bedrock) (modelled historical)
BH1_PS (Weathered Dolerite/ Bedrock) (observed historical)

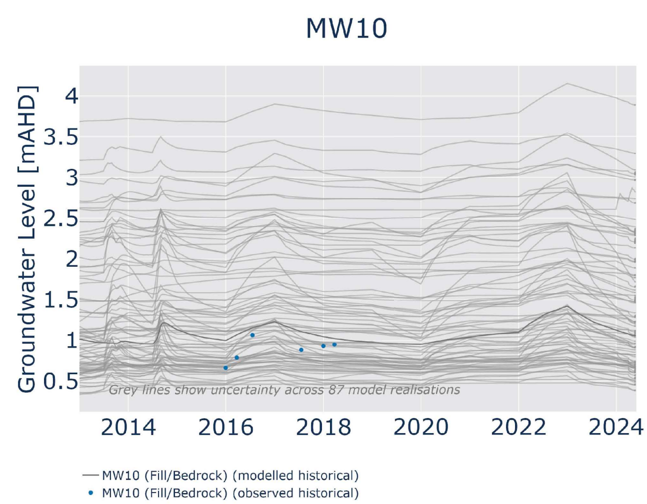

BH2_PS
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
BH2_PS (Fill/Marine Deposits) (modelled historical)
BH2_PS (Fill/Marine Deposits) (observed historical)

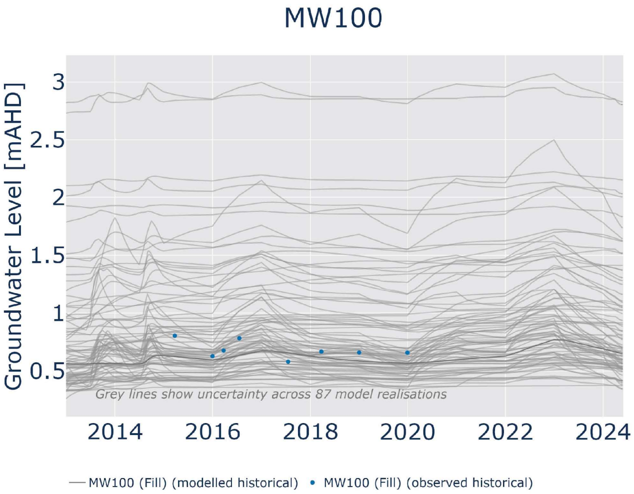

C1
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
C1 (Fill) (modelled historical)
C1 (Fill) (observed historical)

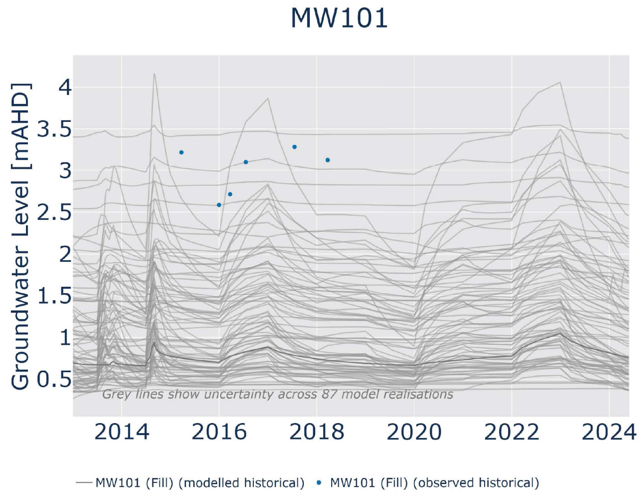

M3
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
M3 (Bedrock) (modelled historical)
M3 (Bedrock) (observed historical)

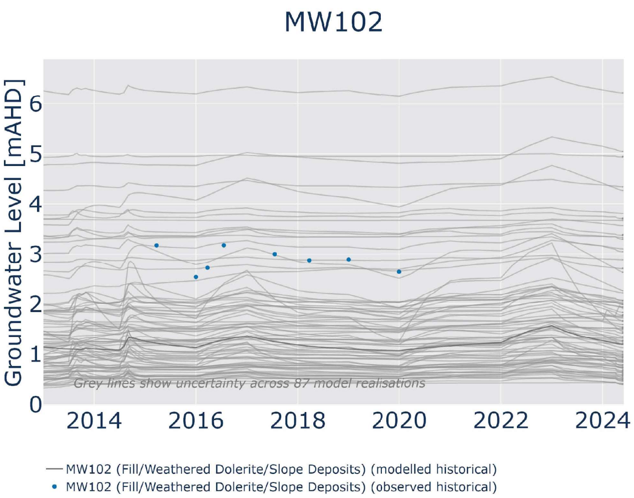

MW03
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW03 (Fill) (modelled historical)
MW03 (Fill) (observed historical)

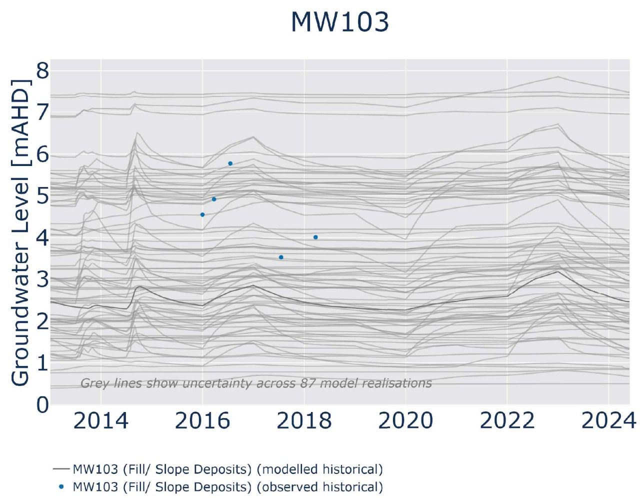

MW05
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW05 (Fill) (modelled historical)
MW05 (Fill) (observed historical)

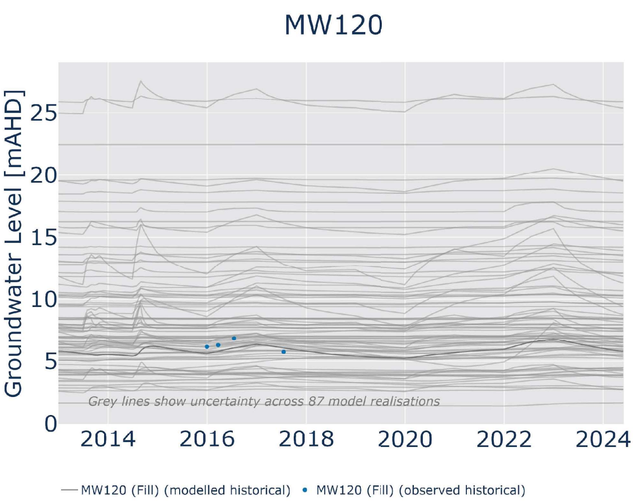

MW10
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW10 (Fill/Bedrock) (modelled historical)
MW10 (Fill/Bedrock) (observed historical)

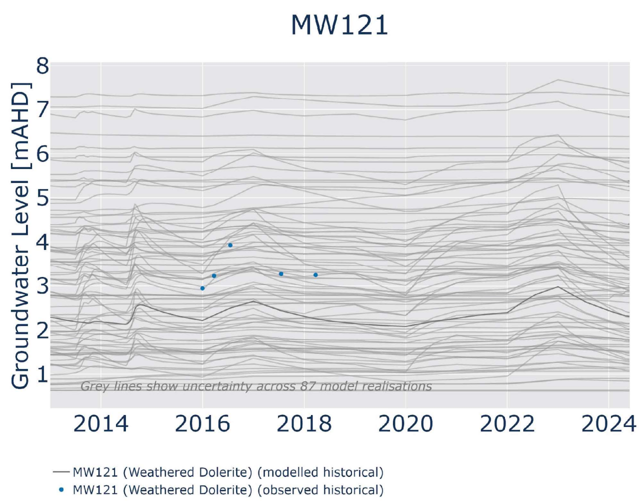

MW100
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW100 (Fill) (modelled historical)
MW100 (Fill) (observed historical)

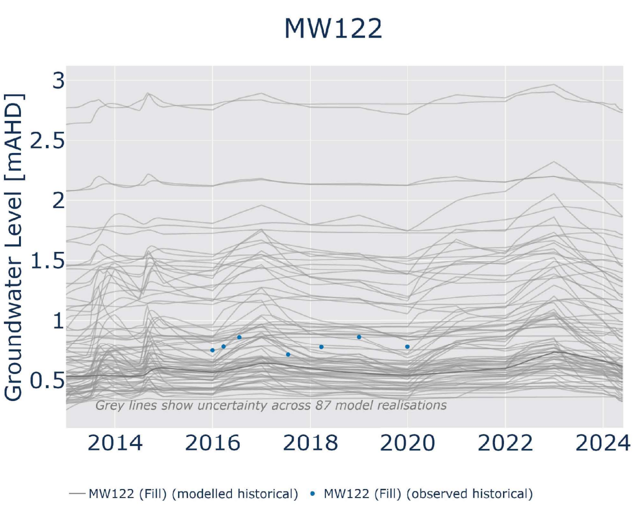

MW101
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW101 (Fill) (modelled historical)
MW101 (Fill) (observed historical)

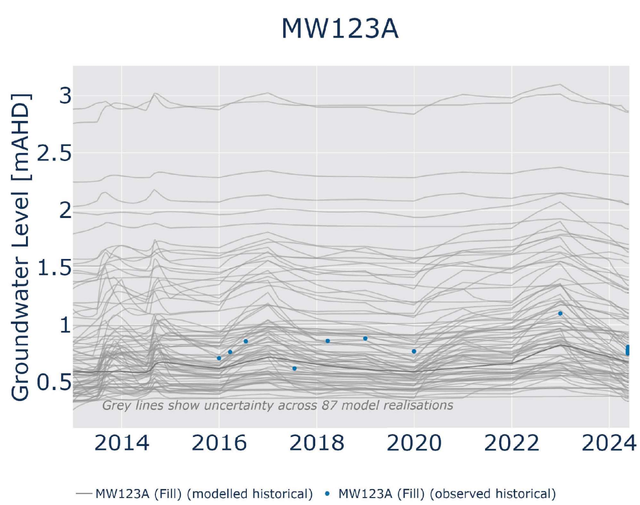

MW102
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW102 (Fill/Weathered Dolerite/Slope Deposits) (modelled historical)
MW102 (Fill/Weathered Dolerite/Slope Deposits) (observed historical)


MW103
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW103 (Fill/ Slope Deposits) (modelled historical)
MW103 (Fill/ Slope Deposits) (observed historical)

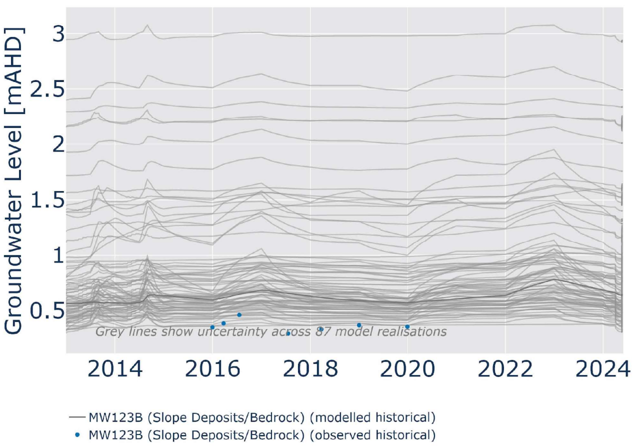

MW120
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW120 (Fill) (modelled historical)
MW120 (Fill) (observed historical)


MW121
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW121 (Weathered Dolerite) (modelled historical)
MW121 (Weathered Dolerite) (observed historical)

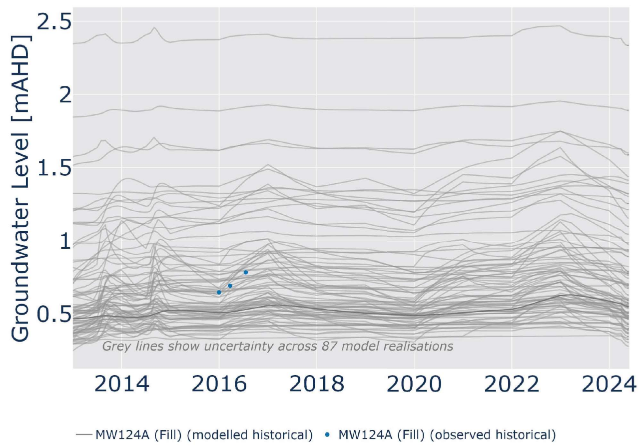

MW122
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW122 (Fill) (modelled historical)
MW122 (Fill) (observed historical)


MW123A
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW123A (Fill) (modelled historical)
MW123A (Fill) (observed historical)

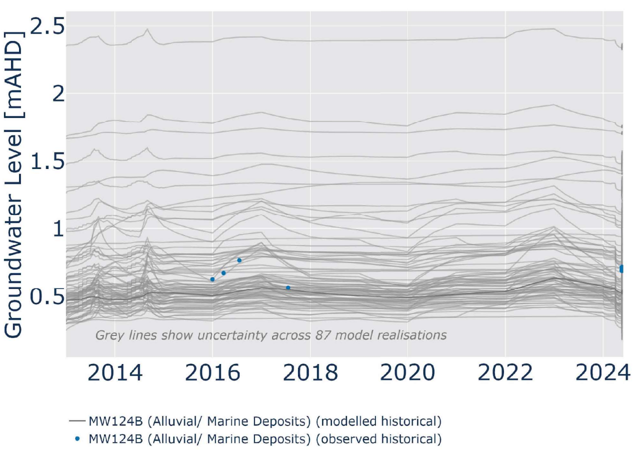
MW123B



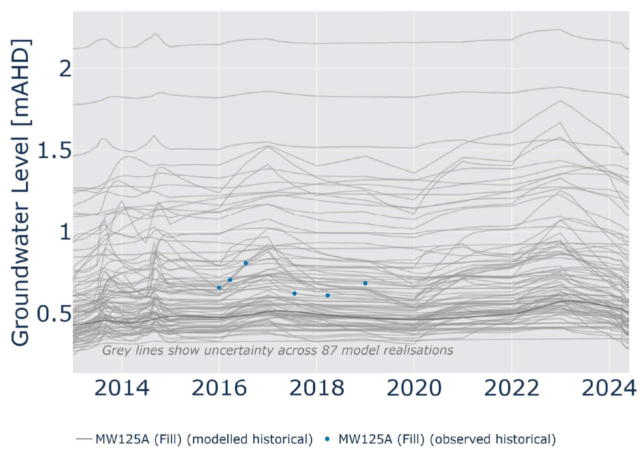
MW124A



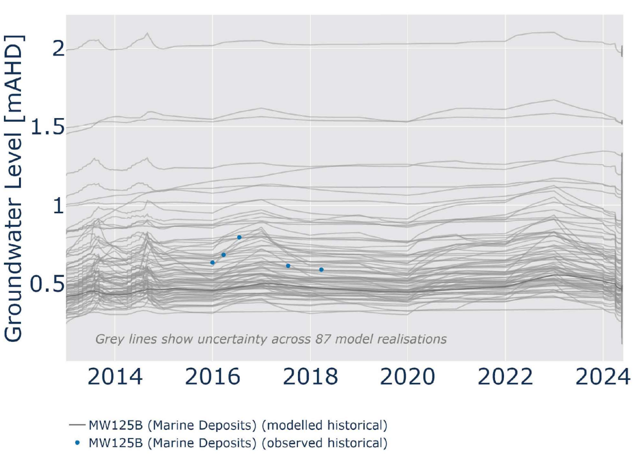
MW124B



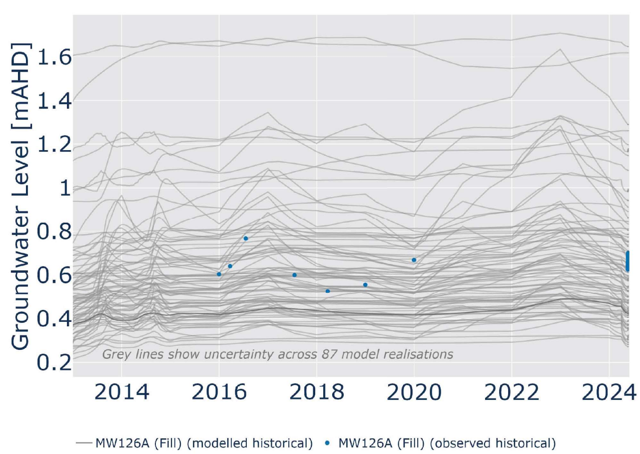
MW125A



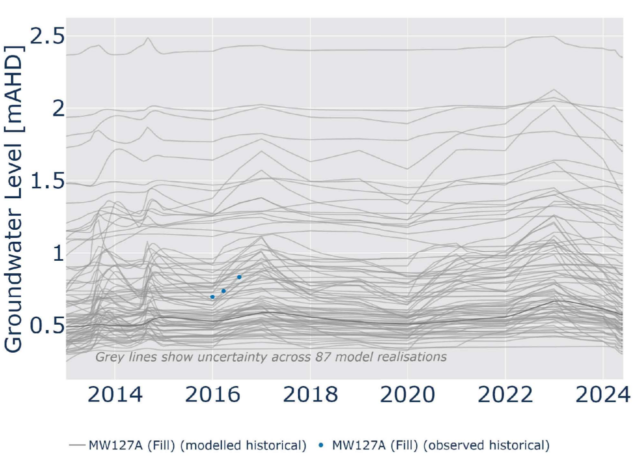
MW125B



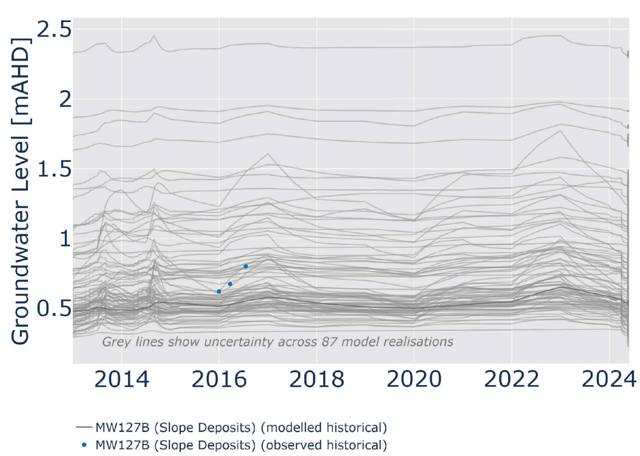
MW126A

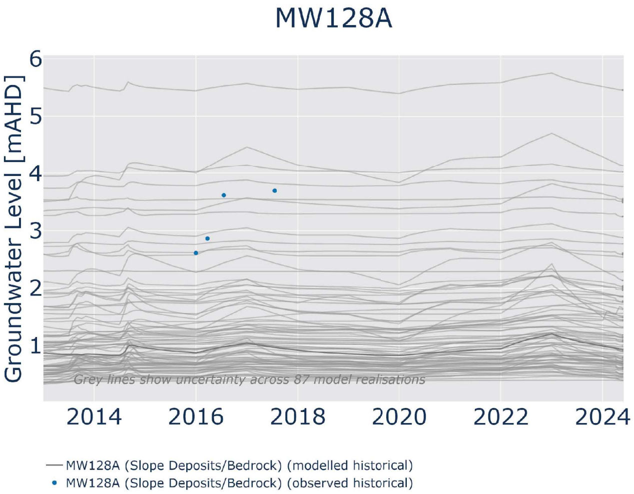


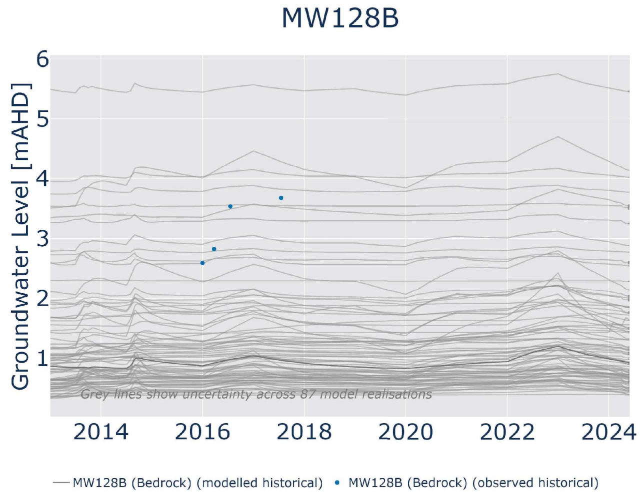
MW127A

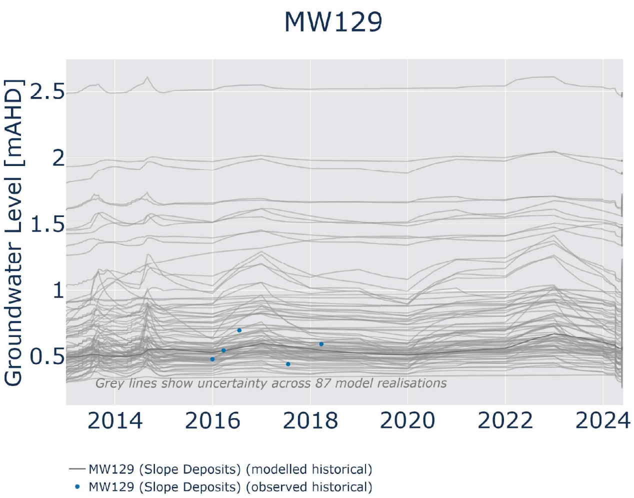


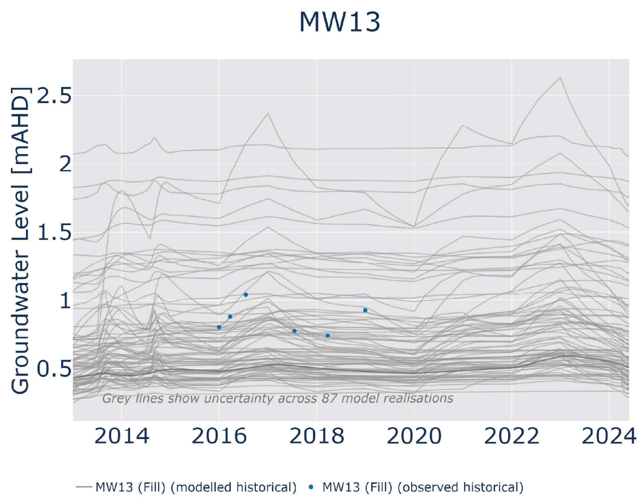
MW127B

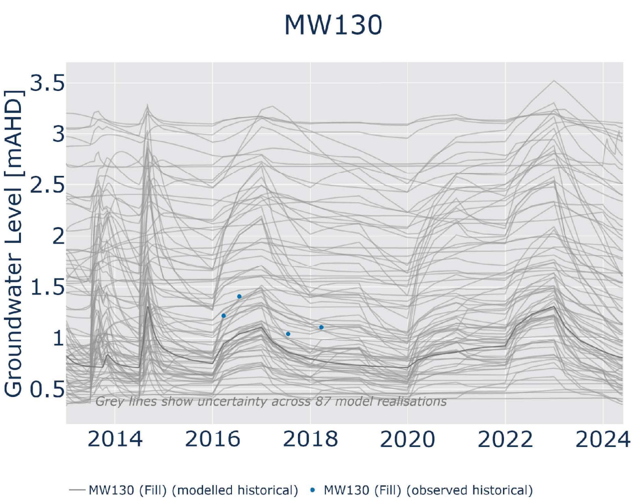


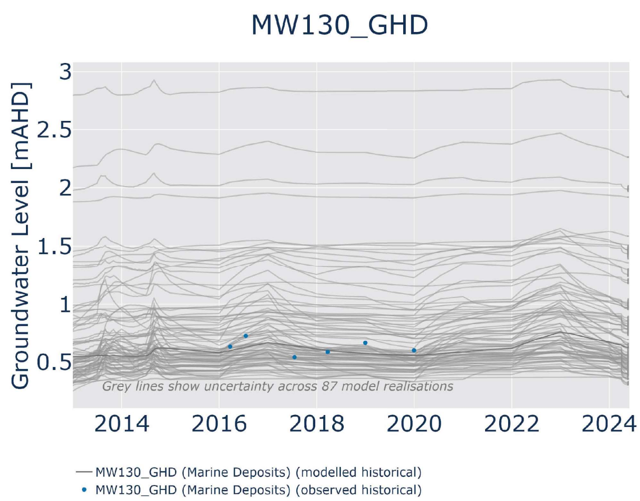

MW128A
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW128A (Slope Deposits/Bedrock) (modelled historical)
MW128A (Slope Deposits/Bedrock) (observed historical)

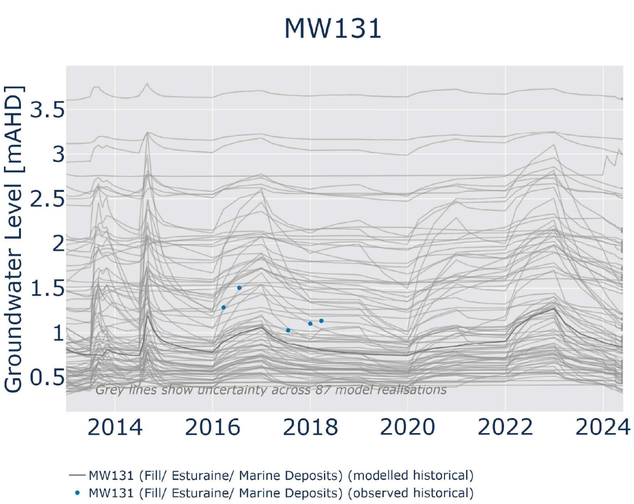

MW128B
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW128B (Bedrock) (modelled historical)
MW128B (Bedrock) (observed historical)

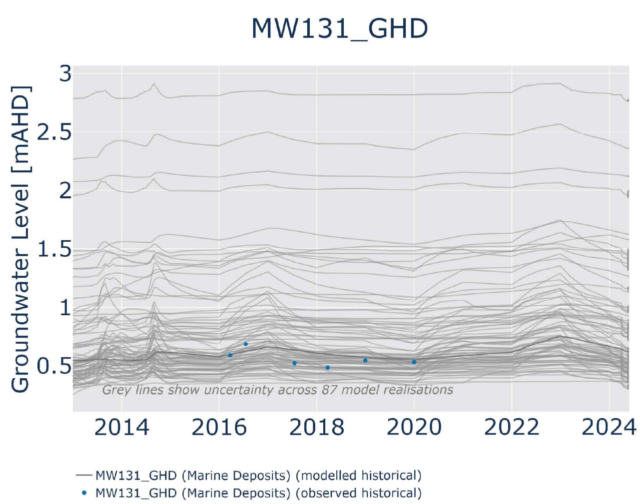

MW129
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW129 (Slope Deposits) (modelled historical)
MW129 (Slope Deposits) (observed historical)


MW13
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW13 (Fill) (modelled historical)
MW13 (Fill) (observed historical)

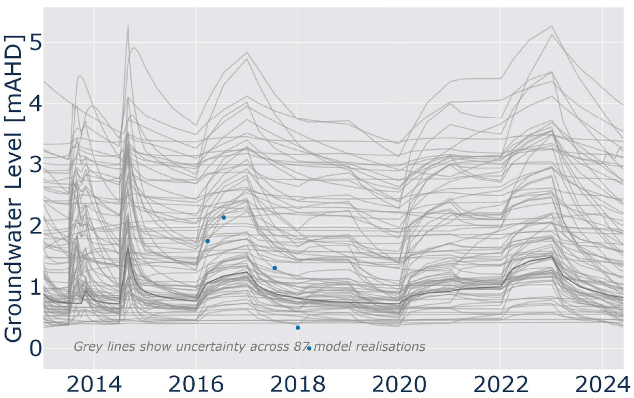

MW130
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW130 (Fill) (modelled historical)
MW130 (Fill) (observed historical)


MW130_GHD
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW130_GHD (Marine Deposits) (modelled historical)
MW130_GHD (Marine Deposits) (observed historical)

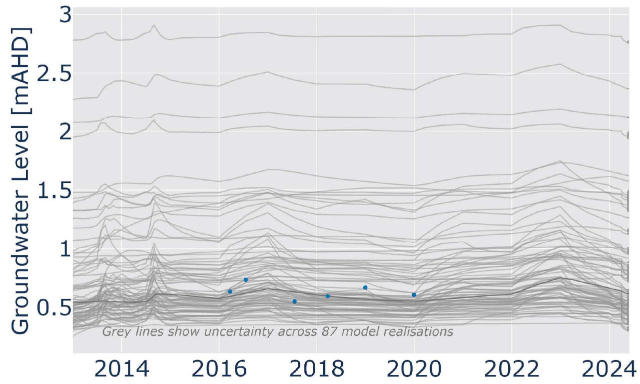

MW131
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW131 (Fill/ Esturaine/ Marine Deposits) (modelled historical)
MW131 (Fill/ Esturaine/ Marine Deposits) (observed historical)


MW131_GHD
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW131_GHD (Marine Deposits) (modelled historical)
MW131_GHD (Marine Deposits) (observed historical)

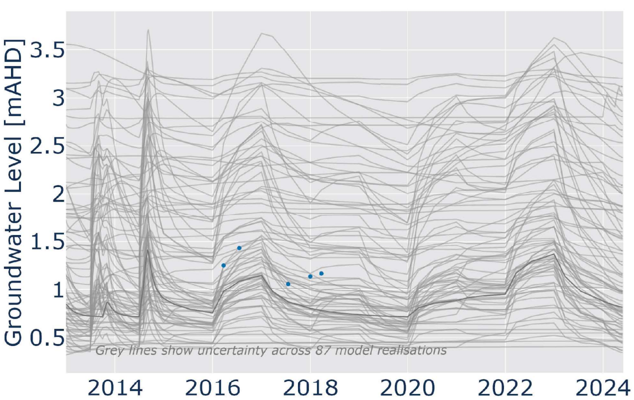
MW132



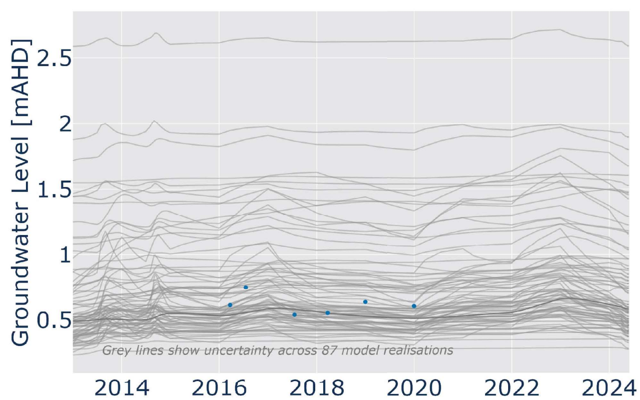
MW132_GHD



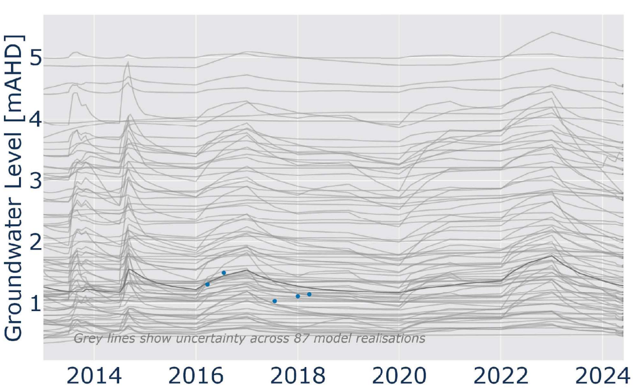
MW133



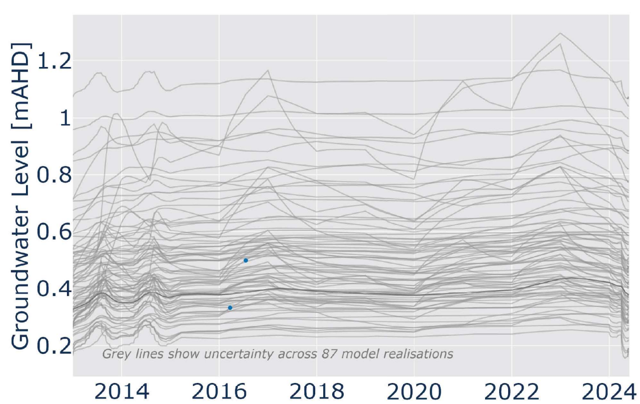
MW133_GHD



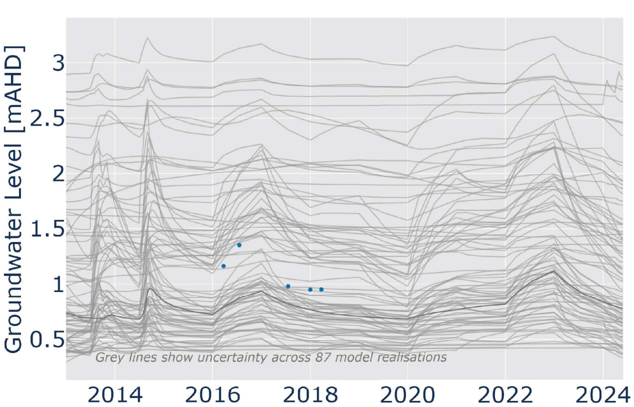
MW134



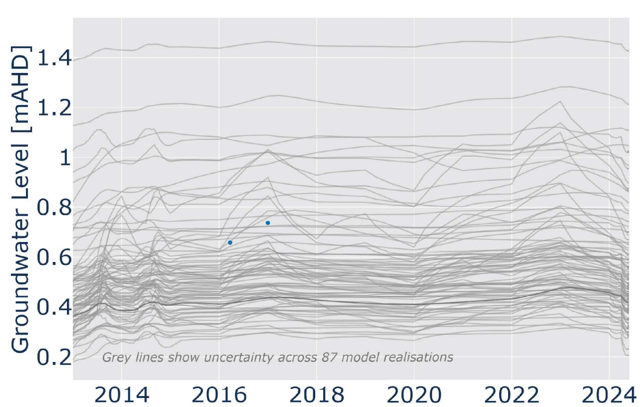
MW134_GHD

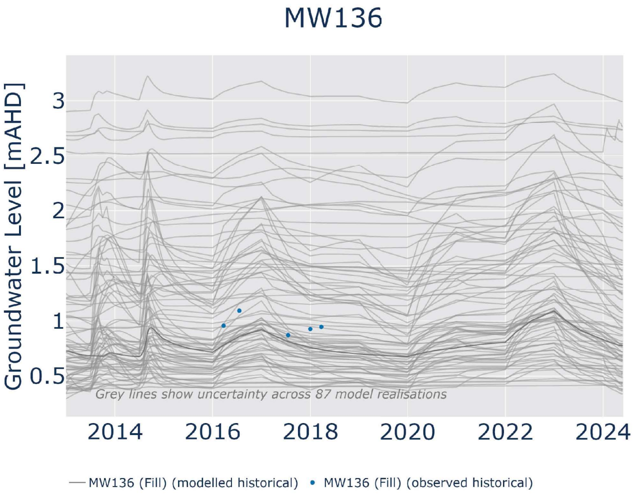


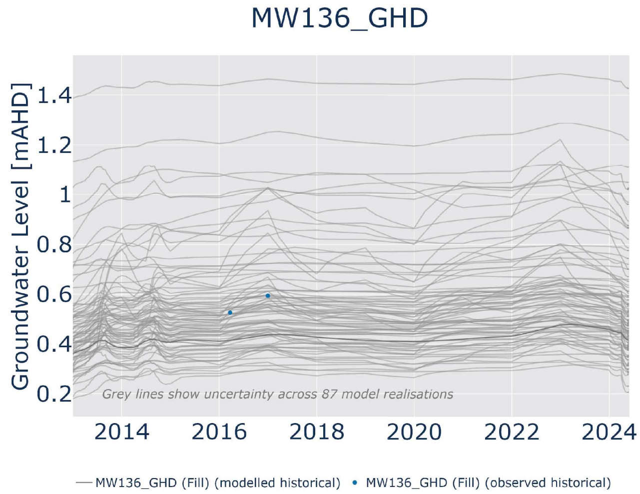
MW135

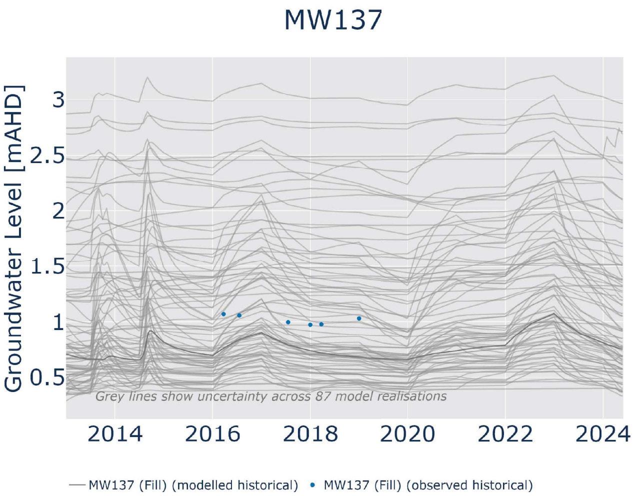


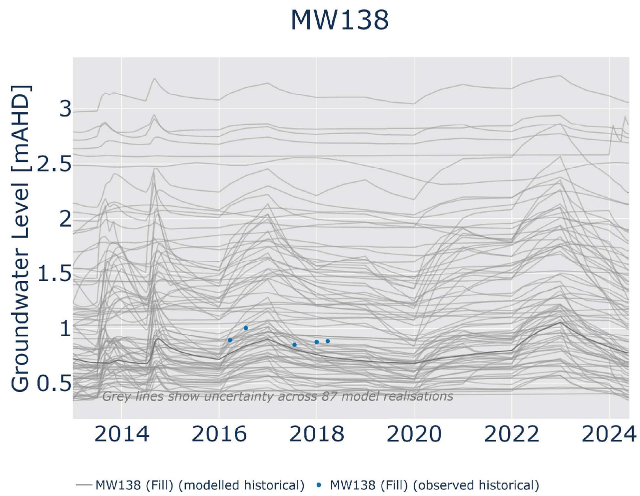
MW135_GHD

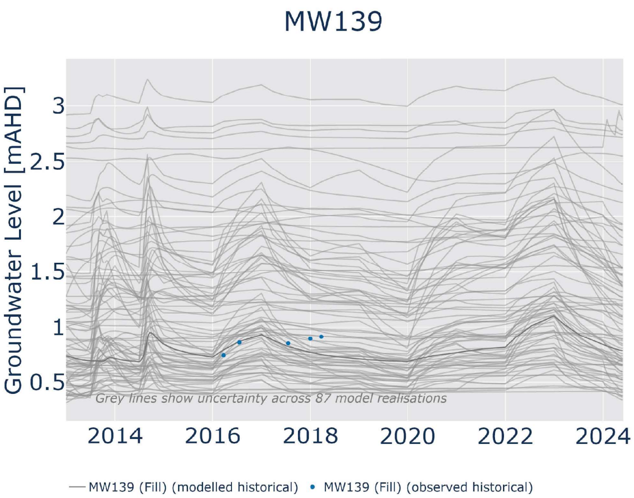


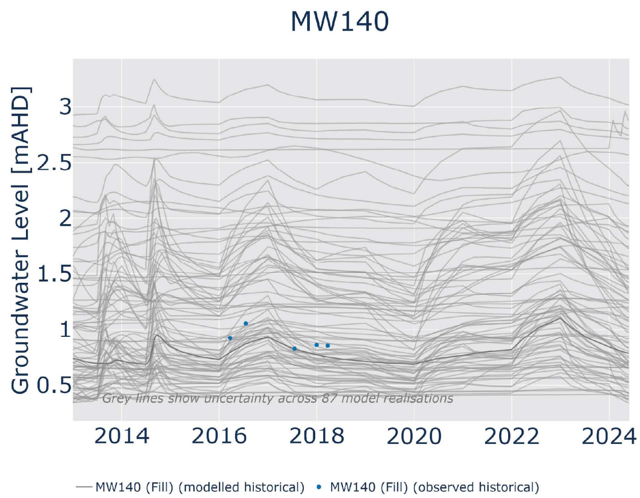

MW136
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW136 (Fill) (modelled historical)
MW136 (Fill) (observed historical)

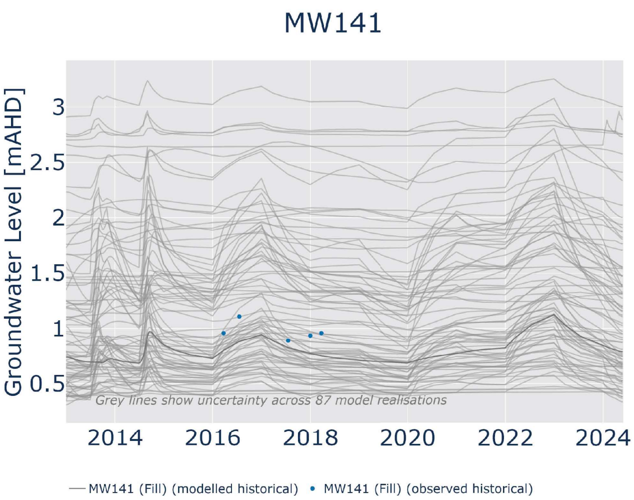

MW136_GHD
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW136_GHD (Fill) (modelled historical)
MW136_GHD (Fill) (observed historical)

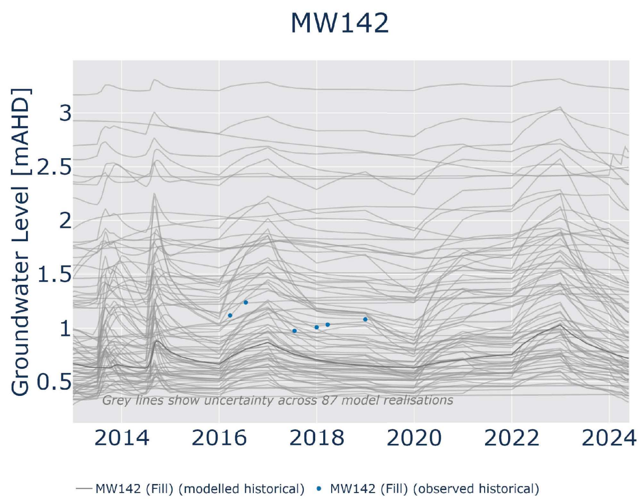

MW137
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW137 (Fill) (modelled historical)
MW137 (Fill) (observed historical)

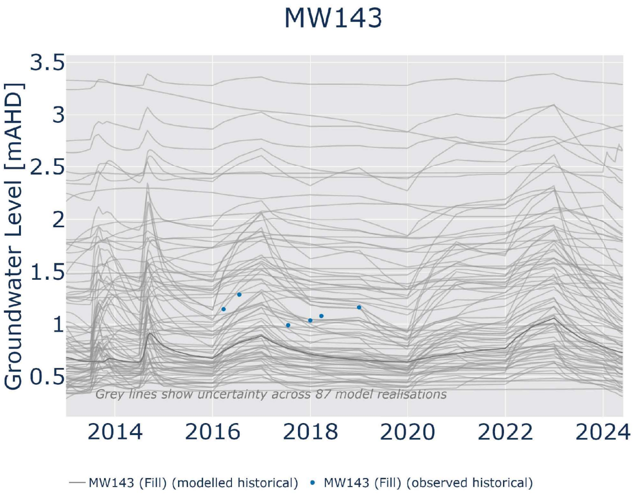

MW138
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW138 (Fill) (modelled historical)
MW138 (Fill) (observed historical)

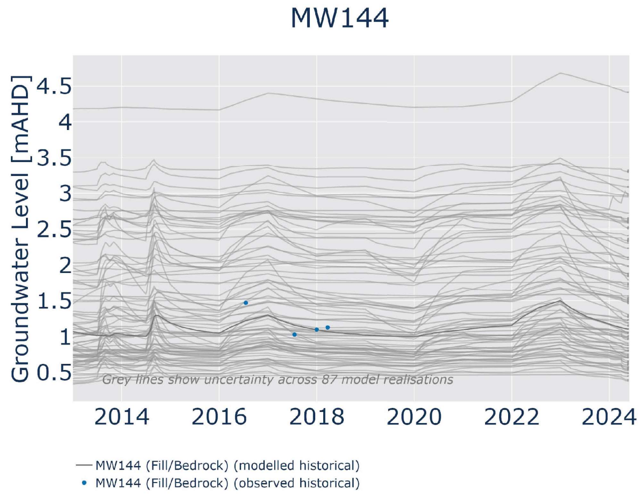

MW139
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW139 (Fill) (modelled historical)
MW139 (Fill) (observed historical)

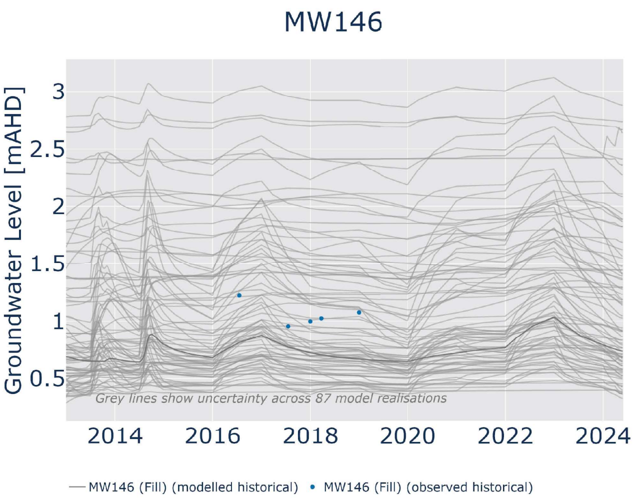

MW140
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW140 (Fill) (modelled historical)
MW140 (Fill) (observed historical)

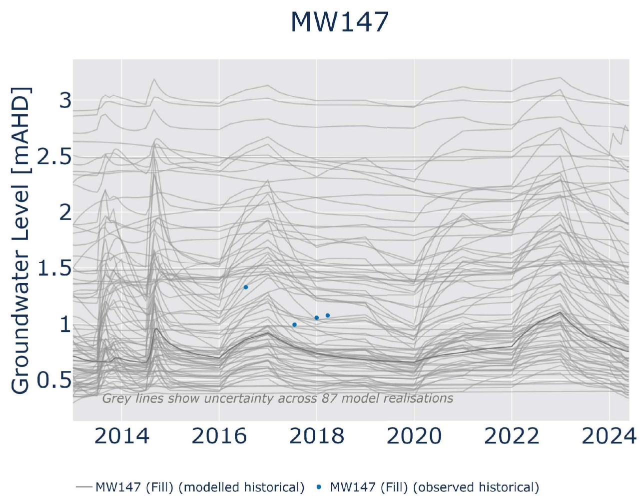

MW141
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW141 (Fill) (modelled historical)
MW141 (Fill) (observed historical)

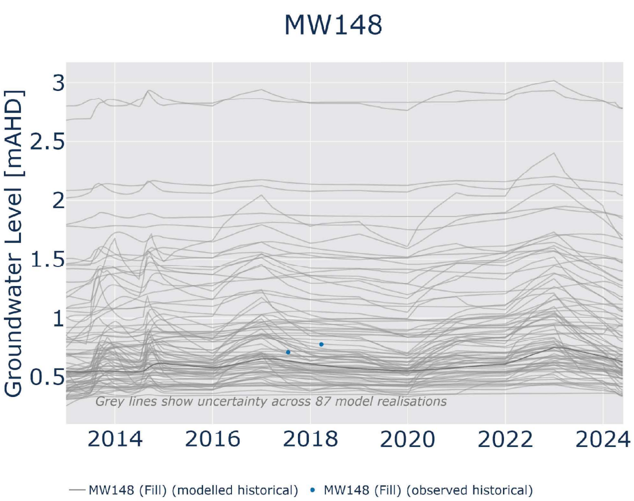

MW142
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW142 (Fill) (modelled historical)
MW142 (Fill) (observed historical)

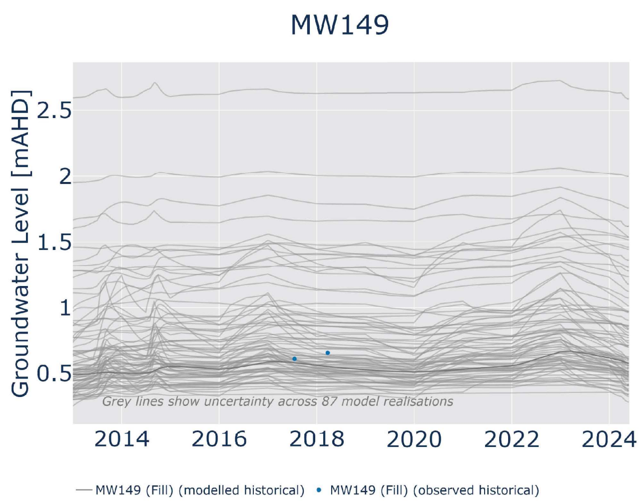

MW143
Groundwater Level [mAHD]
3.5
3
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW143 (Fill) (modelled historical)
MW143 (Fill) (observed historical)

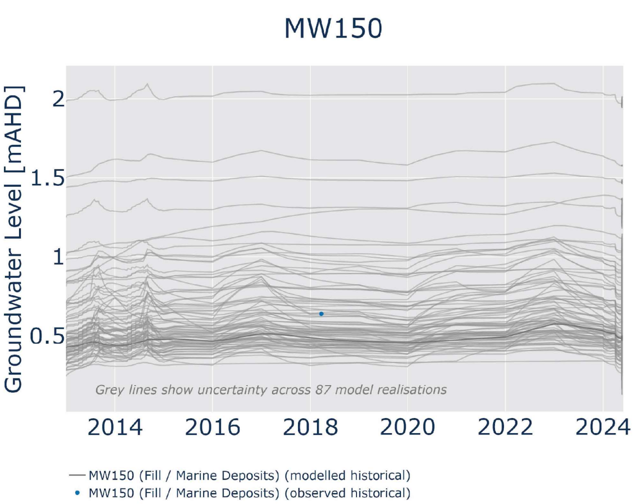

MW144
Groundwater Level [mAHD]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW144 (Fill/Bedrock) (modelled historical)
MW144 (Fill/Bedrock) (observed historical)

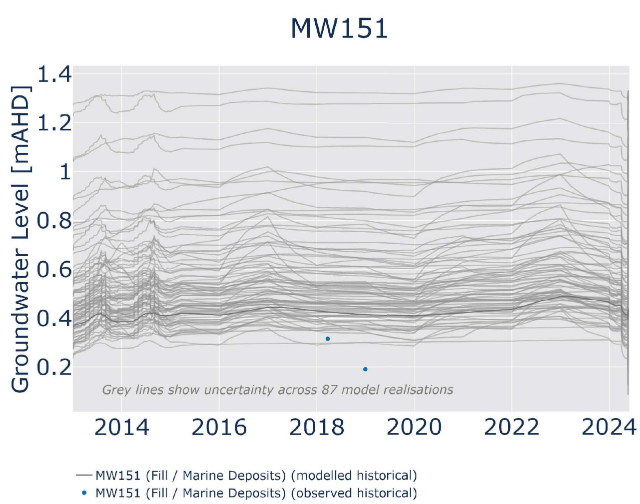

MW146
Groundwater Level [mAHD]
3
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW146 (Fill) (modelled historical)
MW146 (Fill) (observed historical)

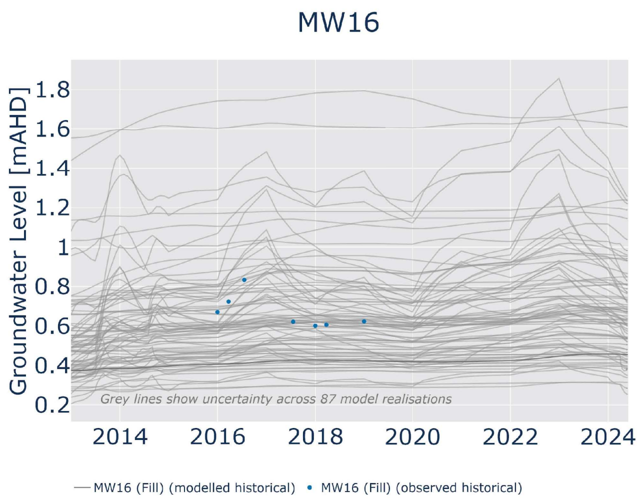

MW147
Groundwater Level [mAHD]
3
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW147 (Fill) (modelled historical)
MW147 (Fill) (observed historical)

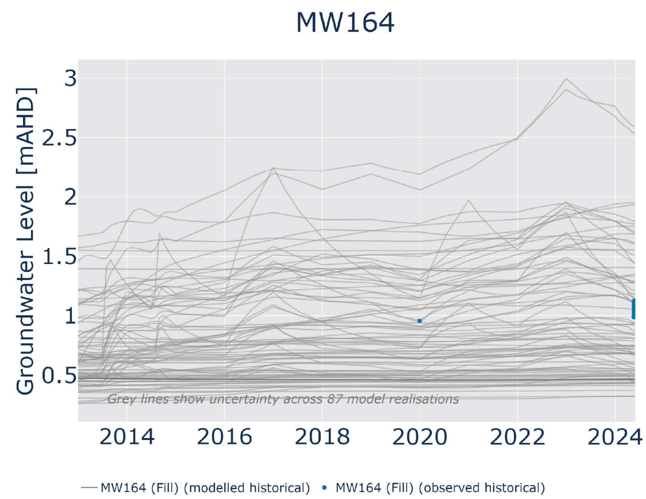

MW148
Groundwater Level [mAHD]
3
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW148 (Fill) (modelled historical)
MW148 (Fill) (observed historical)

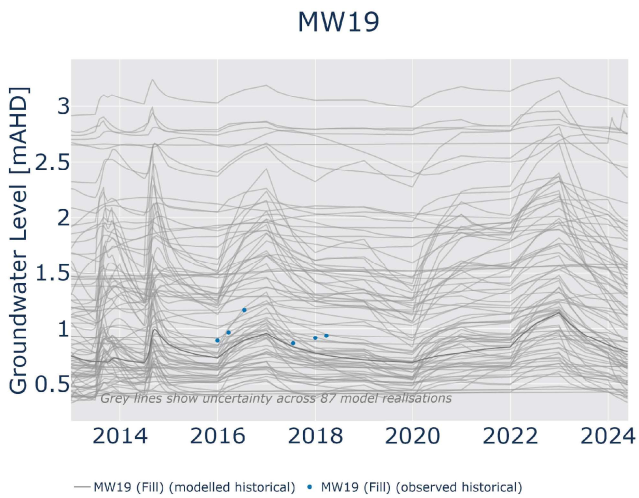

MW149
Groundwater Level [mAHD]
2.5
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW149 (Fill) (modelled historical)
MW149 (Fill) (observed historical)

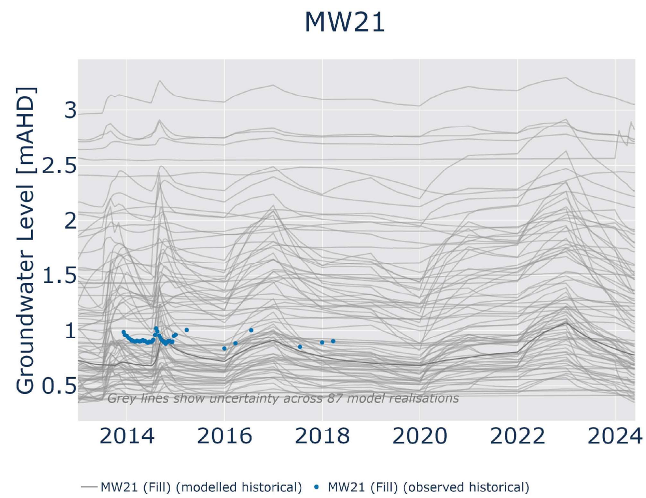

MW150
Groundwater Level [mAHD]
2
1.5
1
0.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW150 (Fill / Marine Deposits) (modelled historical)
MW150 (Fill / Marine Deposits) (observed historical)

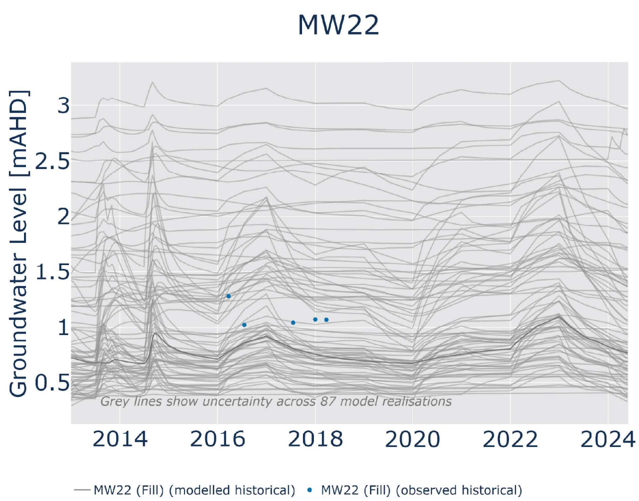

MW151
Groundwater Level [mAHD]
1.4
1.2
1
0.8
0.6
0.4
0.2
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW151 (Fill / Marine Deposits) (modelled historical)
MW151 (Fill / Marine Deposits) (observed historical)

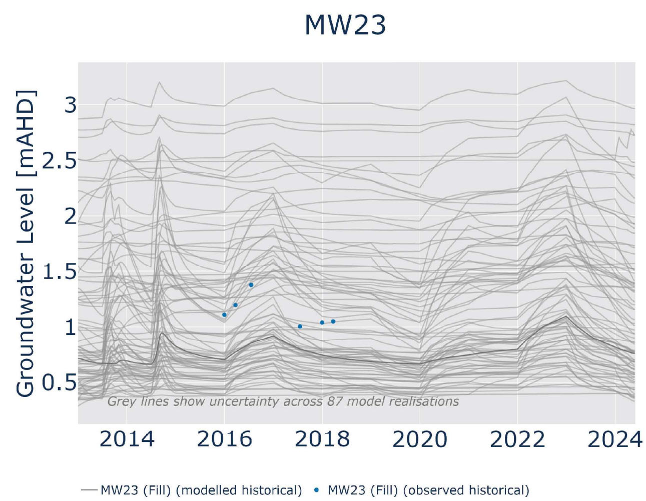

MW16
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW16 (Fill) (modelled historical)
MW16 (Fill) (observed historical)

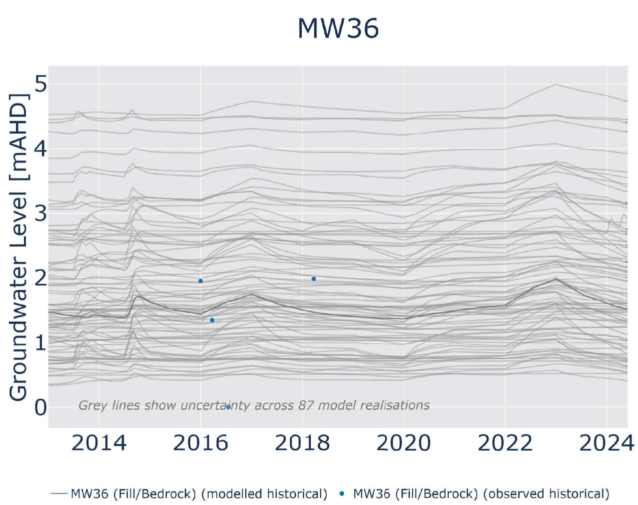

MW164
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW164 (Fill) (modelled historical)
MW164 (Fill) (observed historical)

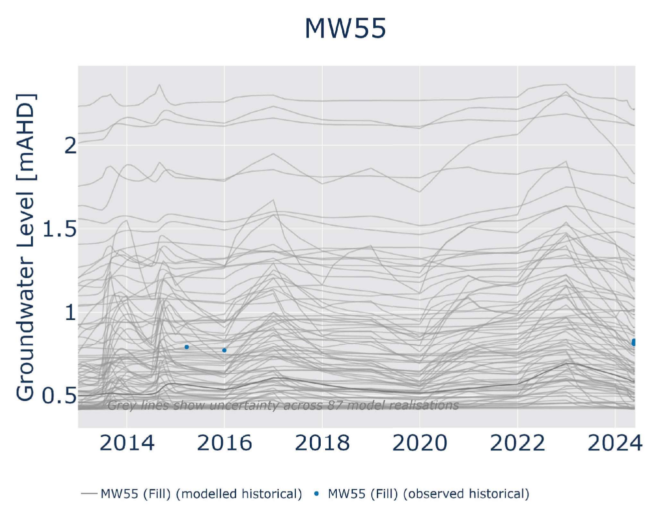

MW19
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW19 (Fill) (modelled historical)
MW19 (Fill) (observed historical)

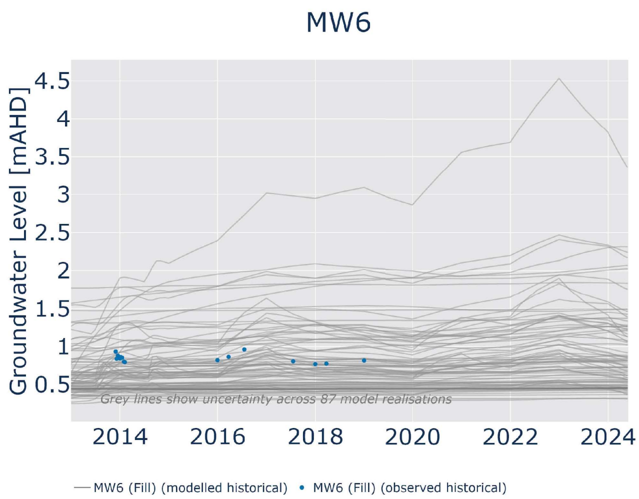

MW21
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW21 (Fill) (modelled historical)
MW21 (Fill) (observed historical)

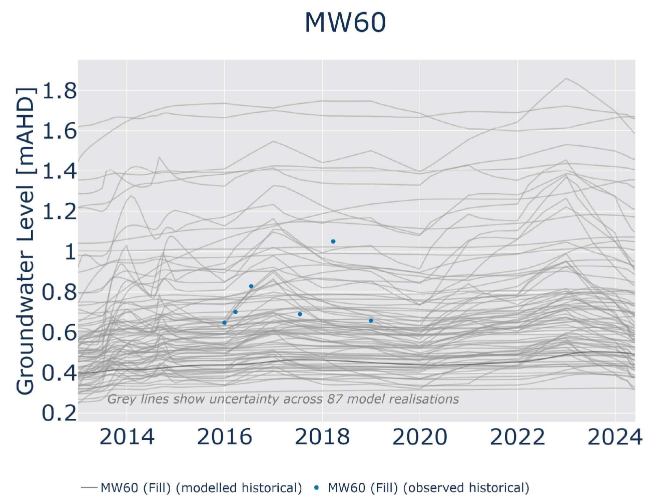

MW22
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW22 (Fill) (modelled historical)
MW22 (Fill) (observed historical)

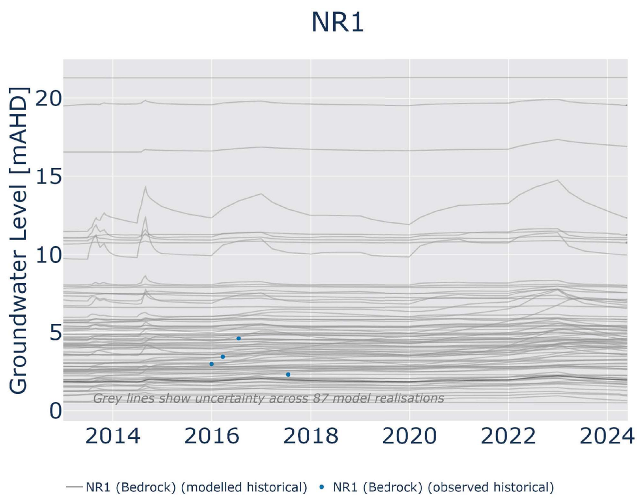

MW23
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW23 (Fill) (modelled historical)
MW23 (Fill) (observed historical)

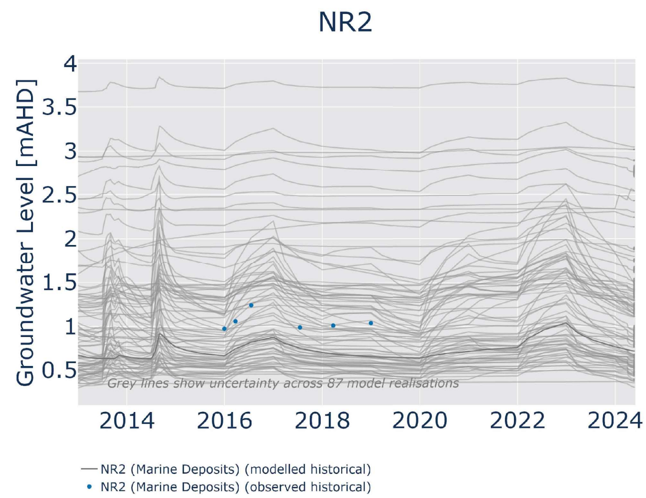

MW36
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW36 (Fill/Bedrock) (modelled historical)
MW36 (Fill/Bedrock) (observed historical)

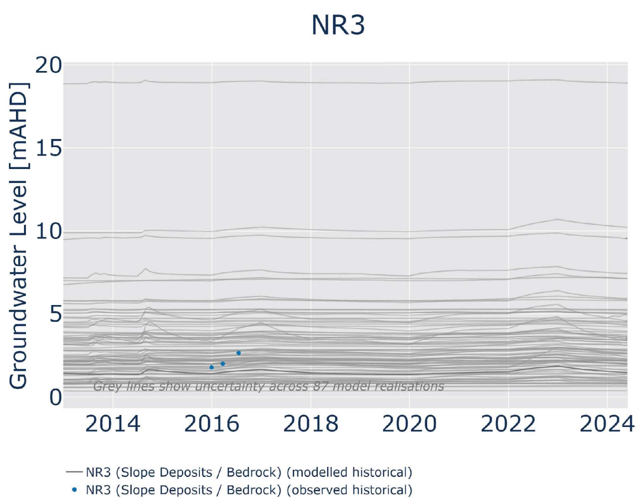

MW55
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
MW55 (Fill) (modelled historical)
MW55 (Fill) (observed historical)

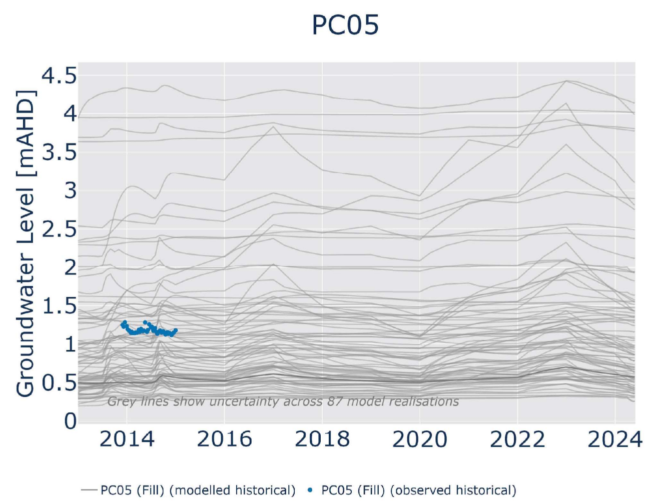

MW6
Groundwater Level [mAHD]
0.5
1
1.5
2
2.5
3
3.5
4
4.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW6 (Fill) (modelled historical)
MW6 (Fill) (observed historical)

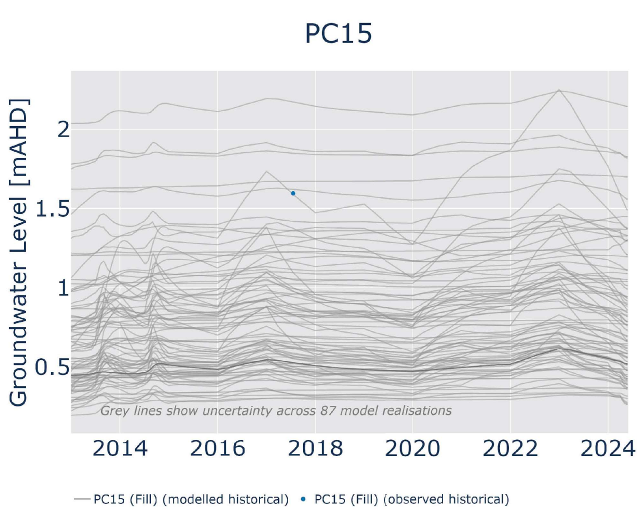

MW60
Groundwater Level [mAHD]
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
MW60 (Fill) (modelled historical)
MW60 (Fill) (observed historical)

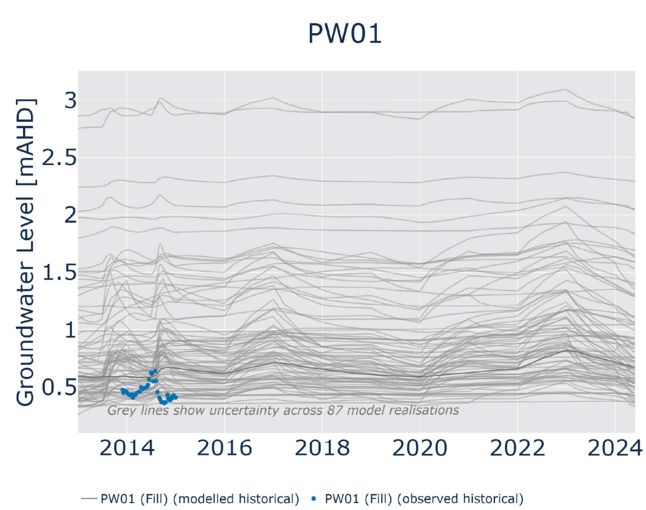

NR1
Groundwater Level [mAHD]
0
5
10
15
20
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
NR1 (Bedrock) (modelled historical)
NR1 (Bedrock) (observed historical)

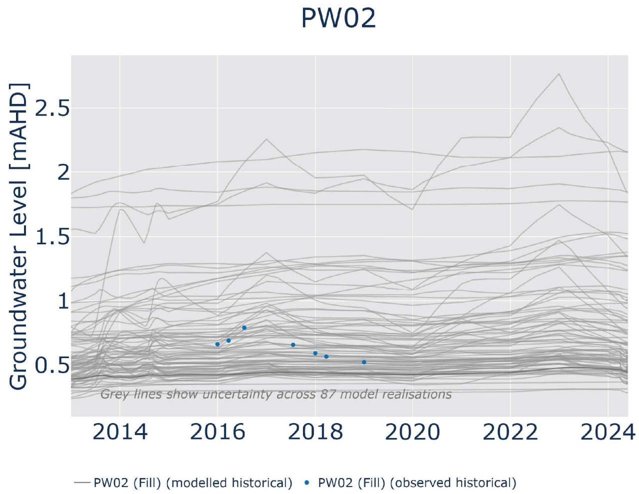

NR2
Groundwater Level [mAHD]
0.5
1
1.5
2
2.5
3
3.5
4
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
NR2 (Marine Deposits) (modelled historical)
NR2 (Marine Deposits) (observed historical)

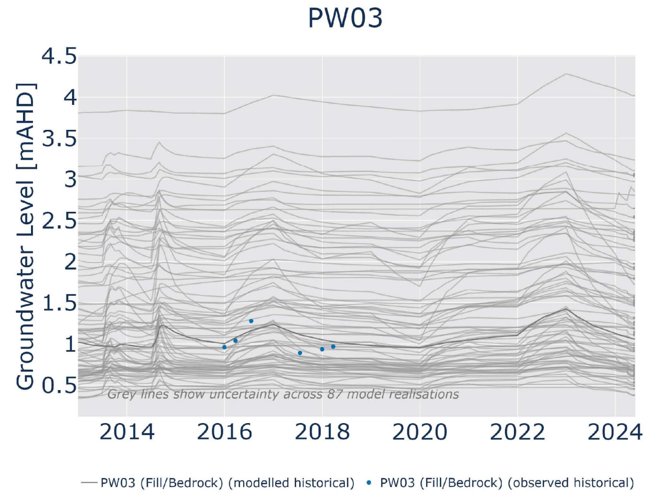

NR3
Groundwater Level [mAHD]
0
5
10
15
20
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
NR3 (Slope Deposits / Bedrock) (modelled historical)
NR3 (Slope Deposits / Bedrock) (observed historical)

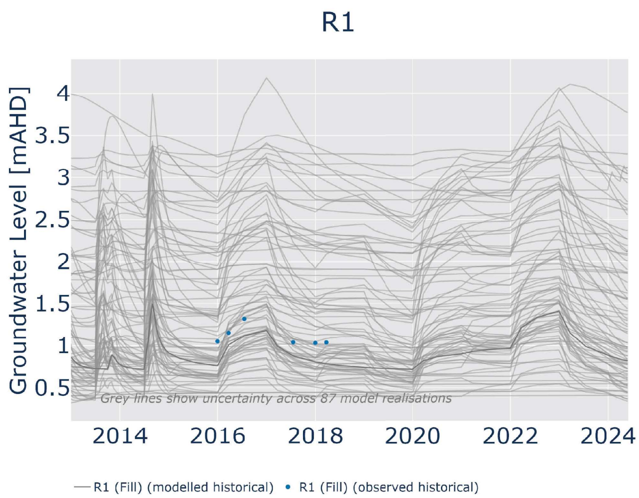

PC05
Groundwater Level [mAHD]
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
PC05 (Fill) (modelled historical)
PC05 (Fill) (observed historical)

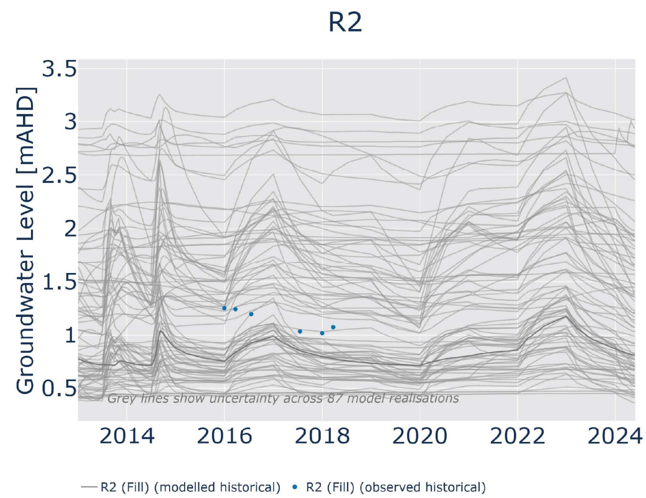

PC15
Groundwater Level [mAHD]
0.5
1
1.5
2
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
PC15 (Fill) (modelled historical)
PC15 (Fill) (observed historical)

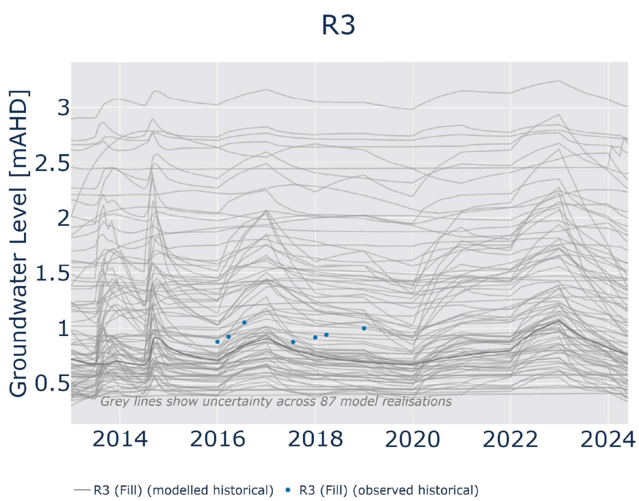

PW01
Groundwater Level [mAHD]
0.5
1
1.5
2
2.5
3
2014
2016
2018
2020
2022
2024
Grey lines show uncertainty across 87 model realisations
PW01 (Fill) (modelled historical)
PW01 (Fill) (observed historical)

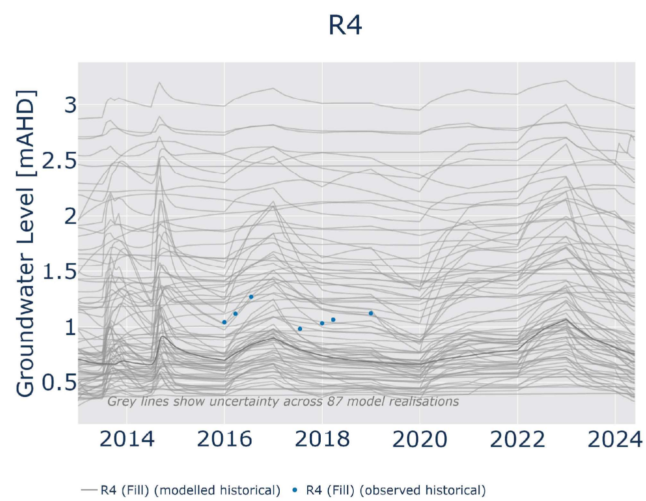

PW02
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
PW02 (Fill) (modelled historical)
PW02 (Fill) (observed historical)

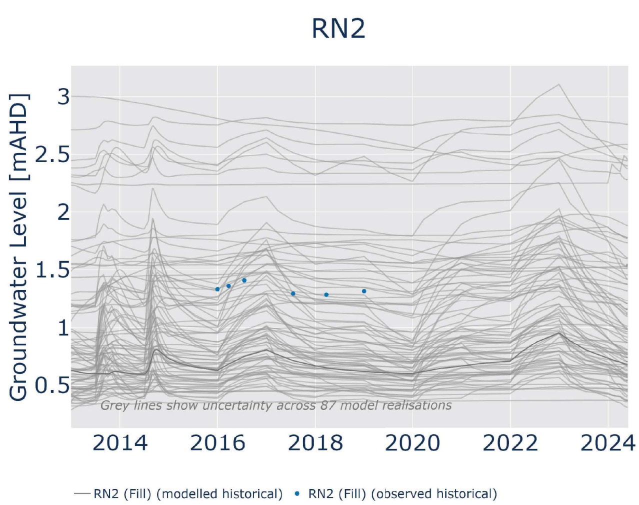

PW03
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
PW03 (Fill/Bedrock) (modelled historical)
PW03 (Fill/Bedrock) (observed historical)

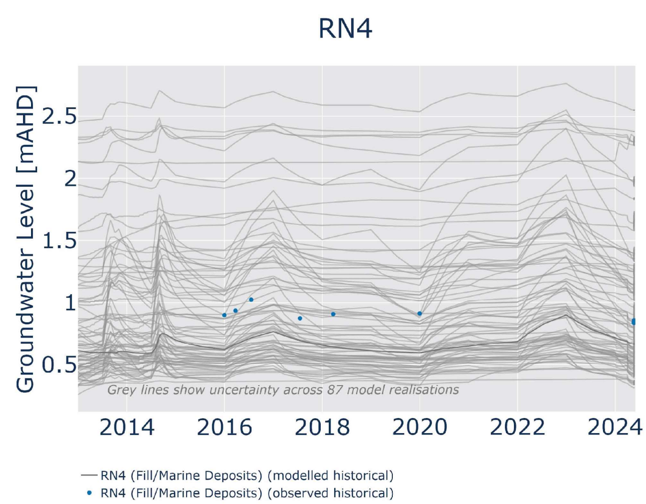

R1
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
R1 (Fill) (modelled historical)
R1 (Fill) (observed historical)

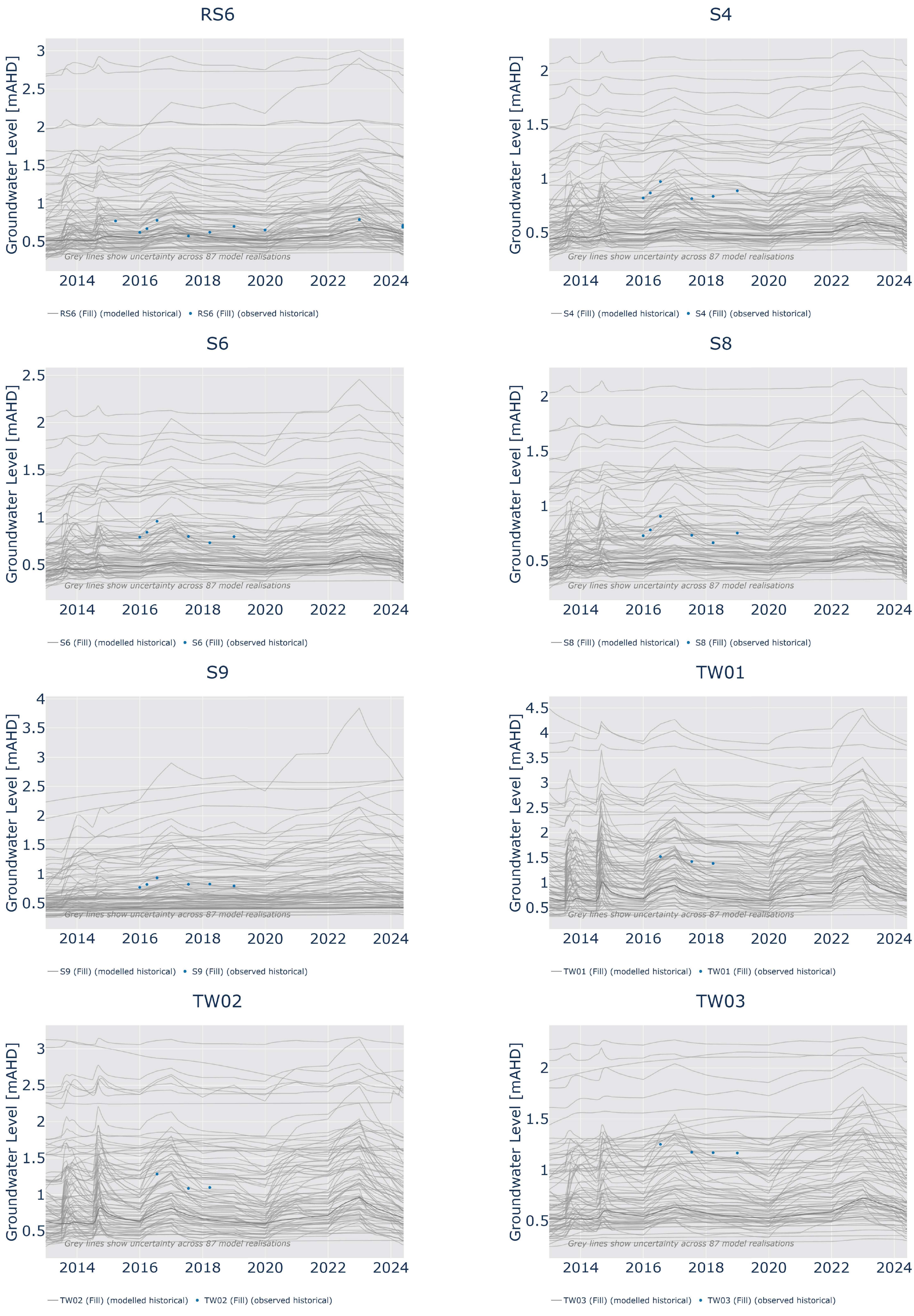

R2
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
R2 (Fill) (modelled historical)
R2 (Fill) (observed historical)


R3
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
R3 (Fill) (modelled historical)
R3 (Fill) (observed historical)


R4
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
R4 (Fill) (modelled historical)
R4 (Fill) (observed historical)


RN2
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
RN2 (Fill) (modelled historical)
RN2 (Fill) (observed historical)


RN4
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
RN4 (Fill/Marine Deposits) (modelled historical)
RN4 (Fill/Marine Deposits) (observed historical)


RS6
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
RS6 (Fill) (modelled historical)
RS6 (Fill) (observed historical)
S4
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
S4 (Fill) (modelled historical)
S4 (Fill) (observed historical)
S6
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
S6 (Fill) (modelled historical)
S6 (Fill) (observed historical)
S8
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
S8 (Fill) (modelled historical)
S8 (Fill) (observed historical)
S9
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
S9 (Fill) (modelled historical)
S9 (Fill) (observed historical)
TW01
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
TW01 (Fill) (modelled historical)
TW01 (Fill) (observed historical)
TW02
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
TW02 (Fill) (modelled historical)
TW02 (Fill) (observed historical)
TW03
Groundwater Level [mAHD]
Grey lines show uncertainty across 87 model realisations
TW03 (Fill) (modelled historical)
TW03 (Fill) (observed historical)