REPORT

UPPER SELWYN HUTS CLIMATE IMPACT ASSESSMENT
Te Waihora levels and groundwater flooding

PREPARED FOR

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1 INTRODUCTION AND BACKGROUND

Situated in a low-lying area, the Upper Selwyn Huts (USH) are vulnerable to flooding from high Te Waihora / Lake Ellesmere levels and floods in the Selwyn River. This vulnerability may increase under future climates This is one factor that Selwyn District Council (SDC) is considering in relation to the future of the USH.

This report has considered the impact of extreme lake levels coupled with projected sea level rise, and the response of the shallow groundwater system to future climate, including lake level and sea level rise. While Selwyn River flooding may contribute to high lake levels, this report has not specifically considered river flooding.

Shallow groundwater is a challenge for the lower Canterbury Plains (e.g. extensive land drainage networks are required to maintain the land in a suitable condition for agricultural production), and groundwater flooding is increasingly being recognised as a hazard for the built environment. Groundwater flooding occurs when the shallow water table rises to the ground surface. It can be longer-lasting than surface flooding as groundwater may not be able to drain away until the water table drops below the surface again. High groundwater levels can also exacerbate surface-water flooding and can lead to other issues such as deterioration of road subgrades, damage to building foundations, chronic health complaints due to rising damp and damage to plants.

The lower Canterbury Plains shallow groundwater system is known to be closely connected to water levels in Te Waihora / Lake Ellesmere: for example, contractors working on infrastructure in the Upper Selwyn Huts have reported that the water level in trenches rises significantly and rapidly when the lake level is higher. The lake level, in turn, is connected to sea level, and a level differential is required to drive flow through Kaitorete Spit and the lake outlet when the lake is open to the sea.

Aqualinc Research Limited (Aqualinc) has previously produced district-scale assessments of the impacts of climate cycles and trends on SDC's infrastructure, most recently in 2023 (Dudley Ward *et al.*, 2023)[1]. While the previous assessments have addressed issues that are relevant to USH, the level of detail is limited by the district-scale approach. Therefore, SDC has engaged Aqualinc to prepare a more detailed assessment of potential effects of future climate change specifically for the USH area. This report summarises the investigations completed and key outputs to inform decision making.

1.1 Structure of this report

Section 2 of this report addresses flooding vulnerability posed by high Te Waihora / Lake Ellesmere level events (similar to the 2013 level), combined with projected future sea level rise.

Section 3 overviews numerical groundwater modelling to predict future changes to shallow groundwater levels and groundwater flooding.

[1] Dudley Ward, N; Kashima, A; Hector, R; Hatley, G: *Impact of Climate Cycles and Trends on Council Assets - 2023 Update*. Selwyn District Council, Aqualinc Report WL23041-1. Aqualinc Research Ltd.

2 TE WAIHORA LAKE LEVEL MAPPING UNDER EXTREME FLOOD AND SEA LEVEL RISE

Inundation maps were created to assess the vulnerability of the USH to surface flooding due to extreme Te Waihora / Lake Ellesmere levels combined with sea level rise (SLR). The inundation levels are based on Te Waihora levels of 1.8 m (the extreme high lake level recorded in July 2013), combined with SLR projections from the NZ SeaRise[2] research programme, which account for vertical land movement (VLM). It has been assumed that lake levels will rise in proportion to SLR due to the level differential needed to maintain flow at the lake outlet when the lake is open to the sea – i.e. if a combination of climate and sea conditions similar to those in June / July 2013 occurred in the future with higher sea levels, the maximum lake level would be higher.

This report section only considers flooding from surface water (lake and sea) and excludes groundwater flooding, which is analysed in Section 3. River flooding is not considered in this report.

The current inundation maps update the mapping reported in 2023 by Aqualinc (Dudley Ward *et al.*, 2023), which were based on earlier SLR projections. For instance, the upper bound (83rd percentile) of the likely range is projected to increase by 0.46 m by 2050 relative to the historic period, which is double the SLR applied in the previous mapping. The current maps use a recent digital elevation model (DEM) for Selwyn, based on LiDAR data from LINZ[3].

2.1 Methodology

The inundation mapping was conducted in ArcGIS Pro[4]. First, the extent of inundation from the July 2013 high lake level event was delineated. The DEM was converted from New Zealand Vertical Datum 2016 to the Lyttleton 1937 datum using the conversion grid tool[5], as the 2013 flood level (1.8 m) is relative to the Lyttleton 1937 datum. The DEM was then reclassified based on this flood level.

The SLR projections were added on top of the 2013 flood level. To conduct this, sea levels in 2013 were linearly interpolated from the 2005 and 2020 values provided by NZ SeaRise. The difference between SLR projections and the interpolated 2013 sea level was added to the 2013 flood level for each scenario, year, and percentile. The DEM was reclassified accordingly. Flood depth maps were created by subtracting topography from inundation levels using the raster calculator. All output rasters were clipped to exclude cells within Te Waihora.

The SLR projections were based on two emissions pathways: SSP2-4.5 (moderate emissions) and SSP5-8.5 (very high emissions) for 2050 and 2100 with medium confidence (moderate polar ice sheet melt). Confidence intervals of 17th, 50th, and 83rd percentiles were provided; this range of percentiles is considered to be the *likely range*, with 33% of the projections falling outside of this range. These projections are based on the lake outlet site (number 4513 on NZ SeaRise, shown in Table 1), which has a VLM rate of -0.8 ± 2.6 mm/year.

Table 1. Sea level rise projections from NZ SeaRise at Te Waihora outlet (site 4513) relative to 2005

Scenario	Year	Percentile		
		17th	50th	83rd
SSP2-4.5 + VLM (medium confidence)	2050	0.10 m	0.26 m	0.42 m
	2100	0.32 m	0.64 m	0.98 m
SSP5-8.5 + VLM (medium confidence)	2050	0.14 m	0.29 m	0.46 m
	2100	0.55 m	0.90 m	1.30 m

2 NZ SeaRise (2024): *Maps*. Retrieved from https://www.searise.nz/maps-2
3 Land Information New Zealand (2024): *Canterbury - Selwyn LiDAR 1m DEM (2023)*. Retrieved from https://data.linz.govt.nz/layer/115805-canterbury-selwyn-lidar-1m-dem-2023/
4 ESRI (2024): *ArcGIS Pro (Version 3.3.0)*. Redlands, CA: Environmental Systems Research Institute.
5 Land Information New Zealand (2022): *Lyttelton 1937 to NZVD2016 Conversion*. Retrieved from https://data.linz.govt.nz/layer/53432-lyttelton-1937-to-nzvd2016-conversion/

2.2 Results

The maps shown in Figure 1 and Figure 2 highlight areas vulnerable to flooding during an extreme flood event under SLR conditions. These maps show the 2013 flood extent combined with projected SLR in 2050 and 2100 under SSP2-4.5 (Figure 1) and SSP5-8.5 (Figure 2). The likely SLR range is defined by the 17th percentile (lower bound) and the 83rd percentile (upper bound), with the 50th percentile representing the median of the range.

In the USH area, flooding progresses east to west, starting from the wastewater application area and eventually reaching the housing area. Under both scenarios (50th percentile), by 2050, minor flooding begins in the wastewater application area. By 2100, the projected flooding extent has covered most of USH. Under SSP2-4.5 (50th percentile), the flooded area increased from approximately 4% of USH in 2050 (mean depth: 0.06 m) to 61% of USH in 2100 (mean depth: 0.22 m) (Table 2). Under SSP5-8.5 (50th percentile), the flooded area increased from approximately 7% in 2050 (mean depth: 0.05 m) to 79% of USH in 2100 (mean depth: 0.41 m).

Table 2. Percentage of Upper Selwyn Huts area that is projected to be flooded under various SLR scenarios

Scenario	Year	Percentile		
		17th	50th	83rd
SSP2-4.5 + VLM (medium confidence)	2050	0.5%	3.5%	27.1%
	2100	20.4%	61.3%	82.7%
SSP5-8.5 + VLM (medium confidence)	2050	0.8%	7.1%	35.1%
	2100	56.2%	79.2%	99.3%

The projected flood depths in 2050 under both scenarios are shown in Figure 3.

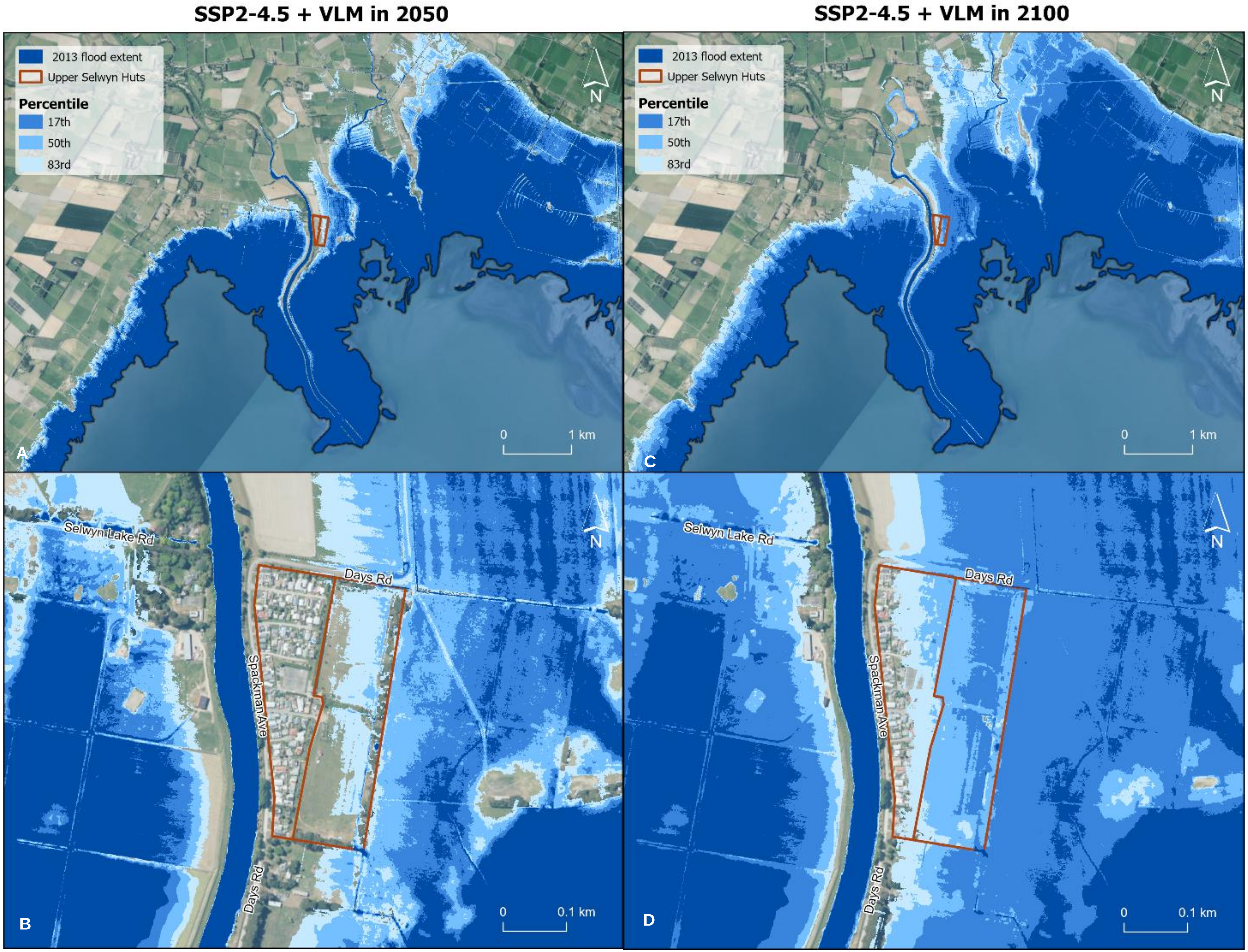

Figure 1. Extent of the 2013 flood and projected SLR under SSP2-4.5 in 2050 (A and B) and 2100 (C and D)

SSP5-8.5 + VLM in 2050 / SSP5-8.5 + VLM in 2100

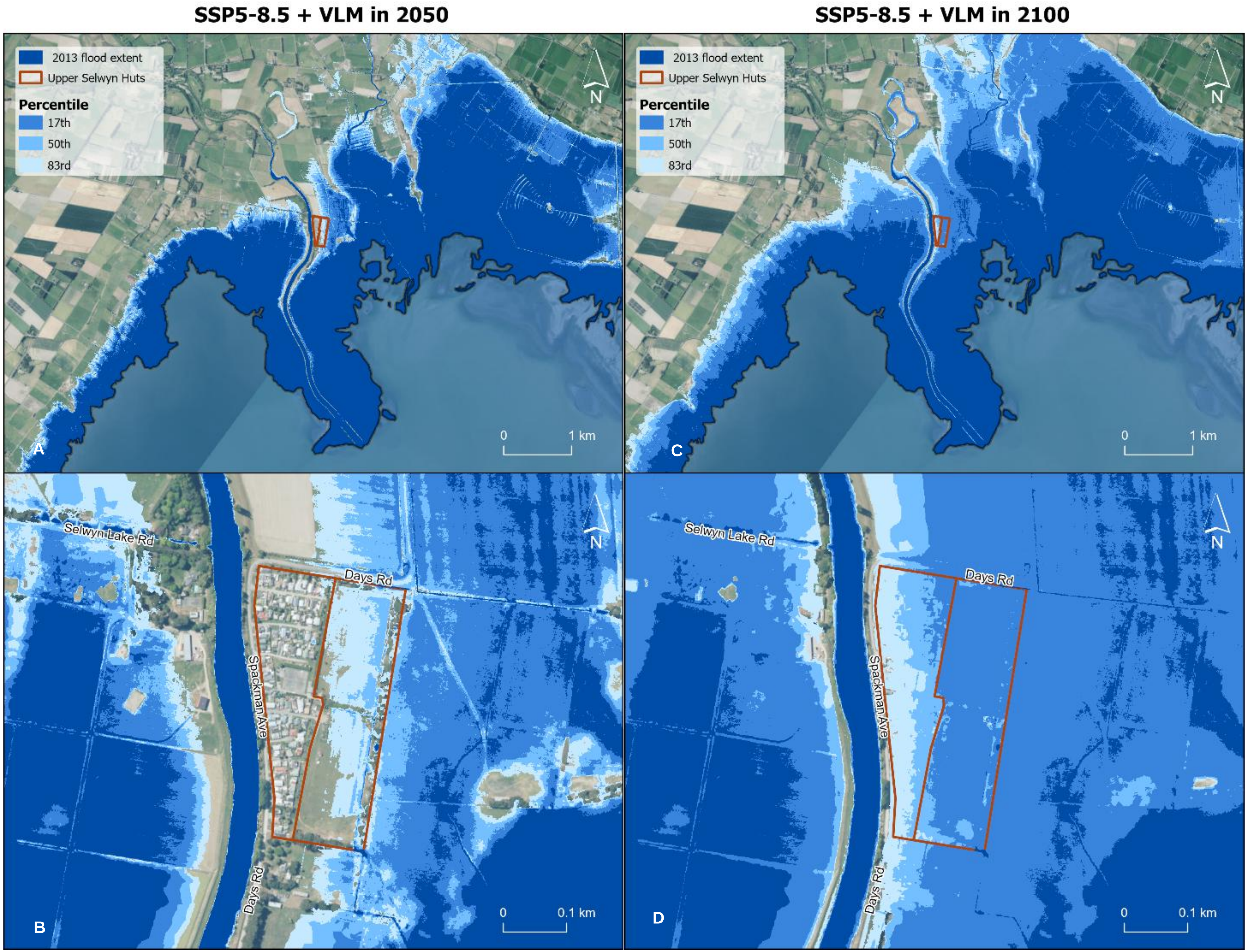

Figure 2. Extent of the 2013 flood and projected SLR under SSP5-8.5 in 2050 (A and B) and 2100 (C and D).

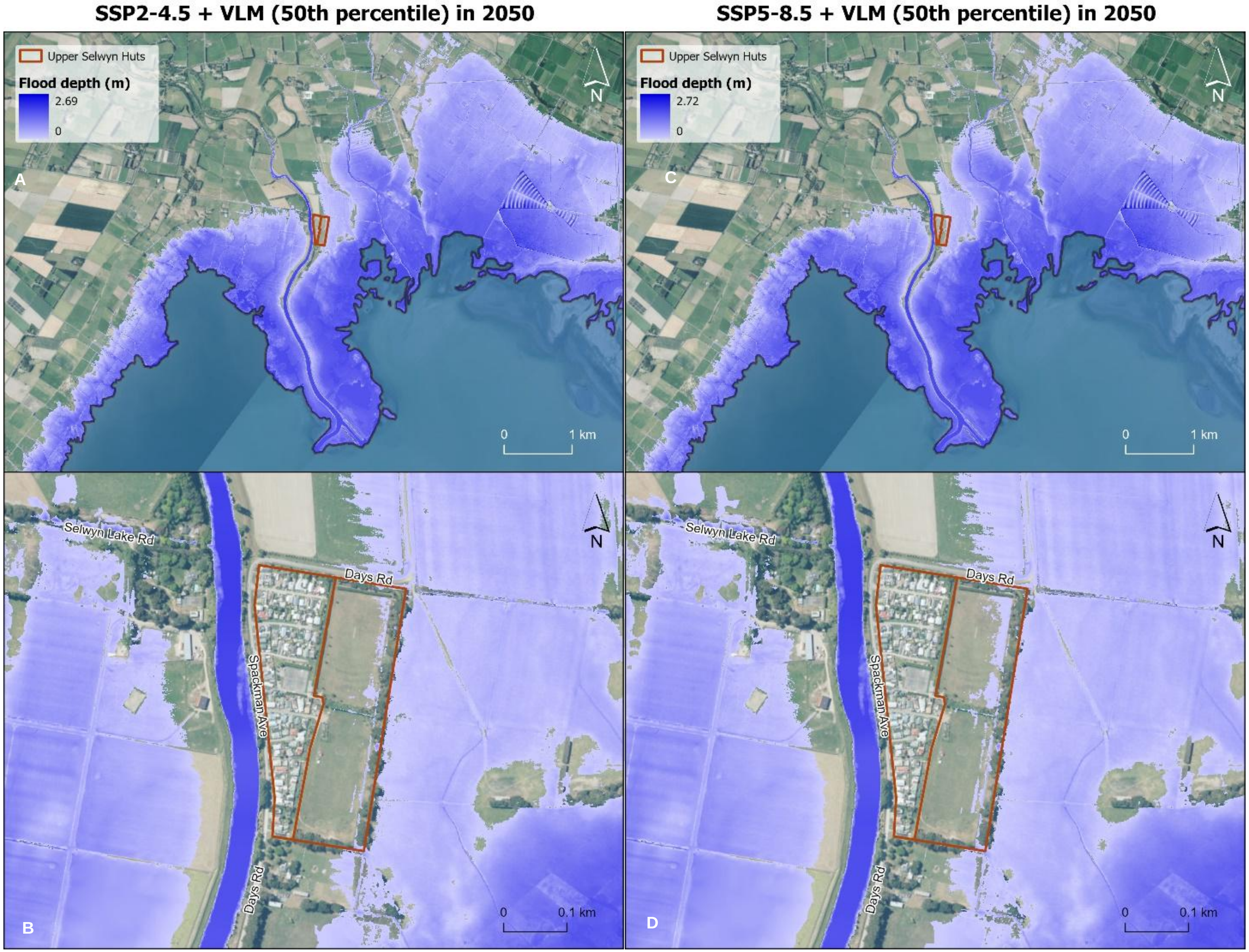

Figure 3. Projected flood depths in 2050 based on 50th percentile values under SSP2-4.5 (A and B) and SSP5-8.5 (C and D)

3 GROUNDWATER MODELLING

National and regional-scale climate projections do not address groundwater directly or in detail. Assessing climate impacts on groundwater systems requires modelling that accounts for projected changes to the drivers of the groundwater system (e.g. rainfall, abstraction and sea levels) under future climates. Impacts can vary spatially. For the USH area, shallow groundwater is highly relevant: the low elevation and connectivity to the lake increases vulnerability to shallow groundwater hazards, including climate change and sea level rise.

Aqualinc has an existing three-dimensional numerical model (referred to as the Canterbury groundwater model, documented in Weir, 2018)[6] of the groundwater system and connected surface-water features in the Selwyn District. This model has been developed over the past 20+ years and, as part of this project, has been locally refined for investigating hydraulic responses in the Upper Selwyn Huts area (particularly how this area is influenced by Te Waihora / Lake Ellesmere levels). Earlier versions of the model have been used to investigate shallow groundwater level scenarios combined with sea level rise in and around Christchurch City. Various model inputs previously developed (Dudley Ward *et al.*, 2023) already incorporate projected future climate inputs for land surface recharge and abstraction, and these scenarios have been applied more specifically to the USH area as part of this study.

3.1 Overview of Model

The Canterbury groundwater model (Weir, 2018) encompasses the aquifer system between the Waimakariri and Rakaia rivers and simulates groundwater levels and stream flows over a 60 year period from 1 June 1960 through to 1 May 2020. The base of the Southern Alps foothills forms the western (inland) boundary of the model, and the eastern boundary extends approximately 10 km offshore to represent the marine discharge of the aquifer system.

Since 2018, the model has been progressively updated to better represent local-scale hydraulic responses and to include newer versions of the software packages used. The latest version of the model has been built using MODLFOW-USG (Sorab, *et al*., 2013)[7], which is a three-dimensional, block-centred, finite difference, unstructured grid, groundwater flow model. Model development has been undertaken with the assistance of the graphical user interface GMS (2024)[8].

The model has been discretised into square cells of variable sizes ranging from approximately 800 m on the plains through to 100 m closer to the smaller rivers and streams. In the vicinity of the USH, the grid sizes are 200 m along the Selwyn River and edges of Lake Ellesmere, expanding out to 800 m over a distance of 2 km from the Huts. This is shown in Figure 4. Included in this figure are the locations of local calibration bores, which are discussed later.

Land surface elevations were derived from a combination of LiDAR surveys, photogrammetry and topographic map contours (in order of preference). Various sources of geological information have been collated to describe the overall geological composition of the aquifer system, with the main data sources being surfaces of the interfaces between the Christchurch formations supplied by GNS Science (Begg *et al.*, 2015)[9], and geological data logged during bore installation (supplied by Environment Canterbury). The base of the alluvial gravels has been defined by University of Canterbury using geophysical techniques (Lee *et al.*, 2016)[10], although the focus of the USH study area is the uppermost (shallow) layer. Aquifer test results have also been used to inform hydraulic parameters (along with model calibration).

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[6] Weir (2018): *Canterbury Groundwater Model 3. Model Documentation.* Prepared for MBIE Wheel of Water Research. August 2018. Project number C15066-11.

[7] Panday, S; Langevin, C; Niswonger, R; Ibaraki, M; Hughes, J (2013): *MODFLOW–USG: An unstructured grid version of MODFLOW for simulating groundwater flow and tightly coupled processes using a control volume finite-difference formulation.* US Geological Survey Techniques and Methods, Book 6, Chapter A45.

[8] GMS (2024): *Groundwater Modelling System (version 10.8.7)*. Software developed and supported by Aquaveo LLC (USA). Final build date 9 September 2024. Copyright 2024.

[9] Begg, JG.; Jones, KE and Barrell, DJA (2015): *Geology and geomorphology of urban Christchurch and eastern Canterbury.* GNS Science geological map 3. Lower Hutt, New Zealand. GNS Science.

[10] Lee, RL; Bradley, BA; Ghisetti, FG; Thomson, EM (2016): *Development of a 3D High-Resolution Velocity Model of the Canterbury, New Zealand Region.* Bulletin of the Seismological Society of America (submitted).

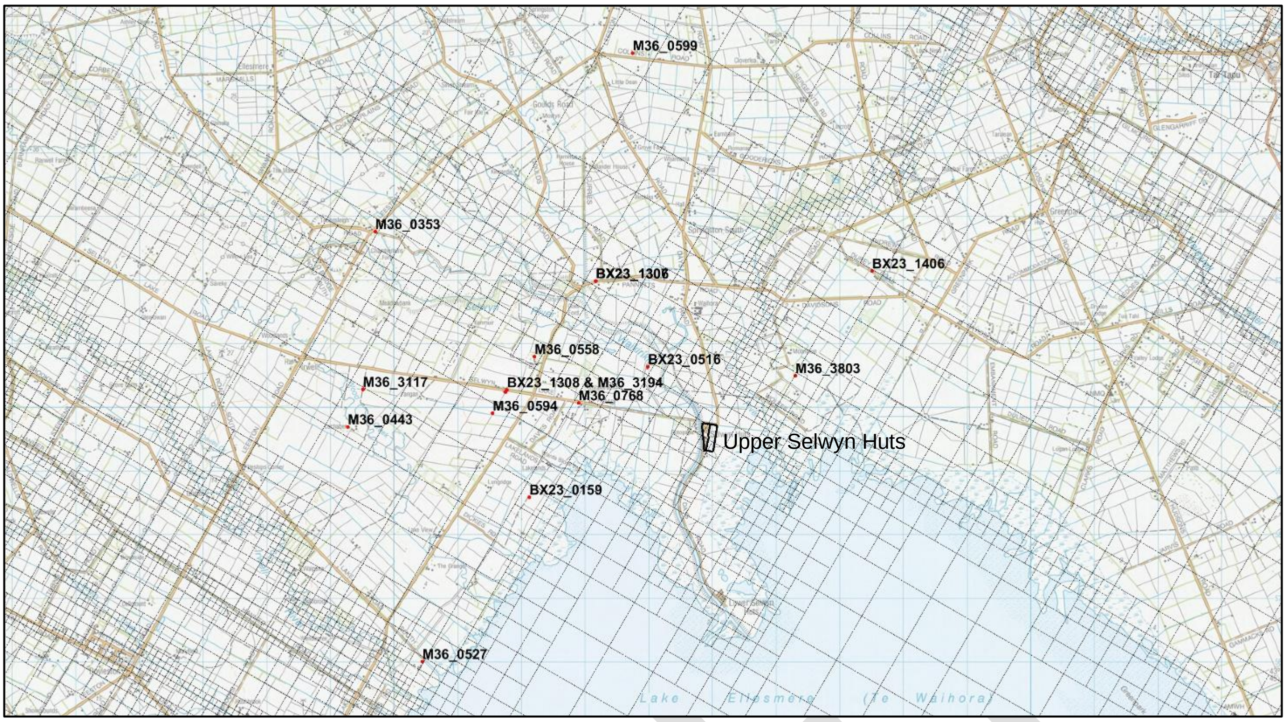


Figure 4: Numerical model grid in the Upper Selwyn Huts area

The model was constructed and calibrated in both steady state (with long-term average inputs and outputs) and transient (time-varying inputs and outputs) conditions. Weir (2018) provides more detail on the construction and calibration of the model. The model used for this study has been further calibrated in the area of the USH with the inclusion of additional local shallow monitoring bores (less than 30 m depth, with most less than 18 m depth). These are shown in Figure 4.

Groundwater level hydrographs demonstrating the comparison between measured and modelled groundwater levels for these shallow bores are provided in Appendix A. Of these bores, the closest to the USH (and therefore most representative of the modelled responses there) are bores BX23/0516, M36/0768 and M36/3803. Although two of these bores have only sparse recorded data, the model matches well to measured groundwater levels. Bore M36/0768, located 2 km to the west of the Huts, has a measured record length of 27 years that overlaps with the model simulation period, and the modelled levels and dynamic response in this bore match well with measured. For convenience, this hydrograph is reproduced in Figure 5. There are a number of periods where the modelled groundwater levels reach ground level, indicating that groundwater flooding / waterlogging would have occurred.

Figure 6 compares measured and modelled river flows in the Selwyn River at Coes Ford, this being the closest river flow monitoring site to the USH. Calibration to river flows has historically been focussed on low-flow periods. However, the dynamic responses also match well for many of the higher-flow events.

The model has been used to run different scenarios (discussed in Section 3.2) of future climate change and predict the changes in groundwater levels (and river flows) relative to the calibration (status quo) scenario. This approach acknowledges that modelled changes in levels (in particular) are likely to be more accurate than the absolute levels. These changes can then be compared to measured levels to provide a robust prediction of future levels. Give this model use, overall calibration is suitable.

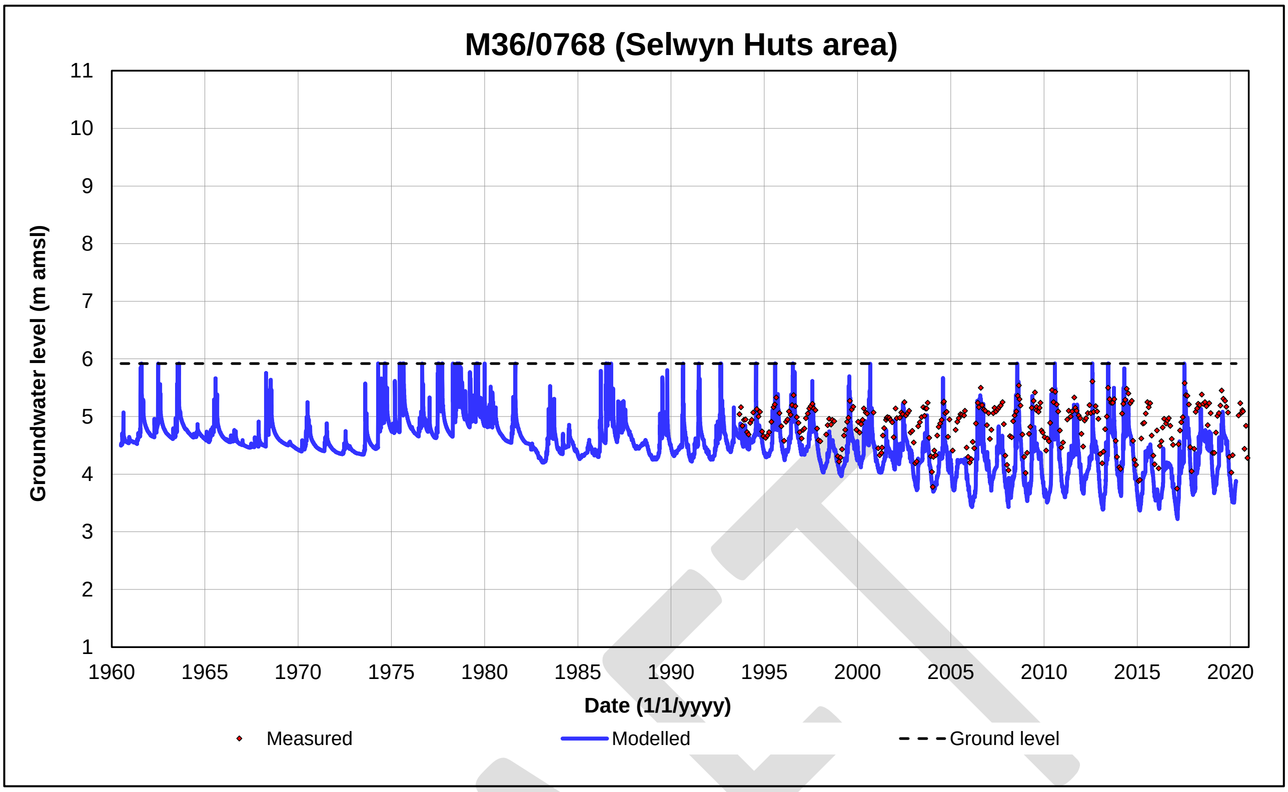


Figure 5: Measured and modelled groundwater level for nearby bore M36/0768

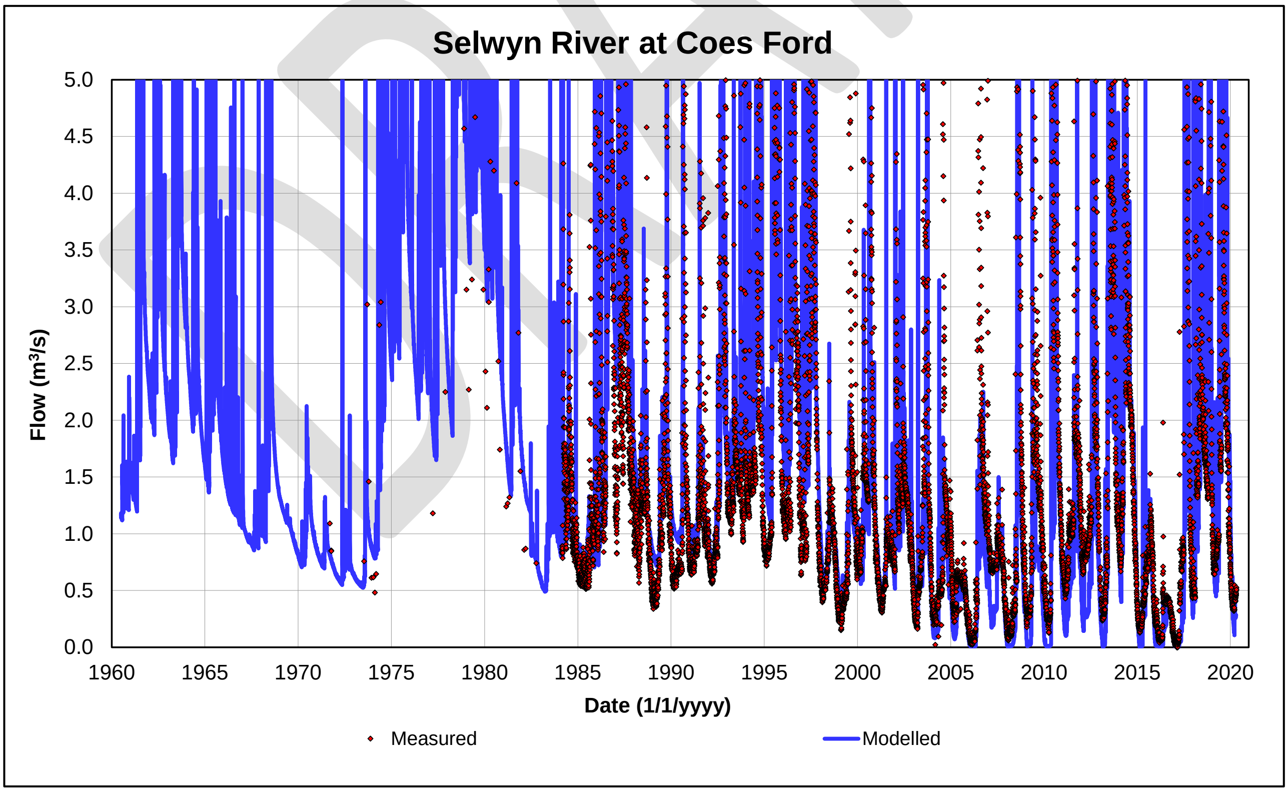


Figure 6: Measured and modelled river flows at Coes Ford

3.2 Scenarios

Model scenarios have been developed to investigate the groundwater system's response to changes in mean lake level under a sea level rise scenario, incorporating the latest sea level rise projections that include vertical land movement (as discussed in Section 2). Scenarios have been developed that simulate climate change projections (as supplied by NIWA) out to 2100, with and without sea level changes. The SLR projections are discussed in Section 2, and the values listed in Table 1 (relative to 2005) have been applied to the model scenario that includes sea level rise.

Table 1: Sea level rise change applied to the model scenario

Year	Sea and lake level change (m)
2005	0
2020	0.08
2030	0.14
2040	0.21
2050	0.29
2060	0.39
2070	0.50
2080	0.62
2090	0.76
2100	0.90

It was not practical within the current project to run the same range of SLR scenarios that were considered for the lake level rise mapping. The values listed in Table 1 are median SLR values under the RCP8.5 projection, and these represent the most likely change expected.

It has been assumed that both the sea and Te Waihora / Lake Ellesmere levels change linearly between the periods specified in Table 1.

Running the two scenarios (with and without sea level rise) enables the isolation of effects of sea level rise from other climatic drivers of the groundwater system.

Due to project constraints, it has been assumed that the stream beds do not aggrade under future higher sea and lake levels. Stream aggradation may occur if channel maintenance is abandoned. Consequentially, it is possible that changes in shallow groundwater levels could be larger than what have been predicted by the model.

3.3 Key Results

The modelled changes in groundwater levels, both temporally (at monitoring bores) and spatially have been assessed and are presented below.

3.3.1 Temporal Groundwater Levels

Hydrographs of modelled groundwater levels for the nearest monitoring bore to the USH (M36/0768) are shown in Figure 7. In this figure, three time periods are presented:

- 1986-2006, which represents NIWA's prediction of historical response (noting that this is different to the 'Calibration' scenario, as for consistency with the modelled future climate it uses inputs based on modelled historic climate rather than measurements).

- 2040-2060, representing a mid-century prediction of response (“2040s”).
- 2080-2100, representing an end-of-century response (“2080s”).

All hydrographs include scenario time series of both ‘with’ and ‘without’ sea level rise.

At bore M36/0768, groundwater levels are expected to lower slightly towards the end of the century compared to historic. However, this reduction is dominated by the rise in sea level, which is predicted to raise groundwater levels at this location by up to 0.5 m. Although the absolute value of groundwater levels modelled under NIWA’s predicted climate (Figure 7) are lower than calibration (Figure 5), the ~0.5 m change between scenarios of ‘with’ and ‘without’ sea level rise indicates that groundwater levels are likely to reach the ground surface much more frequently (multiple times per year) under future climate and sea levels (at this location).

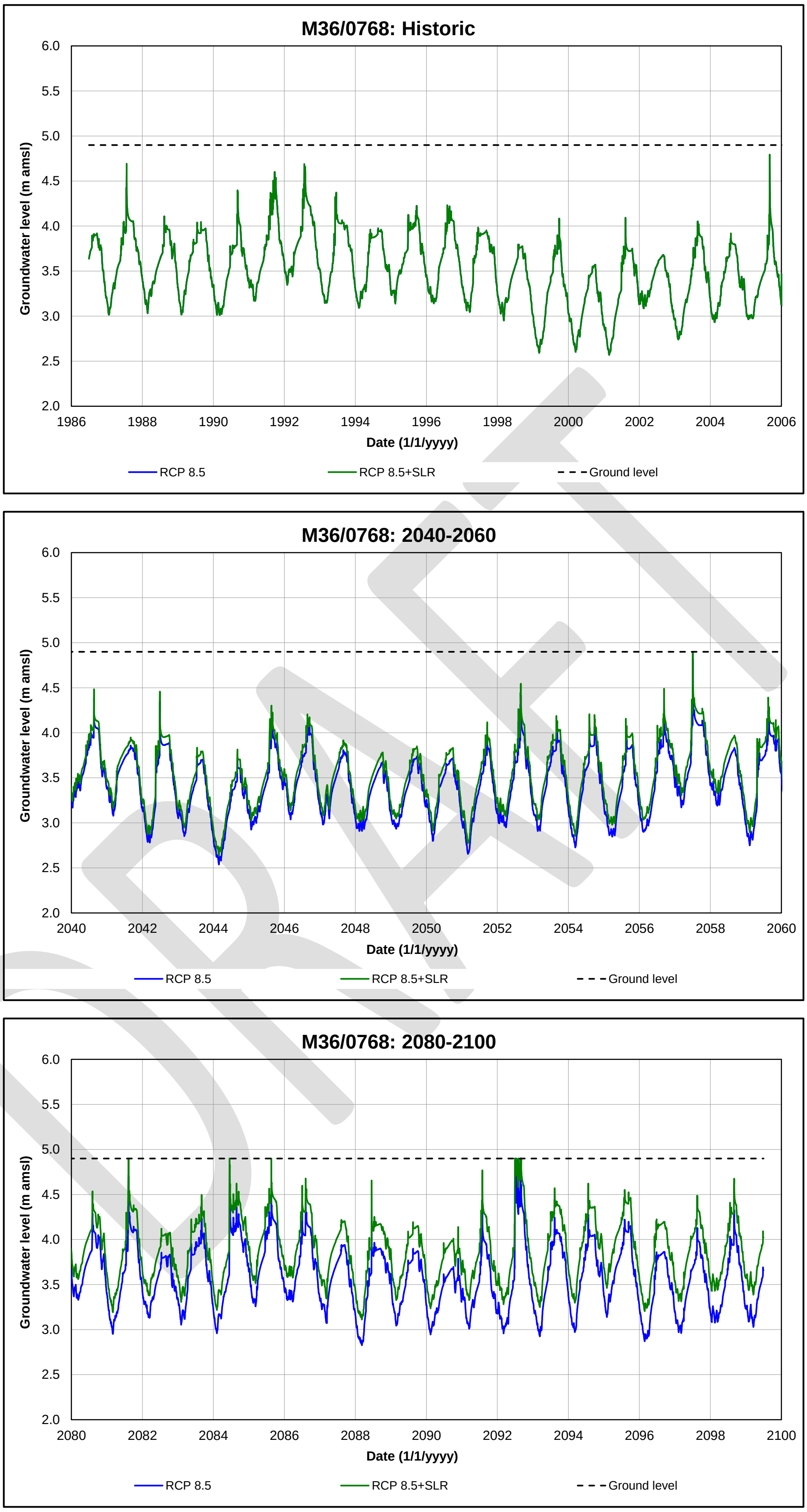


Figure 7: Hydrographs of modelled groundwater levels in M36/0768 over different climate forecast periods

3.3.2 Spatial Groundwater Levels

Figure 8 shows areas where, on average, shallow groundwater is currently near the land surface (0.3 m deep or less). Groundwater levels along the Selwyn River (including the USH) are deeper than 0.3 m due to the stop bank (and other land development) works. At the USH directly, shallow groundwater levels are predicted to be in the order of 1.2 m deep below the land surface, although this is approximate due to the 200 m scale of the model cells in this area. Note that these are average levels, and at times the depth to groundwater may be significantly shallower (see Figure 5).

From Figure 8, surface flooding from shallow groundwater in the area surrounding the USH is predicted to occur at times, including significant lengths of access roads leading into and out of the USH settlement (e.g. Days Road and Selwyn Lake Road).

Figure 9 shows maps of changes in groundwater levels (in the vicinity of the Huts), comparing average historic levels with averages from both the 2040s and 2080s that include sea level rise. Similar maps are not provided comparing the scenarios without sea level rise as the changes are small. Therefore, changes only due to sea (and lake) level rise are provided.

From Figure 9, groundwater levels in the vicinity of the Huts are predicted to rise by less than 0.1 m by the 2040s, and by approximately 0.2 m by the 2080s. As can be seen in these maps, the Selwyn River dominates the response of groundwater levels in this area, and the scenarios assume no change to river bed invert levels (i.e. no aggradation, as mentioned earlier). If river bed inverts were allowed to aggrade (particularly the Selwyn River), then shallow groundwater level changes underlying the USH would be larger than indicated in Figure 9.

The narrow contours along the Selwyn River in the USH area indicates that shallow groundwater is highly connected to the lake, with additional hydraulic control by the Selwyn River. During periods of high Selwyn River flows, and if the river is left to aggrade, it will not mitigate the response in groundwater levels from lake level rises, and correspondingly shallow groundwater levels will be higher in the USH settlement area.

If sea and lake level changes occur at the rate predicted, complications from shallow groundwater level flooding (alone) is unlikely to become significantly more problematic by the 2040s, relative to the status quo. However, by the 2080s, the additional 0.2 m rise in average shallow groundwater levels may result in increased occurrences of flooding, particularly during periods of higher groundwater levels, and will increase the duration and frequency of groundwater levels reaching the ground surface. Should the river channel not be maintained, then adverse impacts are likely to occur earlier than the 2080s.

Figure 8: Areas where historical groundwater levels are typically 0.3 m below ground level or less (calibration scenario)

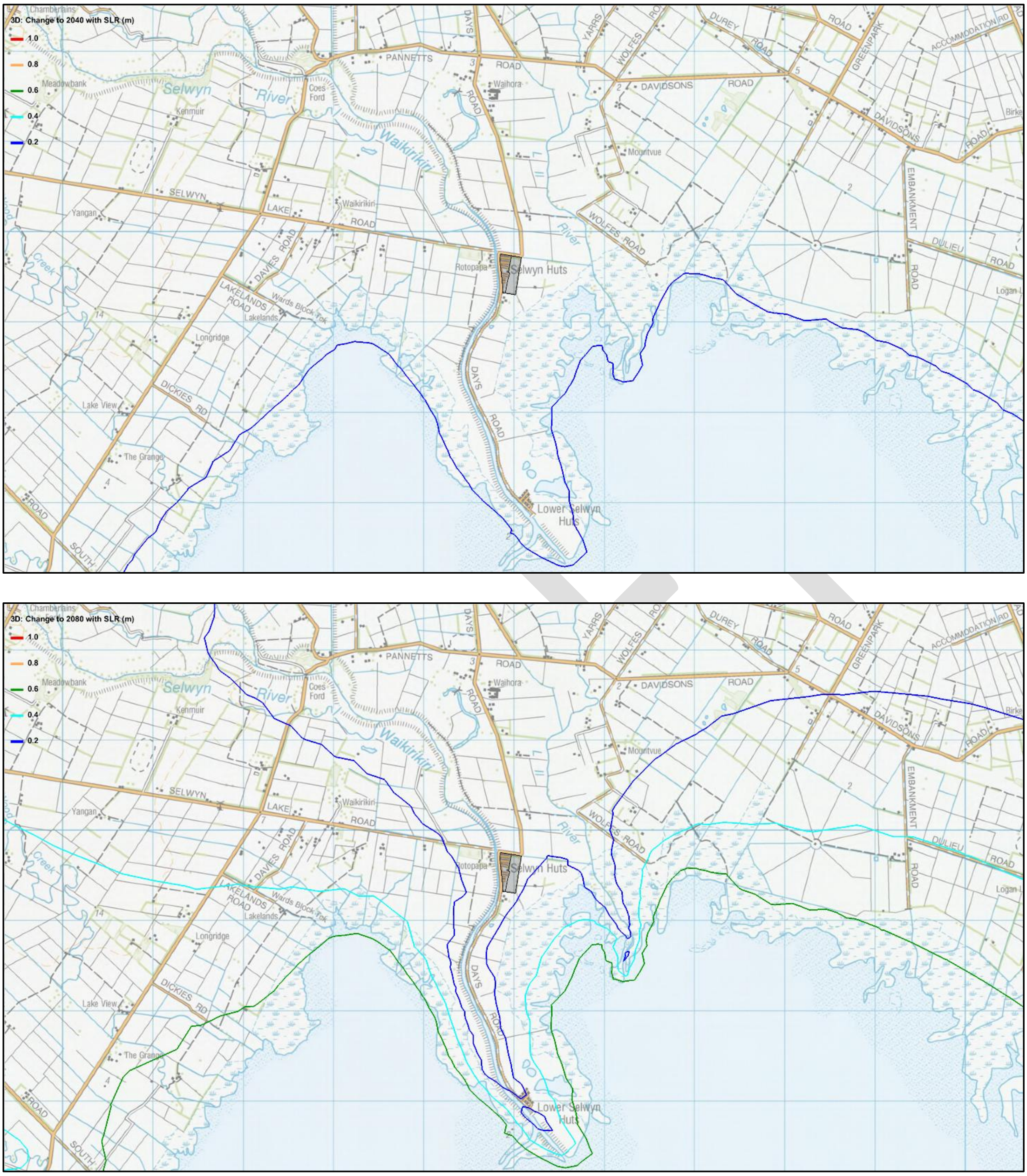


Figure 9: Shallow groundwater level change between scenarios with sea level rise

4 CONCLUSIONS

In this report we have considered the potential impacts on the USH area from:

- Inundation from high Te Waihora / Lake Ellesmere levels under future sea level rise scenarios; and
- The potential for high groundwater levels and groundwater flooding under future climate and sea level rise scenarios.

By mid-century, under both of the climate change scenarios considered, high lake levels are predicted to cause inundation of the area previously used for wastewater disposal to the east of the USH settlement. By the end of the century, the huts themselves would be vulnerable to inundation at high lake levels. It should be noted that the mapped inundation is based on the measured lake level from 2013. If a combination of weather and sea conditions occurred that resulted in higher lake inflows and a longer duration over which the lake was unable to be opened, then the inundation could be greater than predicted.

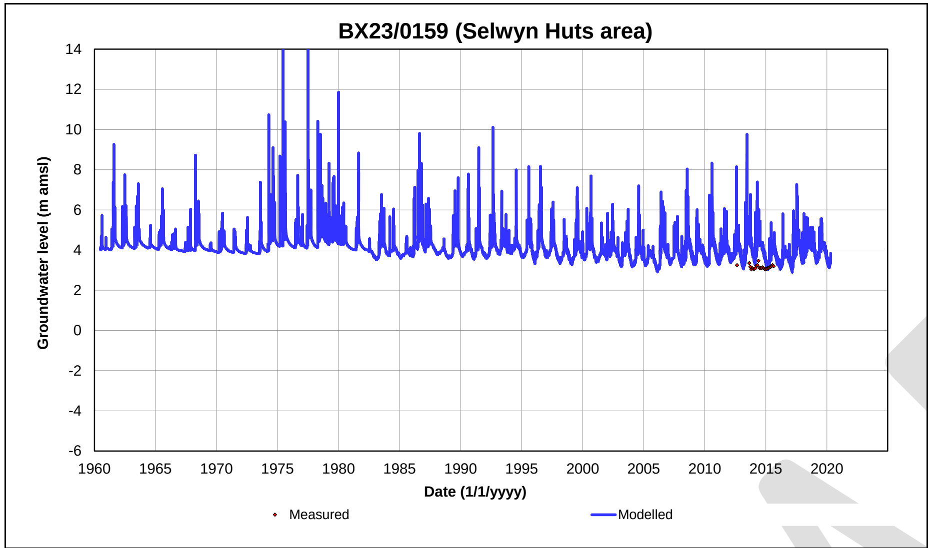
Modelling of the groundwater system around the USH area, using a locally-refined version of Aqualinc's district-scale groundwater model, has shown that, under projected future climate conditions in the absence of sea-level / lake level rise, groundwater levels are expected to drop slightly relative the historic levels. However, the strong connection between the lake and the shallow groundwater system means that under a scenario that includes projected sea (and lake) level rise, groundwater levels in the Selwyn Huts area are expected rise over the century, making the area more vulnerable to groundwater flooding, particularly by late-century. This will compound the projected risks from surface flooding, not just at the USH settlement but also to surrounding land, potentially making entry to, and egress from, the settlement more problematic.

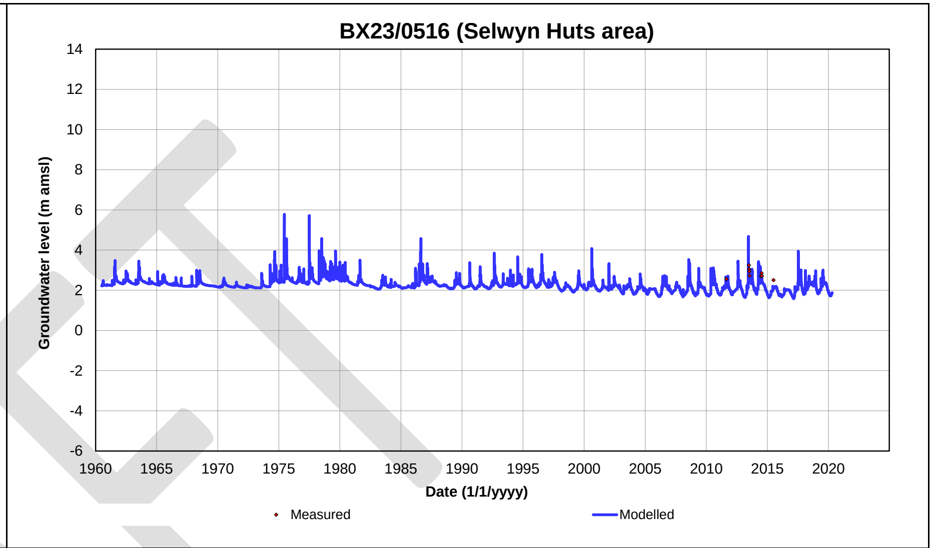
5 LIMITATIONS

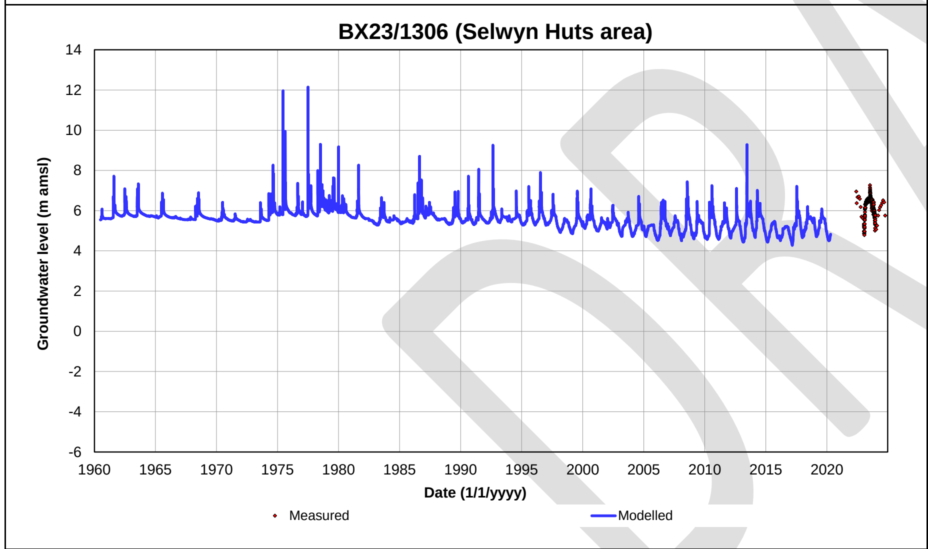
The purpose of this study is not to accurately define the shallow groundwater hazard at a local scale (there is insufficient data to do this), but rather to provide an indicative assessment at the scale surrounding the general USH area. Variability and precision of the available land surface levels and local-scale hydrogeological conditions influence the reliability of the presented findings. In addition, future climate projections are inherently uncertain. Consequently, the predictions should be treated as approximate and it is important to acknowledge the inherent uncertainties and associated limitations. The study findings do not reflect current or future Council policy, but are used to provide a guide to areas that are most likely to be affected by high lake levels and shallow groundwater to inform future decision making.

Selwyn District Council and Aqualinc Research Limited accept no responsibility or liability for any reliance placed on the general information or for any error, deficiency or omission in the information provided to users. Any person using this information does so at their own risk.

Appendix A: Shallow groundwater level calibration bores near the Upper Selwyn Huts


BX23/0159 (Selwyn Huts area)
Groundwater level (m amsl)
14
12
10
8
6
4
2
0
-2
-4
-6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date (1/1/yyyy)
Measured
Modelled


BX23/0516 (Selwyn Huts area)
Groundwater level (m amsl)
14
12
10
8
6
4
2
0
-2
-4
-6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date (1/1/yyyy)
Measured
Modelled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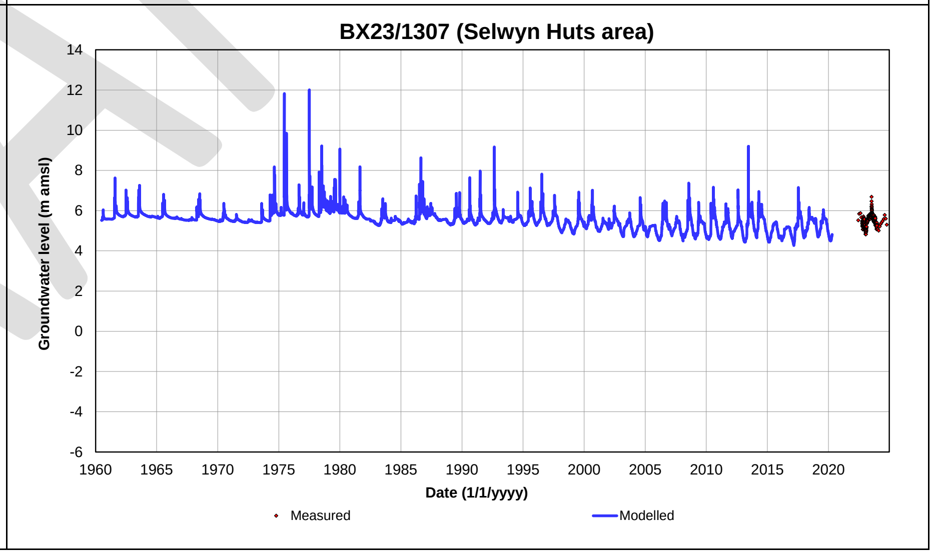
Groundwater level (m amsl)
14
12
10
8
6
4
2
0
-2
-4
-6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date (1/1/yyyy)
Measured
Modelled


BX23/1307 (Selwyn Huts area)
Groundwater level (m amsl)
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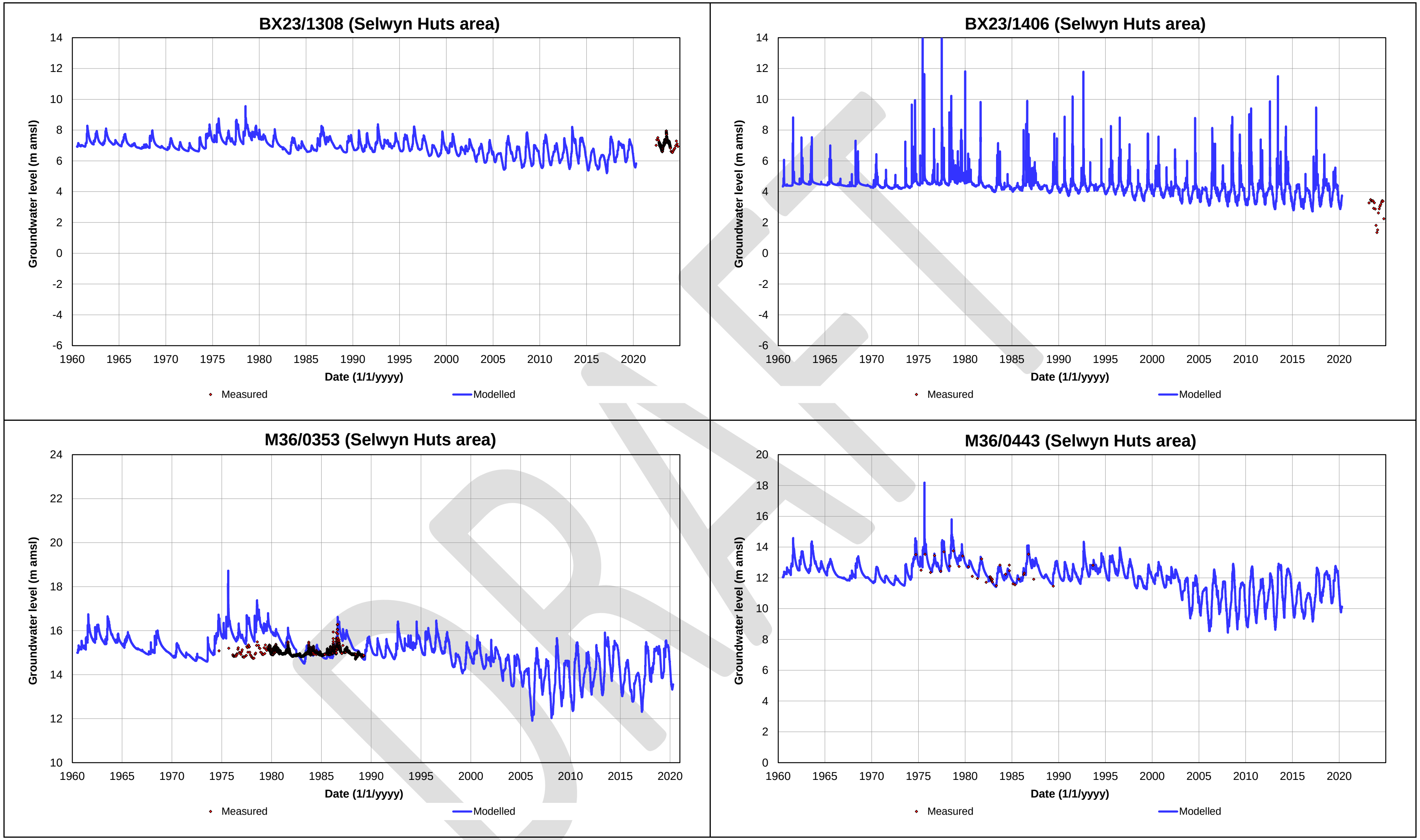
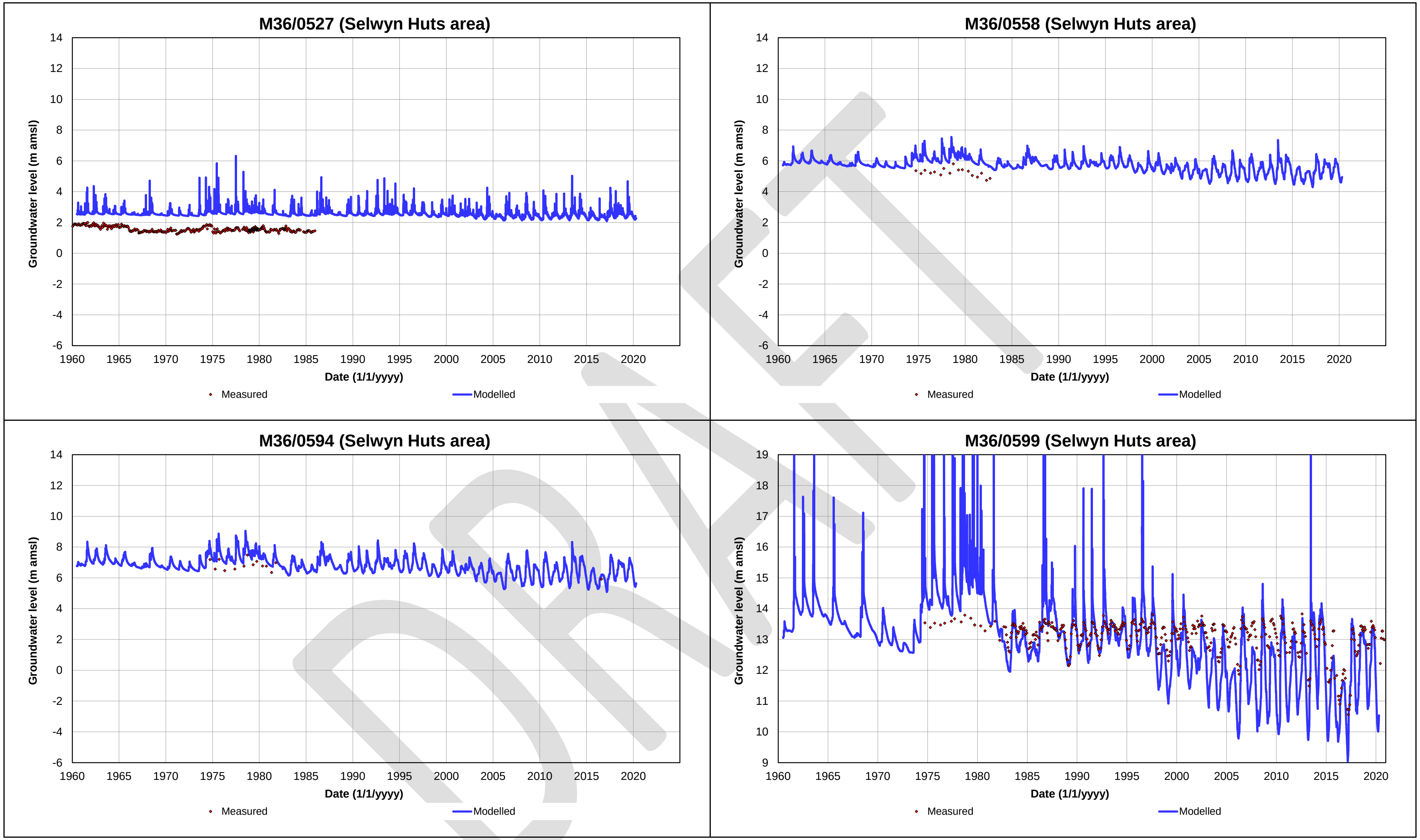
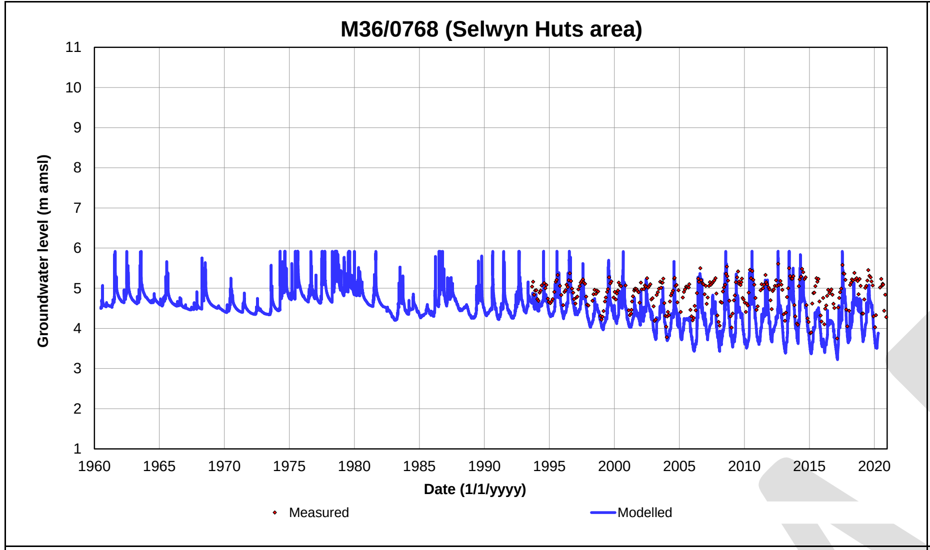
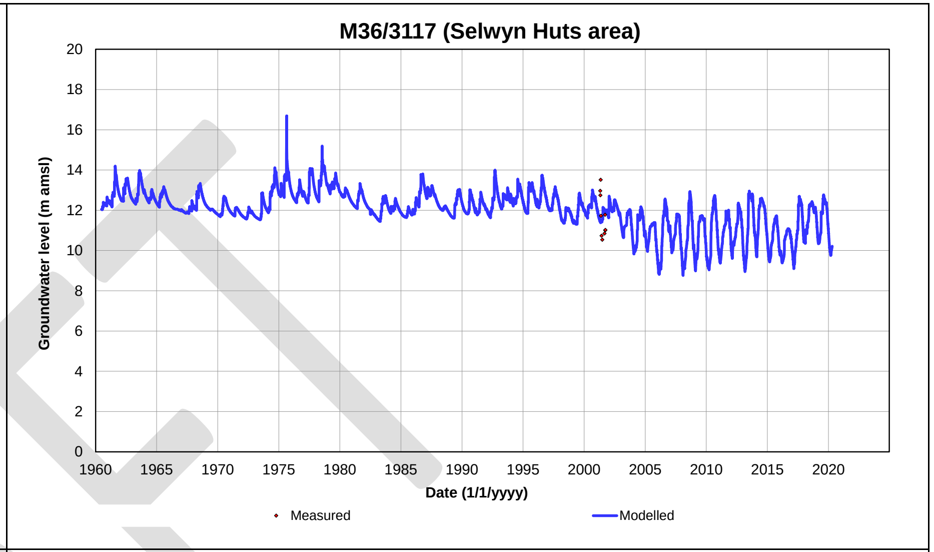
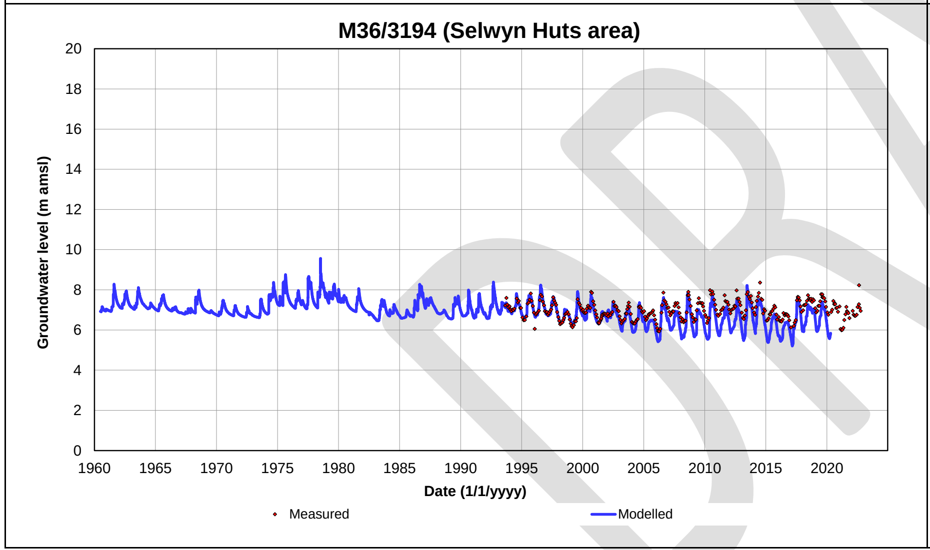
12
10
8
6
4
2
0
-2
-4
-6
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Date (1/1/yyyy)
Measured
Modelled

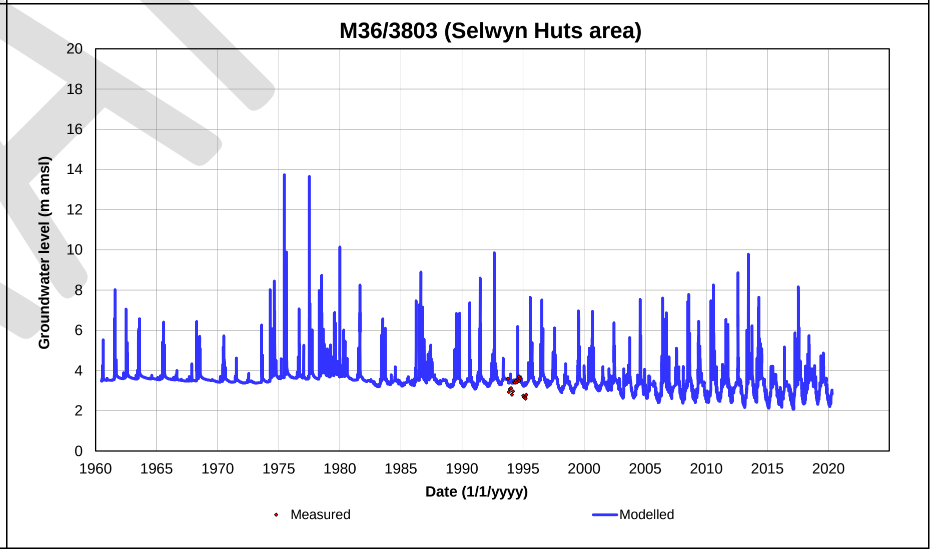

BX23/1308 (Selwyn Huts area)
BX23/1406 (Selwyn Huts area)
M36/0353 (Selwyn Huts area)
M36/0443 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled
DRAFT


M36/0527 (Selwyn Huts area)
M36/0558 (Selwyn Huts area)
M36/0594 (Selwyn Huts area)
M36/0599 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
14
12
10
8
6
4
2
0
-2
-4
-6
19
18
17
16
15
14
13
12
11
10
9


M36/0768 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled


M36/3117 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled


M36/3194 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled


M36/3803 (Selwyn Huts area)
Groundwater level (m amsl)
Date (1/1/yyyy)
Measured
Modelled