Appendix 1

July 26, 2022
Project No.22-01

Lake Weston Water Availability and Climate Change Assessment

Prepared for:

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Executive Summary

Capital Regional District (CRD) Parks & Environmental Services and the Salt Spring Island Local Trust Committee of the Islands Trust required a climate-adapted water availability study for the Lake Weston / Weston Creek watershed on Salt Spring Island (SSI). The purpose of this study is to assess future water supply availability for the Lake Weston watershed in consideration of current water licences and predicted climate change scenarios. The Fulford Water System is currently the only local community water service provider in the Lake Weston/Weston Creek watersheds. There are also 24 point-of-diversion licences to extract water for domestic and irrigation supply from Lake Weston. In consideration of future growth scenarios within, and outside of, the Lake Weston watershed, it is necessary to identify the safe yield of water supplies while ensuring water requirements for environmental flow needs are preserved to ensure aquatic ecosystems (wetlands, creeks, lakes, etc.) are protected.

To meet the goal of project, GW Solutions has developed a water balance model (based on the Thornthwaite-Mather approach) to assess the water availability within the watersheds that contribute to the main study area, Lake Weston watershed. We estimated water withdrawals/usage from groundwater and licenced surface water resources and compared this usage to water availability. Finally, the estimated available water (for both groundwater resources and surface water features) under different climate conditions based on global climate models (scenarios; 2030s, 2050s, and 2070s) has been compared with the current water usage in the study area. This comparison enables us to understand if the study area is likely to experience stress due to withdrawals that exceed available supply. The results also help the CRD to determine if there is potential for community expansion within the study watershed based on sustainable water supply.

The Lake Weston Watershed is dominated by the star-shaped approximately 500-metre-wide Lake Weston and a limited number of stream drainages; however, the majority of creeks and rivers are reported to not flow all year round or have very limited flow during the dry season. Lake Weston has a maximum depth of 12.2 meters and is connected to the upper groundwater system. The lake occurs within a topographic depression at the intersection of two faults which has enabled the lake to form. Groundwater feeds or discharges directly into the lake via the faults on the upgradient side of the lake and seeps out of the lake on the downgradient side back into the groundwater zone. The lake also has a surface water outlet, Weston Creek, which appears to flow all year round.

Water supply in the Lake Weston watershed is obtained from two sources: 1) directly from Lake Weston and 2) Aquifer 1147 which is pumped from wells distributed throughout much of the watershed. The only water usage that is measured (metered) is the Fulford Community Water System taken from Lake Weston. The remainder of the water usage from Lake Weston and Aquifer 1147 is not measured and can only be estimated based on the amounts in the water licences and applicable coefficients. The fire protection water licence (institutional) is the largest licence however this water is licenced for firefighting and firefighting training only and is used only intermittently (e.g. 3000 gallons were drawn in 2019 but none in 2020 and 2021). Most of the water withdrawn for training is circulated back to Lake Weston. There are several private domestic water supplies taken from Aquifer 1147 and significant water usage for irrigation taken from Lake Weston. The highest water usage from Lake Weston is the May-September period likely reflecting increased irrigation in summer. This contrasts to the assumed pumpage from domestic wells which is similar in summer and winter.

The water balance model shows the total annual precipitation in the watershed is about 2585 dam^3/year and the water surplus is 1608 dam^3/year which is comprised of both surface water runoff (993 dam^3/year) and groundwater recharge (615 dam^3/year). Of the total precipitation, evapotranspiration represents 35%, surface water runoff represents 40% and groundwater recharge represents 25%.

A comparison of annual groundwater recharge and total annual water usage (from Lake Weston and wells), as estimated from water licences, indicates that on an annual basis groundwater recharge is sufficient to satisfy the current total demand. However, groundwater recharge occurs mostly in the winter months while the water demand is higher in the dry summer months, mostly for water supply and irrigation. This means that during the summer months, water supply demand exceeds recharge which leads to seasonally declining water levels of Lake Weston and Aquifer 1147. These levels then rise again each fall and winter in response to recharge events.

Climate change models predict that winters in the CRD will be warmer with more rain and less snow. The rain will fall as more intense events leading to higher levels of surface runoff potentially leading to higher soil erosion and flooding and potentially less groundwater recharge. The spring snowmelt will tend to disappear reducing the historical groundwater recharge heading into the dry summer months. During summer, temperatures will be higher, precipitation lower and groundwater baseflow (feeding creeks, lakes, wetlands) will therefore be lower. Runoff is predicted to decrease significantly in the summer months (-20% to -28%) while in the winter months runoff will increase by a small amount (2% to 4%). Water shortage is predicted from March to September when the demand will seasonally exceed the surplus of water. This means that during this period, licenced withdrawals exceed groundwater recharge (replenishment of supply) potentially leading to decreased groundwater baseflow to the creek and thus water available for environmental flow needs (aquatic ecosystems: lakes, creeks, wetlands, etc.).

The Lake Weston level varies from a high of about 61.35 masl (meters above sea level) in January to a low of 60.55 masl in August (average 0.8 m variation) and appears to reach a level where it becomes stable (increasing very slightly) in the summer months. In drainages where fish are present, the minimum flow required to sustain the fisheries resource for fair spawning and rearing habitat is 5-10% of the Mean Annual Discharge (MAD). For Weston Creek, 10%MAD corresponds to a Lake Weston water level of about 61 masl. A 20%MAD corresponds to a lake level 10 cm higher at about 61.1 masl and a 30%MAD is about 61.15 masl.

The relationship between usage and Lake Weston level is represented with an approximate trend line providing an approximation of the usage that corresponds to the 10%MAD, 20%MAD and 30%MAD. It can be seen that to achieve even the minimum 10%MAD in Weston Creek the usage in the summer months would need to be reduced to usage levels similar to the winter months. This would require significant summer restrictions on irrigation (farm and household) usage. This highlights the need for accurate usage data to confirm these results and to allow consideration of the need for more appropriate water conservation programs.

Development and implementation of water conservation measures, for all water users, from March to September is recommended to minimize water shortages during summer months. Additional monitoring is recommended including installation of a new climate station in the upper elevations of the watershed where the majority of groundwater recharge occurs. In addition, it is recommended the installation of dedicated groundwater monitoring wells and/or the identification of suitable existing wells that could be monitored. Monitoring should prioritize understanding the impact of water usage and climate change on the watershed. Additionally, work is needed to better define environmental flow needs for both Lake Weston and Weston Creek based a detailed survey of the groundwater-dependant aquatic habitat and the measurement of the minimum flows necessary to maintain the habitat.

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Glossary

1 BACKGROUND

The Capital Regional District (CRD) Parks & Environmental Services and the Islands Trust Salt Spring Island Local Trust Committee required a climate-adapted water availability study for the Lake Weston/ Weston Creek watershed (ID: 08HA0020) on Salt Spring Island (SSI).

The purpose of this study is to assess future water supply availability for the Lake Weston watershed in consideration of current water licences and predicted climate change scenarios.

The Fulford Water System is currently the only community water supply system in the Lake Weston and Weston Creek watersheds. In consideration of future residential density changes within the study area, it is necessary to identify the safe yield of water supply while ensuring that water requirements for environmental flow needs are preserved.

2 STUDY AREA DESCRIPTION

Figure 1 and Figure 2 present the Lake Weston Watershed boundary and some neighbouring watersheds in the study region. It is noted that the Lake Weston Watershed is a sub watershed of Weston Creek Watershed. The bedrock geology (Figure 3) of Salt Spring Island was mapped in detail by Greenwood and Mihalynuk (2009) by studying outcrops and interpreting existing borehole stratigraphy data. The Lake Weston watershed is comprised of granitic rocks of the Salt Spring intrusions and volcanic rocks of the Nitinat Formation. The structural distribution of the Upper Nanaimo Group was created by multiple ancient deformational (Mustard, 1994) and more recent glacier glacio-isostatic deformations (Clague, 1983). The bedrock throughout the southern Gulf Islands thus has been extensively folded and fractured (Journeay and Morrison, 1999).

The watershed is dominated by a groundwater-fed lake (Lake Weston; Water Body ID: 315620) and largely ephemeral drainages that do not flow year-round but only flow seasonally in the rainy season or temporarily following rain events. Lake Weston has an area of 180,137 m^2 and is in the crude shape of a cross with three distinct arms. The longest span between arms (northeast arm to southwest arm) is about 700m and the maximum depth is 12.2 meters (Figure 4). The lake appears to be at the intersection of several geologic faults which have weakened the rock and produced a depression in which the lake is formed. This type of lake is referred to as “flow-through,” since groundwater feeds and discharges directly into the lake via the faults on the upgradient northern side of the lake and seeps out of the lake on the downgradient southern side back into the groundwater zone. Flow-through lakes occur when the water table is higher on one side of the lake than the other, creating a gradient for groundwater to enter and leave the lake. An illustration of a flow-through lake is provided in Figure 5. The lake also has a stream outlet, Weston Creek, which flows year-round due to a combination of outflow from Lake Weston and groundwater discharge (baseflow) from the aquifer into the creek (see also Figure 38 for a regional cross-section through Lake Weston).

The proportion of water that is from groundwater in the Lake Weston inflow (E1) and the Weston Creek outflow (at the mouth) was studied by Howe and Allen (2020). They found the proportion of groundwater in the inflow varies from 10% during high flows (25 L/s) to 47% during low flow (4 L/s). In the Weston Creek outflow, the proportion varies from 12% during high flow (20 L/s) to 100% during low flow (1.1 L/s). This indicates the high proportion of groundwater discharging into both Lake Weston and Weston Creek.

Land-use in the study region is dominated by rural residences, agricultural and forest (Figure 6).

GW Solutions has developed a water balance model as a tool to assess the water availability within the Lake Weston watershed. This report describes the model to quantify water availability as runoff and groundwater recharge under different conditions of climate change. An analysis of estimated water withdrawals/usage from groundwater and surface water resources was also completed and compared to water availability.

To meet the goals of the project, the estimated available water (from both groundwater resources and surface water features) under different climate conditions has been compared with the current water usage in the study area. This comparison enables an evaluation of whether the area is under stress due to large withdrawals in comparison to water availability. The results will assist the CRD to determine the potential for community expansion within this area, in a sustainable manner.

Two main factors have been considered for this study.

a) *Understanding and planning for climate change*; the results are presented for investigations for three-time frame scenarios: 2030s, 2050s, and 2070s.

b) *Protection of valuable water resources and the aquatic ecosystems*; it is understood that the Water Availability Study should incorporate the baseline requirements for, not only water use by the community, but also for preservation of the health of aquatic ecosystems (aquifers, creeks, springs, wetlands, lakes).

The report is divided into the following four sections:

Section 4: Water Usage. All water usage quantities from surface water and groundwater sources quantified and/or estimated and classified according to use of water (domestic, irrigation, institutional, community water supply).

Section 5: Water Balance. Development of data sets and equations for estimating various components of the water balance including monthly estimates of groundwater recharge and surface water runoff.

Section 6: Climate Change Analysis. Analysis of the impacts of various climate change severity scenarios (based on global climate models) on the water budget for various time periods in the future 2030s, 2050s, and 2070s.

Section 7: Analysis of Results and Data Gaps. Analysis of the key results of the study and additional data (i.e. data gaps) that would help improve the accuracy of the predictions.

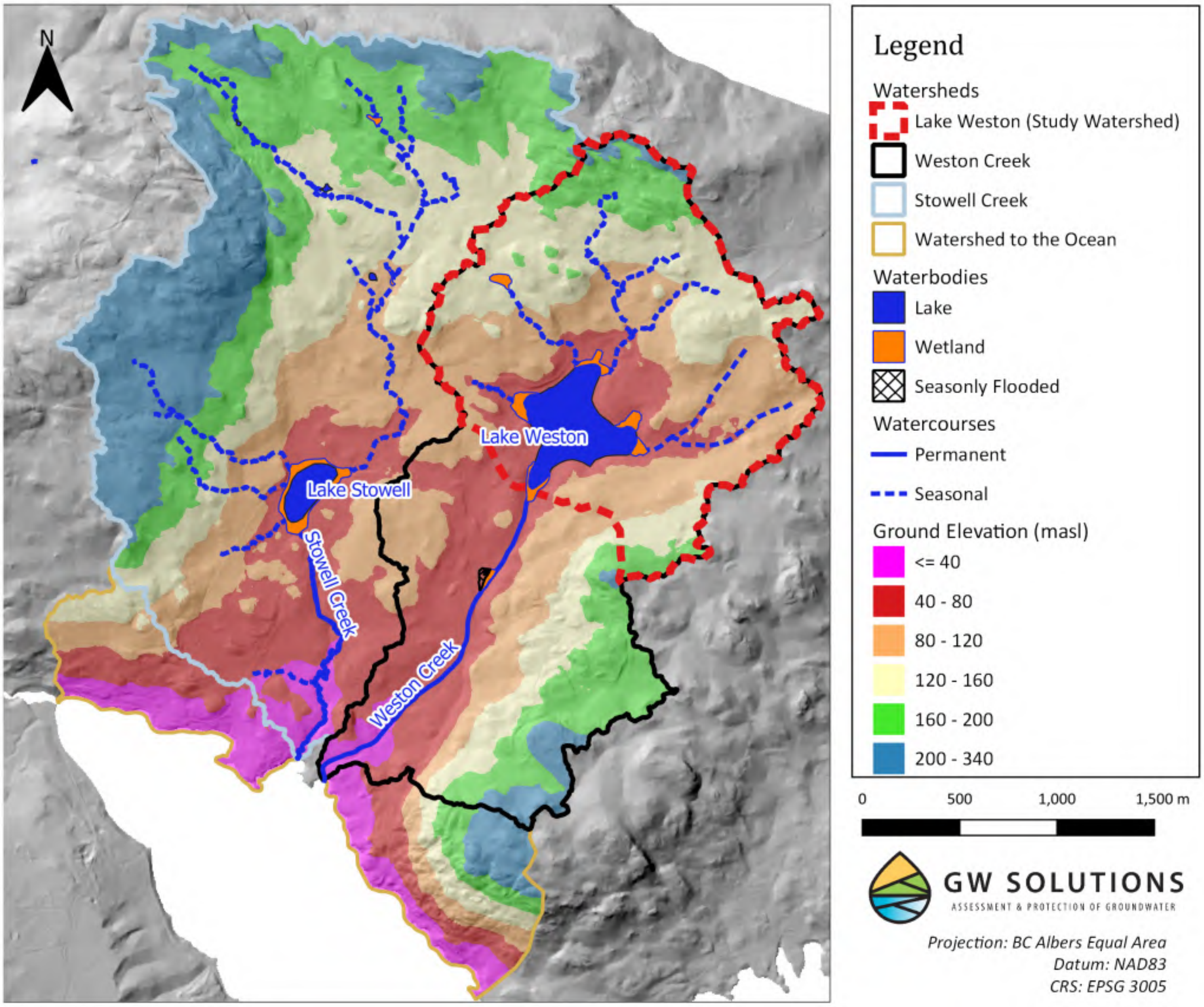


Figure 1. Lake Weston and Weston Creek watersheds.

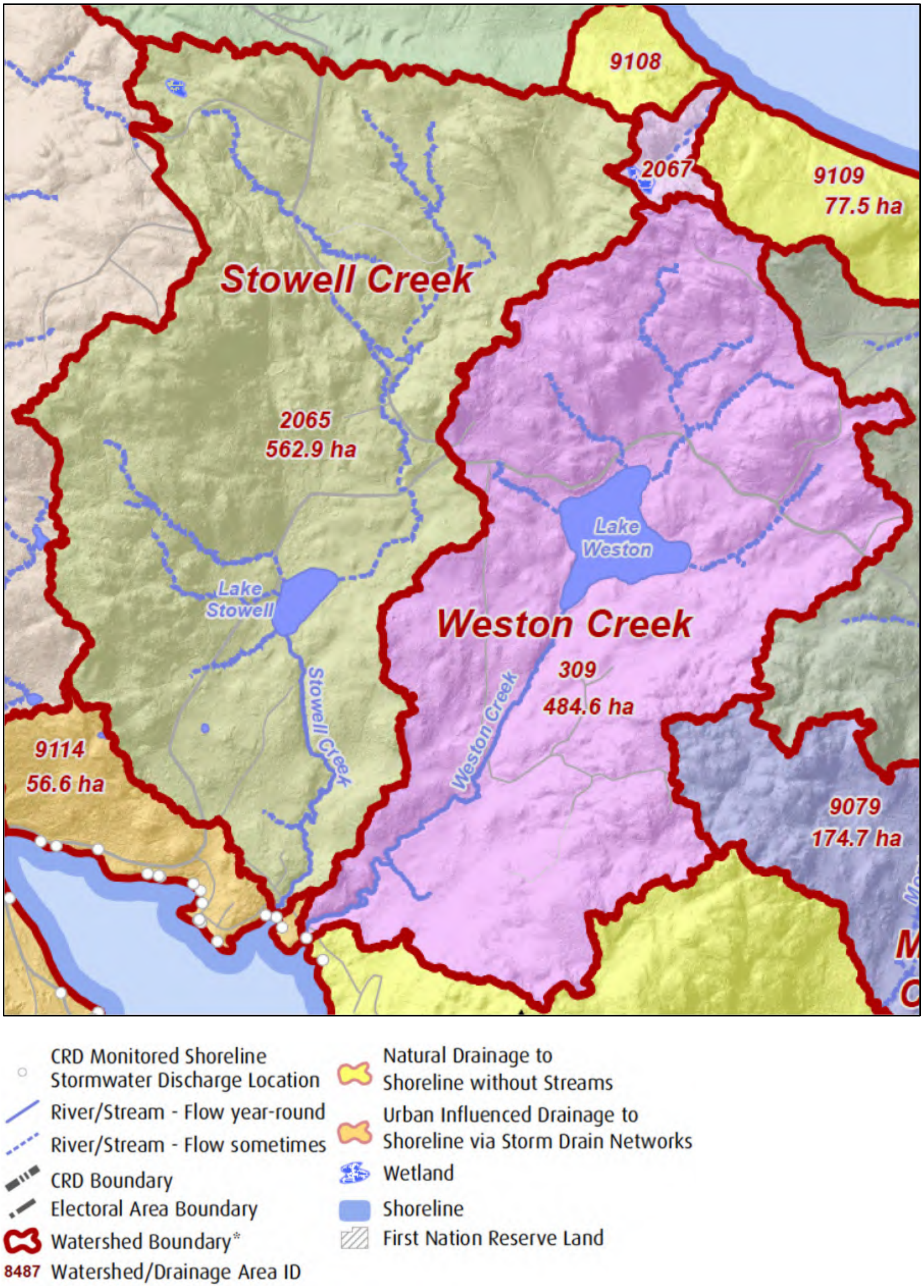
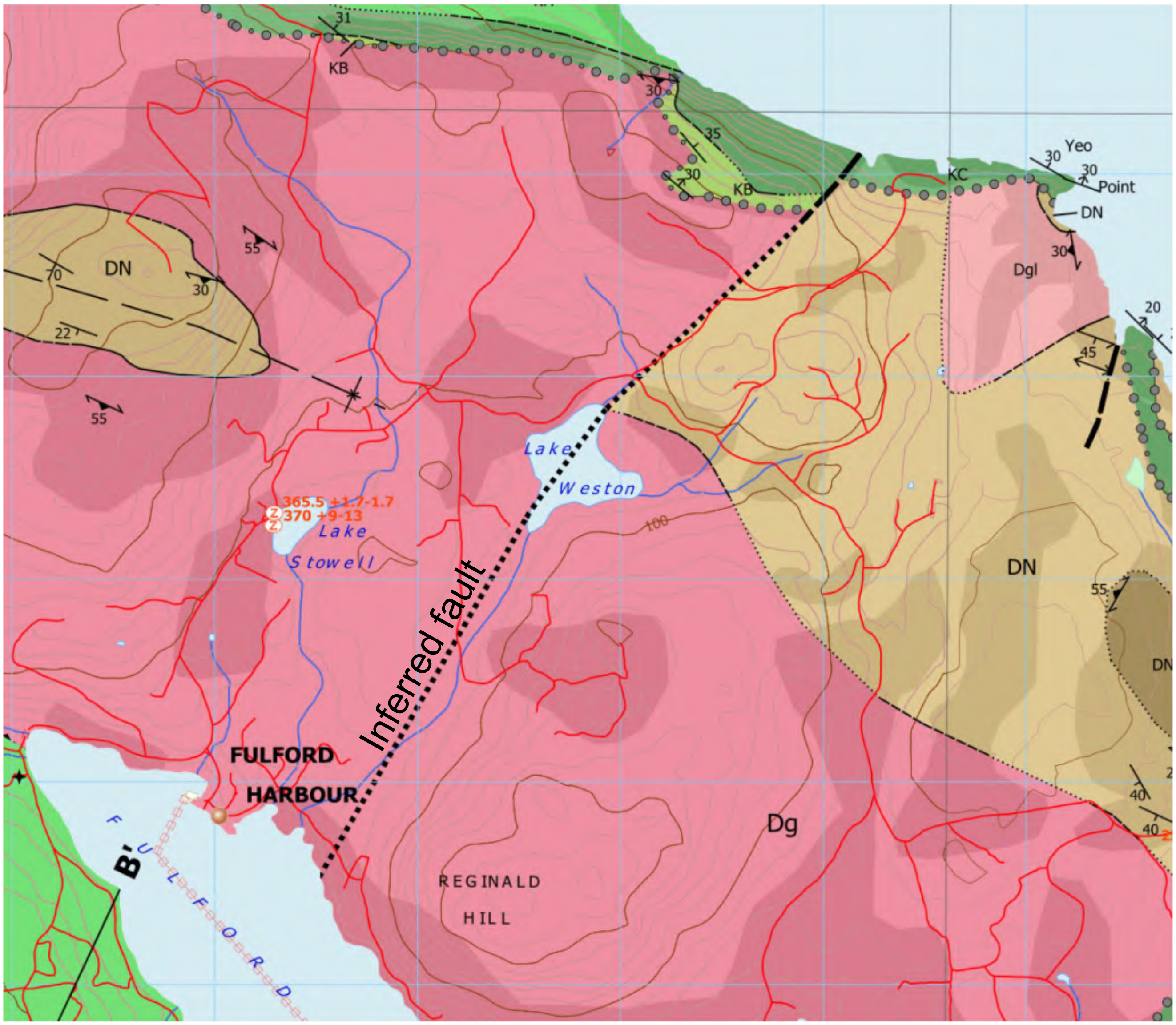


Figure 2. Weston Creek watershed and neighboring watersheds (CRD, 2018)



Sicker Group Volcanics

DN	Nitinat Formation Pyroxene-phyric mafic agglomerate, pyroxene bearing tuffs, lapilli tuffs and flows. Individual sub units and flows are difficult to trace confidently. Pyroxene crystals are commonly altered to actinolite.

Saltspring Intrusions

Dg	Granite and granodiorite, undivided (Dg) commonly protomylonitic with conspicuous quartz 'eyes'. Produces a hornfels texture in Nitinat Formation country rocks.

Figure 3. Study area geology (from Greenwood and Mihalynuk, 2009)

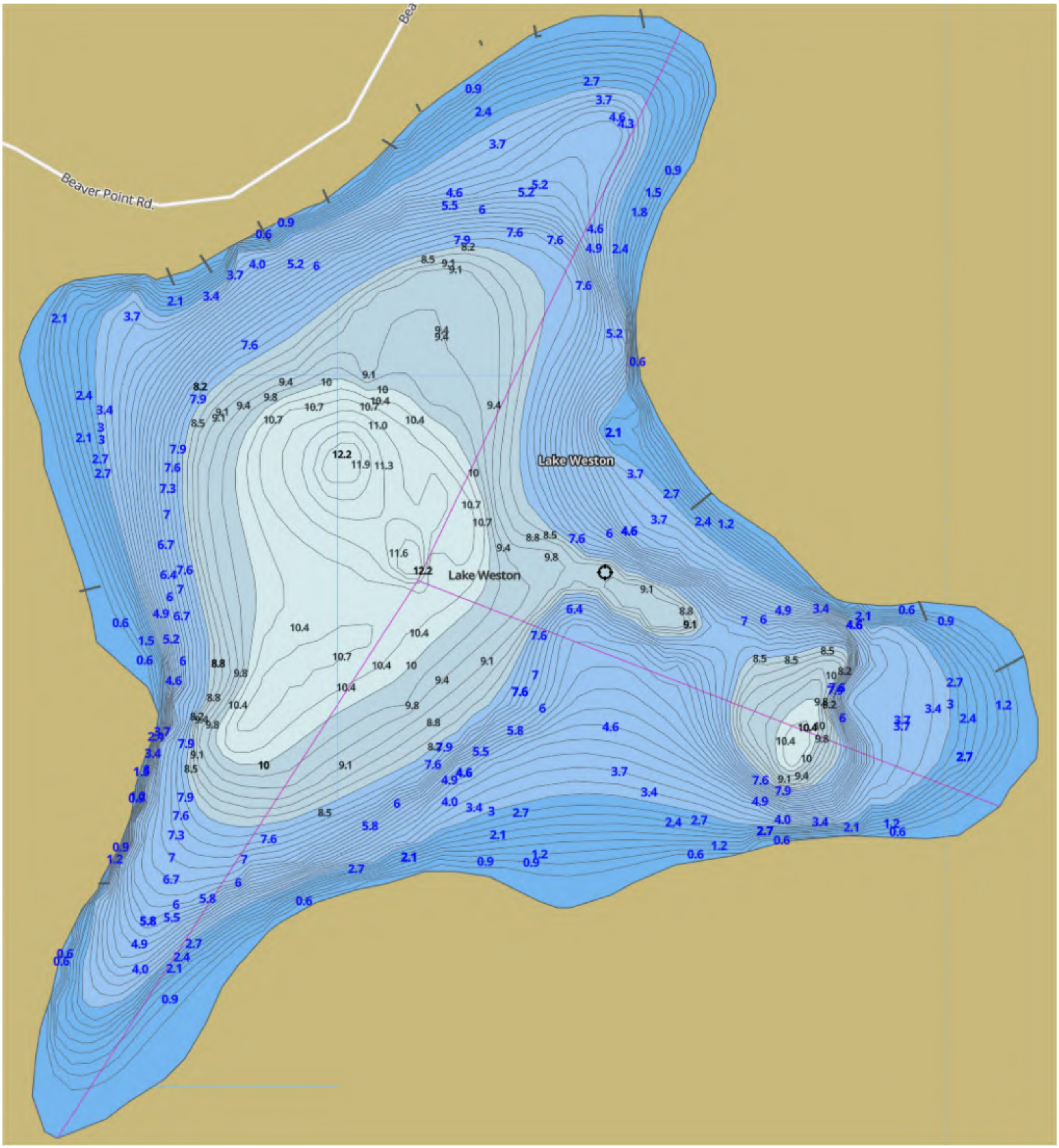


Figure 4. Lake Weston depth in meters, shape and dimensions (www.gpsnauticalcharts.com)

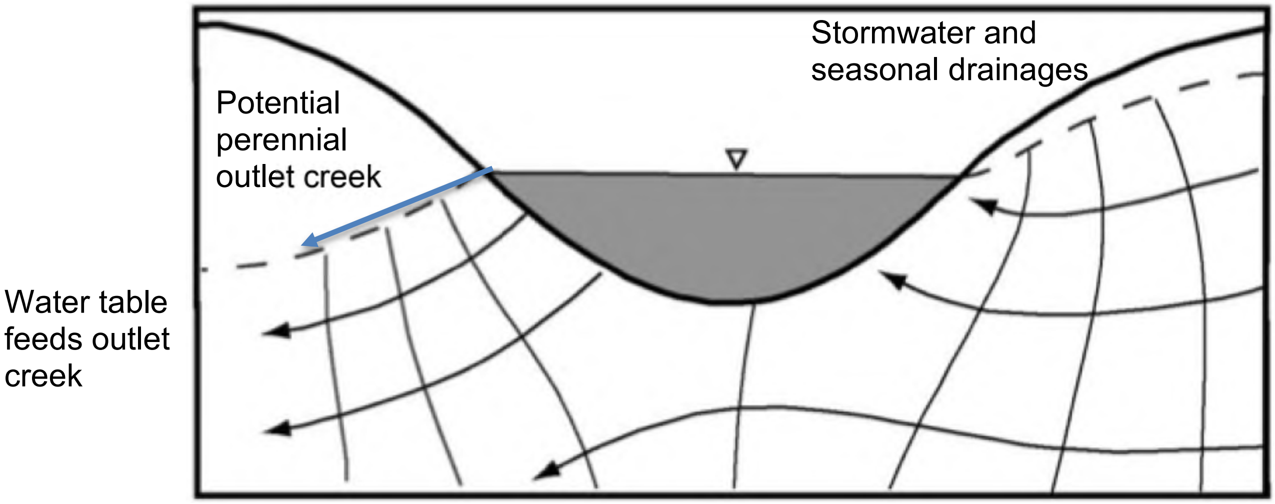


Figure 5. Flow-through lake. The water table is higher on one side of the lake than the other thus groundwater seeps into the lake on the upgradient side and seeps out of the lake on the downgradient side.

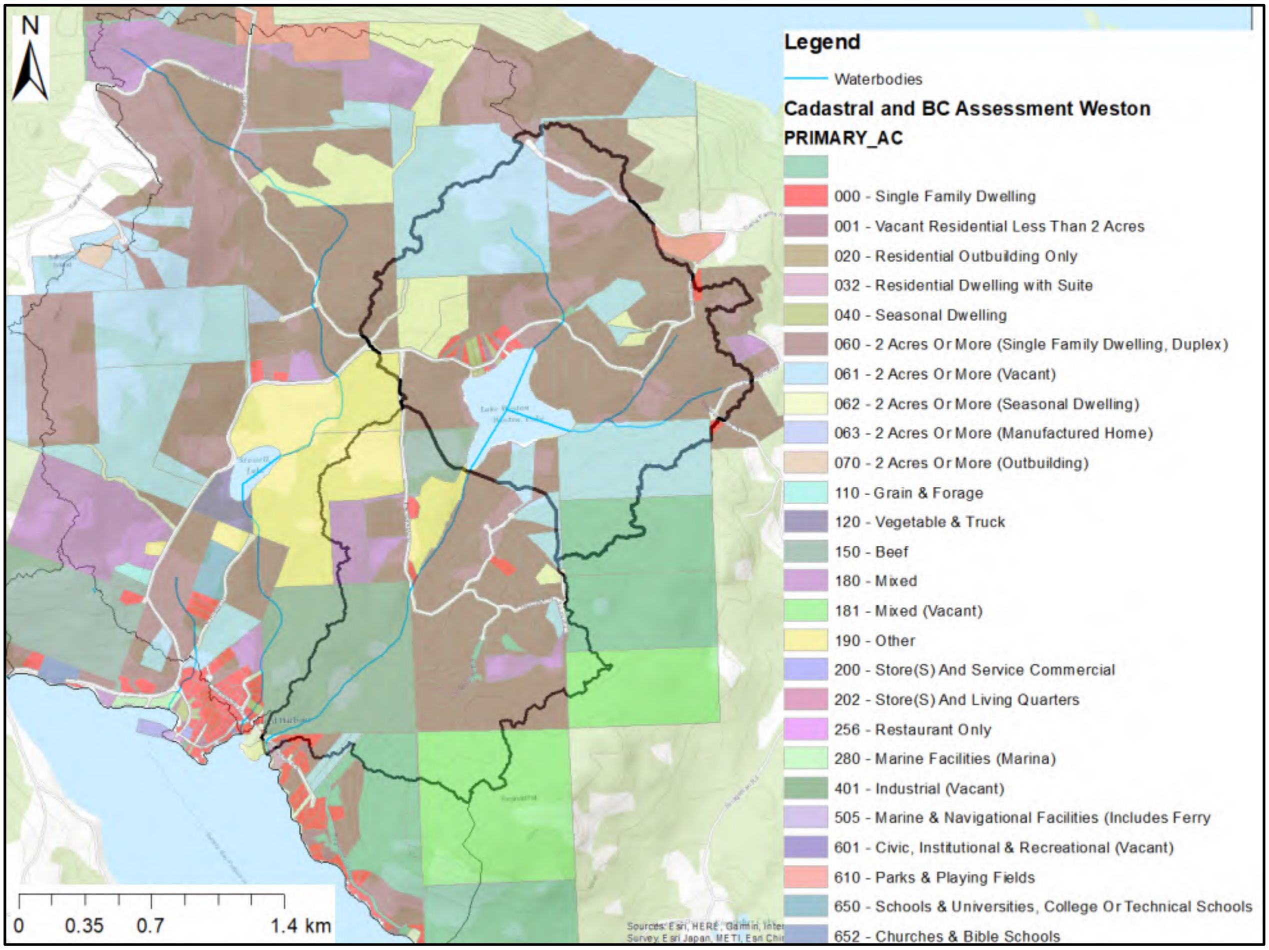


Figure 6. Land-use within and near study area

3 APPROACH

We employed the following approach:

1. To understand the current water demand for the Lake Weston watershed, water usage for surface water and groundwater sources has been estimated using a methodology developed by GW Solutions which includes licensed points of diversion (surface water and springs), points of well diversion, parcel information and the GWELLS database. Metered water use data for the Fulford Water System was provided by the CRD.

2. The next step in our water availability assessment is understanding the water balance for the study area. A baseline water balance model has been developed by using Climate Normals (average monthly climate variables data 1981-2010) as input. For this project, GW Solutions has used an ArcGIS based water balance tool created by James Dyer from the University of Ohio (Dyer, 2019, 2021). The model estimates monthly potential evapotranspiration, soil moisture storage, actual evapotranspiration, soil moisture deficit, and soil moisture surplus using the grid-based Thornthwaite-Mather approach. The water balance methodology is described in detail in Section 5. The water balance model estimates the available moisture *Surplus* (among other outputs), which is defined as the moisture remaining after evapotranspiration and therefore available for surface water runoff and groundwater recharge. GW Solutions on behalf of Island Trust has developed a recharge mapping methodology to estimate groundwater recharge and surface runoff volumes. In this approach the groundwater recharge flux is estimated and differentiated from *Surplus* by applying several deterministic coefficients (e.g. surficial composition, lineaments, estimated depth to groundwater and satellite-based delineations of preferential groundwater recharge and discharge areas) for groundwater recharge. The baseline water balance model is calibrated using a statistical approach for actual measured flow data.

3. The climate change effects on the climate variables such as precipitation, radiation and temperature, have been projected for three time-periods – 2030, 2050, and 2070 using ClimateBC Data Project with selecting the IPCC's most recent *Coupled Model Intercomparison Project* (CMIP6) scenarios.

4. The outcomes of climate change projections were then entered into the calibrated water balance model as input and the water availability/surplus was estimated as the output for different climate change scenarios.

5. Finally, the current water usages were compared to the water availability of surface water and groundwater resources considering different climate change conditions to understand the degree of water stress in the watershed.

4 WATER USAGE

Understanding and estimating the water usage within the Lake Weston area is critical to the sustainable management of surface water and groundwater resources. GW Solutions worked collaboratively with the Capital Regional District (CRD) and Island Trust to compile available measured water usage (groundwater and surface water). The only metered water system in the watershed is Fulford Water System and this data was obtained from CRD. This metered information was critical to understand the temporal variability (month to month) in water usage. For all other water users (without metered data), we estimated water usage as described in the following sections.

4.1 Estimation of Surface Water Withdrawals

The water availability assessment requires an estimation of monthly and yearly surface water withdrawal volumes. The BC Water Rights database, which includes water licence information for surface water sources, was used to estimate the surface water withdrawal volumes. A water source (i.e., spring, pond, or stream) can have multiple licenses and associated Points of Diversion (POD's); and each license can have one or more POD's. For each water license, basic information is provided such as license status, expiry date, licensed volume (units), water use purpose and period of usage.

Figure 7 shows the current licensed PODs for the study area, limited to withdrawals and classified by type of use (i.e., domestic, irrigation, industrial/commercial, institutional and water supply systems). There are 24 PODs within the Lake Weston watershed with the largest associated with the Fulford Water System which as the only metered system in the study area (Figure 8). All other water usage must be estimated based on licences and usage type. However, in an event of fire, the Fire Suppression license will become the largest at a potential maximum rate of 80 liters/second.

Detailed information for Non-Domestic PODs is provided in Figure 9. According to the licences the domestic use ranges between 2 to 5 cubic meters per day per licence. A complete list of Water Rights for Lake Weston is presented in Appendix 5.

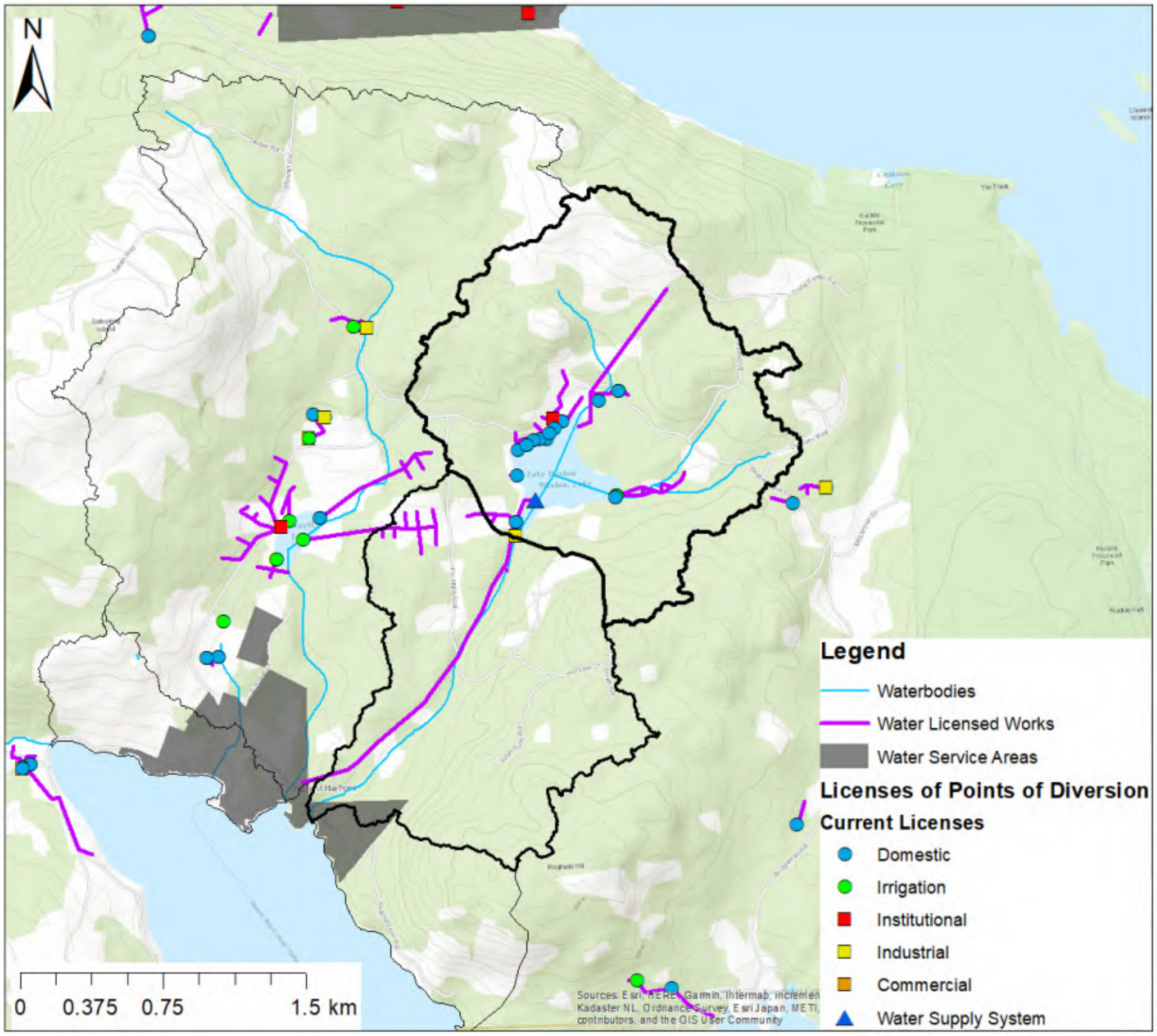


Figure 7. Current water right licences for Points of Diversion according to type of usage

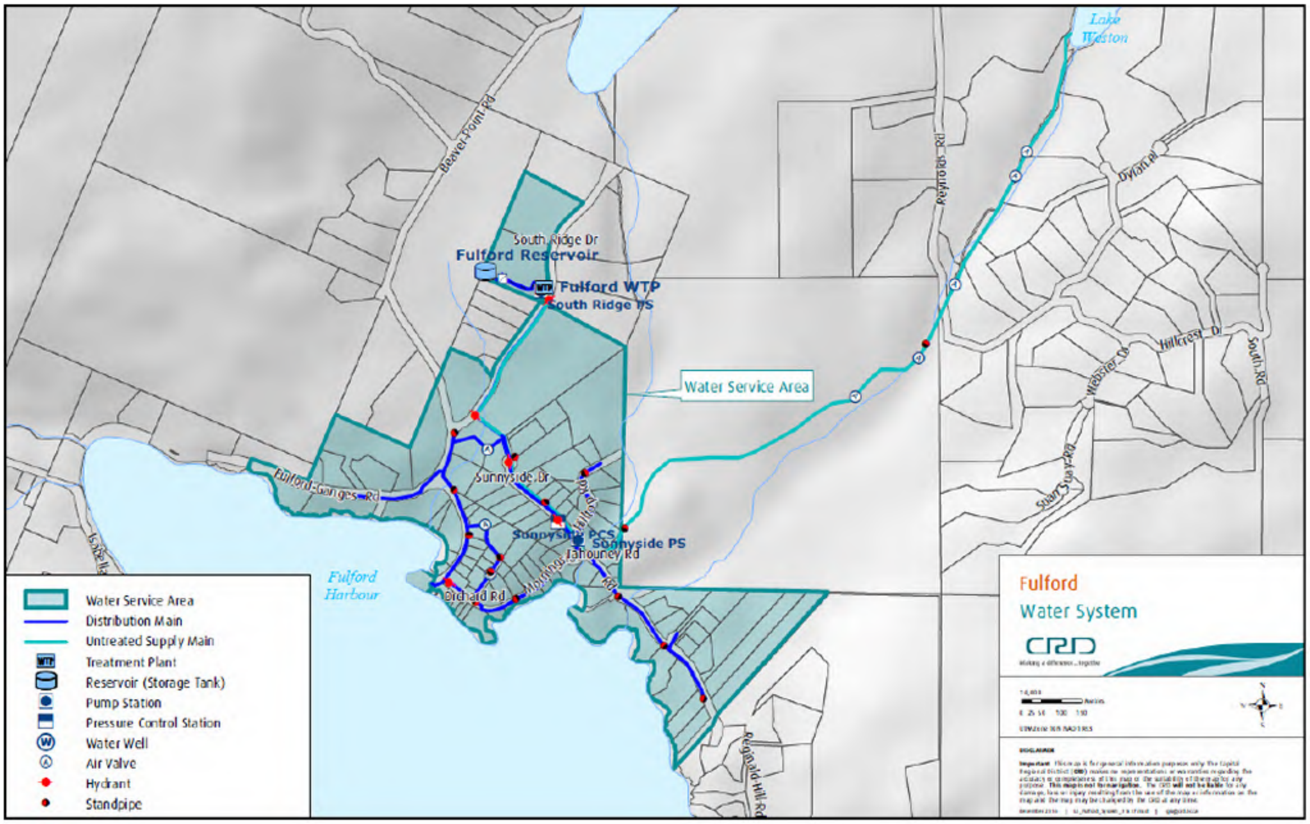
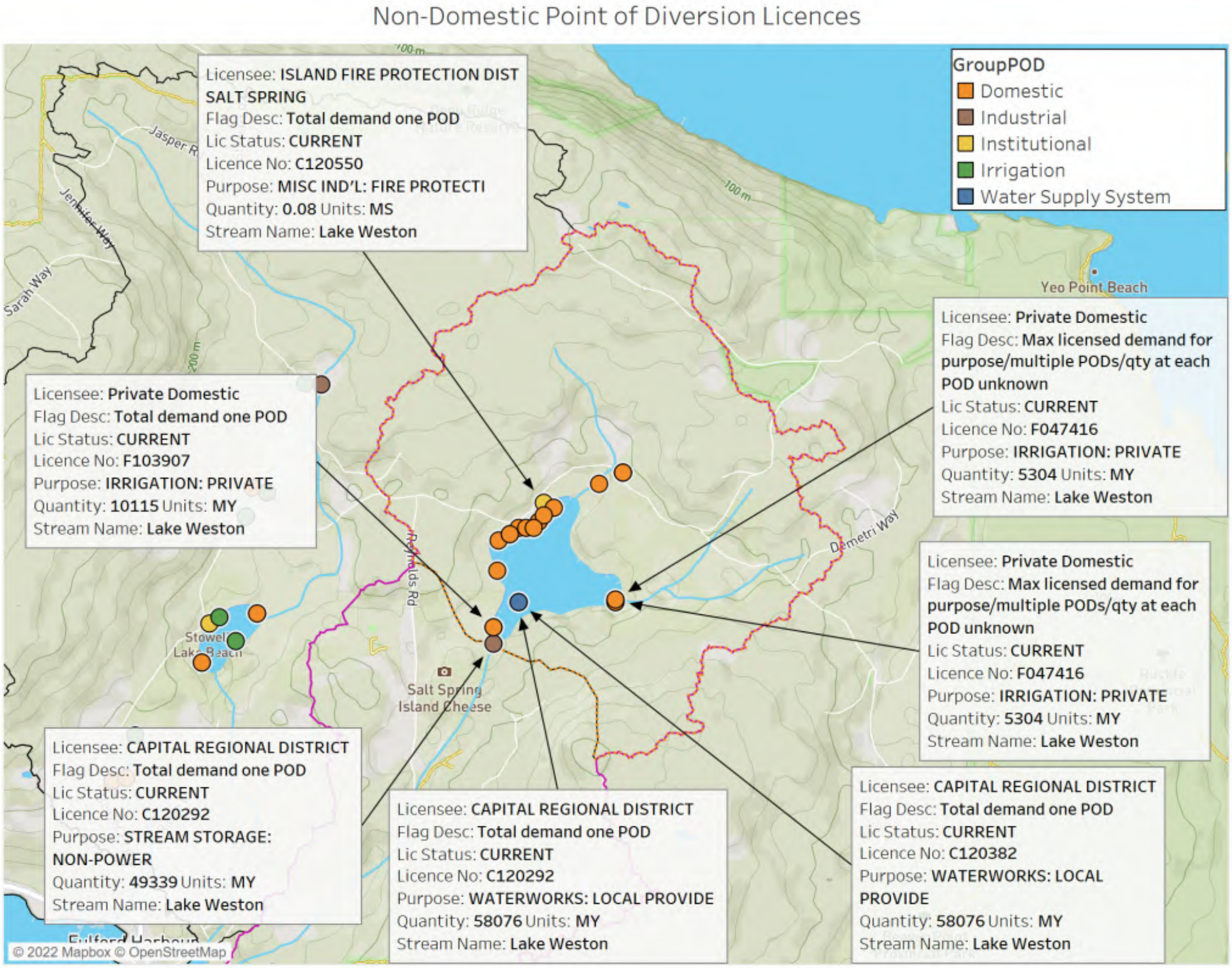


Figure 8. Service areas for Fulford Water Supply System regulated by CRD



Licensee: **ISLAND FIRE PROTECTION DIST SALT SPRING**
Flag Desc: **Total demand one POD**
Lic Status: **CURRENT**
Licence No: **C120550**
Purpose: **MISC IND'L: FIRE PROTECTI**
Quantity: **0.08** Units: **MS**
Stream Name: **Lake Weston**

Licensee: **Private Domestic**
Flag Desc: **Total demand one POD**
Lic Status: **CURRENT**
Licence No: **F103907**
Purpose: **IRRIGATION: PRIVATE**
Quantity: **10115** Units: **MY**
Stream Name: **Lake Weston**

Licensee: **Private Domestic**
Flag Desc: **Max licensed demand for purpose/multiple PODs/qty at each POD unknown**
Lic Status: **CURRENT**
Licence No: **F047416**
Purpose: **IRRIGATION: PRIVATE**
Quantity: **5304** Units: **MY**
Stream Name: **Lake Weston**

Licensee: **Private Domestic**
Flag Desc: **Max licensed demand for purpose/multiple PODs/qty at each POD unknown**
Lic Status: **CURRENT**
Licence No: **F047416**
Purpose: **IRRIGATION: PRIVATE**
Quantity: **5304** Units: **MY**
Stream Name: **Lake Weston**

Licensee: **CAPITAL REGIONAL DISTRICT**
Flag Desc: **Total demand one POD**
Lic Status: **CURRENT**
Licence No: **C120292**
Purpose: **STREAM STORAGE: NON-POWER**
Quantity: **49339** Units: **MY**
Stream Name: **Lake Weston**

Licensee: **CAPITAL REGIONAL DISTRICT**
Flag Desc: **Total demand one POD**
Lic Status: **CURRENT**
Licence No: **C120292**
Purpose: **WATERWORKS: LOCAL PROVIDE**
Quantity: **58076** Units: **MY**
Stream Name: **Lake Weston**

Licensee: **CAPITAL REGIONAL DISTRICT**
Flag Desc: **Total demand one POD**
Lic Status: **CURRENT**
Licence No: **C120382**
Purpose: **WATERWORKS: LOCAL PROVIDE**
Quantity: **58076** Units: **MY**
Stream Name: **Lake Weston**

Figure 9. Details on non-domestic current licences for Points of Diversion

MY=m^3/year, MS=m^3/s

4.1.1 Methodology and estimation of volumes for current PODs (surface water)

Licenced volumes in the POD database are reported in yearly, monthly, daily, or hourly use rates. To normalize the licenced volumes to monthly rates, we applied coefficients that model seasonal patterns of water including seasonality from the Fulford Water System. Coefficients were estimated based on monthly use trends for water supply systems on Vancouver Island (i.e., North Salt Spring Waterworks District, Nanaimo and Fulford Water System), Ecofish Baseline Report and Rood and Hamilton (1995) (domestic), BC Ministry of Agriculture Livestock Watering Factsheets (livestock and irrigation), and the BC Agriculture Water Demand Model (irrigation).

Table 1 summarizes the monthly coefficients used for the conversion to monthly rates including when the information was converted to consistent units. Monthly rates were then added to derive yearly water use for surface streams and springs. The sum of the all the months equals to 12. The coefficient indicates months where greater water use happens and the proportion of water usage for each month. For instance, in *Irrigation: Private* under current climate scenarios there is no water usage from October to April (coefficient=0), the water usage in July and August (coefficient=3.6) is three times higher than in May and September (coefficient=1.2) and 33% more than the usage in June (coefficient=2.4).

Table 1. Monthly allocation coefficients for estimated water use from PODs

Group POD	Purpose	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
Domestic	DOMESTIC	0.85	0.85	0.85	0.85	0.95	1.00	1.50	1.50	1.10	0.85	0.85	0.85
Irrigation	IRRIGATION: PRIVATE	0.00	0.00	0.00	0.00	1.20	2.40	3.60	3.60	1.20	0.00	0.00	0.00
Irrigation	LAND IMPROVE: GENERAL	0.95	0.95	0.95	0.95	1.05	1.07	1.08	1.08	1.07	0.95	0.95	0.95
Irrigation	LIVESTOCK & ANIMAL: STOCK	0.85	0.85	0.85	0.85	0.95	1.00	1.50	1.50	1.10	0.85	0.85	0.85
Irrigation	LWN, FAIRWAY & GRDN: RES	0.00	0.00	0.00	1.20	2.40	2.40	2.40	2.40	1.20	0.00	0.00	0.00
Industrial	GRNHOUSE & NURSERY: GRNHO	0.00	0.12	0.12	0.24	1.20	1.68	2.88	2.88	2.04	0.72	0.12	0.00
Industrial	LWN, FAIRWAY & GRDN: WATE	0.00	0.00	0.00	1.20	2.40	2.40	2.40	2.40	1.20	0.00	0.00	0.00
Commercial	COMM. ENTERPRISE: ENTERPR	0.95	0.95	0.95	0.95	1.05	1.07	1.08	1.08	1.07	0.95	0.95	0.95
Institutional	MISC IND'L: FIRE PROTECTI	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00
Water Supply System	WATERWORKS: LOCAL PROVIDE	0.85	0.85	0.85	0.85	0.95	1.00	1.50	1.50	1.10	0.85	0.85	0.85

BC fire season from April to September

4.2 Estimation of Groundwater Withdrawals

4.2.1 Water wells database, cadastral information, and water service areas

The BC water wells database (GWELLS), land-use from the BC Assessment Authority, and water service areas were used to estimate groundwater withdrawal. The wells database includes the vast majority of wells; however, it does not include all wells since reporting to B.C was voluntary until the *Water Sustainability Act* came into force in 2016. Additionally, dug wells typically are not registered within GWELLS. The well use types are classified as:

Water Supply System, Test Well, Private Domestic, Observation Well, Irrigation, Commercial and Industrial, Other and Unknown Well Use. There are known water supply systems utilizing groundwater within the Lake Weston watershed. Additionally, no non-domestic groundwater license Points of Well Diversion or non-domestic groundwater use applications were found within watershed at the time of data compilation.

Wells that do not extract water were removed from the analysis, including abandoned or decommissioned wells, dry holes, test wells and observation wells.

The GWELLS database does not include information on pumped volumes. To estimate the water use from groundwater wells, we combined the following information:

- Parcel boundary and land use data from BC Assessment, provided by the ITC.
- Active wells from the GWELLS database (Figure 10).

4.2.1.1 *Estimation of water volumes (groundwater) using wells database and cadastral information*

Groundwater use was estimated based on joining active wells to the parcel's land use (the “primary actual use” attribute from BC Assessment). Wells could then be classified by type of use: Water Supply System, Recreational, Irrigation, Institutional, Industrial, Domestic, Transportation and Commercial.

Average groundwater use for each land use type was estimated and adapted from Miles and Guy (2009) and is summarized in Table 2. The effects of seasonality and parcel size on water use were also taken into account. Three seasonality labels are used:

- “Area based”: volume estimation based on parcel area,
- “Seasonal use (May-Sep)”: volume estimation based on 5 months of water use (May to September); and
- “Area based and seasonal use (May-Sept)”: volume estimation based on combination of parcel area and period of use (May to September).

Coefficients from the BC Agricultural Water Demand Model (irrigation) and the BC Ministry of Agriculture's Livestock Watering Factsheets (livestock and irrigation) were used for agricultural users (parcels with an irrigation use). Monthly and seasonal variations were estimated based on reported use for the domestic and water supply systems (Table 1). The coefficients are similar to those used for the POD water use estimation.

It is expected parcels within the Irrigation category will overestimate water demand. The method assumes 50% of the land is actively irrigated with volumes assigned according to the seasonal percentages in Table 3. However, to more accurately estimate the irrigated land, field survey and data collection will be required.

The estimate of total groundwater use was calculated based on data from springs (POD) and water wells.

Table 2. Average water use estimates based on parcel information

Group	Primary Actual Use	Estimation type and seasonality	L/day/parcel	Number per ha
Domestic	000 - Single Family Dwelling		625	
Domestic	040 - Seasonal Dwelling	Seasonal use (May-Sep)	625	
Domestic	060 - 2 Acres or More (Single Family Dwelling, Duplex)		1,250	
Domestic	062 - 2 Acres or More (Seasonal Dwelling)	Seasonal use (May-Sep)	1,250	
Irrigation	150 - Beef	Area based	50	1
Irrigation	180 - Mixed	Area based and seasonal use (May-Sept)	10,000	
Irrigation	190 - Other	Area based and seasonal use (May-Sept)	10,000	

Table 3: Monthly seasonal variations for estimation of monthly pumped volumes

		Irrigation	Water Supply System	Domestic and others
Month	No of days	Distributed (%)	Increased by (%)	Increased by (%)
January	31		0%	0%
February	28		0%	0%
March	31		0%	0%
April	30		0%	0%
May	31	10%	15%	10%
June	30	20%	25%	12%
July	31	30%	80%	14%
August	31	30%	80%	14%
September	30	10%	20%	13%
October	31		0%	0%
November	30		0%	0%
December	31		0%	0%

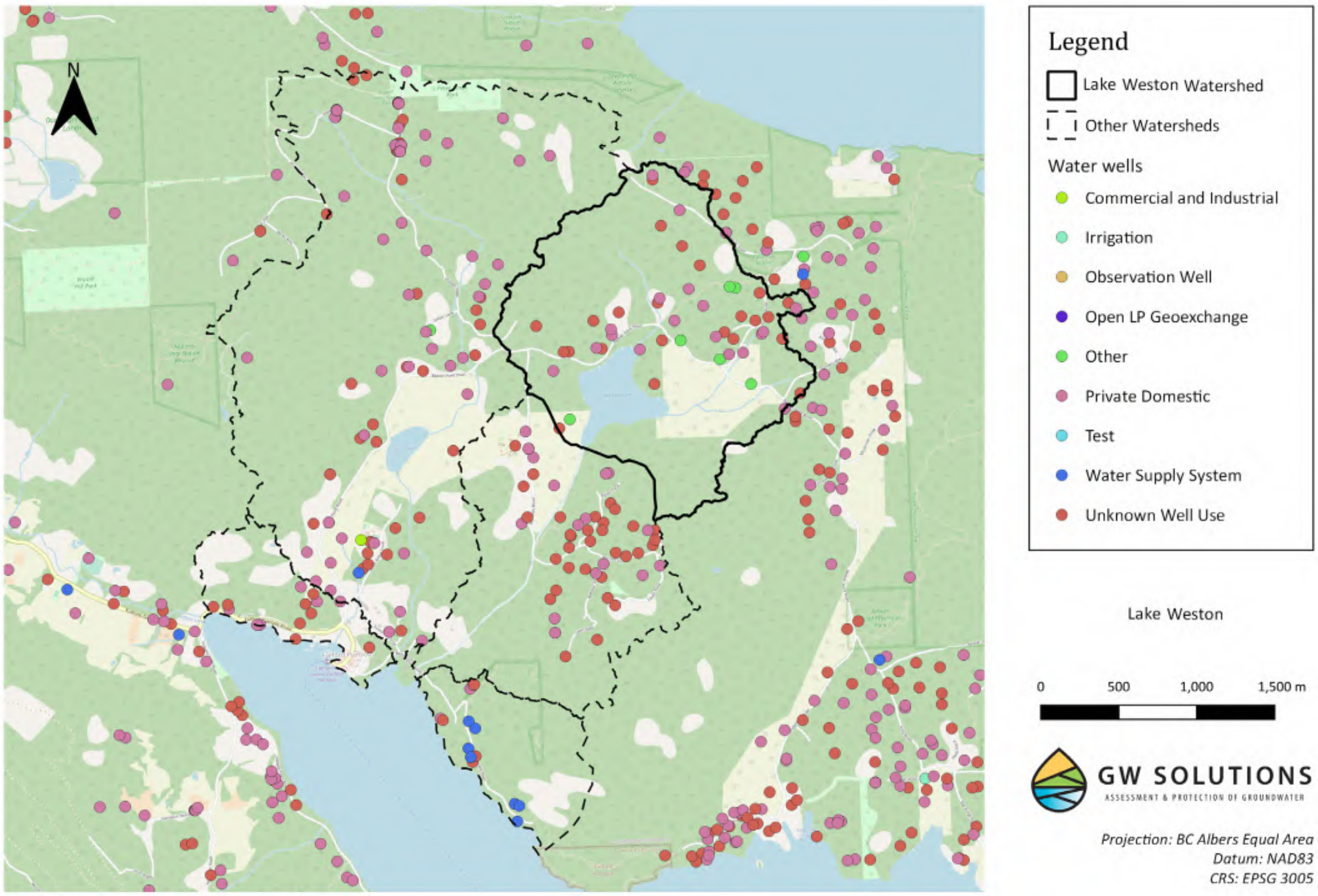


Figure 10. Registered Groundwater Wells in the Study Area

5 WATER BALANCE

5.1 Methodology

A water balance for the Lake Weston Watershed was estimated using an ArcGIS-based model developed by James Dyer from the University of Ohio (Dyer, 2019, 2021). The model estimates monthly potential evapotranspiration, soil moisture storage, actual evapotranspiration, soil moisture deficit, and soil moisture surplus using a grid-based, Thornthwaite-Mather approach (Thornthwaite and Mather, 1955).

Figure 11 summarizes the gridded water balance model methodology as a flowchart.

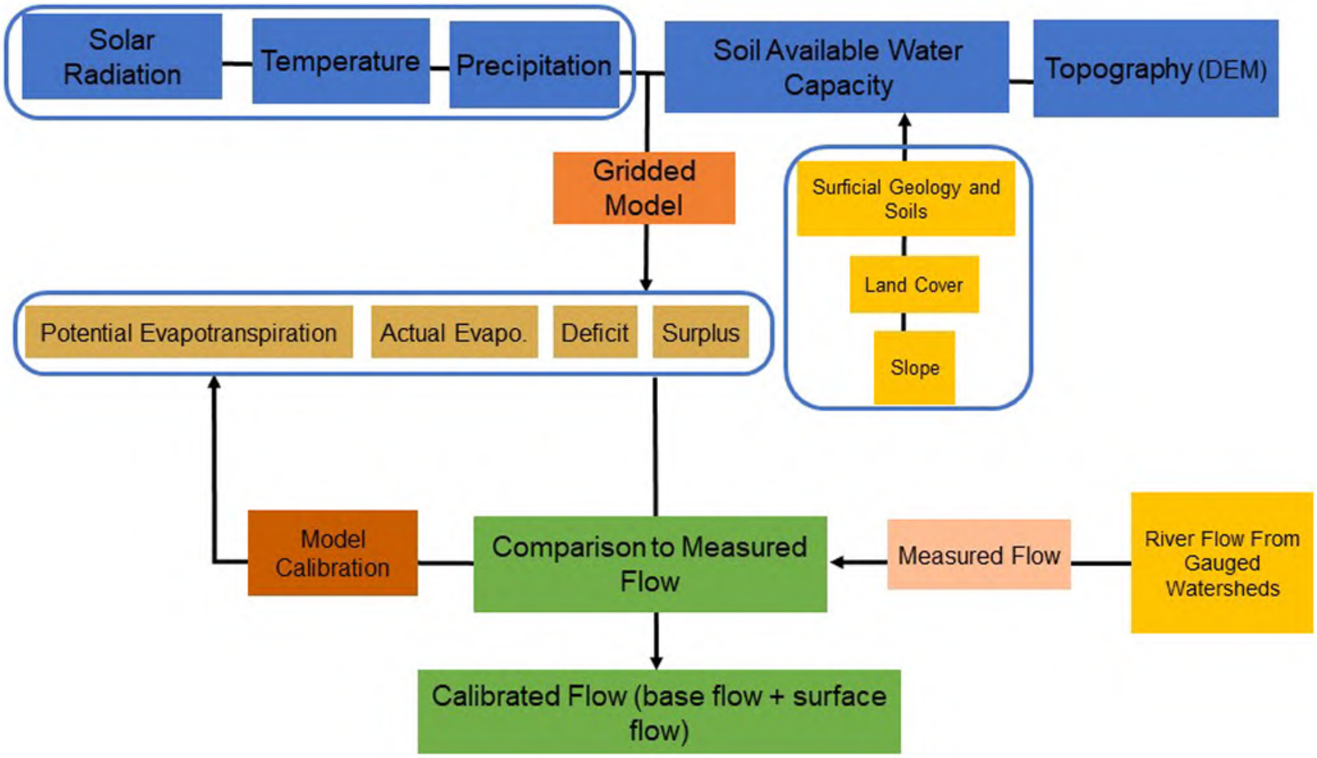


Figure 11. Gridded water balance model methodology

5.1.1 Model inputs

The main data inputs were monthly temperature (average), monthly total precipitation, a digital elevation model (DEM), soil available water capacity (AWC), and monthly total solar radiation. Each input is described in more detail in Table 4.

Table 4. The details of Model Inputs for the water balance

Model Input	Description	Source
Monthly average temperature and total precipitation	Gridded, monthly precipitation and temperature maxima and minima were obtained from the Pacific Climate Impact Consortium (PCIC).	PCIC (2020)
Digital Elevation Model (DEM)	A digital elevation model (DEM) was used to derive rasters of Slope (inclination of the ground), and Aspect (direction of the slope). The DEM was derived from LiDAR elevations and was upscaled to a 20 x 20-meter grid size.	BC Lidar (2021)
Soil Available Water Capacity (AWC)	Soil related data was retrieved from the British Columbia Soil Information Finder Tool that includes soil composition (mineral or organic), texture, coarse fragment content, drainage, layer thicknesses and characteristics, soil physical and chemical properties, as well as landform and parent material. Soil mapping also includes available water holding capacity at different depths (0.15, 0.30, 0.45, 0.60, 0.75, 0.90, 1.05 and 1.20 m).	Province of British Columbia (2020)
Monthly total solar Radiation	Solar radiation was estimated based on topographic surface (DEM), geographic location and time of the year. Solar radiation data (kJ m^{-2} day^{-1}) was obtained from WorldClim (http://worldclim.org/version2) at a resolution of 30 seconds (~1 km^2). This data was converted to watt hours per square meter (wh/m^2) per month for the model.	WorldClim (2020)

5.1.2 Model outputs

The model outputs are:

- **Potential Evapotranspiration (PE)** –the evaporative water loss from vegetation for which water availability is not a limiting factor. PE depends mainly on heat and solar radiation. Estimated using the Turc method.

- **Actual Evapotranspiration (AE)** – the water loss from vegetation given actual water availability (from precipitation and soil moisture storage). If water is not a limiting factor, actual evapotranspiration is equal to potential evapotranspiration.

- **Deficit** – the moisture stress and occurs when the evaporative and vegetation demand is not met by available water. In other words, it is the difference between potential and actual evapotranspiration.

- **Surplus** – the excess water that is not evaporated or transpired or stored in the soil. When soil moisture field capacity is reached, surplus leaves a site through either surface runoff or soil infiltration (groundwater recharge) or a combination of both.

Appendix 3 describes the water balance inputs and output for the study region including the Lake Weston Watershed.

5.1.3 Model calibration

Measured stream flow information for one hydrometric station, Fulford Creek near Fulford Harbour (08HA0020) were used to calibrate the water balance model. The measured flow data was downloaded from BC Aquarius web portal. Figure 12 shows the historical fluctuation of surface water flow and daily and monthly average of surface water flow for Fulford Creek station. Figure 13 shows the delineated watershed for the station.

5.1.3.1 *Water flux model calibration*

Water fluxes calculated with the water balance model were compared to measured flow values for the gauged watershed. Figure 13 shows the measured and modeled flows in cubic decameters (dam^3) for the gauged watershed, Fulford Creek near Fulford Harbour.

The difference in flow (modeled vs measured) could also be attributed to the following:

- Monthly Precipitation Grids are a result of an interpolation of the available climate normal data, the number and spatial distribution of climate stations and topography climate model correction. Errors will also result from interpolation, density of monitoring stations and altitude correction in the interpretation of the temperature grid data. There is no active climate station within the watershed.

- The water balance model does not include measured water extraction (i.e. well pumping volumes or surface water points of diversion). Additionally, water usage might have increased over time which might have influenced the modelled flows in watersheds where the water usage is large.

- The actual timing of snow melt has not been included in the model. Precipitation is the sum of snow and rain in the month they occur, however, most of the snow melt occurs in the late winter and early spring.

- The incompleteness of measured values. For example, Fulford Creek does not have normal data for the period 1981-2010.

5.1.3.2 *Model outputs acceptability assessment*

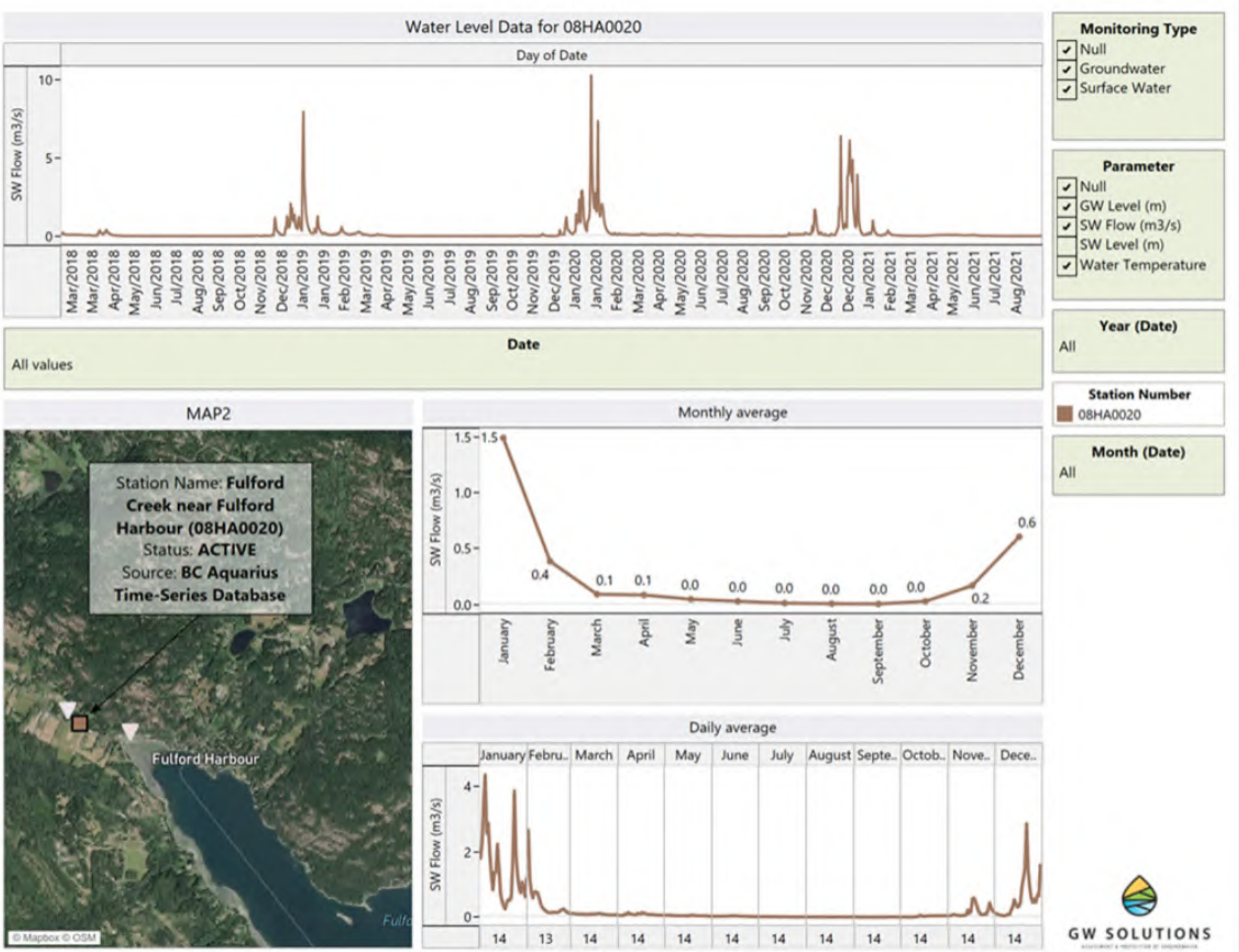
To evaluate the acceptability of the water balance model, measured flows were compared to modelled flows using three statistical approaches: Nash-Sutcliffe Efficiency (NSE), Percent Bias (PBIAS) and the RMSE-Observations Standard Deviation Ratio (RSR).

The statistical results are presented in Table 5. In general, NSE varies from negative infinity to 1 where close to 1 is highly satisfactory. RSR varies from 0 (highly satisfactory) to any large number. PBIAS is reported as percentage where the lower values indicate generally good match between modelled and measured values. GW Solutions considers a satisfactory model if NSE > 0.85, RSR < 0.40, and PBIAS < 15% for streamflow modeling.

Historical flow data for Fulford Creek is presented in Figure 12. The monthly comparison of modelled and measured flows for the Fulford Creek station (Figure 13) indicates a good match between modelled and measured flows.

Table 5. Statistical comparison between modelled and measured flows

Station Number	Station Name	Data Group	RSR	NSE	PBIAS
08HA0020	Fulford Creek near Fulford Harbour	From 2017 to 2021	0.10	0.99	5.5%



Station Name: **Fulford Creek near Fulford Harbour (08HA0020)**
Status: **ACTIVE**
Source: **BC Aquarius Time-Series Database**

Monitoring Type
☑ Null
☑ Groundwater
☑ Surface Water

Parameter
☑ Null
☑ GW Level (m)
☑ SW Flow (m3/s)
☐ SW Level (m)
☑ Water Temperature

Year (Date)
All

Month (Date)
All

Figure 12. Historical flow data for the Fulford Creek station (08HA0020)

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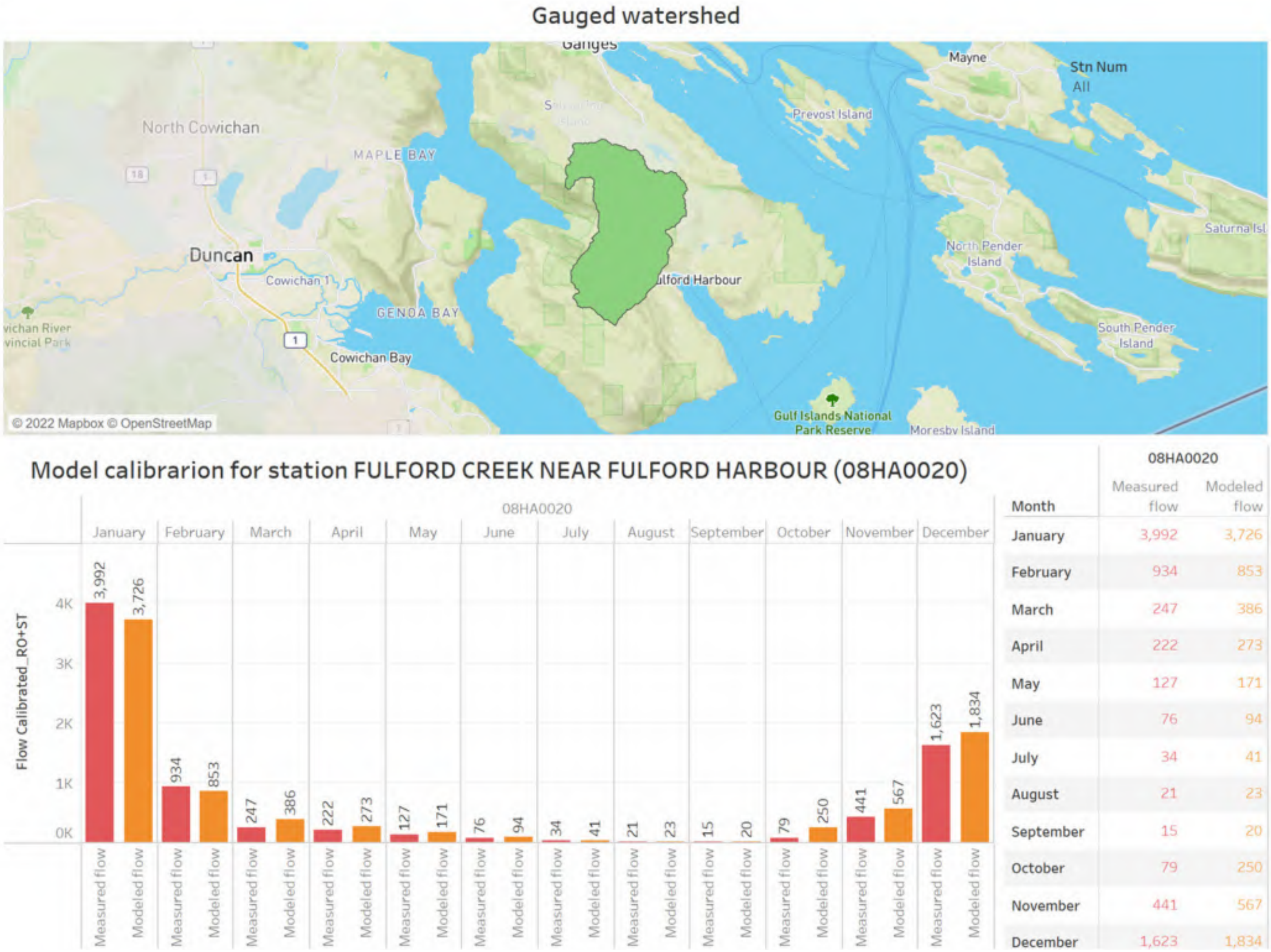

	08HA0020	
Month	Measured flow	Modeled flow
January	3,992	3,726
February	934	853
March	247	386
April	222	273
May	127	171
June	76	94
July	34	41
August	21	23
September	15	20
October	79	250
November	441	567
December	1,623	1,834

Figure 13. Monthly comparison of modeled and measured flows for the Fulford Creek watershed (08HA0020)

5.2 Estimation of Groundwater Recharge and Runoff

The water balance model estimates monthly potential evapotranspiration, soil moisture storage, actual evapotranspiration, soil moisture deficit, and soil moisture surplus (i.e. runoff and groundwater recharge). To differentiate the groundwater recharge component from the surplus, an equation for Groundwater Recharge Potential has been developed and applied. Figure 14 is a flowchart showing how the water surplus (i.e. groundwater recharge and surface water runoff) is calculated.

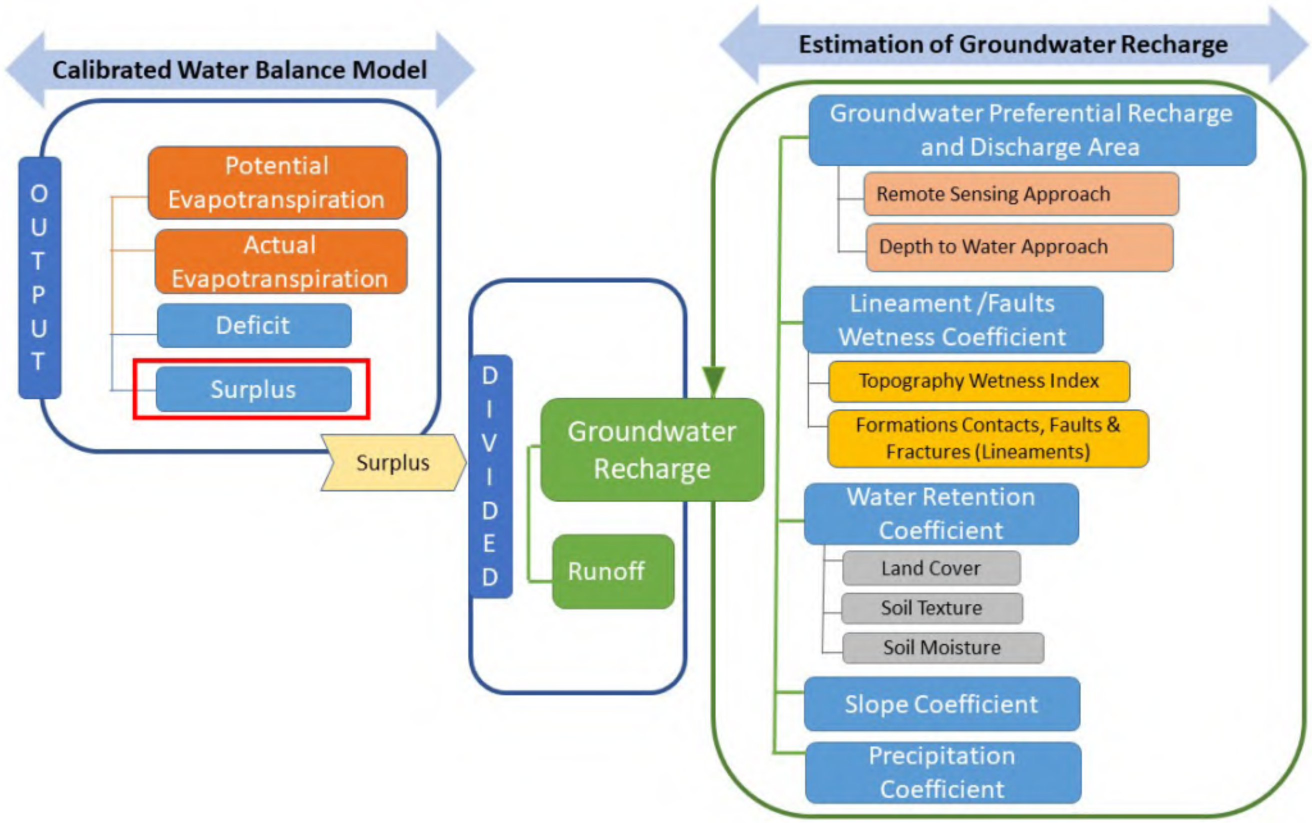

Figure 14. A flowchart presenting a differentiating the groundwater recharge component from surplus

5.2.1 Groundwater Recharge Potential

GW Solutions on behalf of Island Trust has developed a GIS-based methodology that incorporates diffuse and localized recharge pathways to estimate the spatial variability of recharge potential. The method uses infiltration/groundwater recharge coefficients for each of the spatial variables controlling recharge. Figure 15 is a flowchart for the integration of data inputs to estimate the groundwater recharge potential.

Groundwater recharge is the process whereby water moves from precipitation to the subsurface and consequently to replenish aquifers. Groundwater recharge is dependent upon factors such as the amount of precipitation (snow/rain), land surface slope (topography), the amount of water interception by plants (water retention or water used by plants), evaporation of open water or water on the land surface, and the permeability of the soil and subsurface geologic formations. Each of these factors is assigned an appropriate weighting factor in the calculation of recharge potential. Weighting factors were determined based on previous studies and predominant factors influencing groundwater recharge observed across Vancouver Island.

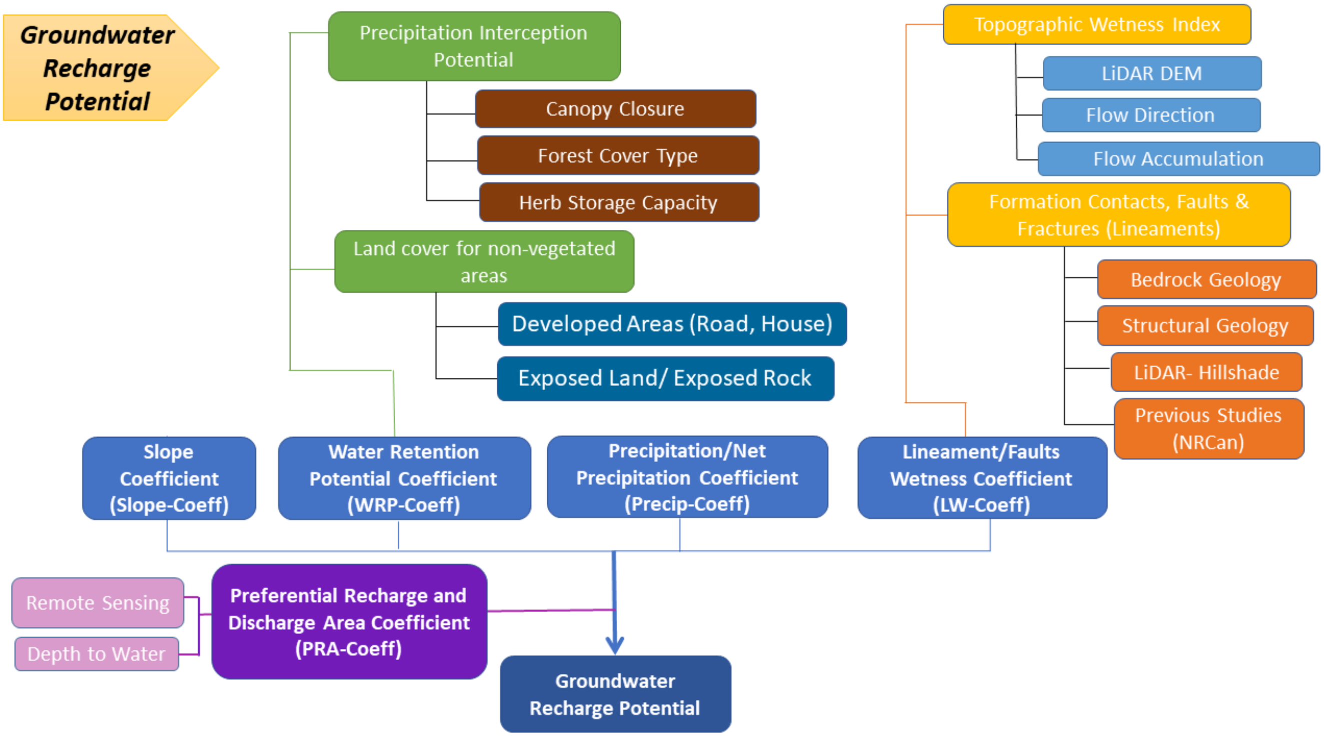

Figure 15. A flowchart showing the integration of data inputs to estimate the groundwater recharge potential

The following datasets or layers of information were used for groundwater recharge mapping and recharge estimation:

Slope Factor

Topography greatly influences the potential for water infiltration to the subsurface. In groundwater recharge areas, low slopes promote infiltration whereas steep slopes promote runoff and decreased infiltration.

LiDAR at 1-meter resolution as well as a 1-meter Digital Elevation Model (DEM) were downloaded from BC LiDAR and processed by GW Solutions. Slope was derived from the 1-meter DEM previously processed from LiDAR imagery.

Water Retention Potential (WRP) Factor

GW Solutions used vegetation effects and land cover data into a Water Retention Potential coefficient.

a) Precipitation Interception Potential

Vegetation affects groundwater recharge through the interception of precipitation by the foliage (i.e., evapotranspiration); Greater foliage interception leads to longer exposure to the atmosphere and increased evaporation. The Islands Trust recently investigated the role of soil and vegetation on precipitation, producing a precipitation interception potential map. The map was developed as follows:

- A literature review to determine which vegetation characteristics contribute significantly to precipitation interception.
- The Vegetation Resource Inventory (VRI) available for the Islands Trust region was correlated with vegetation interception characteristics.
- A weighting scheme was developed, based on the literature review, that assigns a relative importance of relevant VRI attributes that impact precipitation interception.
- The variables that have been considered for quantifying and mapping of precipitation interception include 1) Canopy Closure, 2) Forest Cover Type, and 3) Herb Storage Capacity. Each of the variables of interception were assigned a weight describing their relative importance to rainfall interception.
- VRI attributes were processed in GIS; assigned weighting values were used to create a surface representing precipitation interception potential for the Islands Trust area.

b) Land Cover/Land Surface

For non vegetated areas (exposed rock and developed areas), GW Solutions used NRCAN circa 2000 Land Cover vector polygons to derive land cover classes.

Bedrock geology; faults, lineaments and bedrock formation contacts

Groundwater in bedrock aquifers is mostly stored and transmitted in fractures and faults, which are largely controlled by regional bedrock lineaments (Surrett et. al., 2008; Allen et. al., 2002). Groundwater is also preferentially recharged via bedrock lineaments, however quantifying the role of each lineament is highly complex.

Detailed mapping of the landscape is now possible due to the availability of LiDAR imagery. The LiDAR imagery is processed to derive a “bare earth” model of the landscape, which can reveal subtle structures (bedrock faults, bedding planes and lineaments) not visible from the ground. We have delineated fracture zones using the following sources of information:

1- LiDAR with 1m resolution was obtained from LiDAR BC; Bedrock lineaments were digitized from a high-resolution hillshade

2- Bedrock geology maps of formation contacts and large-scale structural geology (faults and folds).

3- Lineament maps produced by NRCan, which have been reviewed and revised based on the LiDAR-1m.

The lineation is considered to be potential groundwater recharge pathways in the recharge zones and groundwater discharge pathways in the discharge zones.

Topographic Wetness Index

GW Solutions generated the Topographic Wetness Index (TWI) using the 1-metrer LiDAR. The TWI is commonly used to assess topographic effects on hydrologic processes. TWI is a function of the slope and the upstream contributing area. Large values of TWI are typically associated with low slopes (i.e. valleys or flat lowlands) and large catchment areas.

Precipitation

Annual total precipitation gridded data were obtained from the Pacific Climate Impact Consortium (PCIC, 2020). The information corresponds to normal data for the 1981-2010 period. Total annual normal precipitation varies across the study area from 880 to 1033 mm.

Preferential Groundwater Recharge and Discharge Areas

Groundwater recharge mainly occurs where the water table is deeper below the land surface and the soils are sufficiently permeable or “well-drained” to allow infiltration. The areas where the water table is shallow, intercepts the land surface (e.g. springs) and where groundwater feeds wet areas (e.g., creeks, lakes, wetlands) are known as groundwater discharge areas.

Groundwater recharge is typically characterized by the downward movement of groundwater while groundwater discharge is defined as the upward movement of groundwater to the land surface. Groundwater discharge areas are typically located in topographic lows such as stream valleys providing seasonal or year-round discharge (a.k.a. baseflow) to streams, or feeding lakes, wetlands, and estuaries. In contrast, groundwater recharge typically occurs in upland areas where precipitation rates are high and evapotranspiration is low, leading to high amounts of surplus (runoff and recharge).

Many approaches have been proposed for estimating the presence of preferential areas for groundwater discharge and recharge, using a variety of data sources. GW solutions reviewed several academic and public-sector methodologies to select methods for defining and delineating groundwater discharge and recharge potential areas that could be applied to the study area. Two approaches were selected:

- Interpreted depth to groundwater (inferred from the BC GWells database, and Salt Spring Island Leapfrog modelling).
- Remote sensing, satellite-based multispectral image analysis (from the Sentinel satellite mission 20x20 meter resolution)

These selected approaches and their applications are explained as follow:

a) *Depth to Groundwater Methodology*

The depth to groundwater is a dominant control of groundwater recharge across the Salt Spring Island. Previous studies have shown that the depth of water table has a significant role in controlling groundwater recharge rate. Despite surficial conditions that are suitable for groundwater infiltration, a shallow water table limits the amount of water that can infiltrate underground.

When a sufficient number of water level measurements are available in a given area, the depth of the water table is derived from the differentiation of elevation of the ground surface and groundwater elevation surface. We use the terminology “average interpreted groundwater elevation” and “depth to water” to describe the potential for groundwater recharge. For instance, if the groundwater level is above the ground surface, it will limit groundwater recharge and indicate mostly groundwater discharge is occurring. The opposite condition will occur when the groundwater level is below ground and groundwater recharge is the dominant process.

Average Interpreted Depth to Water = Ground Surface Elevation – Average Interpreted Groundwater Elevation

The Average Interpreted Groundwater Elevation surfaces were interpolated from classified groundwater elevation points derived from the Average Interpreted Depth to Water from BC Government’s GWELLS and the locations of known springs from surface water licences. Springs are locations where groundwater discharges to the land surface.

Using a Leapfrog 3-D model developed for Salt Spring Island, a surface of groundwater elevation (Groundwater Elevation Grids) was created then exported into QGIS as a raster file. The Average Interpreted Piezometric Level is the average water level in water wells. The Average Interpreted Depth to Water was generated by subtracting the Average Interpreted Groundwater Elevation from the Land Surface Elevation (DEM) using QGIS.

According to active monitoring wells across Salt Spring Island (e.g. PGOWN and SSI Island Trust community well network), the water table elevation can fluctuate by several meters over the year; groundwater levels are closer to the ground surface in winter and deeper in late summer/early fall. This leads to areas with *temporary groundwater discharge*, especially in the spring or after major rain events, yet these areas are groundwater recharge areas for the remainder of the year. For example, this could include areas at high elevation (i.e. Mount Belcher) where wells periodically exhibit artesian conditions.

For this study, all areas with either permanent or temporary groundwater discharge were classified as groundwater discharge areas. Areas where the range of groundwater fluctuations is always above the water table were classified as groundwater recharge areas.

b) Remote Sensing/ Satellite Multispectral Image Analysis Methodology

The approach of using satellite multispectral image analysis includes application of the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI). This method was chosen due to its ease of implementation, reliance on free and publicly available data, and accuracy in identifying soil moisture levels on the landscape. Soil moisture level is then used as a proxy for groundwater discharge potential.

The method focuses on identifying areas of potential groundwater discharge by using the spectral signatures of soil moisture and green vegetation. High perennial (year-round) soil moisture can darken soils or encourages green vegetation to flourish in otherwise dry climatic conditions. Such indications of landscape “wetness” and “greenness” are thus indications of potential groundwater discharge, and can be isolated from the rest of the landscape using satellite-based spectral indices.

A *spectral index* can be understood as a mathematical manipulation of certain wavelengths of detectable light that are designed to highlight characteristics of the landscape, such as greenness or wetness, while minimizing other confounding effects. A vast number of spectral indices have been defined for various scenarios. The NDVI (Normalized Difference Vegetation Index) and the NDMI (Normalized Difference Moisture Index) are both well-known and widely used indices that have been applied to a broad variety of applications for detecting landscape wetness or vegetation.

The NDVI is designed to highlight the presence of dense, green vegetation, or “greenness”, while the NDMI is designed to highlight the level of moisture within vegetation or soil, defined as “wetness”. By comparing landscape “greenness” and “wetness” between the wet season and the dry, it is possible to observe which areas of the landscape *preserve* their wetness and greenness through the wet and into the dry season. Such areas indicate either direct groundwater discharge (e.g., spring, wetland, lake) or a shallow water table allowing the survival of phreatophyte (groundwater dependent) vegetation. Comparisons between the wet and dry seasons are critical since the method relies on isolating the *persistence* of wetness between seasons.

Implementing this method required multispectral satellite images for the wet and dry season over the study area. These images were available free of charge from both the Landsat and the Sentinel satellite missions. Data from the sentinel mission was preferred due to its higher spatial and spectral resolution compared to Landsat.

C) Preferential recharge/discharge areas (PRDA)

The *Depth to Water* and *NDVI-NDMI* methods were selected as inputs to estimate the spatial variability of recharge/discharge potential. Both these methods could be implemented with the available data, and their respective results matched well.

Based on the groundwater discharge probability maps, an attribute ratings system has been developed to assign specific values to each groundwater discharge/recharge probability group. Table 6 presents the assigned groundwater recharge coefficients based on the discharge/recharge probabilities.

The areas of low probability of groundwater discharge (low-medium, low, very low), are the preferential areas for groundwater recharge.

Table 6. Groundwater recharge potential coefficient based on the probability of groundwater discharge.

Groundwater Recharge Potential	Probability of Groundwater Discharge Area	Groundwater Recharge coefficient
Very Low	High probability	0.1
Moderate	Medium probability	0.3
Moderately High	Low-Medium probability	0.7
High	Low probability	0.9
Very High	Very Low probability	1

5.2.2 Calculation of groundwater recharge potential

GW Solutions has used the following equation (Equation 1) to estimate the groundwater recharge potential.

Within the study area, the groundwater flow system is in both bedrock and overburden media, thus the sum of slope, soil and land cover, precipitation coefficients, and also geological structure coefficient (e.g. faults, geologic contacts) determine the areas of high potential groundwater recharge.

Equation 1) $RP = R_{\mathbf{PRDA}}\ [30\%*(R_{WRP}) + 20\%*((R_{slope}) + 25\%*(R_{LW}) + 25\%*(R_{precipitation})]$

Where:

RP= Recharge potential (0 - 1)

$R_{\mathbf{PRDA}}$= Preferential recharge/discharge areas Factor (0.1-1)

R_{WRP} = Water Retention Potential Factor (0.1 – 0.3)

R_{slope} = Slope Factor (0.03 – 2.0)

R_{LW} = Bedrock Lineaments Wetness Factor (0.1 – 0.25)

$R_{precipitation}$ = Precipitation Factor (0.1 – 0.25)

Appendix 2 provides the maps for all groundwater recharge coefficients. Figure 16 presents the resulting map for the integrated groundwater recharge potential.

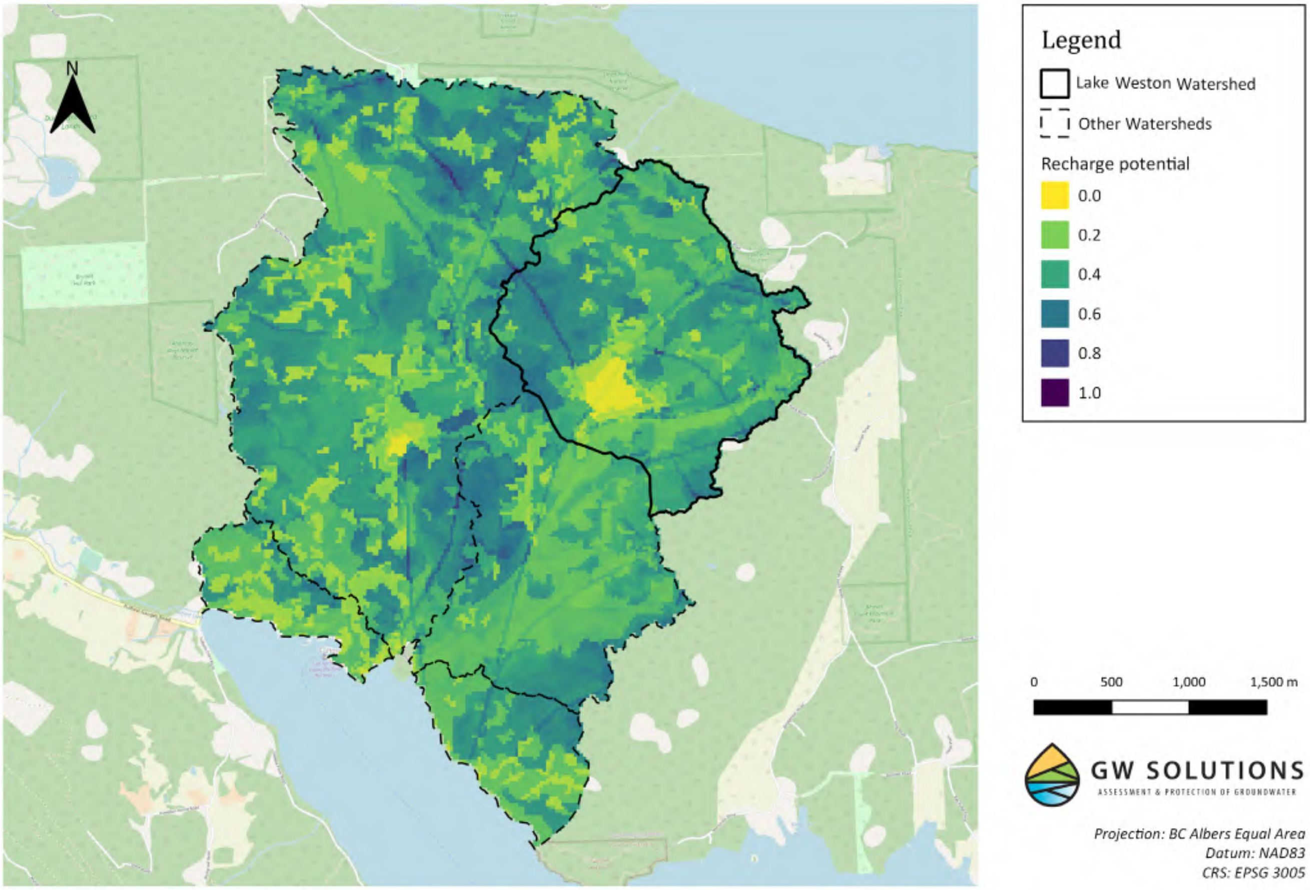

Figure 16: Groundwater recharge potential map for the study region

5.3 Sensitivity Analysis

The Sensitivity Analysis for the water balance analysis consisted of evaluating twelve scenarios which represent the range of possible variations for the following input parameters:

- Precipitation
- AWHC Available Water Holding Capacity (water available to vegetation)
- Solar Radiation
- Temperature

The scenarios, listed in Table 7, are designed to vary the inputs by either + or -15% from normal (i.e. long-term average). Precipitation was also varied by the most extreme values ever recorded (lowest and highest) at meteorologic station 235 (Victoria International Airport). Solar radiation was also varied for only the summer months when values are the highest.

Table 7. Scenarios for Water Balance Sensitivity Analysis

Parameter	Scenario
AWHC	-15% from normal
AWHC	+15% from normal
Precipitation	-15% from normal
Precipitation	+15% from normal
Precipitation	Driest condition experienced in 1985
Precipitation	Wettest condition experienced in 1997
Solar radiation	summer months +15% from normal
Solar radiation	summer months -15% from normal
Solar radiation	all months +15% from normal
Solar radiation	all months -15% from normal
Temperature	+15% from normal
Temperature	-15% from normal

The results, summarized in Figure 17., show that for the study area the most sensitive input parameter is precipitation affecting the surplus estimates by -50% to +87%. The remaining input parameters affect recharge by less than 5%. This highlights the importance of collecting more complete precipitation data over the entire watershed to reduce the uncertainty of this parameter.

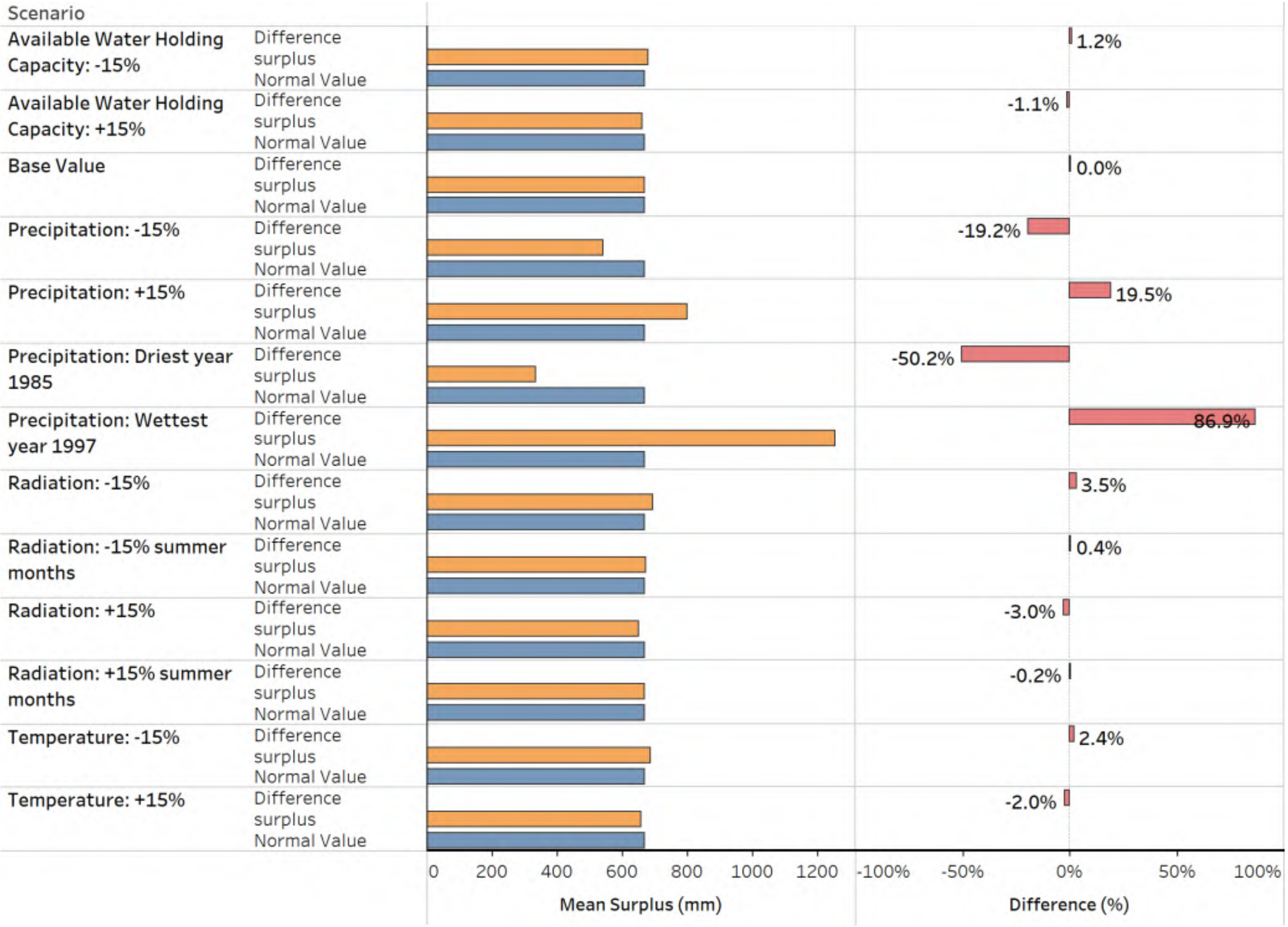

Figure 17. Results of Sensitivity Analysis to water balance inputs

6 CLIMATE CHANGE ASSESSMENT

6.1 Impacts of Climate Change on Freshwater Resources

Over the past 50 years, the amount of rain falling during very heavy precipitation events has increased for much of the world as the amount of rain falling during the most intense 1% of storms has increased as much as 30%. Warming winter temperatures cause more precipitation to fall as rain rather than snow. Furthermore, rising temperatures cause snow to begin melting earlier in the year. This alters the timing of streamflow in rivers that have their sources in mountainous areas.

Alterations in the seasonal timing, type (rain versus snow) and amount of precipitation in a certain area effects the entire freshwater cycle. Shorter and more intense rainy seasons increase surface water runoff and decrease groundwater recharge leading to a lowering of the water table and less groundwater discharge to groundwater dependent ecosystems (e.g., shallow aquifers, springs, creeks, rivers, lakes, wetlands, and estuaries). Thus, there is too much water in the winter and too little water in the summer.

Climate change is probably one of the most challenging pressures facing freshwater resources. Climate change is expected to produce reductions in freshwater availability in the future. The key change associated with global warming is an increase in near-surface air temperature which has profound negative impacts on the global water cycle affecting all freshwater systems. The increase in surface temperature leads to several changes to freshwater resources, as described below, in Table 8.

Table 8: Climate change impacts on water resources

Climate impact	Description
Decreased Snowpack	Decreased snowpack can significantly impact dry-season water availability. If precipitation falls as rain instead of snow, then groundwater recharge occurs throughout the winter instead of the usual pattern of a spring groundwater recharge event. The spring recharge event helps maintain a high water table at the beginning of summer when precipitation is reduced and water levels in general are at their lowest. Continued recharge through the winter results in a shift in peak river runoff to winter/early spring, away from late spring/summer (when water demand is often highest) thus leading to drier or potentially drought-like conditions in late summer/autumn.
Higher Evapotranspiration	Higher evaporation (from all surfaces, soils, and water bodies) and higher transpiration occur due to an increase in temperature, leaving less water to infiltrate into the soil and causing a reduction in groundwater recharge.

Climate impact	Description
Higher Intensity Rainfall Events	When the atmospheric temperature is warmer, particularly during the summer months, the increased evapotranspiration causes precipitation events to tend to occur as high-volume, high-intensity events, especially during winter months. Sporadic, high intensity rainfall – rather than low-volume, temporally distributed rainfall – tends to produce a large amount of surface runoff (soil erosion, flooding) but very little groundwater recharge as there is a limit to the amount of water that can infiltrate in most soils at any given time, based on the soil's "field capacity".
Degradation of Water Quality	Decreased groundwater recharge or increased sporadicity in the timing of recharge can lead to a reduced amount of freshwater to dilute water contamination (e.g., saltwater intrusion, nitrogen/phosphorous from septic systems leading to algal blooms, acid mine drainage), especially during the dry summer months. This can result in increased concentrations of harmful substances in the water (water pollution), negatively affecting aquatic ecosystems, and undermine the health and sustainability of groundwater and groundwater-dependent ecosystem. These reduced-flow conditions may also result in the accumulation of water-borne contaminants at water supply intakes being used by humans and animals, and the deterioration of lakes and rivers often used for recreational purposes. Changes in hydrological and thermal regimes may further increase the risk of disease outbreaks in aquatic systems, impact eutrophication, create hypoxic and dead zones, as well as lead to community transitions that alter ecosystem structure and function.

6.2 Projected Climate Change for the Capital Regional District

The 2017 report Climate Projections for the Capital Regional District (CRD) uses current climate model outcomes to provide a "best estimate" snapshot of how climate change will unfold across the CRD over the coming decades. All models project daytime high and nighttime low temperatures to rise. While temperature can be expected to increase year-round, the greatest increases will occur in the summer months. Monthly high and low temperatures show that the "new normal" for the region may be very unlike the past. Rising temperatures will lead to hotter summer days and nights, milder winters with the near loss of frost days and snowpack in all but the highest elevations. There will be a modest increase in annual precipitation by the 2050s, though the increase in precipitation will be distributed unevenly over the seasons. The largest increases will occur in the fall season, while rain will decrease significantly in the summer months. Our region can expect stronger and more frequent extreme rainfall events, longer summer dry spells, and an extension of the dry season into September and October.

6.3 Model-Predicted Climate Change for the Next Decades

The impact of climate change to the water resources of the study region was analyzed using data from the ClimateBC data project (Wang et al., 2016), which provides statistically downscaled climate projection data across BC, based on a selection of models from the IPCC's most recent *Coupled Model Intercomparison Project* (CMIP6). The CMIP6 *Global Climate Models* (GCMs) aim to estimate the patterns of future climate change under different scenarios of climate "forcing". These scenarios are called "shared socio-economic pathways" (SSPs) and are meant to represent various possible socio-economic pathways that society could take to attend to climate change in the coming years (Riahi et. al., 2017). In the present analysis, 4 SSP scenarios have been considered, SSP 2.6, 4.5, 7.0 and 8.5 spanning the range from most optimistic (high rates of emission reduction and mitigation policies over the coming decade) to pessimistic (little to no climate change mitigation, leading to runaway climate change). Additionally, future climate change under each of these scenarios has been predicted for three time-periods – 2030, 2050, and 2070. Further details about climate models and input data selection are presented in Appendix 4.

Once data representing projected climate change for the 4 SSPs in the three future periods was obtained, we calculated future projected water budgets for each of these scenarios and compared the results to the current "normal" values observed in the past 30 years (1981-2010). The comparison was done spatially over the Lake Weston watershed as well as its adjacent watersheds. Model-predicted changes to the Lake Weston water budget are thus described for each climate variable followed by an interpretation of how these changes will impact water resources in the region.

The data is presented in two types of figures to show the predicted changes across the watershed for the major climate and water budget variables (temperature, precipitation, soil storage and moisture surplus). Charts are generated for every combination of projection years and SSP scenarios:

- charts for each variable by month, showing: the projected values, the absolute change in the value compared to present normals and the percentage change in the value compared to normal

- summary charts comparing the percentage change of all variables compared to normal ; and

- maps of Lake Weston and the surrounding watersheds showing the predicted amount of change for each variable and how it varies within each region

Figure 18 presents an example for summary charts comparing the percentage change of climate variables such as precipitation, temperature and radiation for different projection year compared to normals for SSP 8.5.

Figure 19 to Figure 21 show the spatial change of predicted climate variables comparing to normals for the projection year of 2050 for SSP 8.5.

Appendix 4 provides the summary charts and related maps for predicted climate variables and their comparison to normals for 4 SSP scenarios (SSP 2.6, 4.5, 7.0 and 8.5) and for three time-periods – 2030, 2050, and 2070.

The projected data from the 13-model ensemble predict a significant increase in precipitation during the winter, and a smaller yet still considerable increase in spring and fall precipitation. The magnitude of increase is greatest during the December to February period. The data also predict a decrease in summer precipitation. These patterns are consistent across all the SSP scenarios, and indeed the magnitude of these changes is higher the more pessimistic the SSP is.

Solar radiation is projected to increase during the summer months and decrease during the fall and spring periods, remaining relatively unchanged during the rest of the winter. Interestingly, the magnitude of change is projected to be the strongest within the 2030s period, suggesting that the most meaningful shifts in radiation patterns will happen within the next 2 decades. As with precipitation, the magnitude of change is higher with more pessimistic SSPs. Additionally, all SSPs and year periods seem to project a slight increase in radiation during March alone, amid an otherwise reduced-radiation Spring.

Average temperatures are projected to increase in all months for 2030, 2050 and 2070 across all SSP scenarios, with the highest increases being in July and August. Even under the most optimistic scenario (SSP 2.6), temperatures are projected to rise by nearly 2 degrees Celsius in July and August by 2070. In contrast, under SSP 8.5 the projected increase in July and August is nearly 5 degrees.

Available moisture surplus is projected to increase considerably during the winter months of December to February, while also increasingly slightly during the fall months of October and November. Additionally, surplus is projected to decrease during the spring period, especially in March. As with the others, the magnitude of these patterns is exacerbated under less optimistic SSPs.

These patterns are consistent with changes expected under climate change globally. Increasing temperatures, particularly during the summer months, combined with higher solar radiation and lower summer precipitation will mean a reduced potential for groundwater recharge during the summer. The current hydrological regime, however, already operates within a pattern of excess water during the winter months and low precipitation during the summer. The impact of climate change on this system appears to be a reduction in the available window or annual time-period for groundwater recharge.

Precipitation is projected to occur in higher magnitudes within a smaller time-period (primarily December to February). There is also an increase in precipitation during September which is attributed to rain events associated with the change in seasons from summer to fall weather patterns. This combined with reduced solar radiation during months leads to an excess of moisture surplus during the winter, increasing the possibility of flash flooding since the capacity for groundwater infiltration at any given time cannot be exceeded upon saturation. Furthermore, reduced precipitation and higher temperatures during the summer reduces the potential for groundwater recharge during the months when groundwater uptake is greatest. The projected decline in moisture surplus during March illustrates a reducing temporal window within which moisture surplus can recharge aquifers. Overall, these patterns will adversely affect the sustainability of the groundwater system by leading to a pattern of excess water when it is not needed and water deficits during periods when it is necessary.

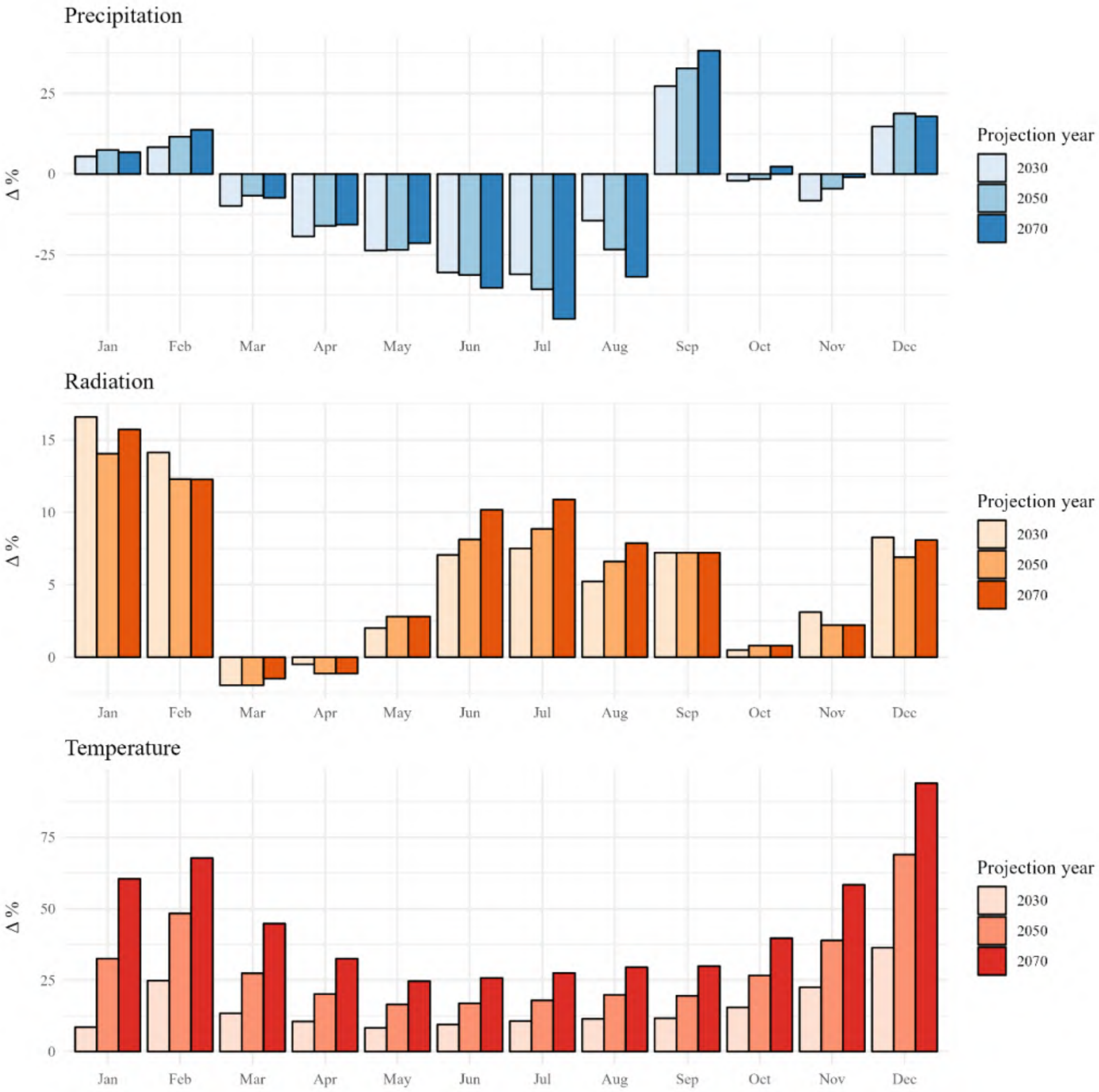

Figure 18. Percentage change relative to climate normal, summarized by month for the Lake Weston watershed, SSP 8.5

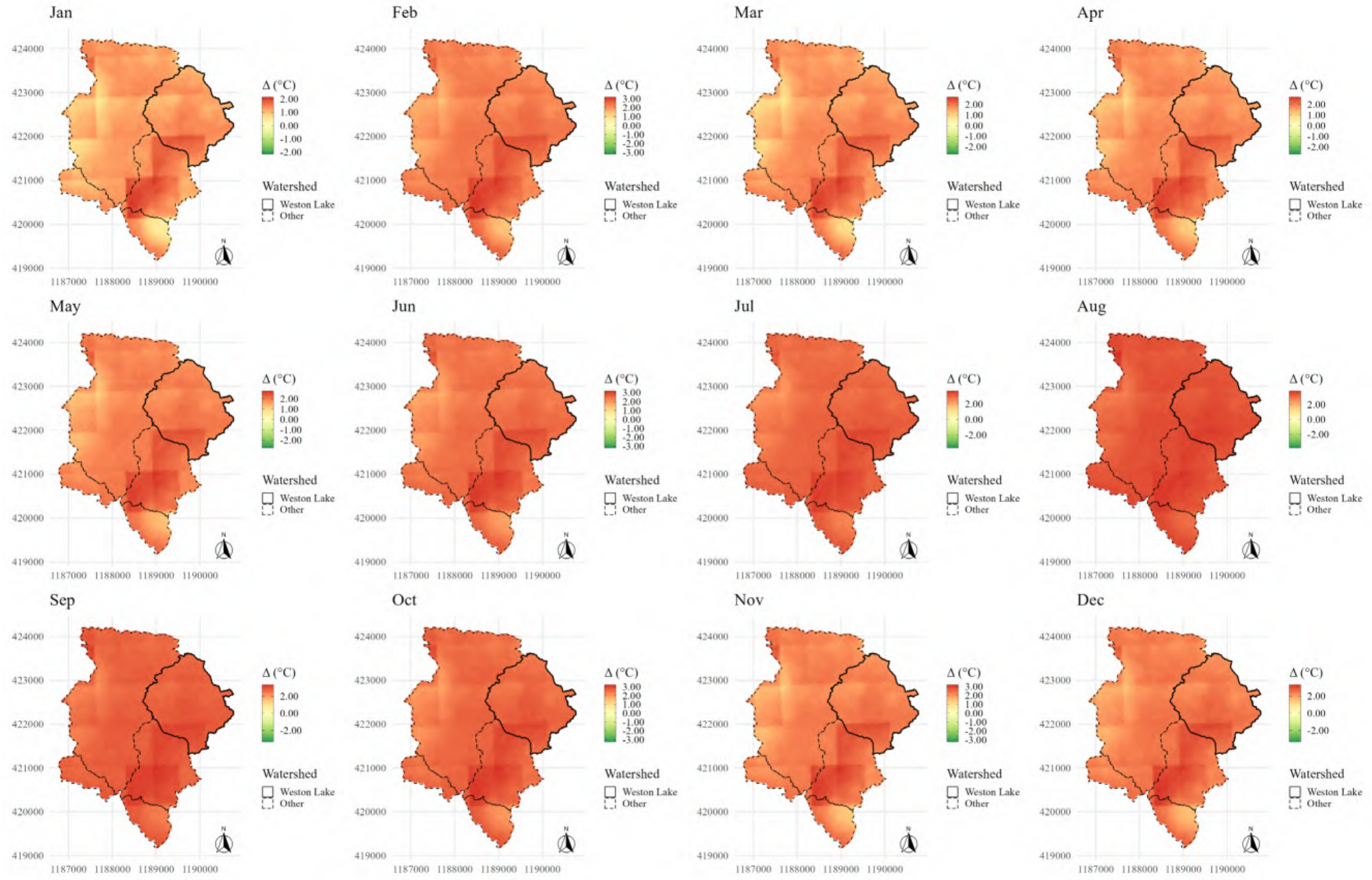

Figure 19: Monthly change in average temperature between year 2050 and present normals, SSP 8.5

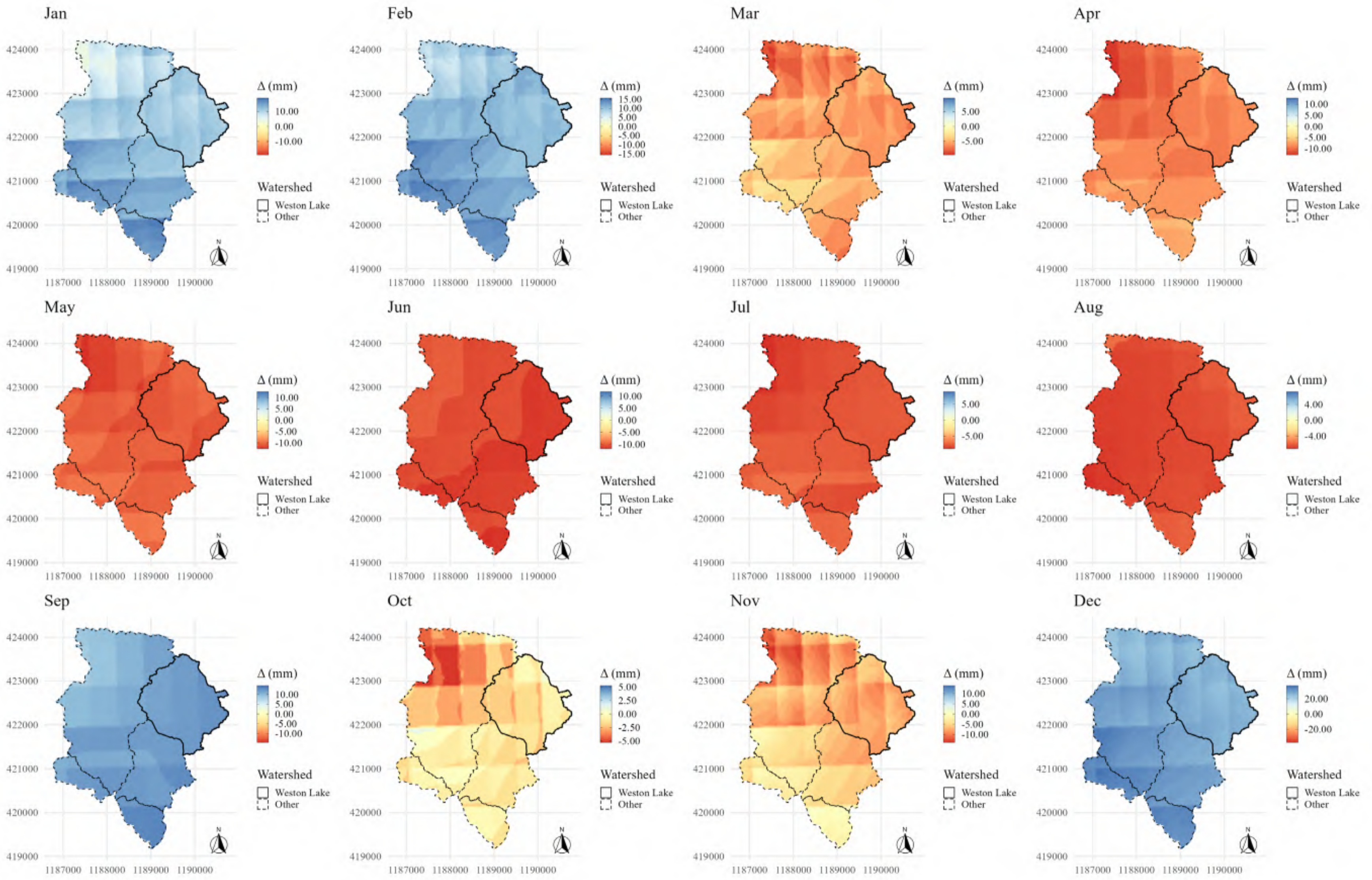

Figure 20: Monthly change in precipitation between year 2050 and present normals, SSP 8.5

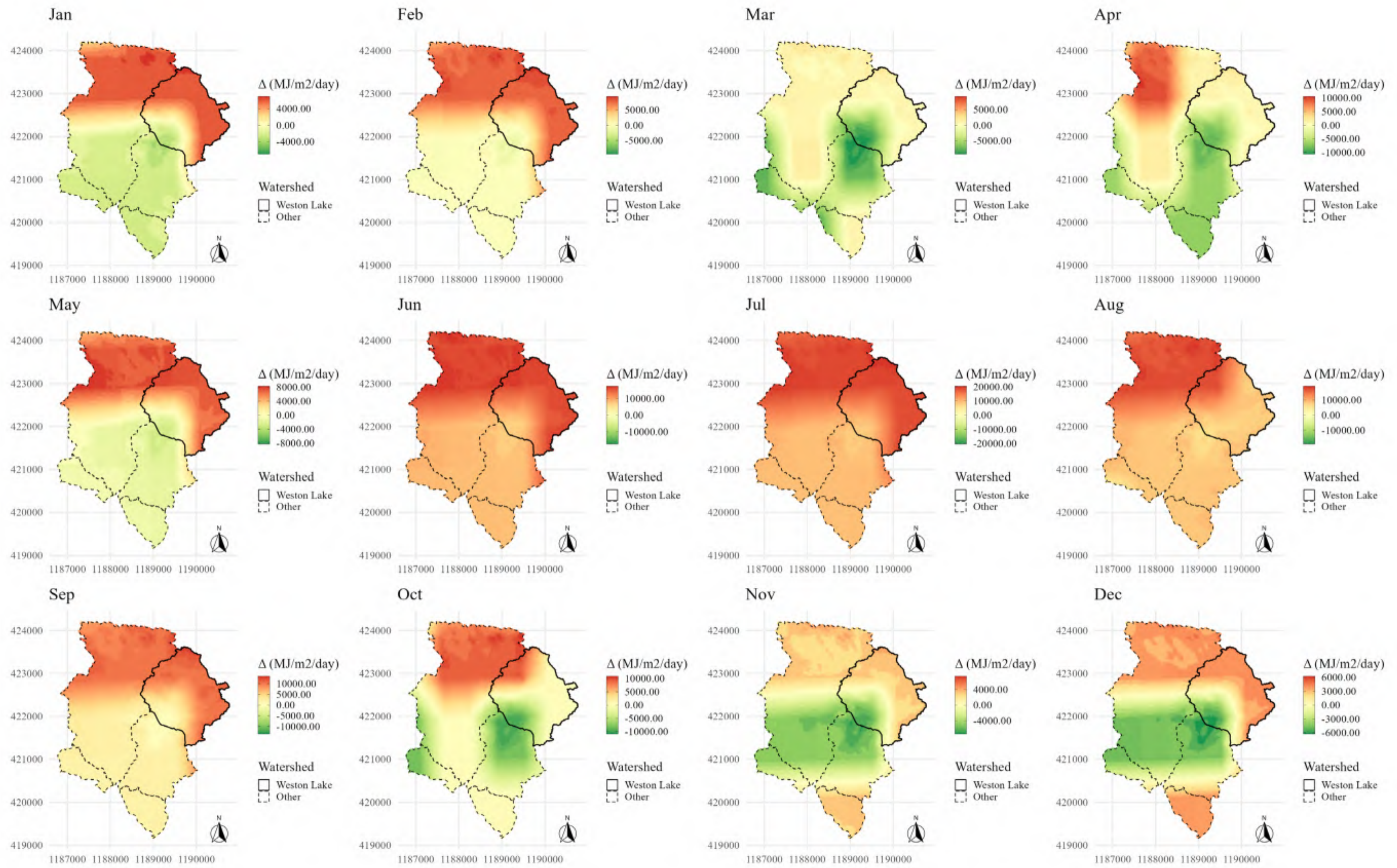

Figure 21: Monthly change in radiation between year 2050 and present climate normals, SSP 8.5

6.3.1 Temperature

Minimum, average, and maximum temperatures are projected to increase in all months for 2030, 2050 and 2070 across both modeled areas, with the largest increase in July and August.

6.3.2 Precipitation

Generally, the climate change model predicts a significant increase in precipitation for fall and winter (October to February), mostly as rain, and a slight increase in spring precipitation. The model also predicts a considerable decrease in precipitation in summer. Precipitation as rain therefore occurs over a shorter period (fall-winter) with more intense rainfall events thus leading to an increase in surface water runoff (increasing soil erosion and flood risk) and a decrease in groundwater recharge as the soil infiltration rate is limited as soils become saturated to their field capacity.

The largest increase in precipitation (during winter) and the largest decrease in precipitation (during summer) occurs at the higher elevations where most of the precipitation falls.

6.3.3 Solar Radiation

Solar radiation is projected to increase during the summer months and decrease during the late-winter, early-spring period, remaining relatively unchanged during the rest of the winter.

7 RESULTS ANALYSIS

7.1 Water Usage

Water use is estimated in cubic decameters or dam^3 (1,000 m^3 equals 1 dam^3) and presented for groundwater (Aquifer 1147) and Surface Water (Lake Weston). Figure 22 shows the results for the current estimated water usage including the fire protection licence. Figure 23 shows the seasonal usage for both surface water and groundwater resources without the fire protection licence.

The Lake Weston withdrawals are much larger than the groundwater withdrawals and the fire protection licence (institutional) water usage is by far the largest amount. Aside from the fire protection licence, the major water usage is for the Fulford Water System. It is noted the Fulford system usage increases significantly in July, August and September presumably due to household irrigation. There are also several private domestic water supplies taken and significant amount of water usage for irrigation taken from Lake Weston. Many residents within the study area obtain their domestic water from groundwater wells (15.74 dam^3- aquifer 1147). It is also noted that the highest water usage from Lake Weston is the May-September period. This contrasts to groundwater usage which is similar in summer and winter.

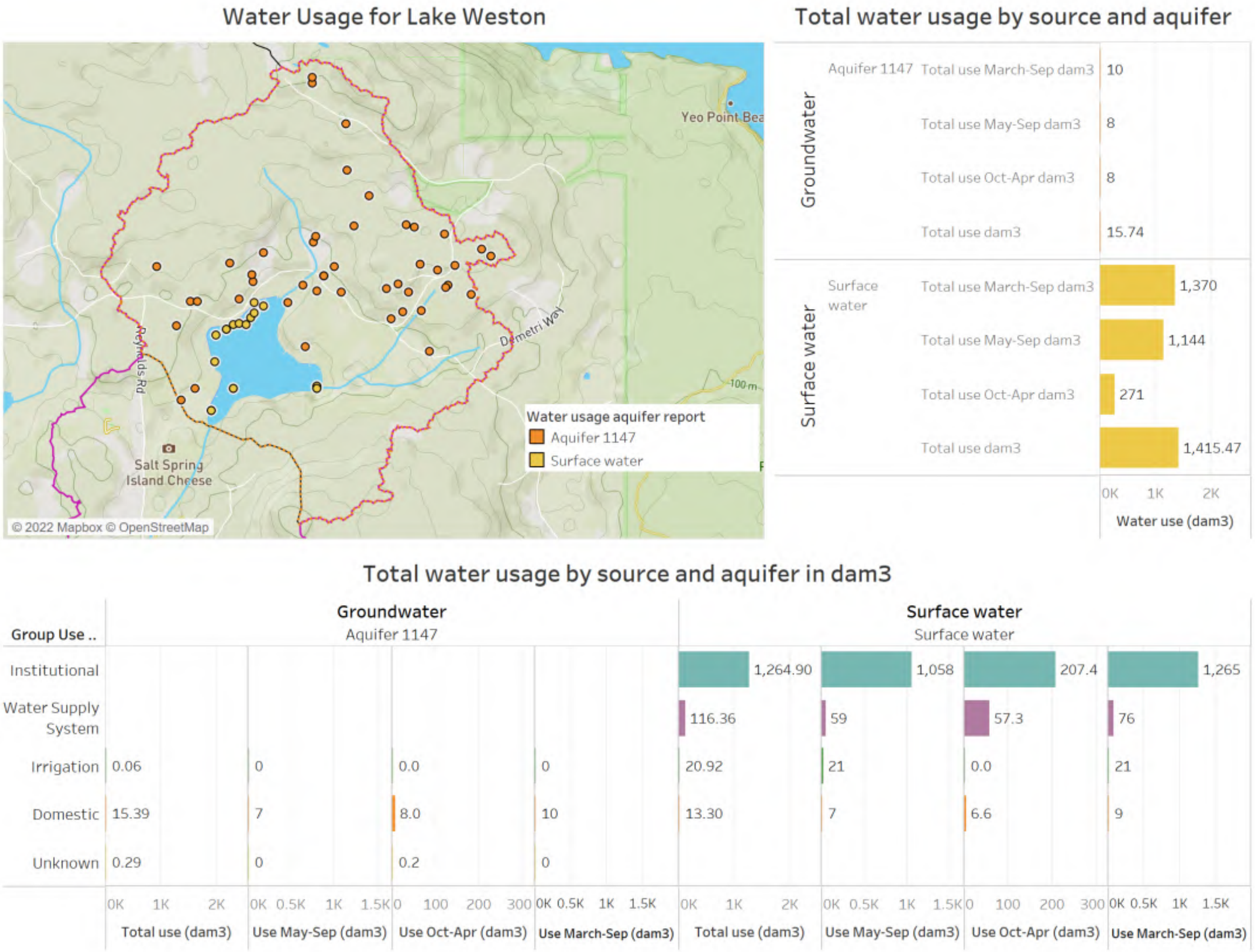

Figure 22. Total water usage by aquifer number and licenced surface water source (including fire protection licence)

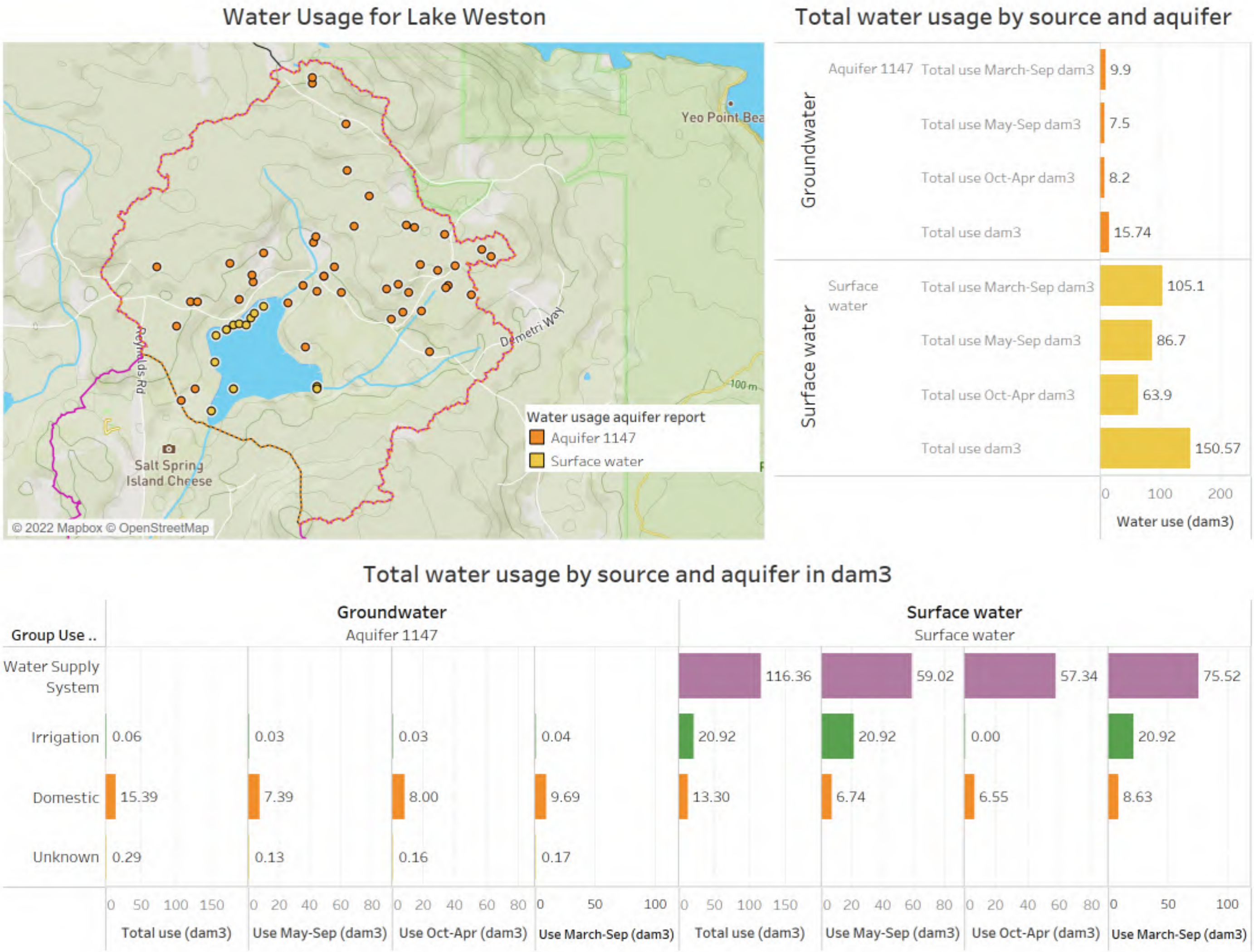

Figure 23. Total water usage by aquifer number and licenced surface water source (not including fire protection licence)

7.2 Watershed Budget

The groundwater surplus in a watershed is the difference between in the annual volumes of groundwater recharge and groundwater usage for a watershed or aquifer. This surplus groundwater is a major component of the water cycle and feeds springs, creeks, rivers, lakes, wetlands and coastal areas and is accounted for in B.C. as environmental flow needs (EFNs).

Figure 24 presents the water balance components for an entire year, including precipitation, evapotranspiration and water surplus (surface water runoff and groundwater recharge). On the usage side, it can be seen that groundwater usage (16 dam^3) is significantly less than surface water usage (Lake Weston 151 dam^3) and both are significantly less than groundwater recharge (615 dam^3) which feed the groundwater and Lake Weston.

Figure 25 shows the seasonal water balance components (Wet: October to February and Dry: March to September). It is observed during the dry period (March to September) the water usage is larger than both runoff and groundwater recharge.

Figure 26. presents the average monthly water balance components and water usage for the study region. It can be seen the highest water usage is from April to September which also coincides with the period of little or no precipitation, groundwater recharge or runoff.

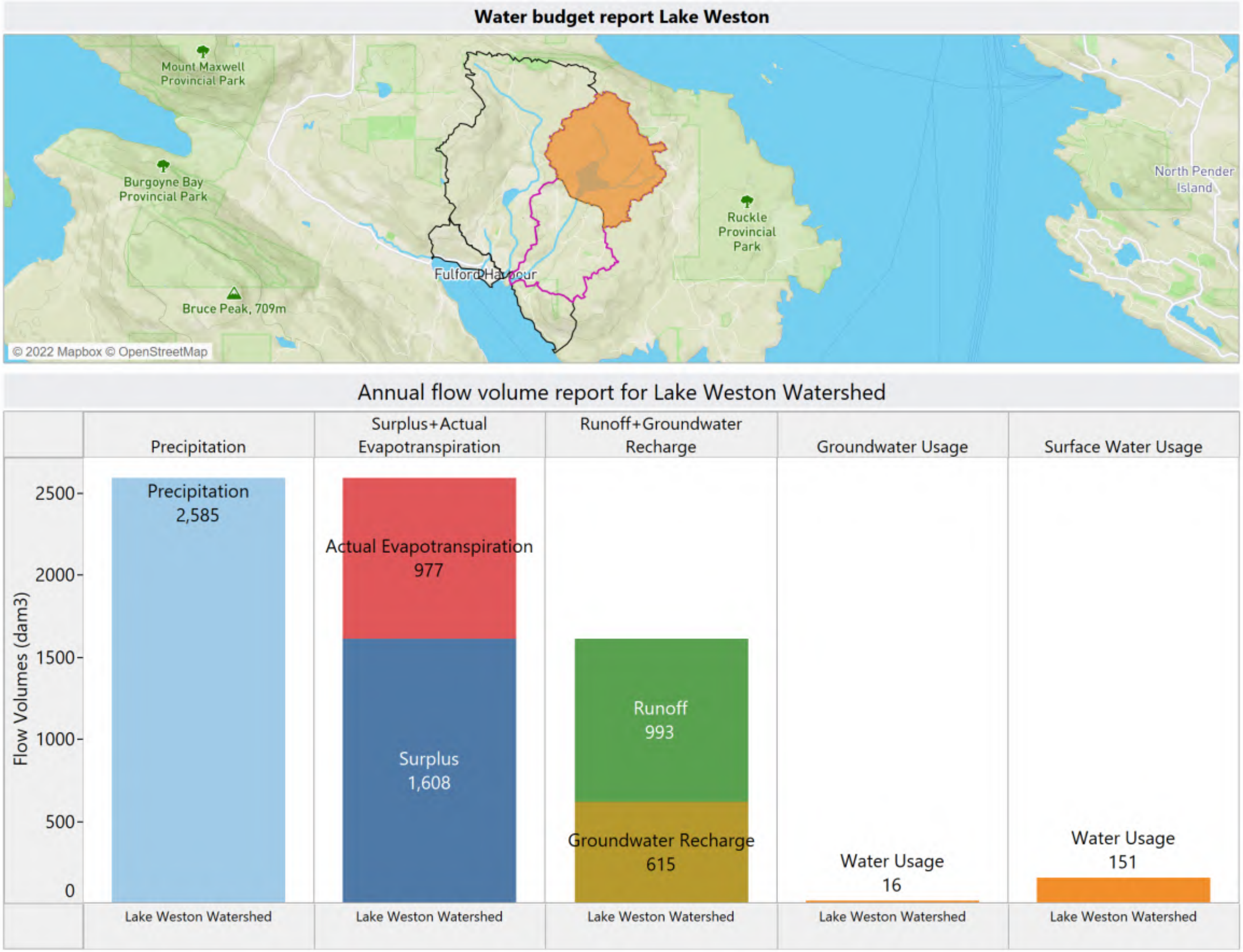

Figure 24: Water balance components compared to water usage from groundwater and surface water (Fire protection licence not included).

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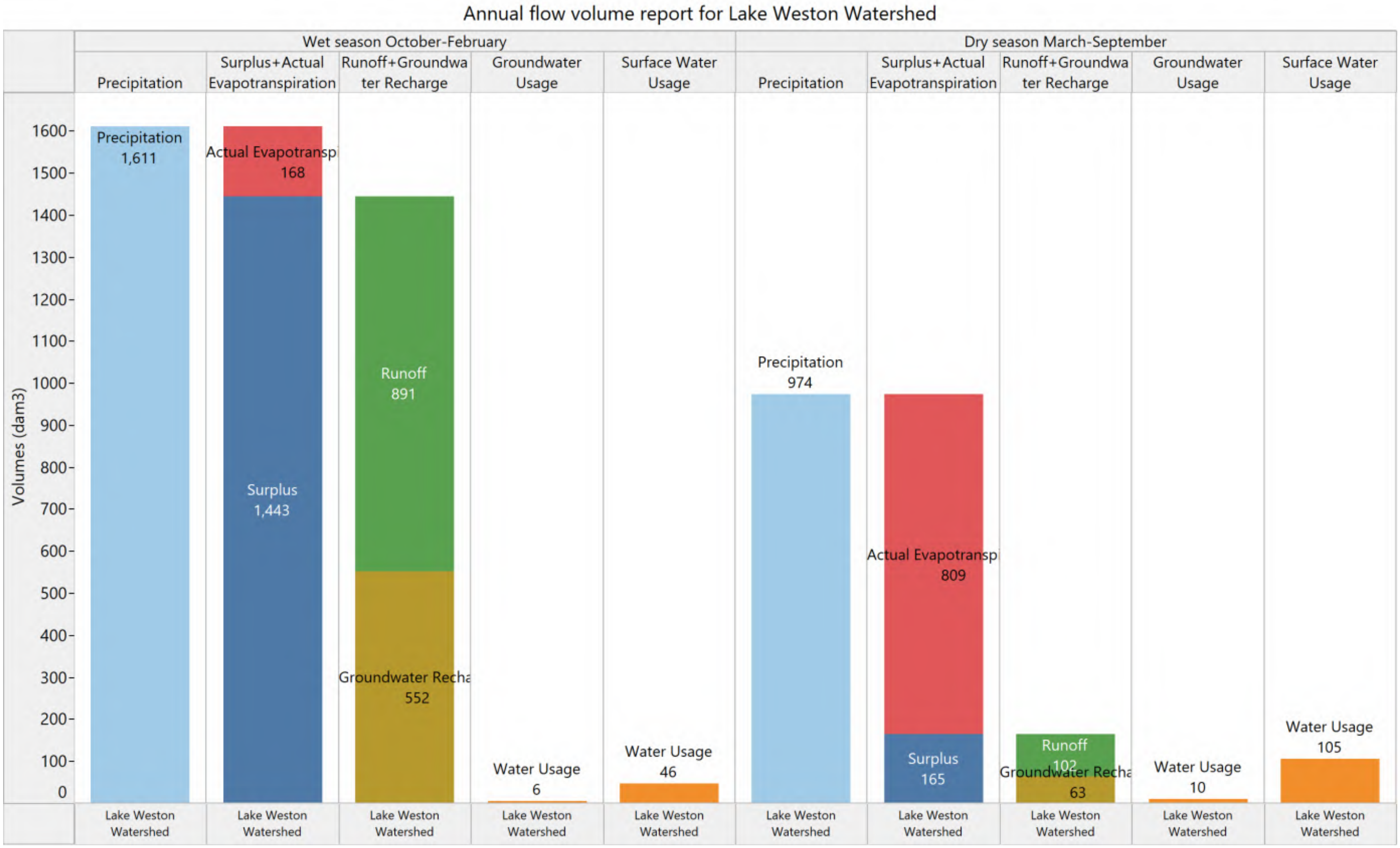

Figure 25. Annual water budget volumes for the wet season (Oct-Feb) and dry season (Mar-Sep) (Fire protection licence not included).

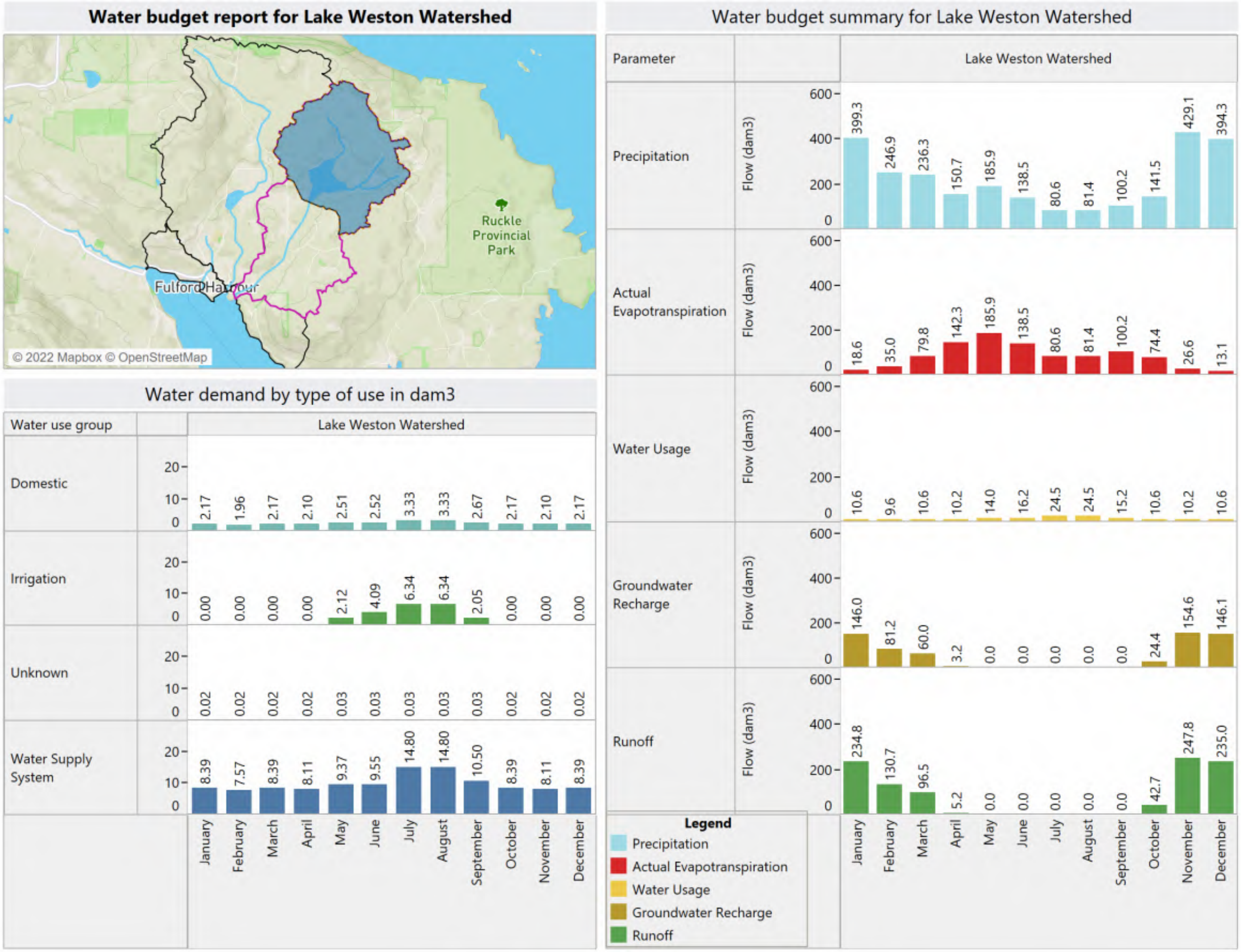

Figure 26. Monthly water demand by type of use and water budget summary (Fire protection licence not included).

7.3 Climate Change Predictions for the Lake Weston Watershed

The climate of the Lake Weston watershed is predicted to be significantly different in the coming decades. The winters will be warmer with more rain and less snow. The rain will fall over a shorter period (i.e. more intense events) leading to higher levels of surface runoff potentially leading to higher soil erosion and flooding and less groundwater recharge as saturated soils do not allow for infiltration. The spring snowmelt will tend to disappear reducing the historical groundwater recharge heading into the dry summer months. During summer, temperatures will be higher, precipitation lower and groundwater baseflow (feeding creeks, lakes, wetlands) will therefore be lower. It will be common to experience too much water in winter and droughts in summer.

Estimated runoff for March to September (Figure 27), October to February (Figure 28) and December to January (Figure 29) is presented for various climate severity scenarios for the years 2030, 2050 and 2070. For the summer months, runoff is predicted to decrease significantly (-20% to -30%) while in the winter months runoff will increase by a small amount (2% to 4%). This reduction in runoff is translated to water deficit in the future where demand will surpass surplus.

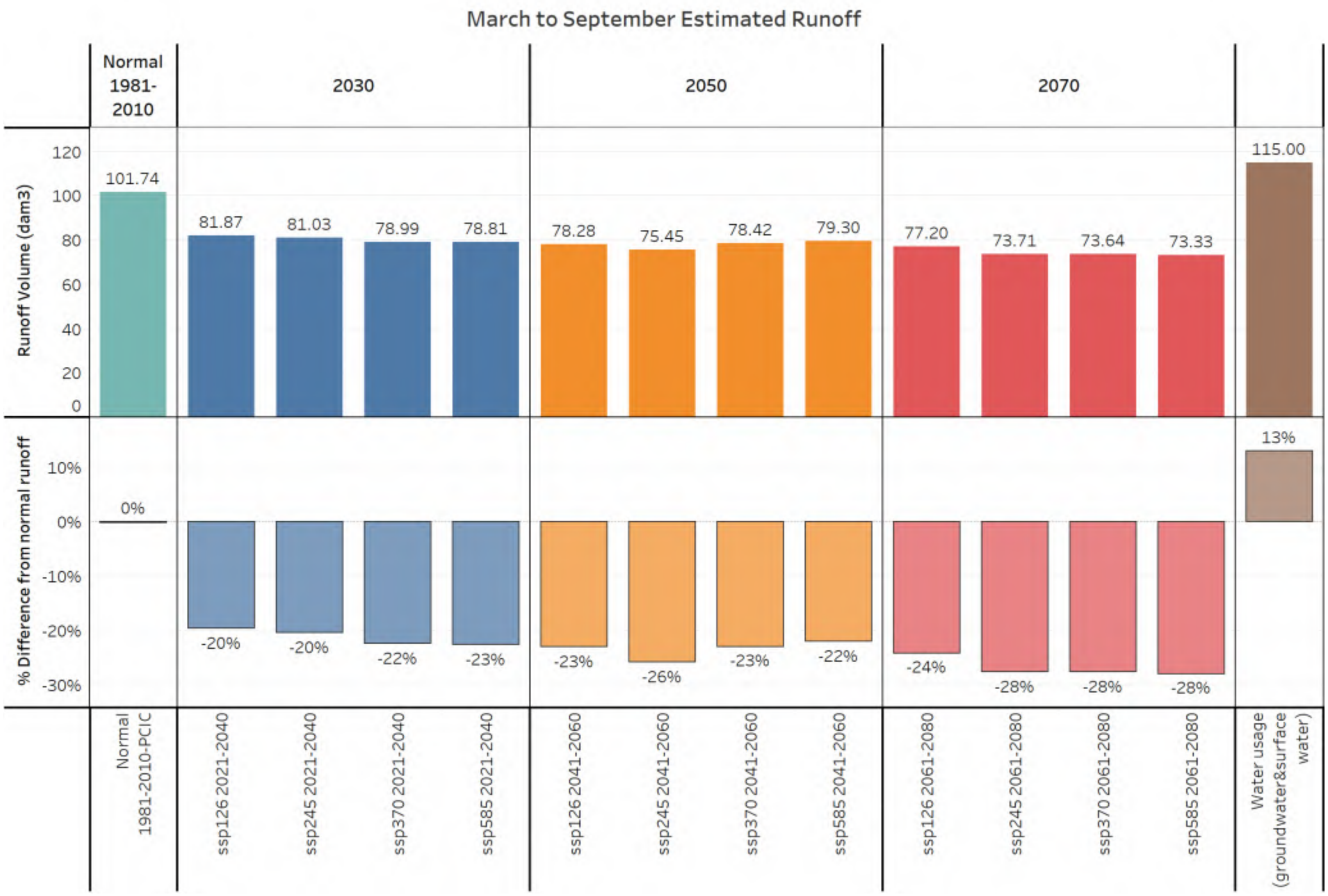

Figure 27. Estimated Runoff for March to September for various climate scenarios for the current conditions (normals), and years 2030, 2050 and 2070 compared to licensed surface water (fire protection licence not included).

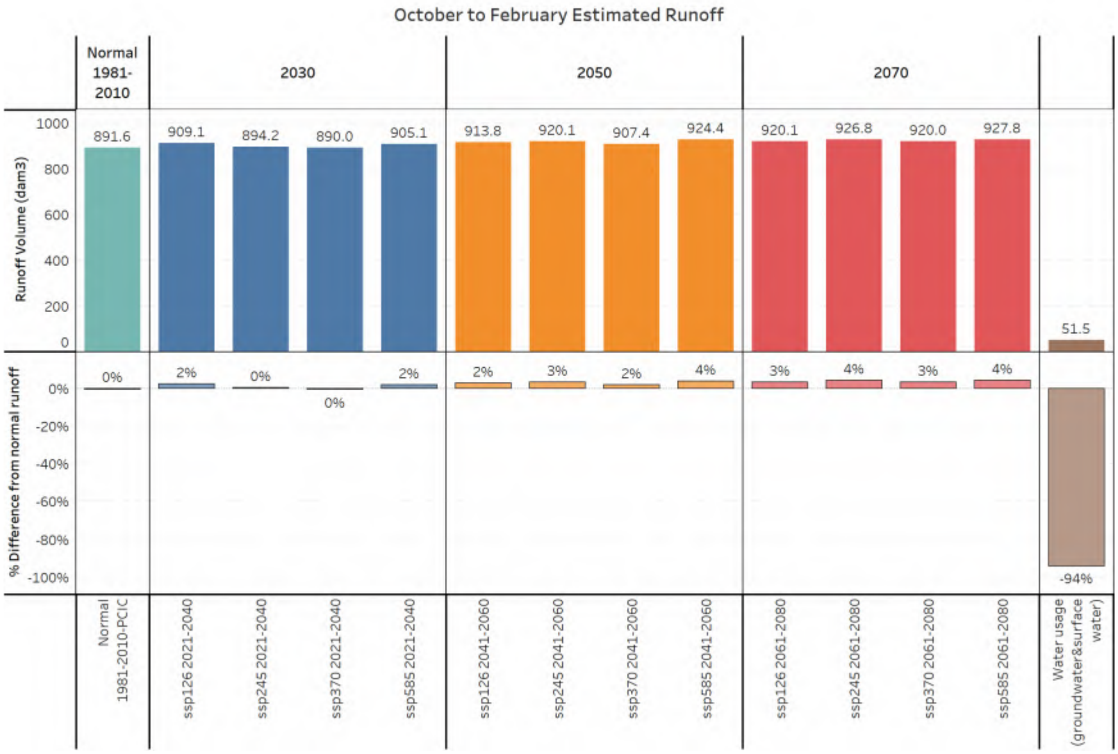

Figure 28. Estimated Runoff for October to February for various climate severity scenarios for the years 2030, 2050 and 2070 (fire protection licence not included).

Figure 29. Estimated Runoff for January to December for various climate severity scenarios for the years 2030, 2050 and 2070 (fire protection licence not included).

7.3.1 Surface Water and Groundwater Monitoring on Salt Spring Island

There are several active and inactive groundwater and surface water monitoring points located within and near the study area (Figure 30).

There are two active groundwater monitoring wells:

- SSIWPAGWM-1009 (ITC) data from 2018-2020.
- Figure 31, although the data covers a short time period, it indicates a slight decrease in water level of 20-30cm over these years.

As there are no groundwater monitoring wells in the study area with a long-term data set, data from Provincial Groundwater Observation Well OW373 on Salt Spring Island to the north of Lake Weston was obtained. The data shows a downward trend line of water levels for all months except November, December and February for the years 2006 to 2021 (Figure 32). The black dashed lines indicate the statistical trend for all the years during each month (upward/increasing over time, downward/decreasing over time or flat/unchanged with time). The downward trends are especially pronounced during August and September.

There is one active streamflow station:

- Fulford Creek (BC Aquarius database) monthly streamflow data from 2017-2021. This data is plotted in Figure 33 and indicates increasing trends from October to February, decreasing trends in March and April (reflecting less snow melt) and steady trends during the summer months.

There are three active surface water stations in the Weston Creek watershed:

- Lake Weston Inflow creek E1 which is monitored by the Water Preservation Society (WPS) SSI FWC Project (SSI Freshwater Catalogue).
- Lake Weston at outlet (SSIWPA) with data from 2019-2020.
- Weston Creek near mouth which is monitored by the WPS SSI FWC Project (SSI Freshwater Catalogue).

Data from these stations is presented in Section 7.5.

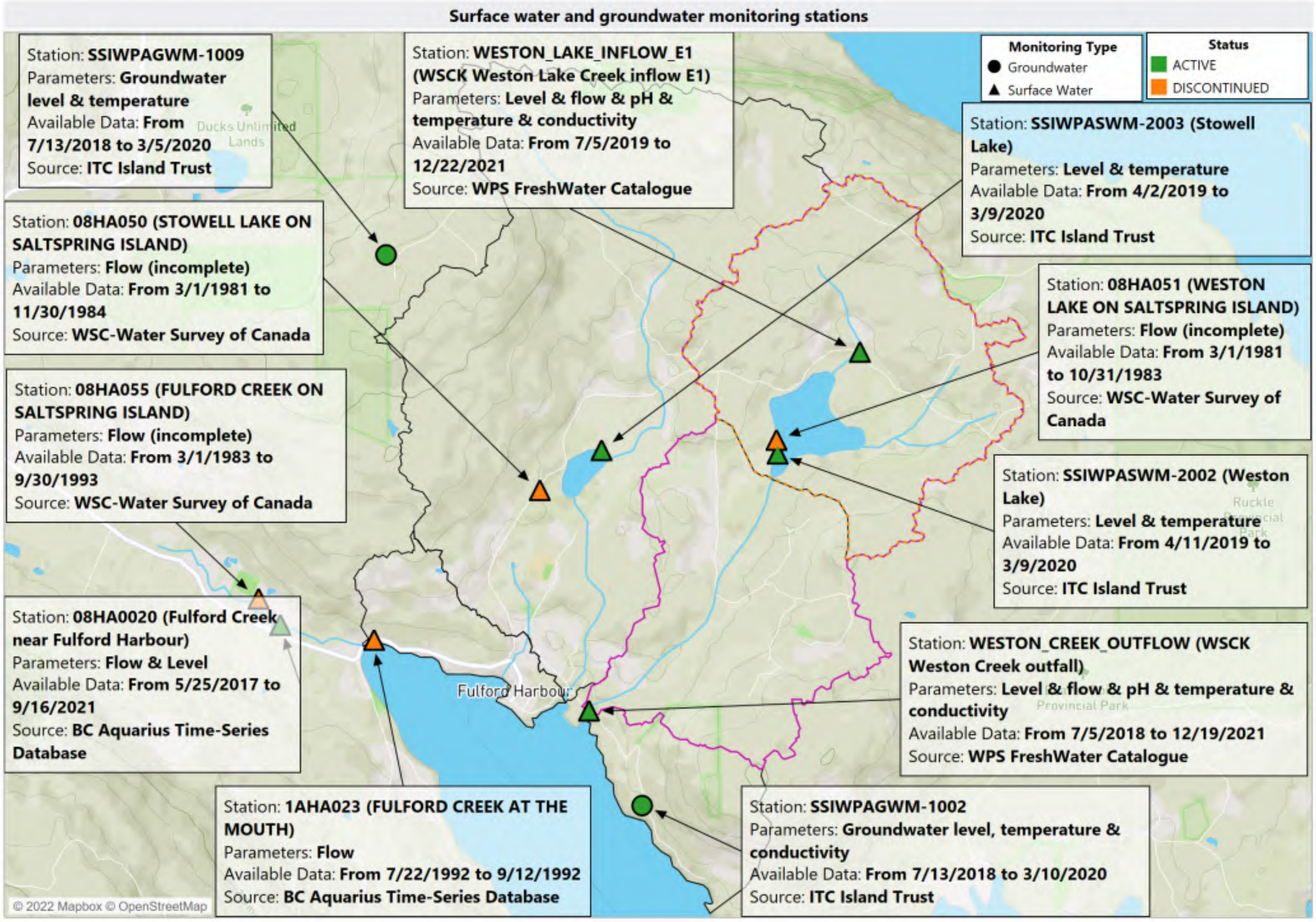

Figure 30 Surface water and groundwater monitoring stations

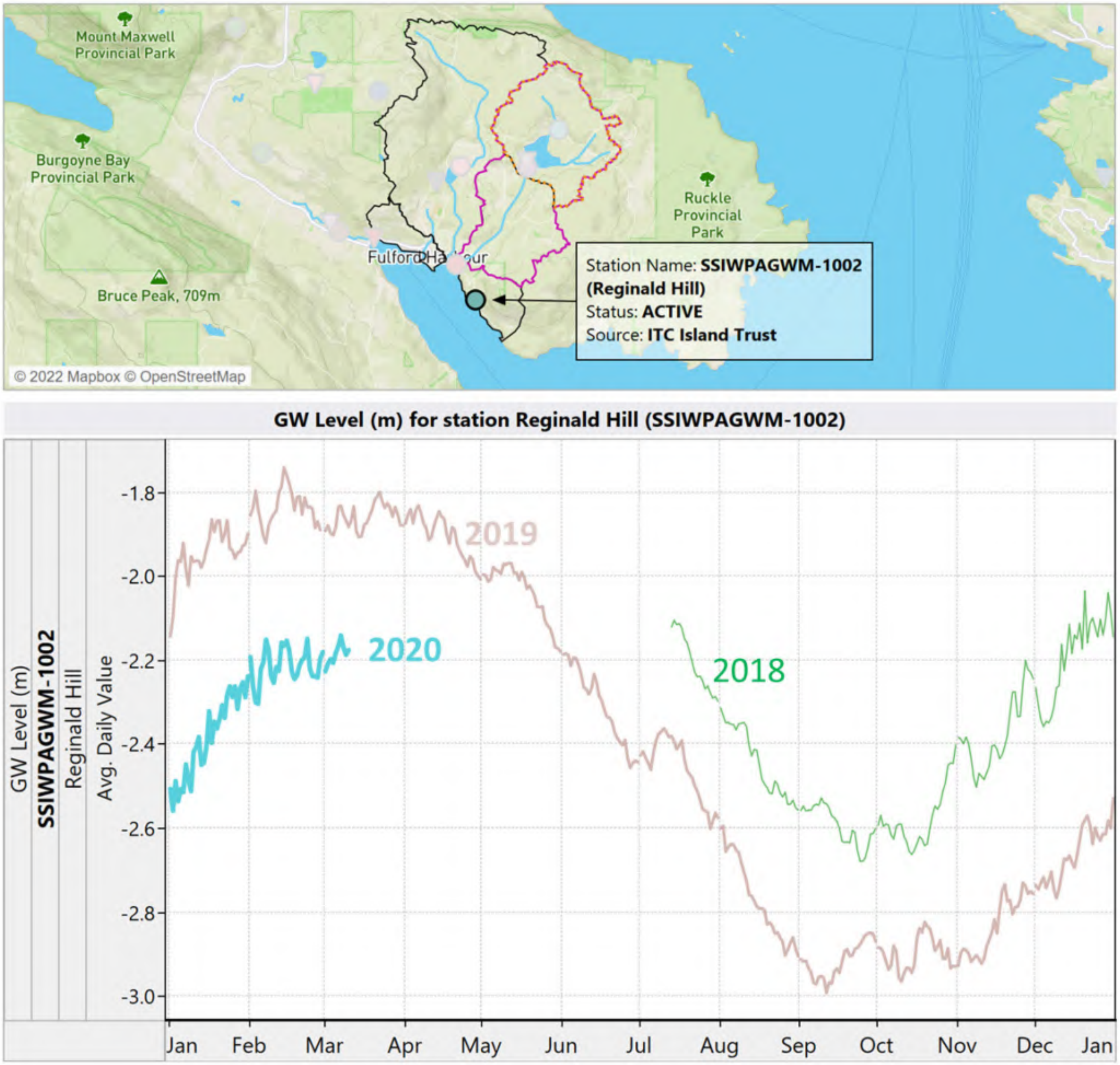

Figure 31 Groundwater level for Reginald Hill volunteer observation well.

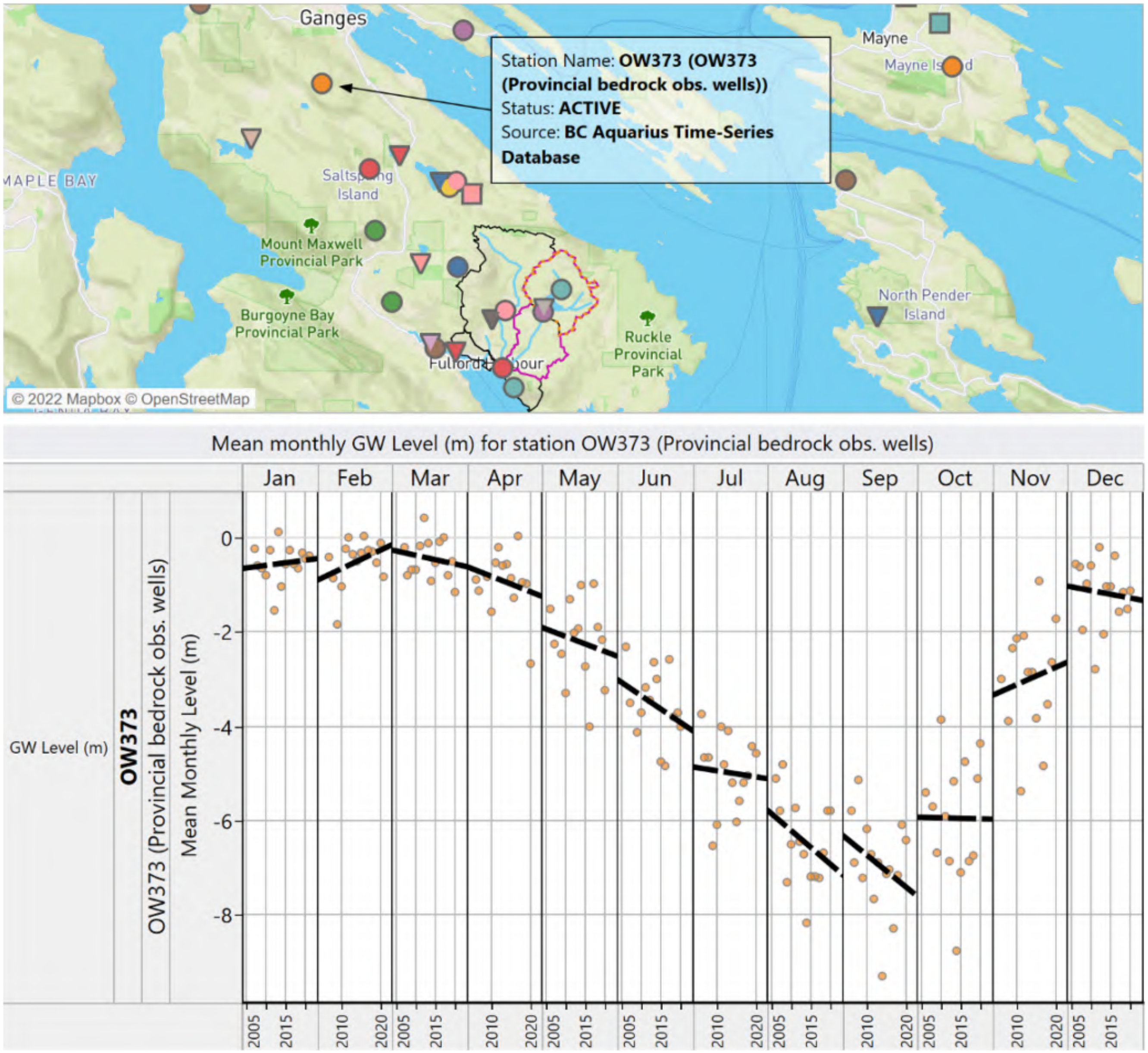

Figure 32. Mean monthly groundwater levels for OW373 (Provincial Observation Wells Network) from 2006 to 2021.

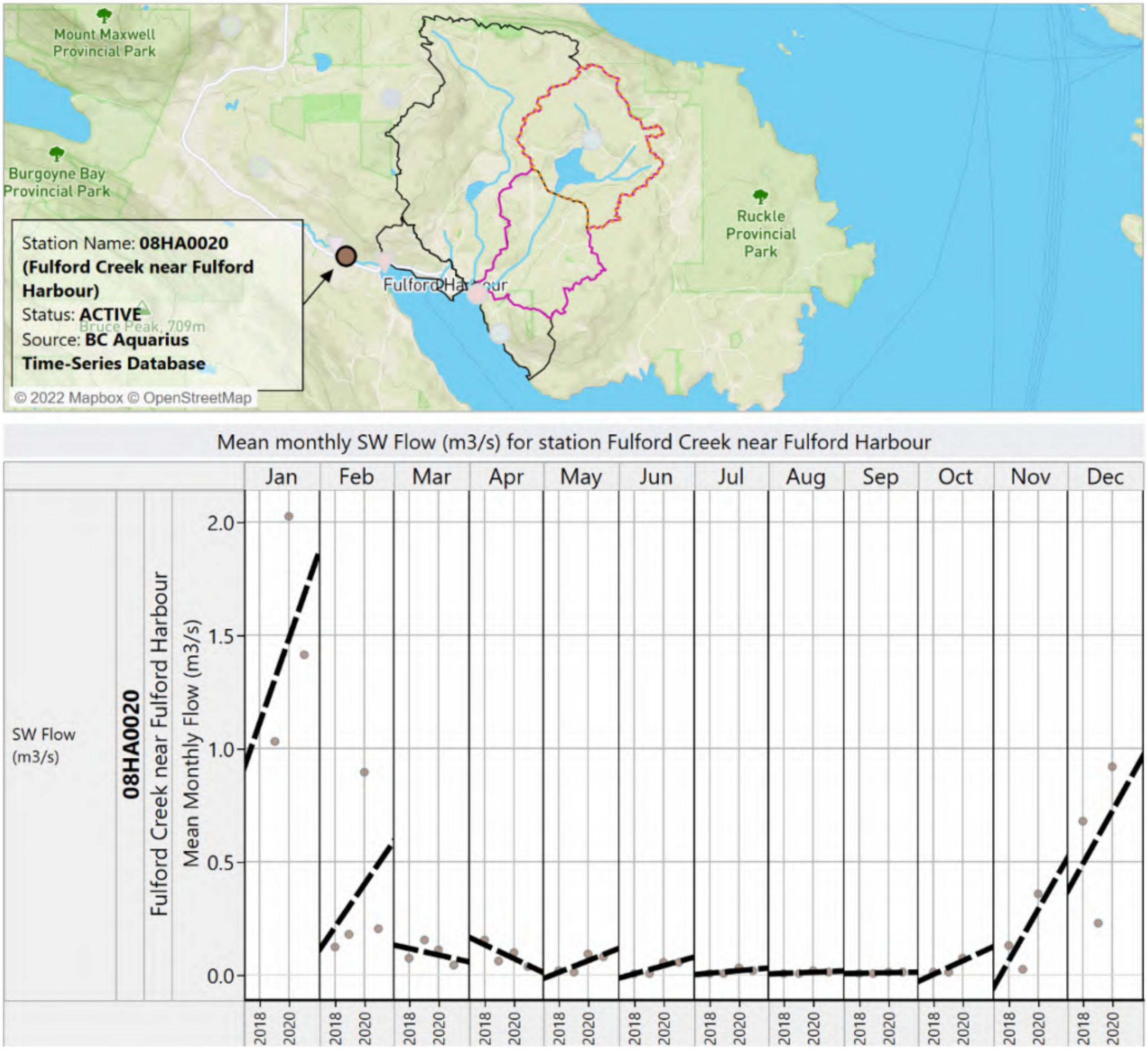

Figure 33. Mean monthly flow trends in Fulford Creek from 2018-2021.

7.4 Environmental Flow Needs

Aquatic ecosystems consist of groundwater, springs, creeks, rivers, lakes, wetlands and estuaries and the water allocated to protect aquatic ecosystems is referred to as Environmental Flow Needs (EFNs). The aquatic ecosystem most commonly used to define EFNs is fish habitat in streams which is referred to as Instream Flow Requirements (IFR). Lake Weston and Weston Creek have been identified as habitat for cutthroat trout (Barnet et. al., 1993) and thus it is important that a minimum lake water level and creek flow be maintained year-round.

The most common method of defining IFRs to protect fish habitat is based on the Modified Tennant (a.k.a. Montana) Method (Table 9; Tennant, 1976) which assumes that some proportion of the mean annual discharge (MAD) is required to sustain the biological integrity of a river ecosystem to sustain fish spawning and rearing. Based on original field data collected from 11 rivers in Montana, Nebraska and Wyoming and further supplemented with additional data from hundreds of gauged flow regimens in 21 states, Tennant (1976) recommended percentage values of MAD predicted to sustain predefined ecosystem attributes. In drainages where fish are present, the minimum flow required to sustain the fisheries resource for fair spawning and rearing habitat is 10% of the Mean Annual Discharge (MAD).

Table 9: Creek flows as a percentage of Mean Annual Discharge and fish spawning/rearing habitat condition (Tennant, 1976).

Creek Flows as % of Mean Annual Discharge	Spawning/Rearing Habitat Condition
30-60% MAD	Excellent
20-30% MAD	Good
10-20% MAD	Fair
5-10% MAD	Poor
<5% MAD	Severely degraded

The B.C. Water Sustainability Act (WSA; 2014) specifically identifies stream flow requirements for ecosystems and species. Authority is given to temporarily protect flows in times of drought and to order mitigation measures where water removal is likely to have significant adverse impacts on a stream.

The key sections of the WSA pertaining to EFNs are:

Section 15: Statutory decision makers must consider EFNs when issuing new surface and groundwater licences (for aquifers that are connected to surface water). This policy is not a method or enforceable law for determining EFNs but instead provides guidelines for assessing risk to EFNs. It sets out different management actions depending on different levels of risk and assist the decision maker in identifying where cautionary measures could be taken or additional analysis is needed.

Sections 86-88: Water users are required to cease water withdrawals during drought under a *critical flow protection order* or *fish population order*.

Section 43: Water and land-use decision makers have the ability to set water objectives (including water flows and quality) that must be considered when issuing authorizations.

The BC EFN policy establishes three risk management levels by evaluating stream sensitivity, stream size, cumulative withdrawals from the stream, and hydrological characteristics of the stream.

In many parts of B.C. groundwater discharges contribute a high percentage of base flow in streams and groundwater extractions from aquifers that are hydraulically connected to a stream can significantly diminish streamflow, particularly in small streams during critical low flow periods. The WSA recognizes the hydraulic connection between groundwater and surface water, particularly in shallow sand and gravel aquifers where groundwater withdrawals directly affect availability of stream water for other users and for aquatic ecosystems. The WSA thus recognizes that groundwater and surface water must be managed under the same regulatory regime. Groundwater use is integrated into the water-licensing system, similarly to how surface water was previously managed. The WSA applies the consideration for EFN to aquifers that are *reasonably likely to be hydraulically connected to a stream*. For an application to be successful, the technical assessment would need to demonstrate that sufficient water is available to meet the needs of the intended use, and that the requested water withdrawal will not cause undue harm to other water users or the EFNs of hydraulically connected streams.

It is important to note the very different time frames between groundwater, which generally flows very slowly (e.g. months to centuries) and surface water, which flows relatively quickly (e.g. days). This results from the flow restriction of the natural geologic materials and, as a result, the time required for the impacts of groundwater pumping (or water-diversion from a spring) can take decades to be observed with declining water levels in wells or baseflow to creeks or other groundwater-dependant ecosystems.

Case Study: Sooke River, Vancouver Island

A value of 10% MAD (mean annual discharge) was determined using the modified Tennant method as the conservation flow (i.e. EFN) in the low flow months (Burt, 2006). Monitoring of the conservation flow releases has been carried out and the results indicate that flow releases from the Sooke reservoir result in an increase in the variety and abundance of aquatic invertebrates. An improvement in the health of trout fry has also been observed.

Case Study: Tsolum River, Comox, Vancouver Island

The Courtenay Water Allocation Plan uses the Modified Tennant (Montana) Method to recommend that an estimated minimum of 10% of MAD (mean annual discharge) be maintained in the Tsolum to support aquatic life (Riddell & Bryden, 1996). Provincial scientists have decided that maintaining flows of 10% MAD in Vancouver Island streams may not be realistic. Many streams on the east coast of Vancouver Island have highly variable flow regimes and may not have had flows above 10% MAD in the summer prior to human disturbance. It has been suggested that a more appropriate target may be to maintain 5% MAD in the Tsolum River watershed during low flows (Szczot, 2018).

7.5 Lake Weston Safe Yield

Lake Weston is directly fed by groundwater and its pumping is similar to that of a large well. The safe yield of a water well (or lake acting as a well) is the maximum annual water volume that can be sustainably extracted year-round and year after year without gradually drawing groundwater out of storage (causing declining levels in the well and/or nearby wells) or decreasing the groundwater seepage that feeds aquatic ecosystems (aquifers, springs, wells, wetlands, creeks, lakes) referred to as Environmental Flow Needs. The safe yield for Lake Weston consists of two components.

1. Water storage in Lake Weston. Water storage is important for aquatic life within the lake including maintaining water temperatures sufficiently low enough for certain species. Water storage in the lake also allows for a certain amount of water to be drawn for short-term emergency purposes (fire department or wildfire) or to sustain water supplies during a drought or the predicted hot dry summers in the decades to come.

2. Flow in Weston Creek. Sufficient flow during “normal” climatic variations year-round and year to year to maintain the creek as an aquatic ecosystem and habitat for cutthroat trout and other species.

Water Storage in Lake Weston:

Lake Weston water volumes corresponding to different lake levels are shown in Figure 34 to Figure 36. The Lake Weston level varies from a high of about 61.35 masl in January to a low of 60.55 masl in August (average 0.8 m variation) and appears to reach a level where it becomes stable (increasing very slightly) in the summer months. It can also be seen that as the water level declines the decrease in volume becomes more pronounced as the lake is a conical shape (Figure 36).

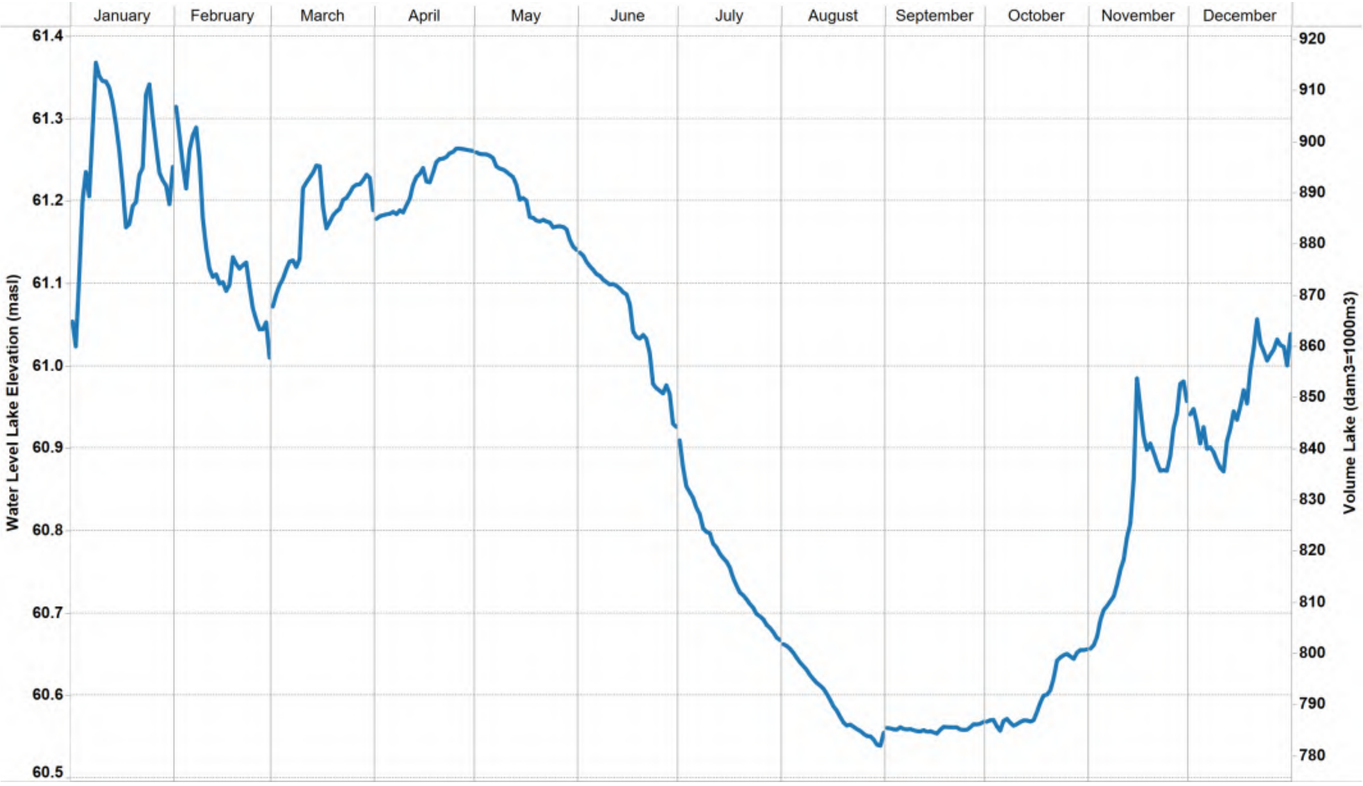

Figure 34. Lake Weston water level and storage volume from April, 2019 to March, 2020.

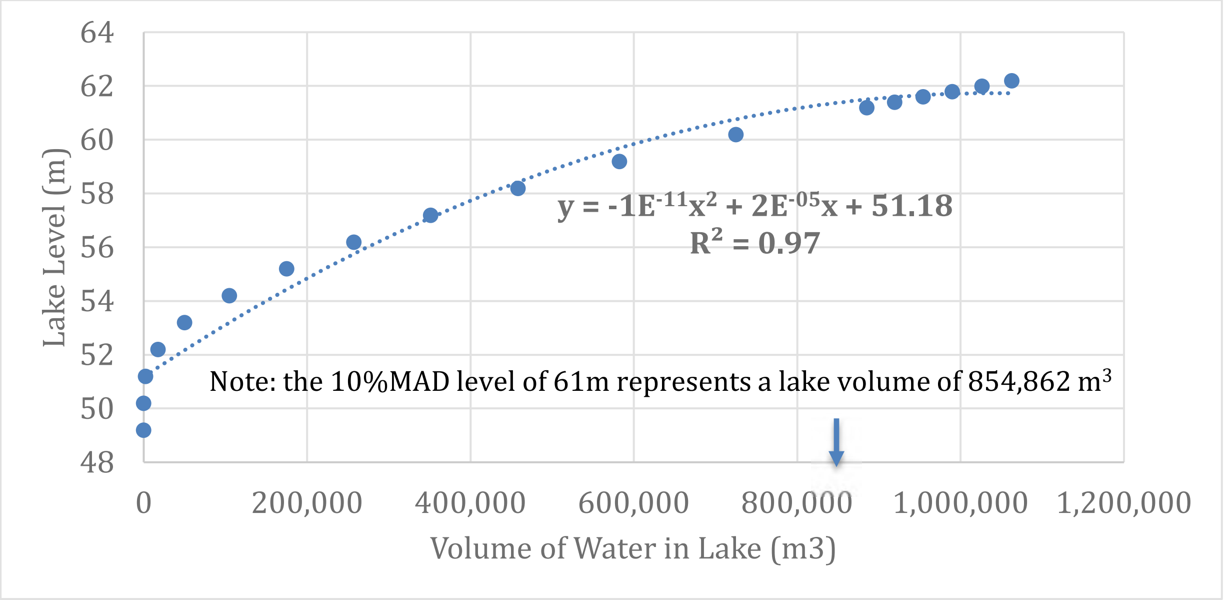

Figure 35. Lake Weston water level (April, 2019 to March, 2020) versus volume of water in lake.

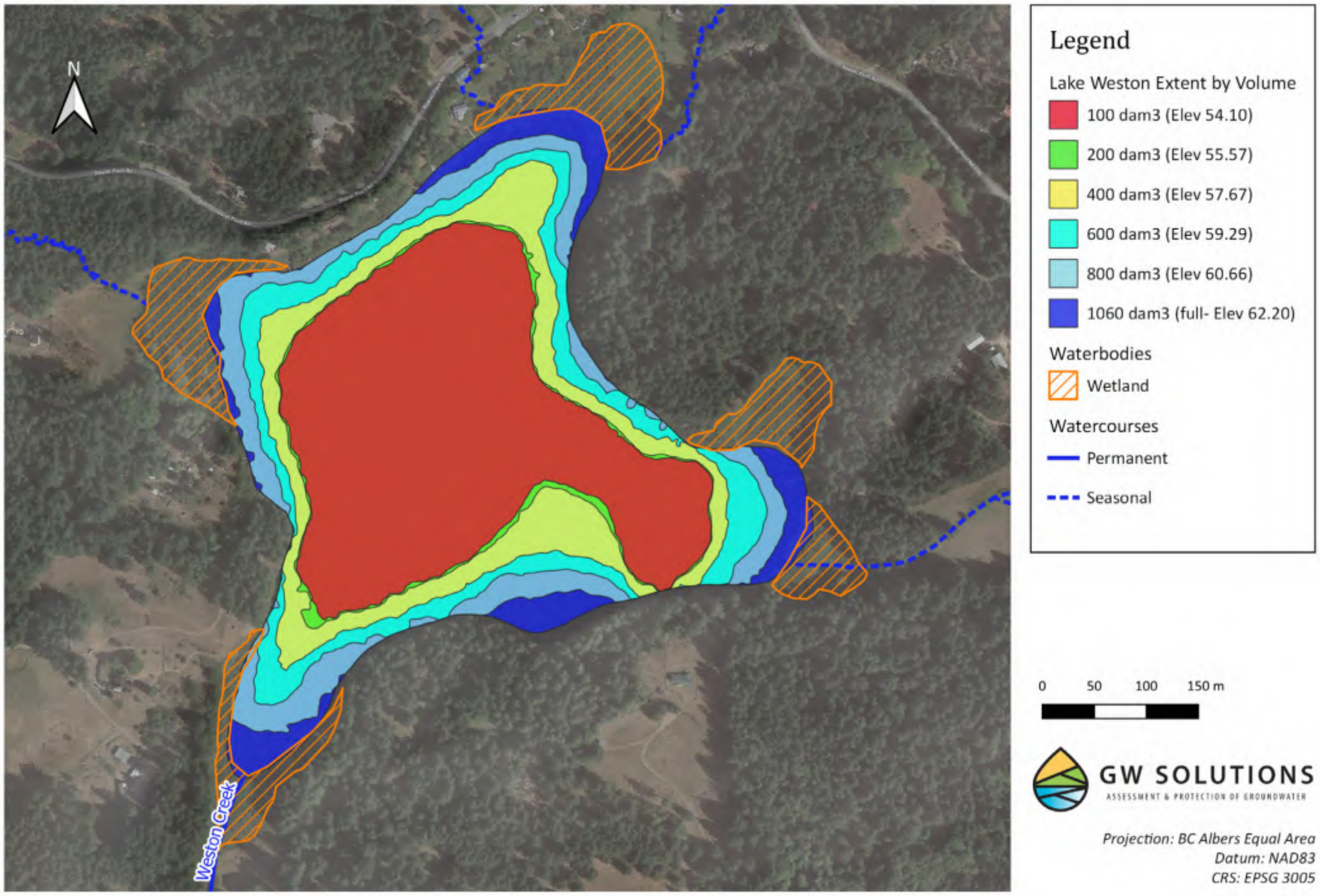

Figure 36. Lake Weston volumes for various areal extents.

Figure 37 is a monthly graph of water volumes of Lake Weston for various climate scenarios (2030, 2050, 2070). It can be seen Lake Weston volumes are predicted to decrease significantly in the next decades during the summers when groundwater recharge and runoff are non-existent or negligible.

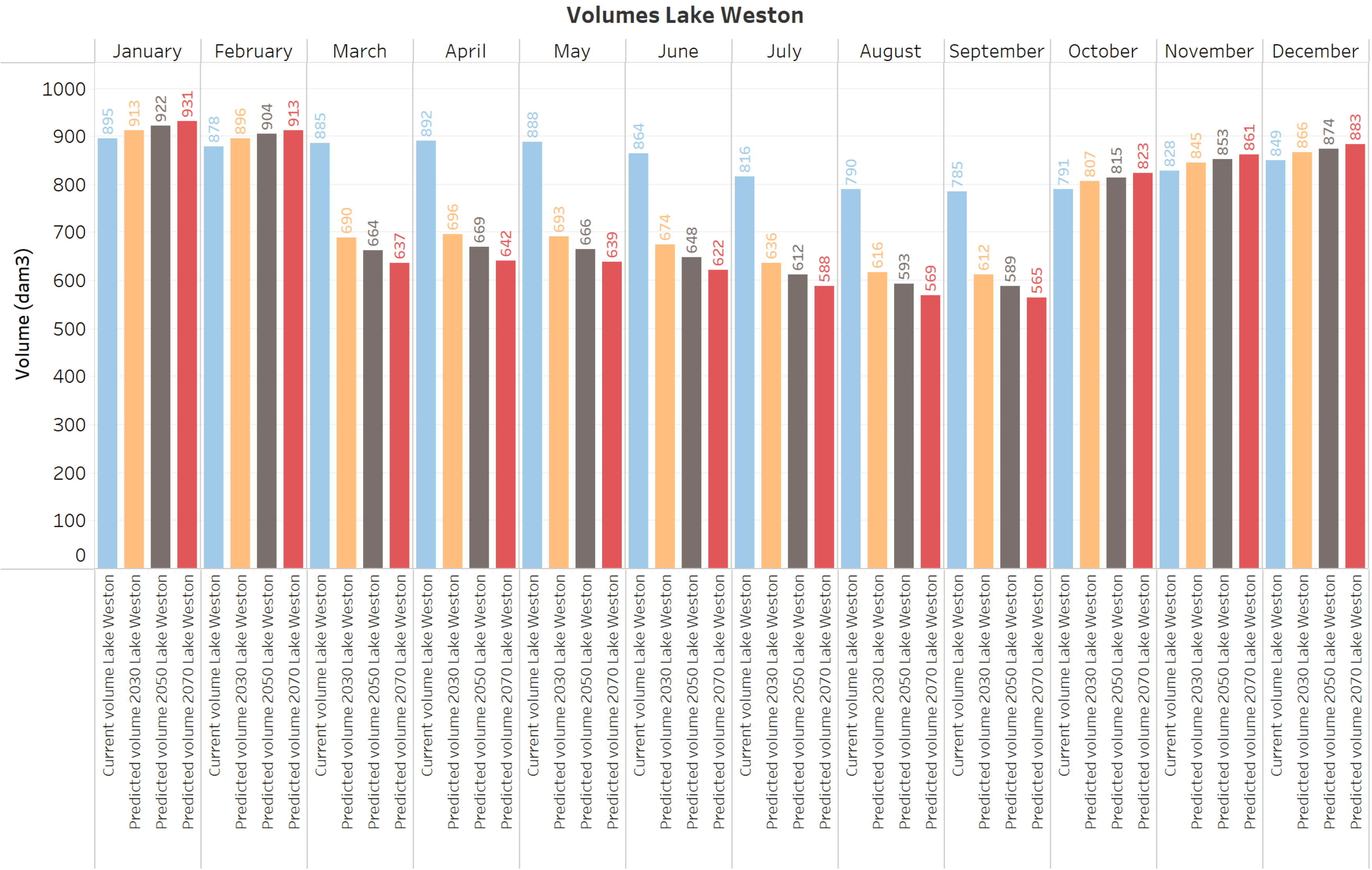

Figure 37. Lake Weston monthly volumes for climate scenarios.

Weston Creek Flow:

Figure 38 shows an illustrative cross-section of the watershed passing through Lake Weston and following the approximate route (slightly off-section) of Weston Creek. It can be seen that Lake Weston is directly connected to and fed by the groundwater system. Weston Creek is fed by both outflow from Lake Weston and also by groundwater discharge at specific groundwater discharge locations controlled by faults along the course of the creek. These faults have not been mapped but are assumed based on the uneven (i.e. flat then steep drop) topography along the creek and evidence of groundwater discharge (flooding or fish habitat).

Figure 39 is a map of key groundwater discharge and fish habitat locations in the watershed. It can be seen that there are springs in several locations above Lake Weston and key areas of groundwater discharge along the various arms or creeks feeding Lake Weston. These is fish habitat in two of these arms, the northeast arm and east arm. Along Weston Creek there are several fish migration gradient barriers (i.e. steep gradient) and at least one fish habitat identified directly adjacent to an area of frequent groundwater discharge (leading to field flooding seasonally). There may be other smaller fish habitats fed by groundwater discharge along Weston Creek that have not been identified.

Figure 40 shows a plot of Lake Weston water level, the Weston Creek outflow and total water usage (groundwater and surface water). Weston creek varies seasonally from a high monthly average of 0.017 m^3/s in March to a low of 0.0010 m^3/s in August. Based on the data obtained, it appears the flow can become very low during the summer, from the three plus years of flow records (WPS SSIFWC) Weston Creek flows year-round, though with very limited summer flow.

As noted earlier in this report, water usage is highest in the May-September period and it is especially high in July and August when rainfall is low and evaporation is high. If increased water usage leads to lowered groundwater levels then groundwater-dependent creeks (like Weston Creek) can temporarily become dry or almost dry during late summer.

In Figure 41, water temperature and electrical conductivity follow distinct seasonal trends for the inflow and outflow, however, it is noted the inflow electrical conductivity and pH become gradually higher in the summer season due to the predominance of groundwater (which is more mineralized than surface water or rainwater) at this time of year. As expected, the inflow E1 increases substantially during the winter season diminishing during the summer, this inflow creek shows clearer indications of groundwater baseflow (Millson, 2020, cf Howe and Allen 2020) than the Weston Creek outflow. The Weston creek outflow chemistry, in contrast to the inflow, does not increase significantly in the winter months as the outflow emanates mostly from Lake Weston which absorbs much of the runoff and dilutes groundwater baseflow in the discharge into Weston Creek, though Weston Creek is also fed through groundwater seepage along its course as it, like Lake Weston, is in direct connection with the aquifer.

It is noted that inflow E1 is not the only inflow to Lake Weston as the lake is natural groundwater discharge body. Inflow E1 is one of two major surface water inflows to Lake

Weston (the other inflow is the east arm) and there may be other water-bearing faults intersecting the lake that are unseen. Lake Weston also likely receives some inflow in the subsurface through seepage from the smaller fractures in the aquifer.

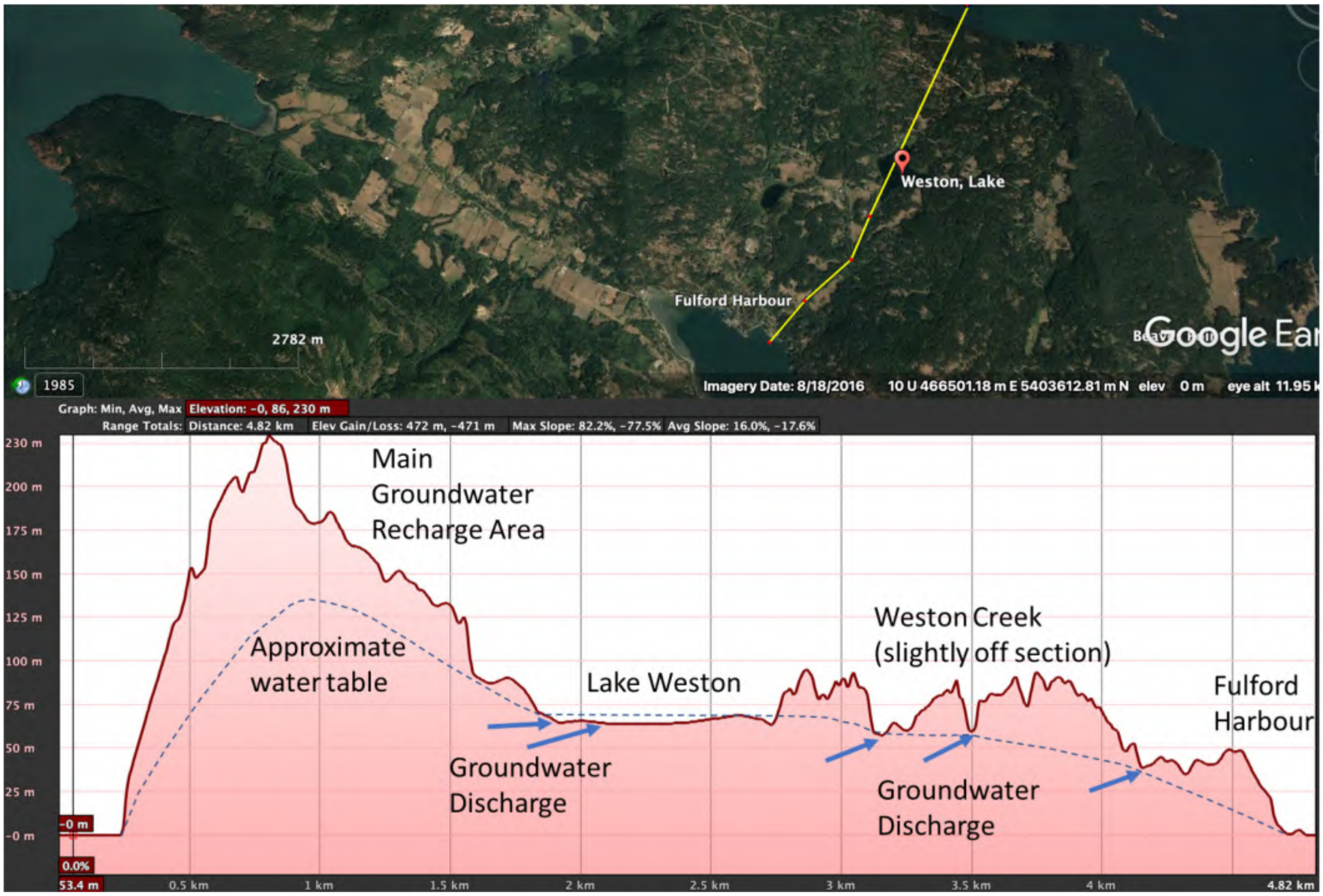

Figure 38. Topographic profile and illustrative cross-section across entire Lake Weston and Weston Creek watershed.

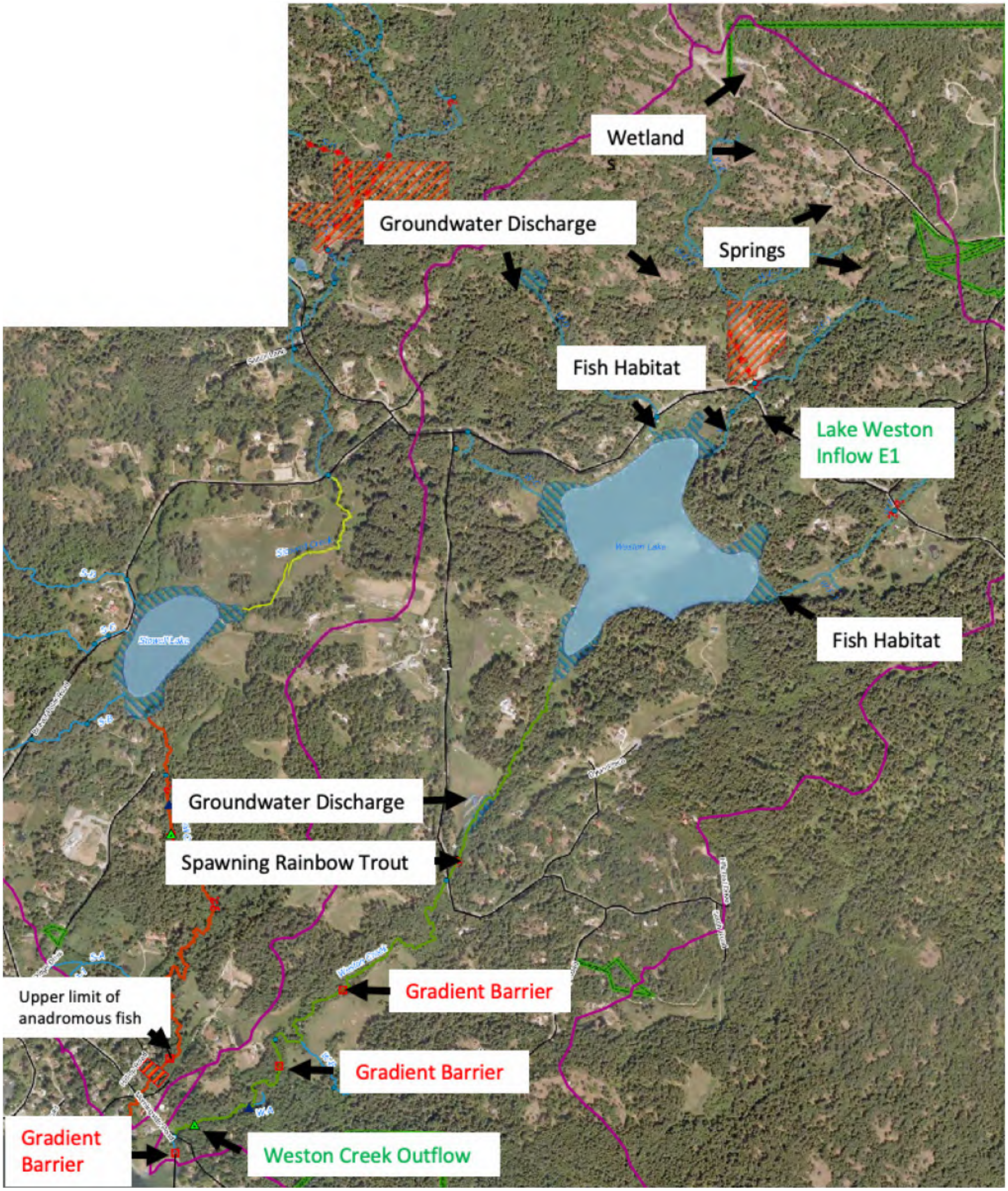

Figure 39. Groundwater discharge and fish habitat in Lake Weston and Weston Creek.

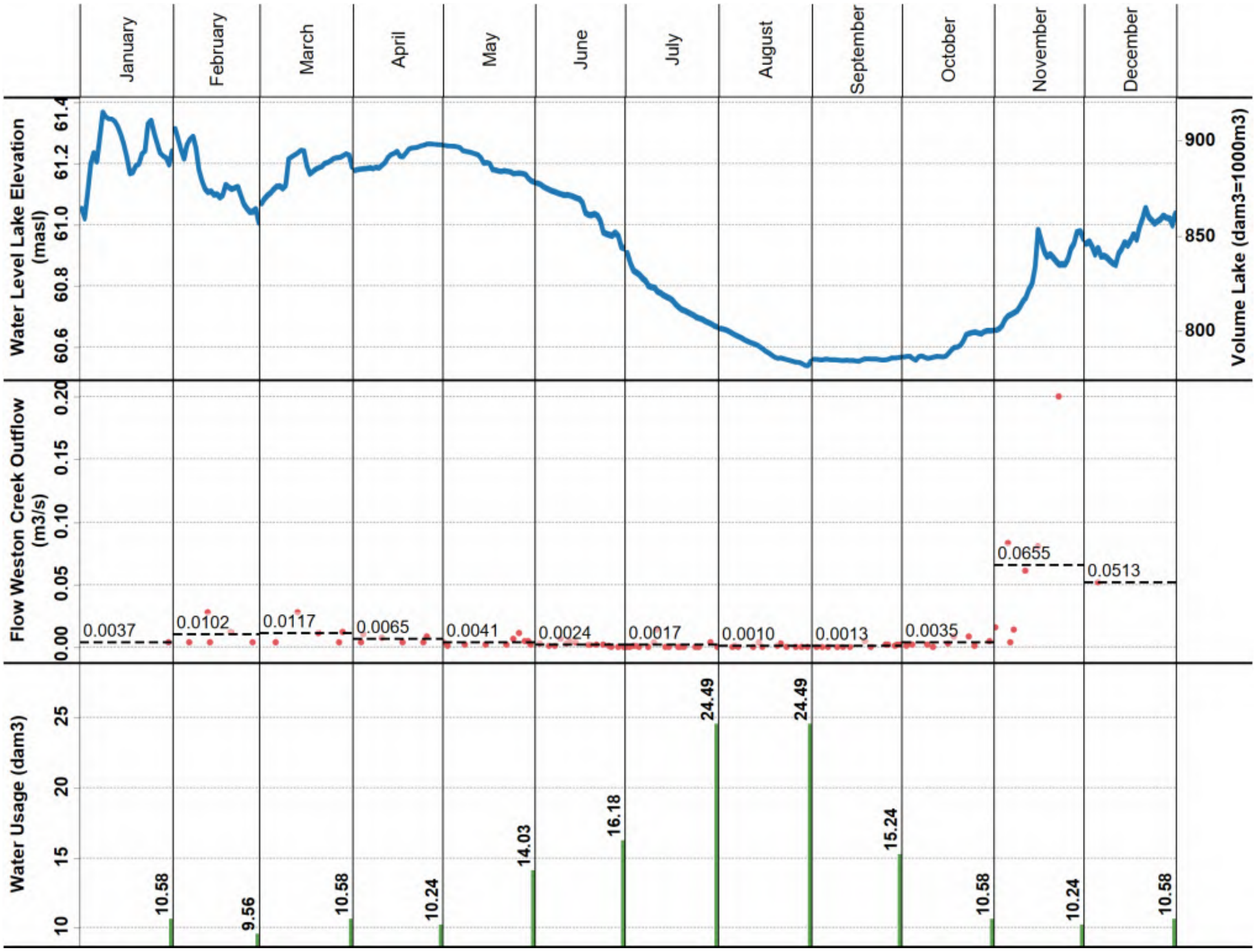

Figure 40. Lake Weston water levels, Weston Creek flow (April, 2019 to March, 2020) compared to estimated water usage (fire protection licence not included).

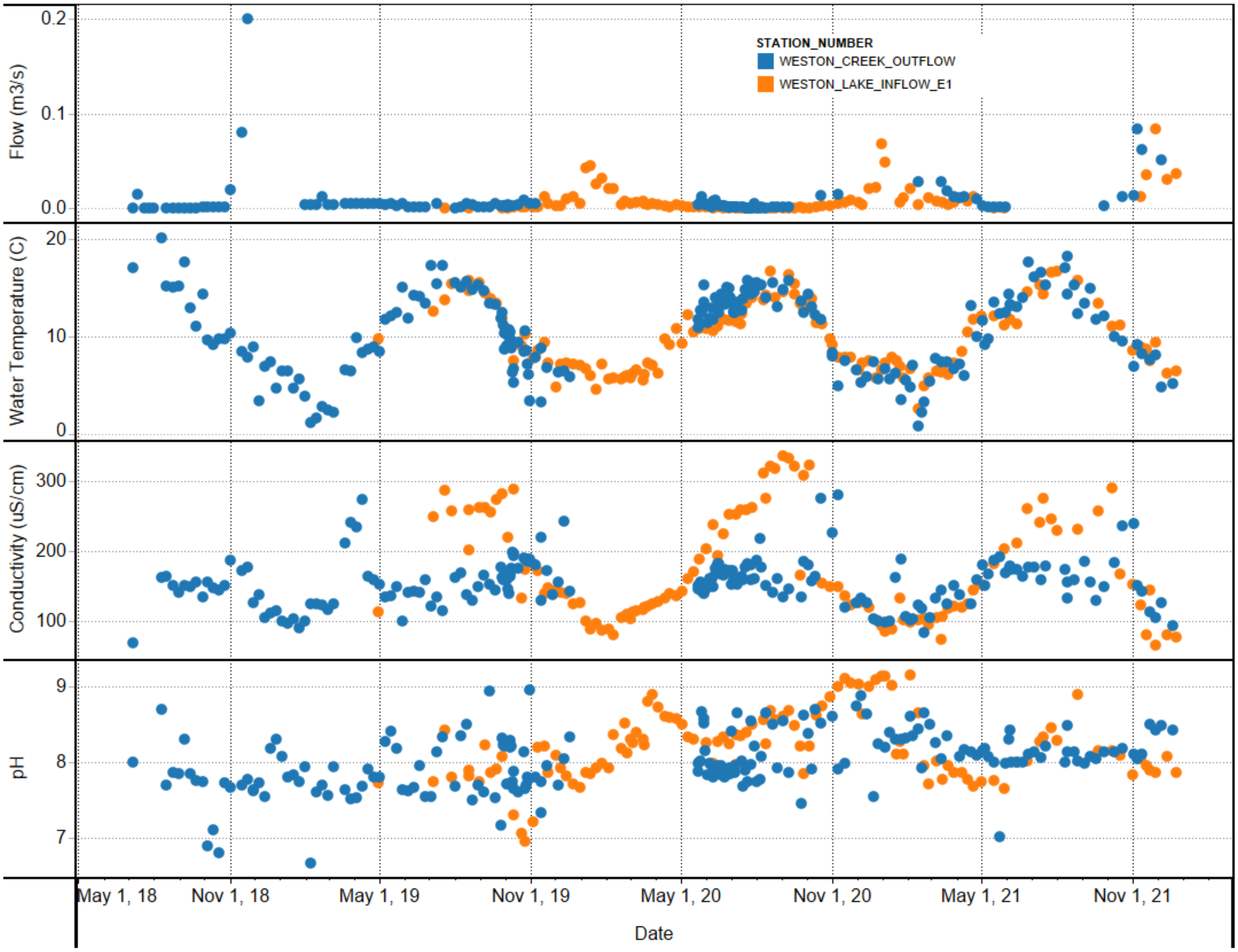

Figure 41. Lake Weston inflow, Weston Creek outflow, temperature, electrical conductivity and pH from May, 2018 to December, 2021 (NB not all flow data is plotted).

Figure 42 is a scatter plot comparing Weston Creek flow (vertical axis) and Lake Weston water levels (horizontal axis). An approximate trend line is drawn through the data points with the lower flows (less influenced by short-term spikes from storms) to give an approximate relationship between the lake water level and the creek flow. As explained in the section on Environmental Flow Needs, the minimum flow to maintain an aquatic habitat for fish varies between 10%MAD and 30%MAD (Tennant, 1976). The minimum 10%MAD for Weston Creek corresponds to a Lake Weston water level of about 61 masl (meters above sea level). A 20%MAD corresponds to a lake level 10 cm higher at about 61.1 masl and a 30%MAD is about 61.15 masl.

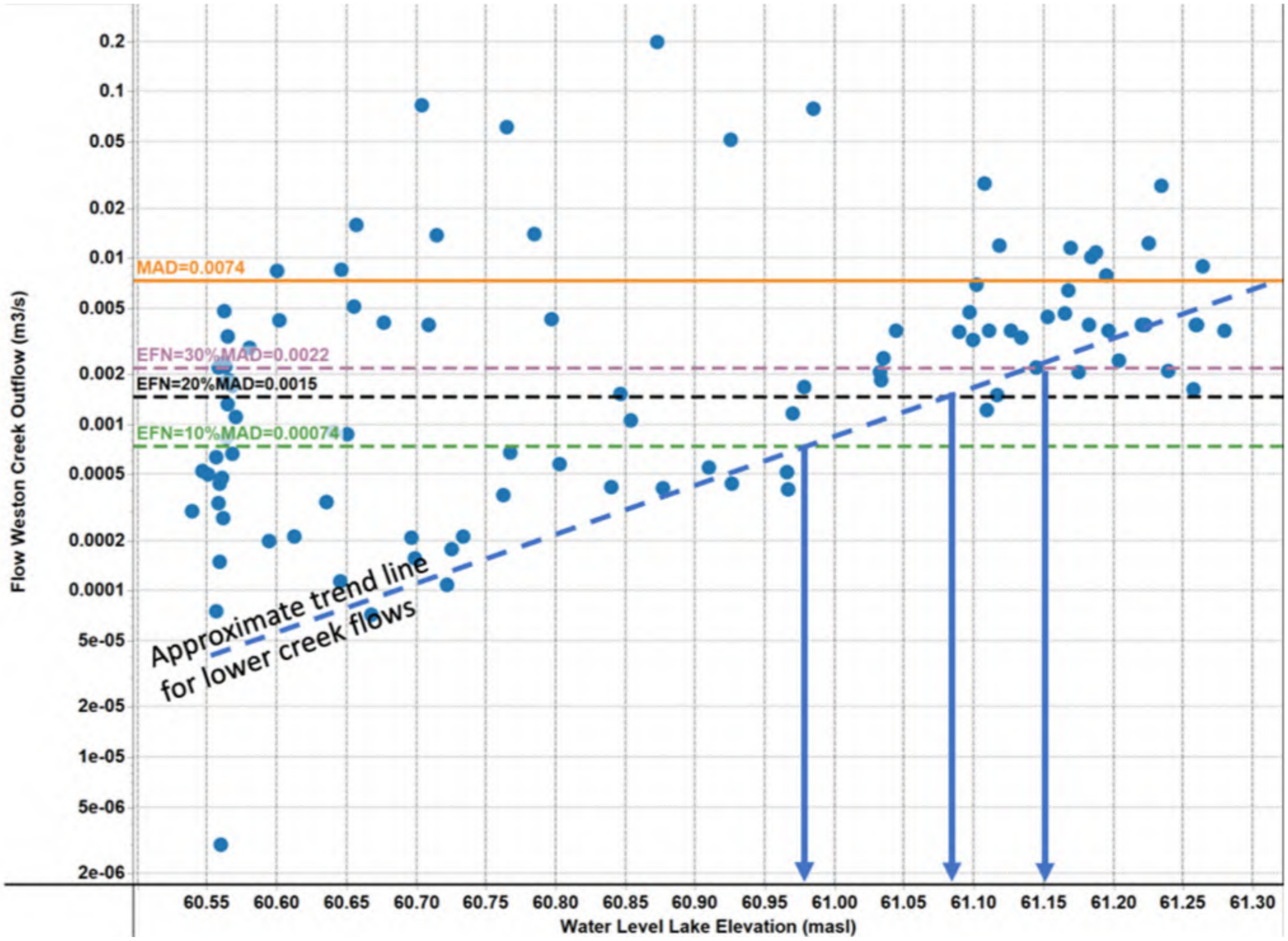

Figure 42. Lake Weston water level versus Weston Creek outflow with various %MAD (mean annual discharge).

Figure 43 is a plot of Lake Weston water level on the vertical left axis and the Weston Creek outlet on the vertical right axis showing all data collected over several years for each month. Although the Weston Creek outflow average in August is 0.001 m^3/s, the flow is significantly less than this value for much of the summer months. The level of Lake Weston is clearly lower that the 10%MAD (61 masl) level during the July-November period and, to achieve this level in the summer, the usage during the summer would need to be reduced. It is noted that the volume of water in Lake Weston at a level of 61 masl is approximately 854,862 m^3 (see Figures 35 and 36).

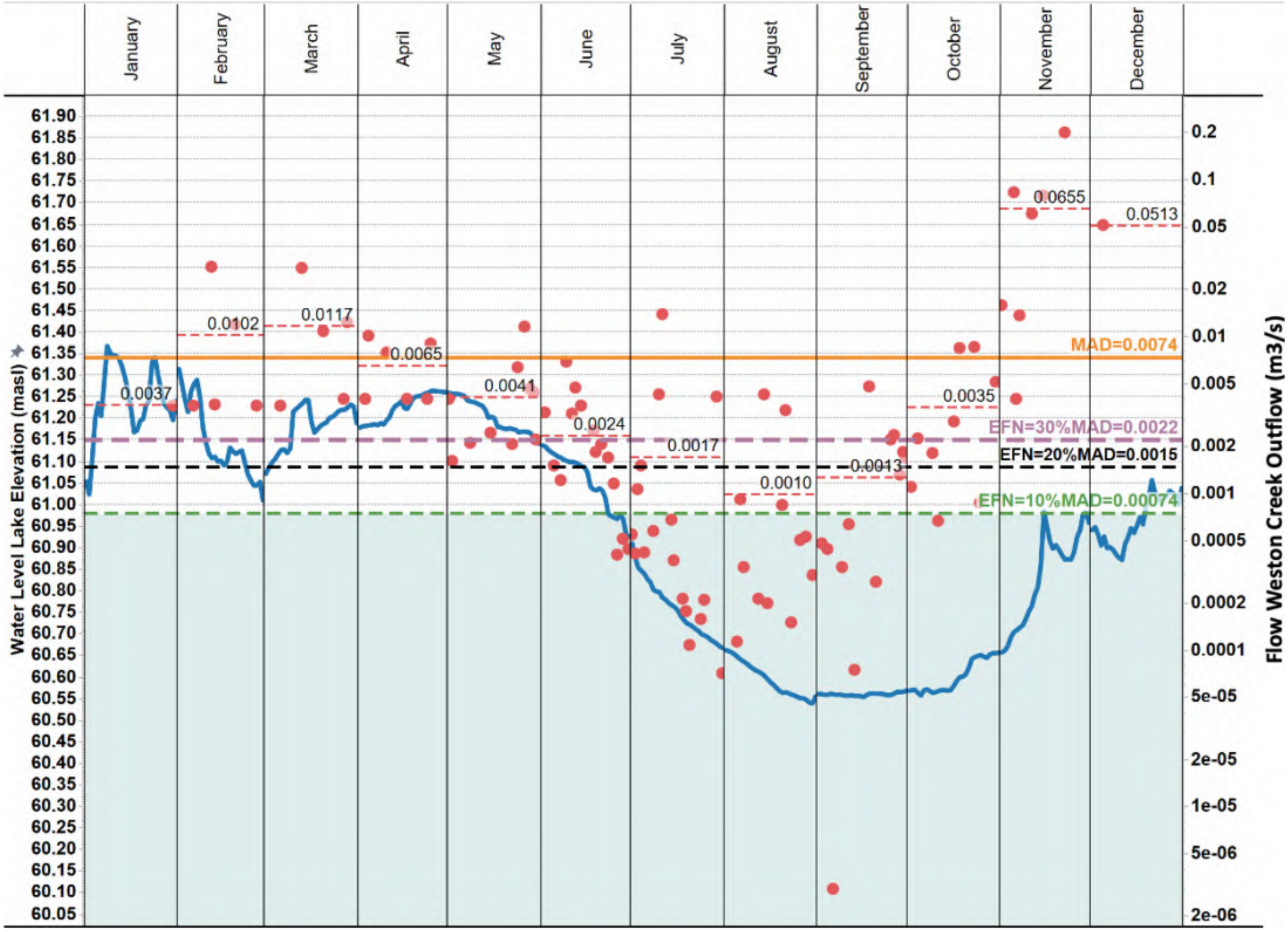

Figure 43. Lake Weston water level (blue line), Weston Creek outflow (red dots; with monthly averages) and various %MAD (mean annual discharge).

Figure 44 is a scatter plot comparing total water usage (groundwater and surface water) to Lake Weston level. It can be seen there is a weak inverse relationship and an approximate trend line has been drawn. Based on two data points a second trend line was drawn “Trend line upper limit” to provide the highest potential relationship between water usage and Lake Weston level. The high amount of scatter in the plot (indicating a weak correlation) is expected as water usage is not the only factor affecting the Lake Weston level. The lake level is also impacted by precipitation events (especially in the winter) which can produce short-term storm runoff and medium term increases in groundwater inflow. It also noted that the water usage is an estimate as the Fulford Water System is the only water usage that is actually measured. The basic relationship between usage and Lake Weston level is represented with an approximate trend line providing an approximation of the usage that corresponds to the 10%MAD, 20%MAD and 30%MAD. It can be seen that in order to achieve even the minimum 10%MAD in Weston Creek the usage in the summer months would need to be reduced to usage levels similar to the winter months. This would require significant summer restrictions on irrigation (farm and household) usage. This highlights the need for accurate usage data to confirm these results and water conservation programs.

The climate change analysis has indicated that in the coming decades the water surplus (groundwater recharge and surface water runoff) could decrease by as much as 30% in the summer. Although higher precipitation is predicted for the winter, much of this will come as storms that are too intense to allow for significant recharge. This means the total annual recharge could decrease leading to a gradual lowering of the water table. Recharge will certainly be reduced in the summer months however this decrease may not be balanced by increased recharge in the winter if the precipitation occurs as high intensity storms as predicted.

The other major factor that can affect the Lake Weston water level (and thus Weston Creek) is land-use in the watershed which can affect the ability of the land to absorb water and recharge groundwater. It is critical in a small groundwater-dependent watershed like Weston Creek that land-use is not altered (e.g. deforestation, buildings, pavement) to ensure groundwater recharge is not affected. Finally, it is noted that the groundwater of the Weston creek watershed does not have a natural geologic layer above it to protect it from contamination thus the groundwater (and lake) is highly vulnerable to contamination from septic systems or agricultural runoff and various geochemical studies (e.g. Nordin, 1986) have confirmed the rise in nutrients in Lake Weston.

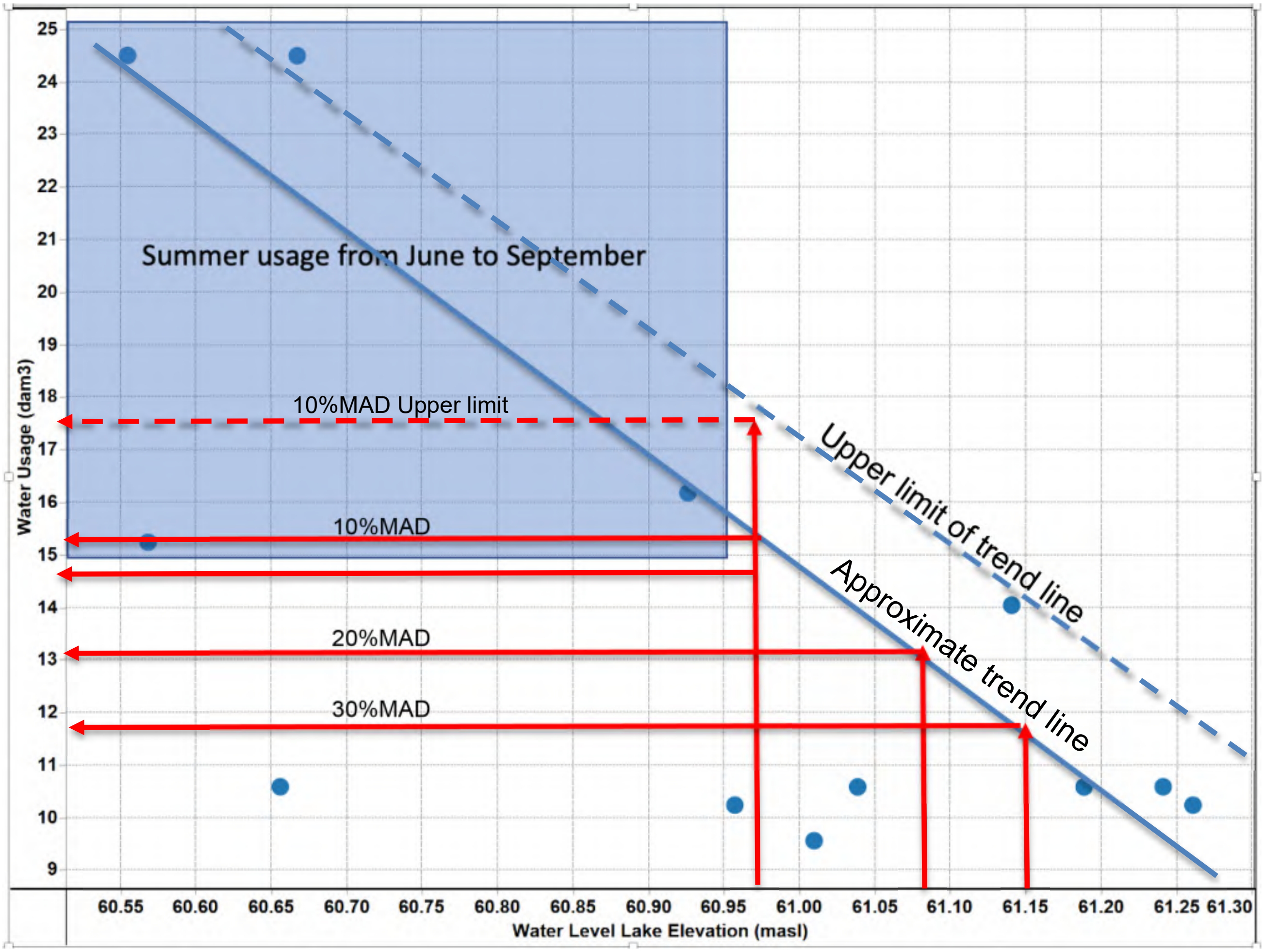

Figure 44. Lake Weston water levels versus estimated total water usage (groundwater and surface water; fire protection licence not included). Trend line is very approximate due to poor correlation. Upper limit of trend line indicates highest possible water usage for the Lake Weston level that maintains a 10%MAD.

Table 10 is a monthly summary of water usage volumes, volumes for Lake Weston and flow in Weston Creek. This data is plotted as monthly bar graphs in Figure 45. It can be seen that estimated water usage during the summer months, July and August in particular, is significantly higher than the remainder of the year. Actual usage of the Fulford Water System only increases slightly in the summer months. This is in contrast to the licenced surface water withdrawals for irrigation in the summer which are significantly higher than the remainder of the year.

7.6 Lake Weston Safe Yield Without Consideration of EFNs

An analysis of the safe yield of Lake Weston without consideration of EFNs was requested and provided as follows. Note that the consideration of EFNs is fundamental for the determination of safe yield and a lack of consideration of EFNs could have significant consequences to the aquatic ecosystem which is naturally vulnerable due to the small island setting (i.e. small recharge areas).

It is important to understand that the safe yield of Lake Weston cannot determined independently of the safe yield of the entire aquifer within the watershed as Lake Weston is directly connected to and fed by the aquifer. This any additional lowering of the water level of Lake Weston will lead to a lowering of the water table in the aquifer immediately surrounding the lake which could affect water wells. Thus, the safe yield of the entire watershed must be considered and not only that of Lake Weston.

A common index of aquifer stress compares the total amount of recharge in the watershed to the total water usage. For the Lake Weston watershed the total annual groundwater recharge is 615 dam^3 and the total water usage is 167 dam^3 (151 dam3 from Lake Weston and 16 dam^3 from groundwater wells). The amount of usage is thus 27% of recharge for this watershed which is reasonably high and indicates the maximum amount of water is already being pumped from this aquifer.

Another indicator of aquifer stress is water quality degradation. When wells (or groundwater-fed lakes being pumped like a well) are pumped heavily, such that the water table is lowered, they will draw water from further and further away increasing the well's zone of capture and the potential to draw contaminated groundwater. Excessive pumping can also induce recharge directly from poorer quality surface waters. Additionally, Excessive pumping can also divert groundwater that would have discharged into a surface water thus decreasing the baseflow of the surface water with resultant lower flows and higher concentrations of contaminants.

Table 10. Weston Creek flow, Lake Weston level and Water Usage.

Month	Estimated current use of GW (dam^3)	Estimated current use of SW (dam^3)	Estimated current use GW+SW (dam^3)	Current use FWS (dam^3)	Current Max use FWS (dam^3)	Licensed use FWS (dam^3)	Licensed use SW (dam^3)	Licensed use SW (dam^3)	Licensed use GW (dam^3)	Licensed use GW+SW (dam^3)	Total volume in Lake Weston (dam^3)	Monthly mean flow Weston Creek (m^3/s)	Monthly mean flow Weston Creek (dam^3)	Predicted volume 2030 in Lake Weston (dam^3)	Predicted volume 2050 in Lake Weston (dam^3)	Predicted volume 2070 in Lake Weston (dam^3)	GW recharge (dam^3)	Runoff (dam^3)
JAN	1.2	3.3	4.5	2.4	3.9	8.4	9.3	9.3	0	10.5	895	0.0037	9.9	913	922	931	146	235
FEB	1.1	3.2	4.3	2.4	4.5	7.6	8.4	8.4	0	9.5	878	0.0119	28.8	896	904	913	81	131
MAR	1.2	3.7	4.9	2.7	7.4	8.4	9.3	9.3	0	10.5	885	0.0131	35.1	690	664	637	60	97
APR	1.2	3.4	4.5	2.4	3.7	8.1	216.4	9.0	0	10.2	892	0.0088	22.8	696	669	642	3	5
MAY	1.4	6.1	7.6	2.9	2.6	9.4	226.8	12.6	0	14.0	888	0.0035	9.4	693	666	639	0	0
JUN	1.4	8.4	9.8	3.2	3.4	9.6	222.1	14.7	0	16.1	864	0.0024	6.2	674	648	622	0	0
JUL	1.6	11.7	13.3	3.6	2.8	14.8	237.1	22.8	0	24.5	816	0.0014	3.7	636	612	588	0	0
AUG	1.6	11.8	13.5	3.8	5.6	14.8	237.1	22.8	0	24.5	790	0.001	2.7	616	593	569	0	0
SEPT	1.5	5.9	7.3	2.6	3.9	10.5	221.1	13.7	0	15.2	785	0.0013	3.4	612	589	565	0	0
OCT	1.2	3.3	4.5	2.3	3.4	8.4	9.3	9.3	0	10.5	791	0.0042	11.2	807	815	823	24	43
NOV	1.2	3.2	4.3	2.2	4.0	8.1	9.0	9.0	0	10.2	828	0.0593	153.7	845	853	861	155	248
DEC	1.2	3.2	4.4	2.3	3.6	8.4	9.3	9.3	0	10.5	849	0.0513	137.4	866	874	883	146	235
Totals	**16**	**67**	**83.0**	**33**	**49**	**116**	**1415**	**151**	**0**	**166.3**			**424**				**615**	**993**
Comments		Is assumed Fire Suppression use of 57 m3		Average 2011-2020	2011 recorded use	Two licenses C120382 and C120292	It includes Fire Suppression at 7000 m^3/day from April to September	It does not include Fire Suppression	No license applications	For GW use we include the estimated since no groundwater license is present. No fire protection		January to March might not be representative due to the lack of data		March to September -22%. Oct to Feb +2%	March to September -25%. Oct to Feb +3%	March to September -28%. Oct to Feb +4%	Water balance model	Water balance model

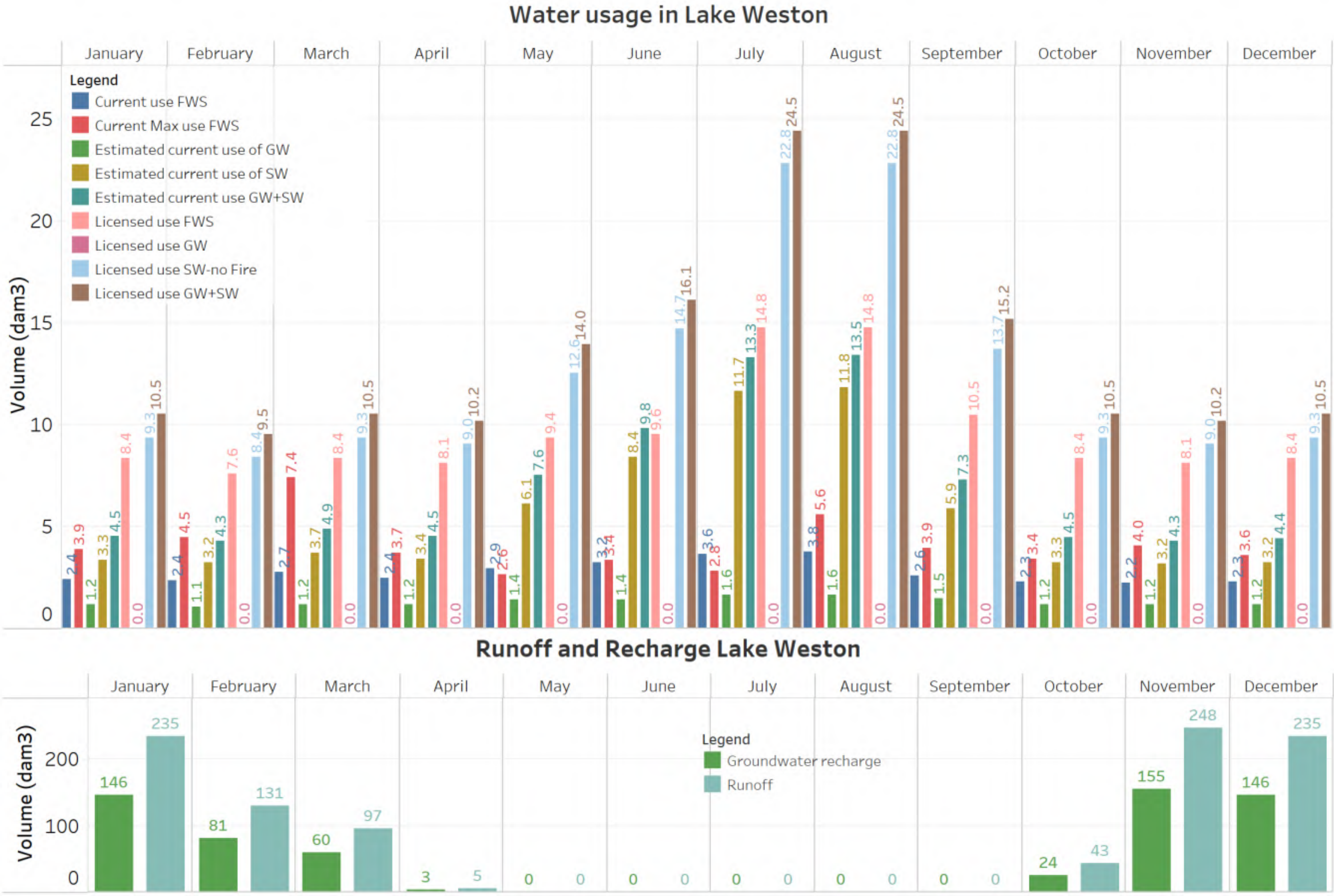

Figure 45. Monthly volumes comparing current estimated and licenced usages.

8 CONCLUSIONS

1. **Water Usage (Actuals).** Water usage consists of a combination of water wells, surface water (Lake Weston) and springs used for domestic water supply, irrigation, a community water system (Fulford Water System) and fire protection. The only available metered water usage data is from the Fulford Water System (average usage of 33 dam^3). Fire protection usage is sporadic (e.g. 3000 gallons were drawn in 2019 but none in 2020 and 2021). The total annual Lake Weston (surface water) usage is 151 dam^3 without any fire protection usage. Groundwater usage is much less at 16 dam^3. The highest total (combined surface water and groundwater) usage is from April to September (peaking in July and August).

2. **Water Usage (Licences).** The total amount of licenced water is 1415 dam3 which is comprised of the fire licence (1264 dam^3), the Fulford Water System (116 dam^3) and several private irrigation licences (totalling 35 dam^3).

3. **Water Balance.** Total annual precipitation in the Lake Weston watershed is about 2585 dam^3/year and the surplus is 1608 dam^3/year which is divided between surface water runoff (993 dam^3/year) and groundwater recharge (615 dam^3/year). Surface water runoff represents approximately 40% of total precipitation and groundwater recharge represents 25% of total precipitation. These values are typical for humid coastal hydrogeologic environments. A comparison of annual groundwater recharge and total annual water usage (from Lake Weston and wells) indicates that, on an annual basis, groundwater recharge is sufficient to satisfy the current demand. However, groundwater recharge occurs mostly in the winter months while the water demand is higher in the dry summer months, mostly for water supply and irrigation. This means that during the summer months, water supply demand exceeds recharge which leads to seasonally declining water levels of Lake Weston and Aquifer 1147. These levels then rise again each fall and winter in response to recharge events.

4. **Climate Change.** Climate change models for 2030, 2050 and 2070 predict that winters in the CRD will be warmer with more rain and less snow. The rain will fall as more intense events leading to higher levels of surface runoff potentially leading to higher soil erosion and flooding and potentially less groundwater recharge. The spring snowmelt will tend to disappear reducing the historical groundwater recharge heading into the dry summer months. During summer, temperatures will be higher, precipitation lower and groundwater baseflow (feeding creeks, lakes, wetlands) will therefore be lower. Runoff is predicted to decrease significantly in the summer months (-20% to -28%) while in the winter months runoff will increase by a small amount (2% to 4%). Water shortage is predicted from March to September when the demand will seasonally exceed the surplus of water. This means that during this period, licenced withdrawals exceed groundwater recharge (replenishment of supply) potentially leading to decreased groundwater baseflow to the creek and thus water available for environmental flow needs (aquatic ecosystems: lakes, creeks, wetlands, etc.).

5. **Environmental Flow Needs.** The Lake Weston level varies from a high of about 61.35 masl in January to a low of 60.55 masl in August (0.8 m variation) and appears to reach a level where it becomes stable in the summer months. For Weston Creek, to achieve 10%MAD flow the level of Lake Weston must be maintained at an elevation of at least 61 masl. Currently, this level is not maintained between July and September each year and this situation will worsen in the future according to the climate change predictions.

6. **Safe Yield of Watershed and Lake Weston.** The relationship between usage and Lake Weston level is represented with an approximate trend line providing an approximation of the usage that corresponds to the 10%MAD, 20%MAD and 30%MAD. To achieve even the minimum 5-10%MAD in Weston Creek the usage in the summer months would need to be reduced to usage levels similar to the winter months. This would require significant summer restrictions on irrigation (farm and household) usage. This highlights the need for accurate usage data to confirm these results and water conservation programs in the summer. It is not recommended that Lake Weston be pumped without consideration of EFNs (fish habitat in Lake Weston and Weston Creek) as the pumping of Lake Weston will lower the water table in the nearby aquifer affecting nearby water wells and inducing further degradation of water quality in Lake Weston.

9 RECOMMENDATIONS AND DATA LIMITATIONS

1. **Water level monitoring**: Additional groundwater monitoring throughout the area to create a watershed level water monitoring network and understand where in the watershed surface water or groundwater levels are declining over time. The importance of a groundwater monitoring network is accentuated by the fact that Lake Weston is a groundwater fed lake thus it is very dependent on healthy groundwater levels in the aquifer and natural groundwater recharge in the watershed above the lake. Groundwater monitoring data throughout the watershed is very important to ensure any changes in groundwater levels (e.g. due to higher well pumping) or decreased recharge are observed providing early indications of potential problems before they grow too large. Groundwater monitoring can be done either through the use of dedicated observation wells, or with privately-owned wells (volunteer observation wells) that are equipped with dataloggers that continuously measure water level and electrical conductivity (a proxy for salinity which is an indicator of salt-water intrusion and/or contamination). Further in-creek flow and chemistry monitoring may refine the understanding of in-creek groundwater baseflow contributions to lake recharge and ecosystem health.

2. **Climate stations.** Given that precipitation is the most sensitive parameter for estimating groundwater recharge and runoff, it is especially important to collect local precipitation data. The only climate station in the study area is at the Fulford Elementary School; however, this station has not been active since 2020. It is

recommended that this station be operated continuously and maintained by the Islands Trust or CRD to ensure data integrity and continuity.

3. **Hydrometric stations.** There is one active hydrometric station in Lake Weston which is maintained and operated by Island Trust. This station measures water level and temperature. In addition to this, we recommend measuring flow at the mouth of the lake. This information will be critical for future decisions regarding impact of climate change on the water availability and further calibrate water balance model.

4. **Water use metering**. There is only one metered water system in the area, the Fulford Water System thus water use for all other water supplies has been estimated using information from proxy models. An improved estimate of water usage is very important, and it is recommended that for each water well and surface water extraction system either a flow meter be added to the system or another method be applied to estimate the volume used over time. In addition, is it recommended that flow meters be added for each property supplied by the Fulford Water System.

5. **Water conservation.** Increased measures should be promoted to minimize water consumption from March to September and especially during July and August when the aquatic ecosystem is most stressed. Reducing usage in the summer months will also help maintain a sufficient amount of water in storage in the lake and the surrounding and thus avoid more serious water restrictions (e.g. limits on domestic usage) and maintaining sufficient flow in Weston Creek to maintain fish habitat even during late summer.

6. **Environmental flow needs**. EFNs for the Lake Weston watershed consist of sufficient baseflow to Lake Weston and sufficient flow in Weston Creek to maintain fish habitats that have been identified at three locations: the two arms of Lake Weston and a groundwater discharge area along the creek. The maintenance of these fish habitats by ensuring sufficient water level of Lake Weston and flow in Weston Creek will also have the added benefit of continuing the natural discharge of freshwater to Fulford Harbour. Each of these three locations should be assessed in the field to determine: a) the fish species present, b) the minimum flow required to maintain the habitat and c) how to monitor the water level or flow at each location. The minimum flow may or may not be 10%MAD (i.e. the minimum MAD level) as there is evidence (e.g. Toslum Creek, BC) that lower MAD levels may be suitable. The level of Lake Weston depends on natural groundwater recharge from the watershed and thus land-use (Recommendation 7). The flow in Weston Creek depends on the level of Lake Weston and on natural groundwater discharge to the creek (baseflow) from the aquifer. Thus, to protect the fish habitat of Lake Weston and Weston Creek, the overall watershed and aquifer need to be protected to ensure the continuation of natural groundwater recharge and the maintenance of groundwater levels in the aquifer. The incorporation of EFNs into a water budget will impact the local community by reducing the amount of water available for water supply.

7. **Watershed protection and land-use decision making.** Place a high importance on land development and land management decisions that do not jeopardize water resources. Given the high importance of groundwater in the watershed it is highly

recommended that the areas with the highest groundwater recharge potential be protected to ensure land-use activities do not disturb the soil and its ability to absorb water and recharge groundwater.

10 STUDY LIMITATIONS

This document was prepared for the exclusive use of ITC and CRD. The inferences concerning the data, site and receiving environment conditions contained in this document are based on information obtained by GW Solutions and others and are based solely on the condition of the site at the time of the site studies. Soil, surface water and groundwater conditions may vary with location, depth, time, sampling methodology, analytical techniques, and other factors.

In evaluating the subject study area and water quality data, GW Solutions has relied in good faith on information provided. The factual data, interpretations and recommendations pertain to a specific project as described in this document, based on the information obtained during the assessment by GW Solutions on the dates cited in the document, and are not applicable to any other project or site location. GW Solutions accepts no responsibility for any deficiency or inaccuracy contained in this document as a result of reliance on the aforementioned information.

The findings and conclusions documented in this document have been prepared for the specific application to this project and have been developed in a manner consistent with that level of care normally exercised by hydrogeologists currently practicing under similar conditions in the jurisdiction.

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If new information is discovered during future work, GW Solutions should be requested to re-evaluate the conclusions of this document and to provide amendments, as required, prior to any reliance upon the information presented herein. The validity of this document is affected by any change of site conditions, purpose, development plans or significant delay from the date of this document in initiating or completing the project.

The produced graphs, images, and maps have been generated to visualize results and assist in presenting information in a spatial and temporal context. The conclusions and recommendations presented in this document are based on the review of information available at the time the work was completed, and within the time and budget limitations of the scope of work.

ITC and CRD may rely on the information contained in this memorandum subject to the above limitations.

11 CLOSURE

Conclusions and recommendations presented herein are based on available information at the time of the study. The work has been carried out in accordance with generally accepted engineering and geoscience practice. No other warranty is made, either expressed or implied. Engineering judgement has been applied in producing this report.

This report was prepared by personnel with professional experience in the fields covered. Reference should be made to the General Conditions and Limitations attached in Appendix 1.

GW Solutions is pleased to produce this document. If you have any questions, please contact us.

Yours truly,

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APPENDIX 1

GW SOLUTIONS INC. GENERAL CONDITIONS AND LIMITATIONS

This report incorporates and is subject to these "General Conditions and Limitations".

1.0 USE OF REPORT

This report pertains to a specific area, a specific site, a specific development, and a specific scope of work. It is not applicable to any other sites, nor should it be relied upon for types of development other than those to which it refers. Any variation from the site or proposed development would necessitate a supplementary investigation and assessment. This report and the assessments and recommendations contained in it are intended for the sole use of GW SOLUTIONS's client. GW SOLUTIONS does not accept any responsibility for the accuracy of any of the data, the analysis or the recommendations contained or referenced in the report when the report is used or relied upon by any party other than GW SOLUTIONS's client unless otherwise authorized in writing by GW SOLUTIONS. Any unauthorized use of the report is at the sole risk of the user. This report is subject to copyright and shall not be reproduced either wholly or in part without the prior, written permission of GW SOLUTIONS. Additional copies of the report, if required, may be obtained upon request.

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This report is based solely on the conditions which existed within the study area or on site at the time of GW SOLUTIONS's investigation. The client, and any other parties using this report with the express written consent of the client and GW SOLUTIONS, acknowledge that conditions affecting the environmental assessment of the site can vary with time and that the conclusions and recommendations set out in this report are time sensitive. The client, and any other party using this report with the express written consent of the client and GW SOLUTIONS, also acknowledge that the conclusions and recommendations set out in this report are based on limited observations and testing on the area or subject site and that conditions may vary across the site which, in turn, could affect the conclusions and recommendations made. The client acknowledges that GW SOLUTIONS is neither qualified to, nor is it making, any recommendations with respect to the purchase, sale, investment or development of the property, the decisions on which are the sole responsibility of the client.

2.1 INFORMATION PROVIDED TO GW SOLUTIONS BY OTHERS

During the performance of the work and the preparation of this report, GW SOLUTIONS may have relied on information provided by persons other than the client. While GW SOLUTIONS endeavours to verify the accuracy of such information when instructed to do so by the client, GW SOLUTIONS accepts no responsibility for the accuracy or the reliability of such information which may affect the report.

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The client recognizes that property containing contaminants and hazardous wastes creates a high risk of claims brought by third parties arising out of the presence of those materials. In consideration of these risks, and in consideration of GW SOLUTIONS providing the services requested, the client agrees that GW SOLUTIONS's liability to the client, with respect to any issues relating to contaminants or other hazardous wastes located on the subject site shall be limited as follows:

(1) With respect to any claims brought against GW SOLUTIONS by the client arising out of the provision or failure to provide services hereunder shall be limited to the amount of fees paid by the client to GW SOLUTIONS under this Agreement, whether the action is based on breach of contract or tort;

(2) With respect to claims brought by third parties arising out of the presence of contaminants or hazardous wastes on the subject site, the client agrees to indemnify, defend and hold harmless GW SOLUTIONS from and against any and all claim or claims, action or actions, demands, damages, penalties, fines, losses, costs and expenses of every nature and kind whatsoever, including solicitor-client costs, arising or alleged to arise either in whole or part out of services provided by GW SOLUTIONS, whether the claim be brought against GW SOLUTIONS for breach of contract or tort.

4.0 JOB SITE SAFETY

GW SOLUTIONS is only responsible for the activities of its employees on the job site and is not responsible for the supervision of any other persons whatsoever. The presence of GW SOLUTIONS personnel on site shall not be construed in any way to relieve the client or any other persons on site from their responsibility for job site safety.

5.0 DISCLOSURE OF INFORMATION BY CLIENT

The client agrees to fully cooperate with GW SOLUTIONS with respect to the provision of all available information on the past, present, and proposed conditions on the site, including historical information respecting the use of the site. The client acknowledges that in order for GW SOLUTIONS to properly provide the service, GW SOLUTIONS is relying upon the full disclosure and accuracy of any such information.

6.0 STANDARD OF CARE

Services performed by GW SOLUTIONS for this report have been conducted in a manner consistent with the level of skill ordinarily exercised by members of the profession currently practicing under similar conditions in the jurisdiction in which the services are provided. Engineering judgement has been applied in developing the conclusions and/or recommendations provided in this report. No warranty or guarantee, express or implied, is made concerning the test results, comments, recommendations, or any other portion of this report.

7.0 EMERGENCY PROCEDURES

The client undertakes to inform GW SOLUTIONS of all hazardous conditions, or possible hazardous conditions which are known to it. The client recognizes that the activities of GW SOLUTIONS may uncover previously unknown hazardous materials or conditions and that such discovery may result in the necessity to undertake emergency procedures to protect GW SOLUTIONS employees, other persons and the environment. These procedures may involve additional costs outside of any budgets previously agreed upon. The client agrees to pay GW SOLUTIONS for any expenses incurred as a result of such discoveries and to compensate GW SOLUTIONS through payment of additional fees and expenses for time spent by GW SOLUTIONS to deal with the consequences of such discoveries.

8.0 NOTIFICATION OF AUTHORITIES

The client acknowledges that in certain instances the discovery of hazardous substances or conditions and materials may require that regulatory agencies and other persons be informed and the client agrees that notification to such bodies or persons as required may be done by GW SOLUTIONS in its reasonably exercised discretion.

9.0 OWNERSHIP OF INSTRUMENTS OF SERVICE

The client acknowledges that all reports, plans, and data generated by GW SOLUTIONS during the performance of the work and other documents prepared by GW SOLUTIONS are considered its professional work product and shall remain the copyright property of GW SOLUTIONS.

10.0 ALTERNATE REPORT FORMAT

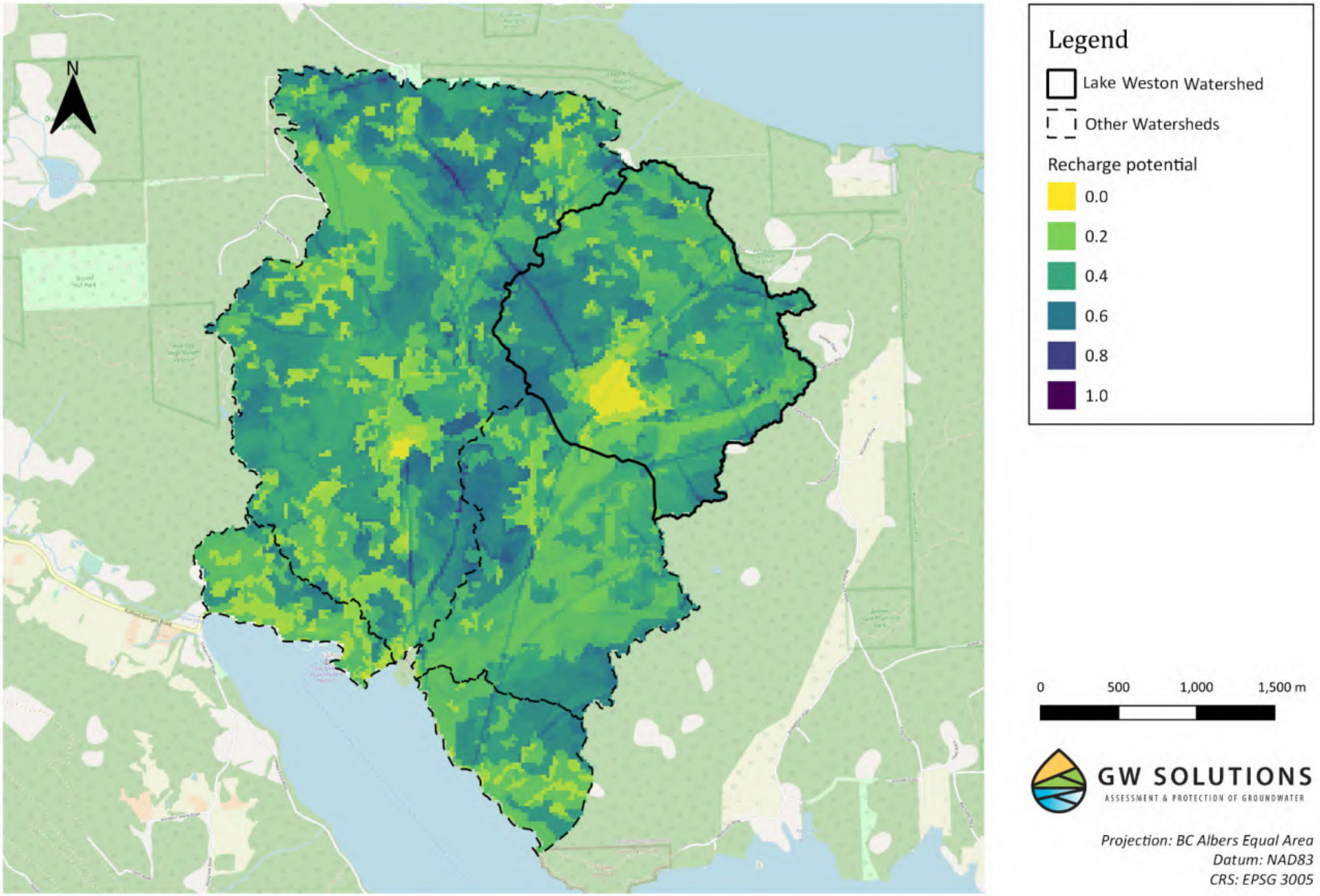
Where GW SOLUTIONS submits both electronic file and hard copy versions of reports, drawings and other project-related documents and deliverables (collectively termed GW SOLUTIONS's instruments of professional service), the Client agrees that only the signed and sealed hard copy versions shall be considered final and legally binding. The hard copy versions submitted by GW SOLUTIONS shall be the original documents for record and working purposes, and, in the event of a dispute or discrepancies, the hard copy versions shall govern over the electronic versions. Furthermore, the Client agrees and waives all future right of dispute that the original hard copy signed version archived by GW SOLUTIONS shall be deemed to be the overall original for the Project. The Client agrees that both electronic file and hard copy versions of GW SOLUTIONS's instruments of professional service shall not, under any circumstances, no matter who owns or uses them, be altered by any party except GW SOLUTIONS. The Client warrants that GW SOLUTIONS's instruments of professional service will be used only and exactly as submitted by GW SOLUTIONS. The Client recognizes and agrees that electronic files submitted by GW SOLUTIONS have been prepared and submitted using specific software and hardware systems. GW SOLUTIONS makes no representation about the compatibility of these files with the Client's current or future software and hardware systems.

APPENDIX 2

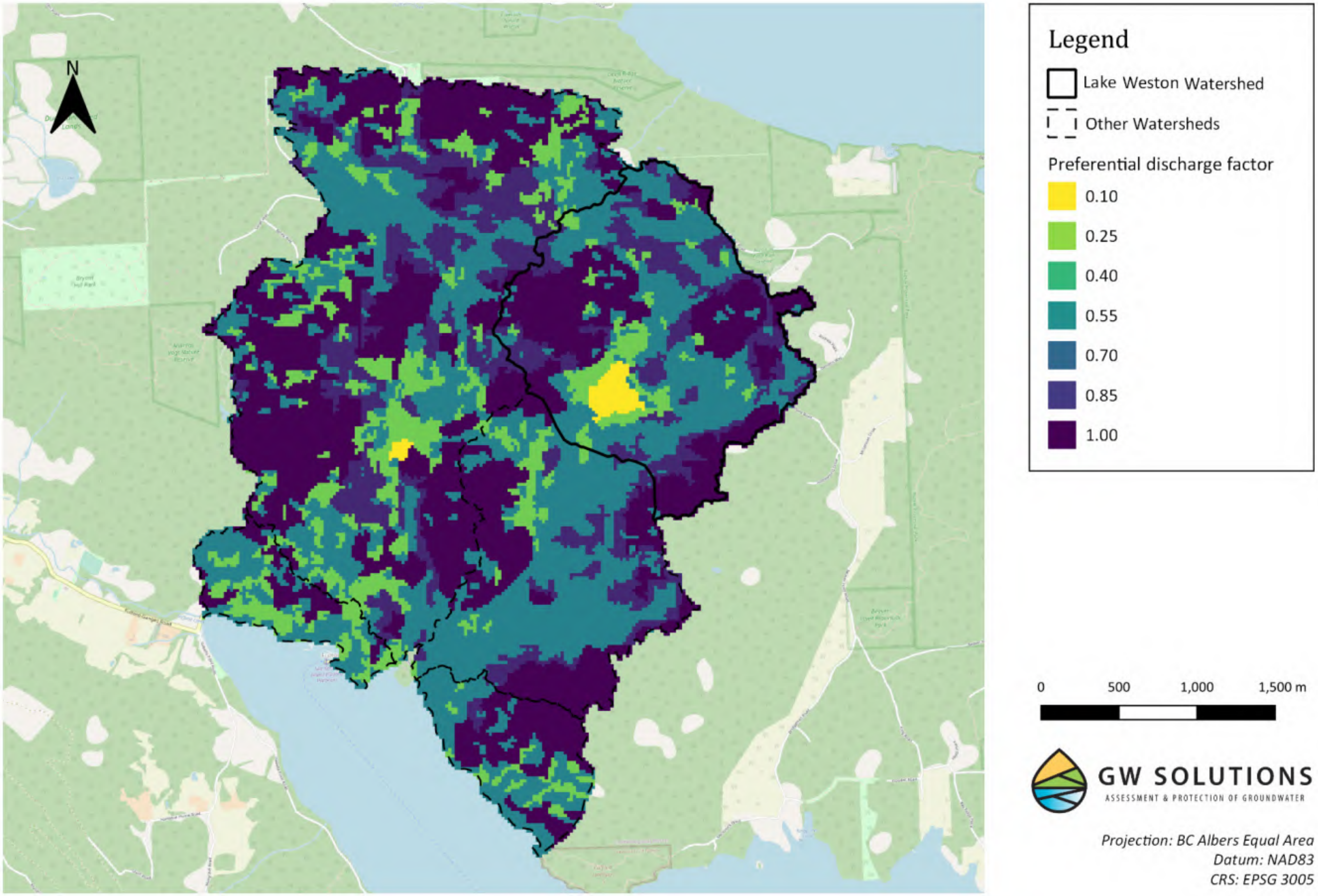
Groundwater Recharge Coefficients and Groundwater Recharge Potential and Recharge Coefficients

APPENDIX 2: MAPS OF GROUNDWATER RECHARGE POTENTIAL INPUTS

1.1 Groundwater recharge potential



1.2 Preferential recharge/discharge factor



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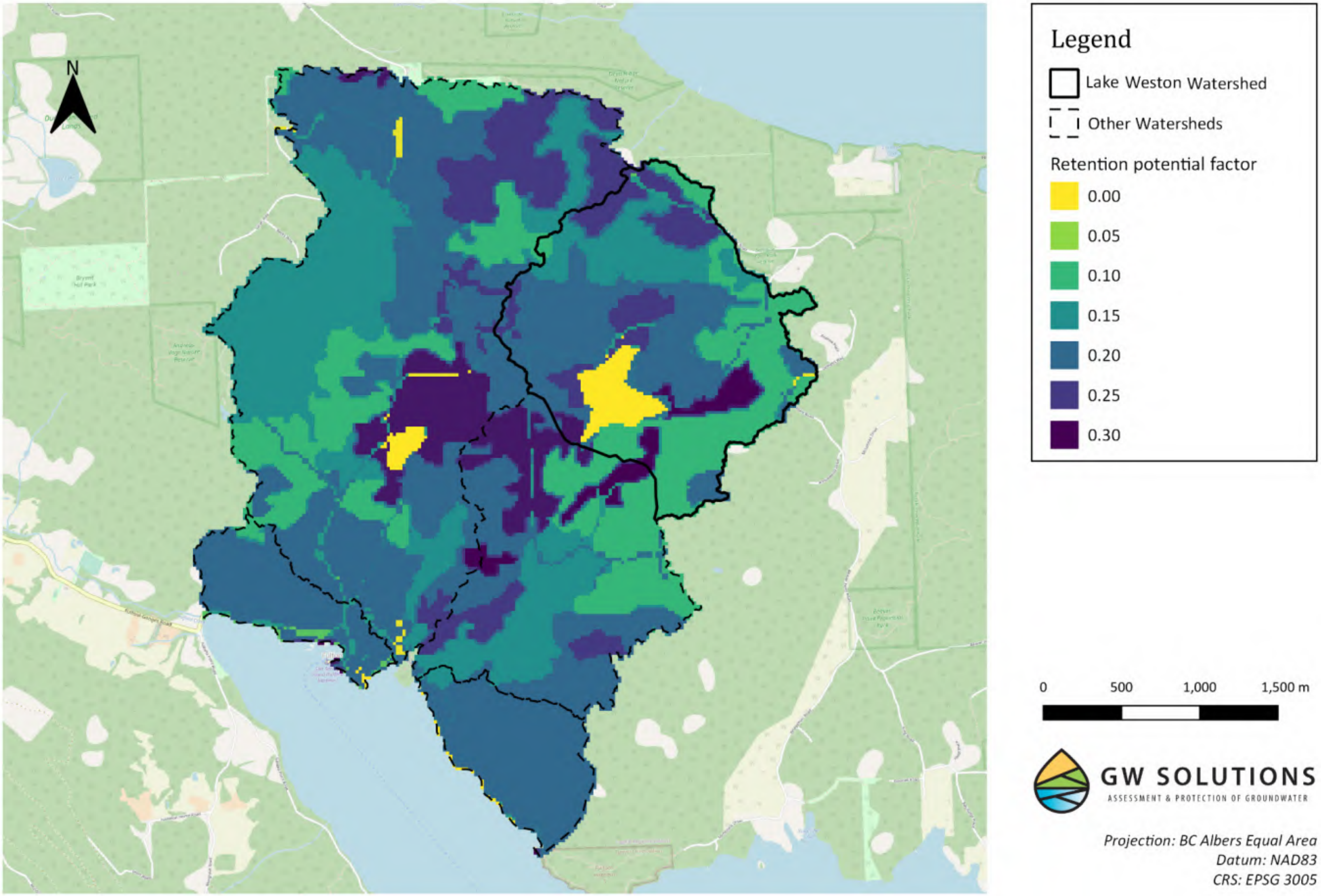
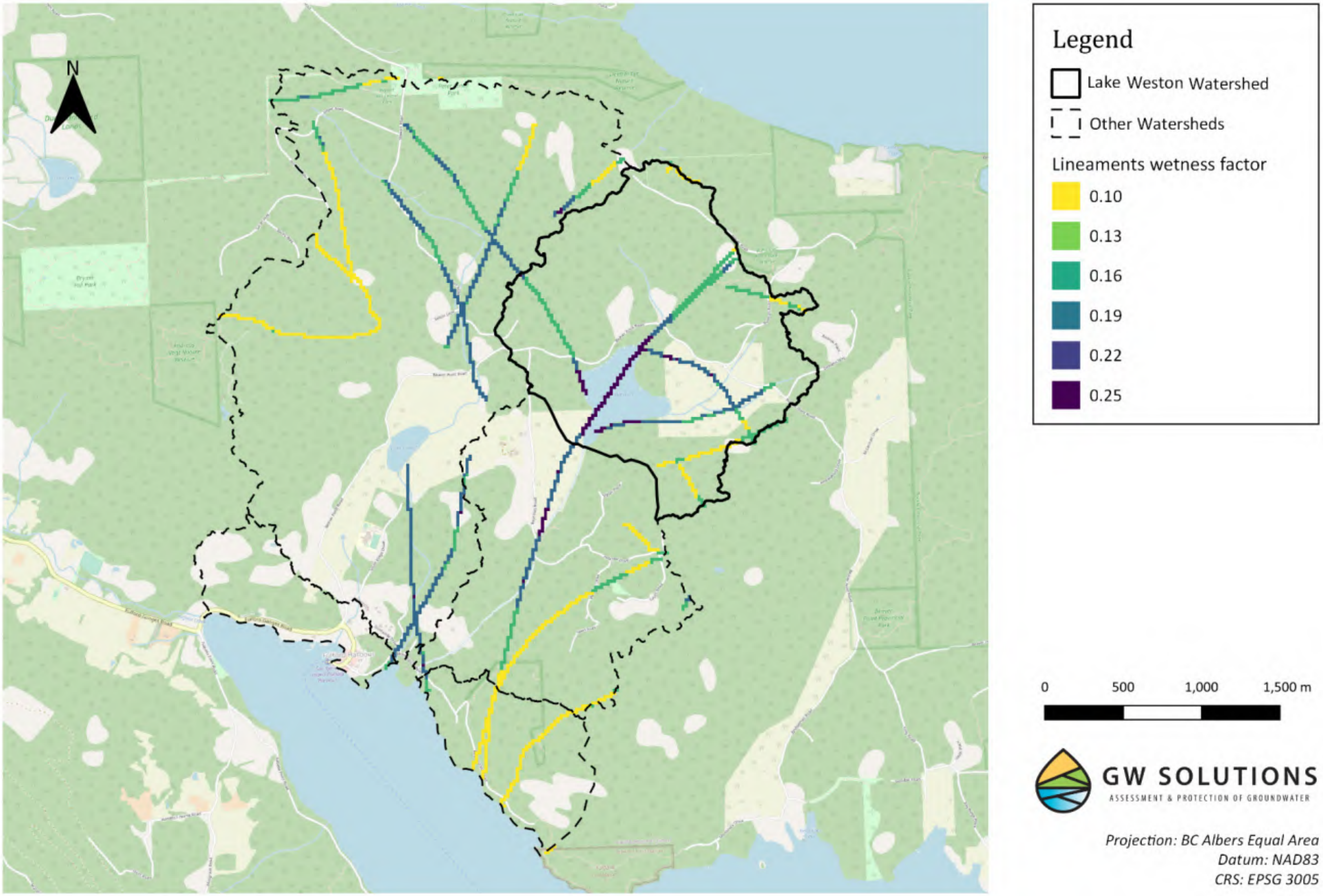
Projection: BC Albers Equal Area
Datum: NAD83
CRS: EPSG 3005

1.3 Water retention potential factor

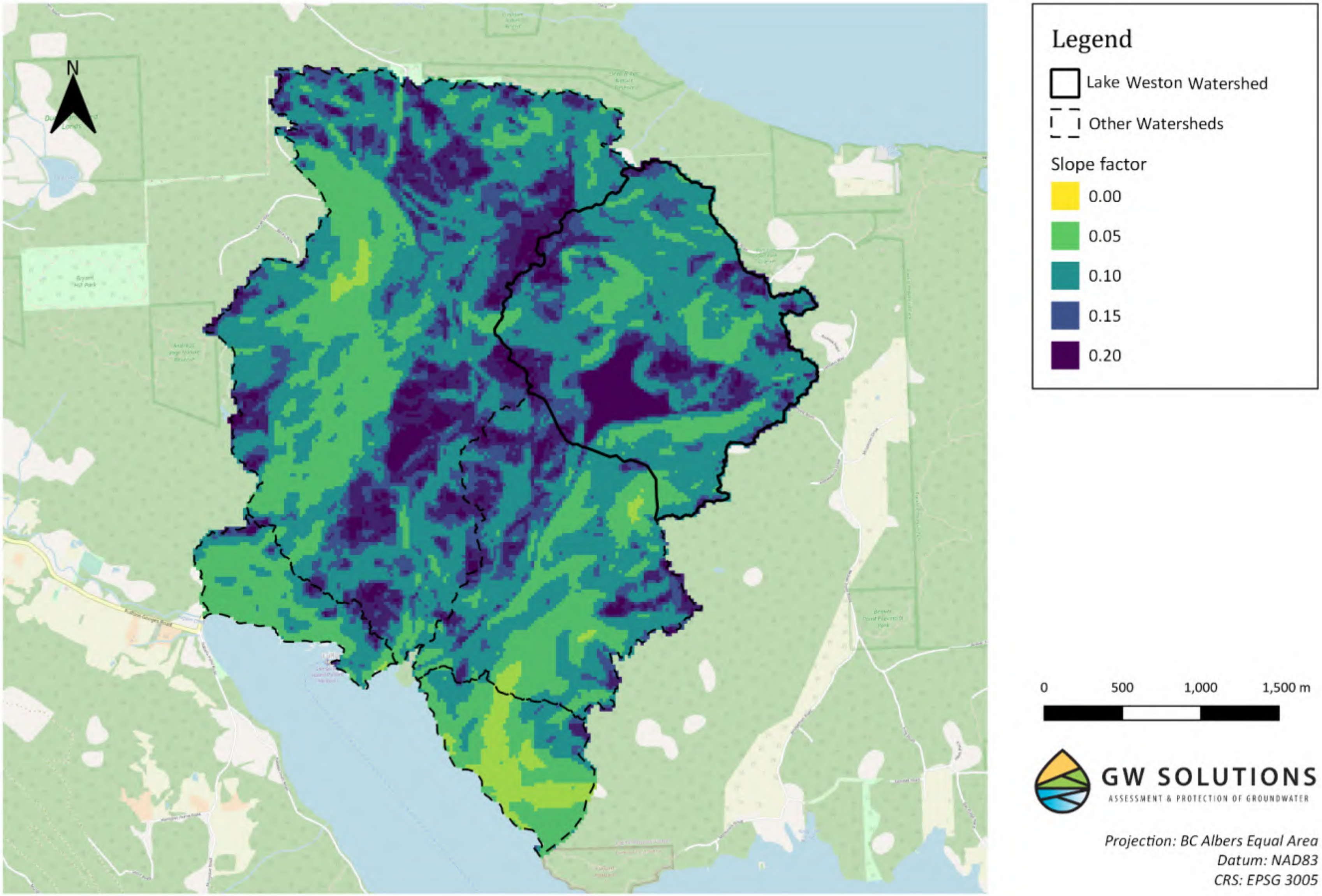


1.4 Bedrock lineament wetness factor



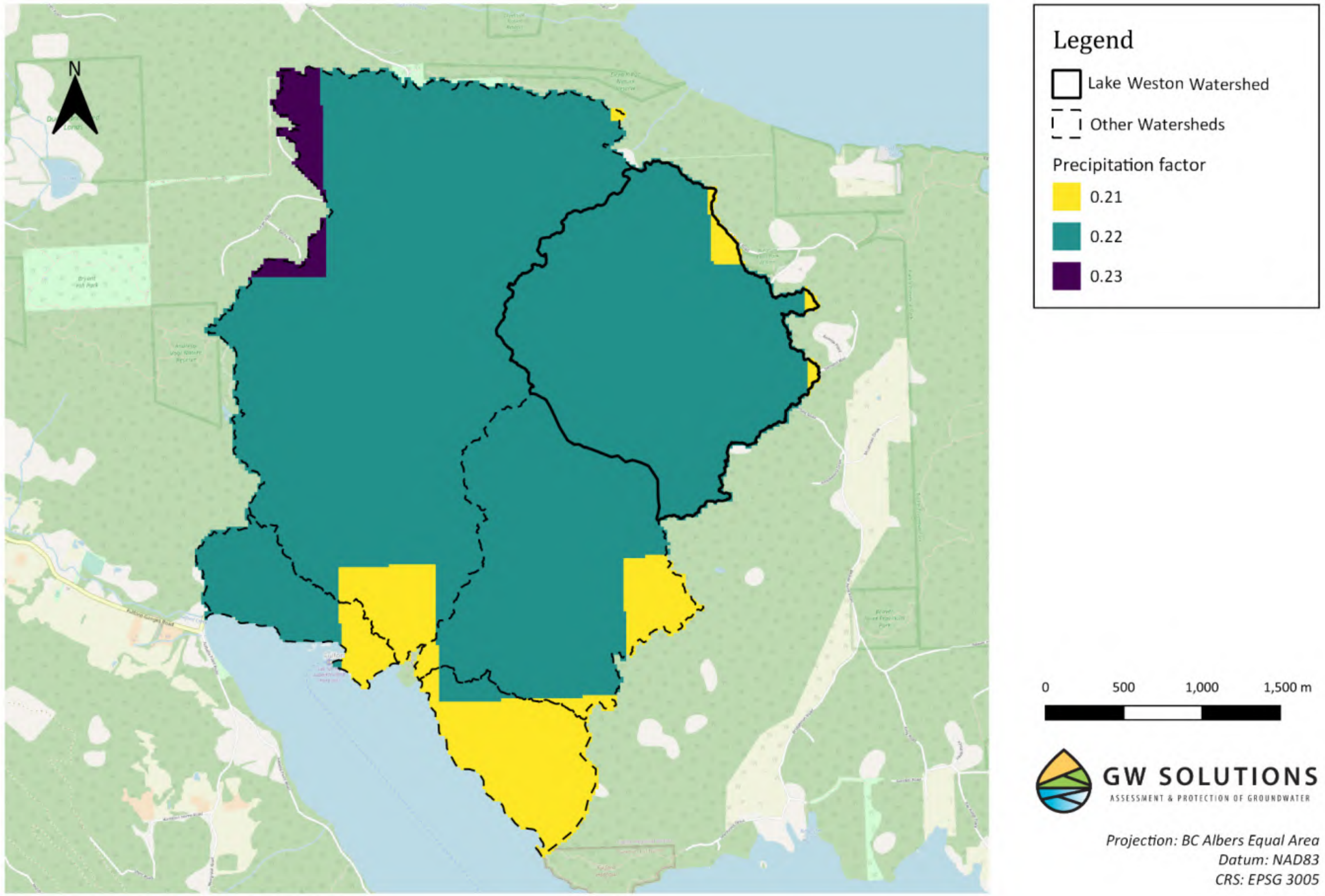
Projection: BC Albers Equal Area
Datum: NAD83
CRS: EPSG 3005

1.5 Slope factor



Projection: BC Albers Equal Area
Datum: NAD83
CRS: EPSG 3005

1.6 Precipitation factor



APPENDIX 3

Water Balance Inputs and Outputs

APPENDIX 3: WATER BALANCE OUTPUTS FOR LAKE WESTON

1.1 Summary of Water Balance Parameters

The water balance model used by GW solutions requires four primary inputs: precipitation, average temperature, total solar radiation, and soil available moisture capacity (AWC). All inputs are obtained as monthly raster layers at a 20m resolution, with exception of AWC, which does not vary over an annual timescale and thus is only a single layer.

Using these as inputs, the water balance model used by GW solutions produces several outputs. These are described as follows:

Output name	**Short Name**	**Description**
Potential evapotranspiration	PET	The evaporative water loss from a vegetated surface in which *water is not a limiting factor*. It represents moisture demand, and is calculated using the Turc method, depending mainly on temperature and radiation.
Soil storage	ST	The amount of moisture stored in the soil in any given month. It depends on the soil AWC as well as PET. When soil storage is full, it is equal to the AWC. When soil storage is 0, any precipitation input must first restore soil moisture capacity to be equal to AWC before it can contribute to runoff or groundwater recharge.
Actual evapotranspiration	AET	The evaporative water loss from a vegetated surface *given water availability* (where water availability is combination of both precipitation and current soil moisture storage). If water is not limiting (that is, soil storage is full and precipitation exceeds PET), actual evapotranspiration is equal to potential evapotranspiration.
Surplus	S	The excess water not evaporated or transpired, thereby contributing to runoff or subsurface flow. There can be no surplus if storage is not full.
Deficit	D	A theoretical value representing moisture stress. It occurs when evaporative demand is not met by available water. In effect, it is the difference between potential and actual evapotranspiration.

Following the calculation of the water balance output for Lake Weston and it's surrounding watersheds, GW solutions combined the available moisture surplus output with the recharge potential layer created through the enhanced recharge potential mapping process. The combined results thus allow the calculation of two additional outputs:

Output name	**Short Name**	**Description**
Groundwater recharge	GWR	The amount of surplus that is estimated to contribute to subsurface flow, or groundwater recharge. This is a proportion of the total moisture surplus, and it depends on the landscape's recharge potential.
Surface runoff	RO	The amount of surplus that is estimated to contribute to overland flow, through surface runoff. This is a proportion of the total moisture surplus, and it depends on the landscape's recharge potential.

1.2 Water Balance Model Outputs

Outputs from the water balance model for Lake Weston and the surrounding watersheds are summarized in the following plots. The maps show the spatial pattern for each variable by month. The boxplots summarize the overall distribution of values by month, helping emphasize any seasonal patterns present for each variable.

1.2.1 Precipitation

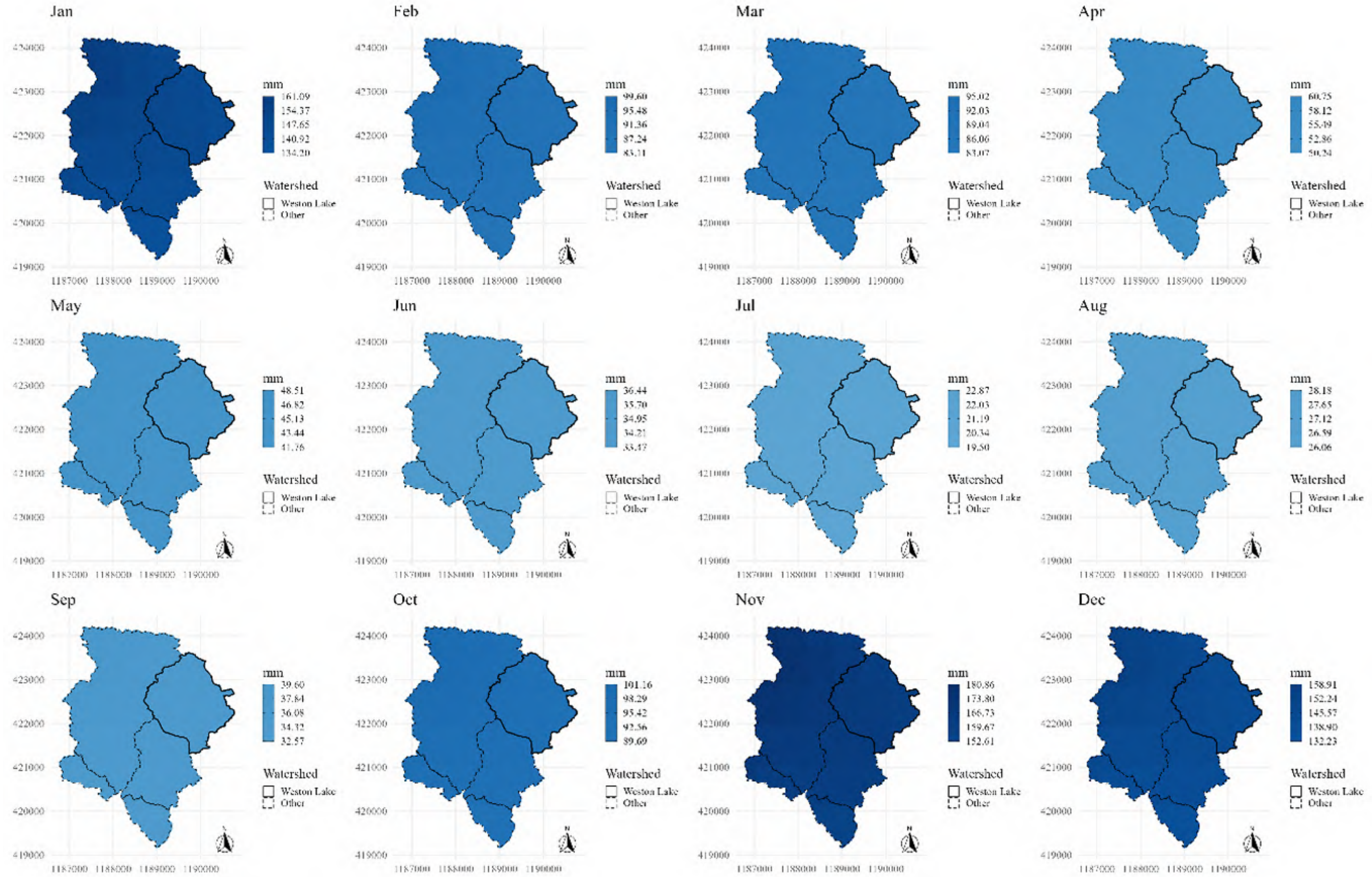


Figure 1: Precipitation by month over Lake Weston and its surrounding watersheds

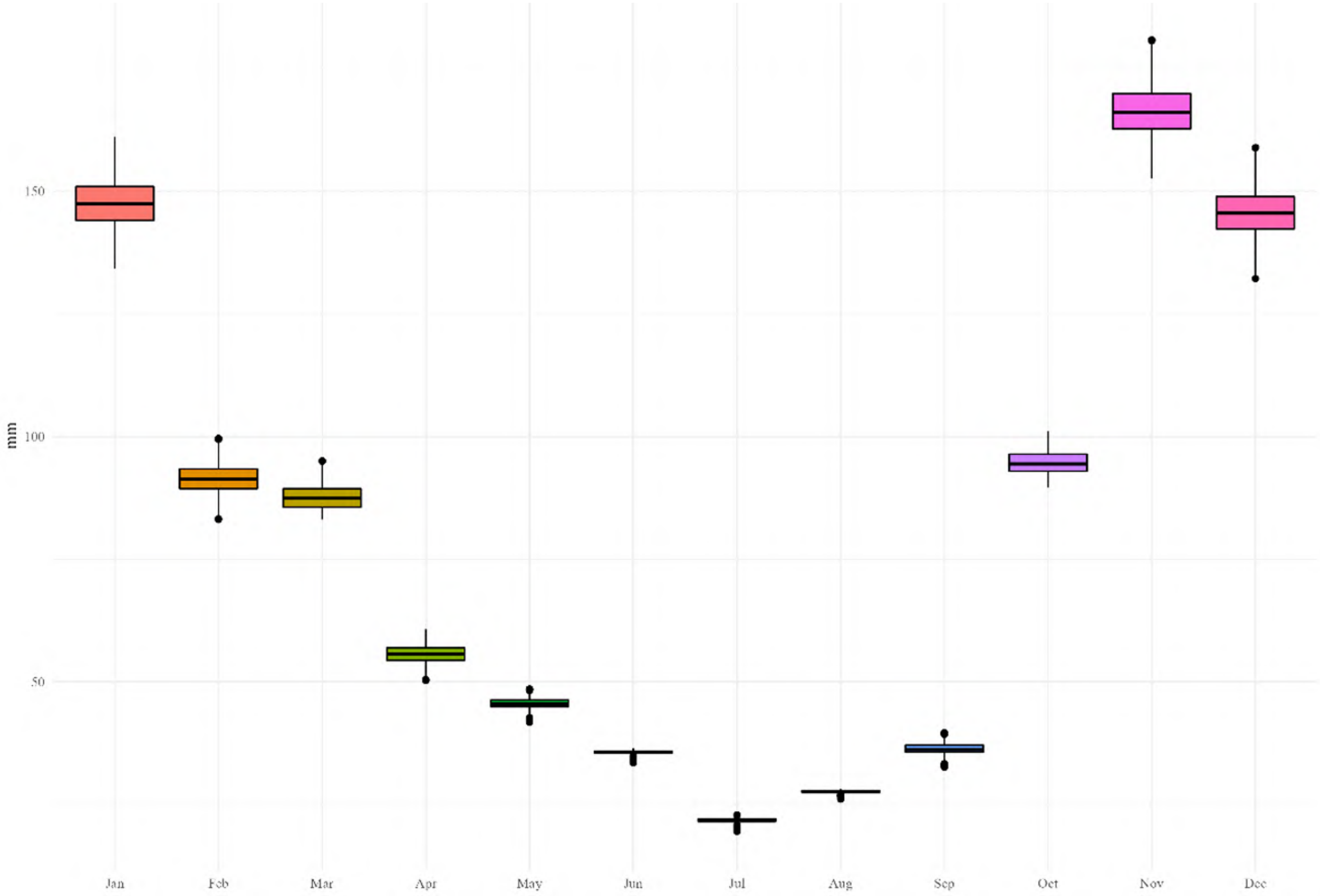


Figure 2: Monthly spread in precipitation over Lake Weston and its surrounding watersheds

1.2.2 Temperature

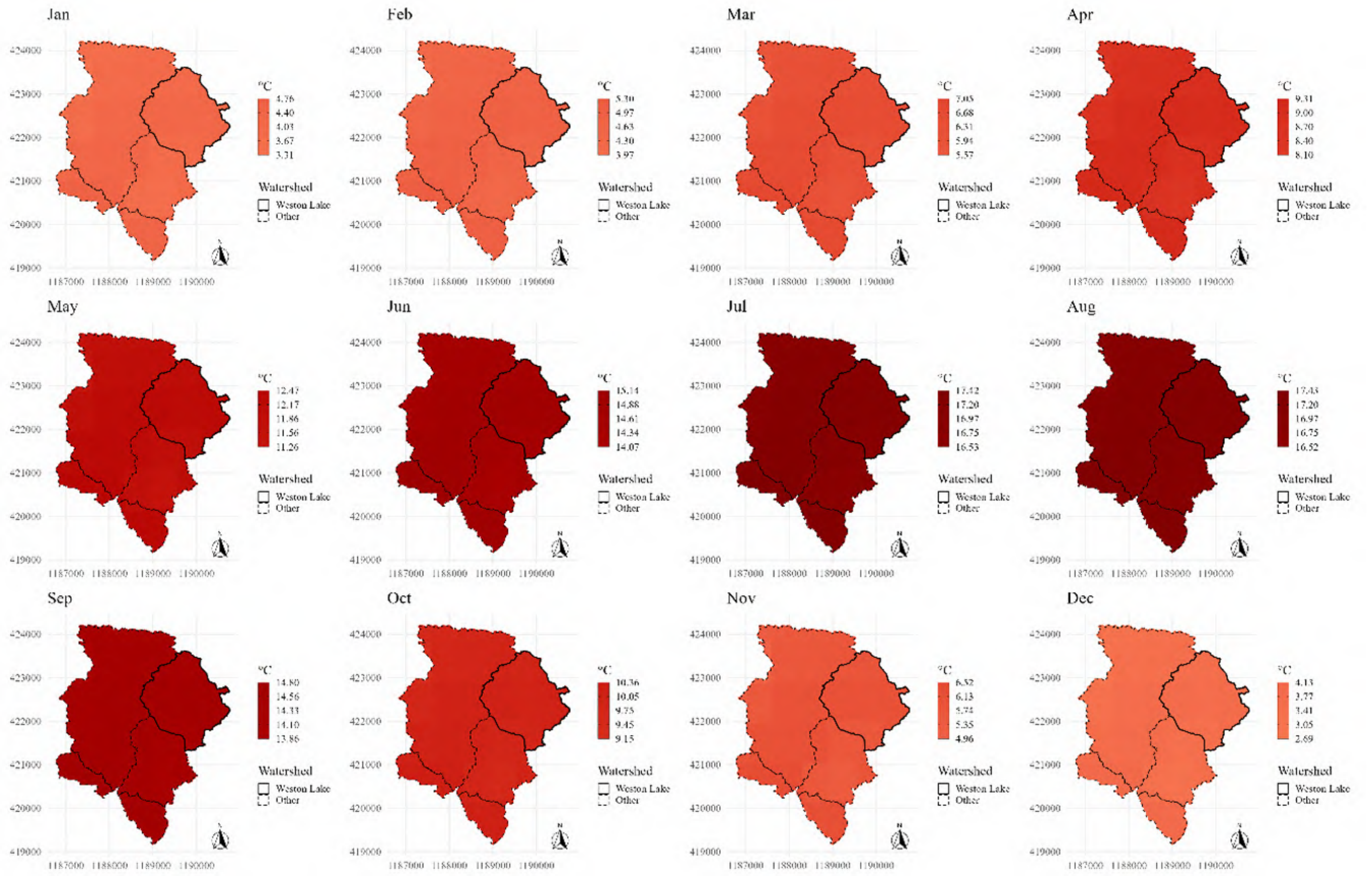


Figure 3: Temperature by month over Lake Weston and its surrounding watersheds

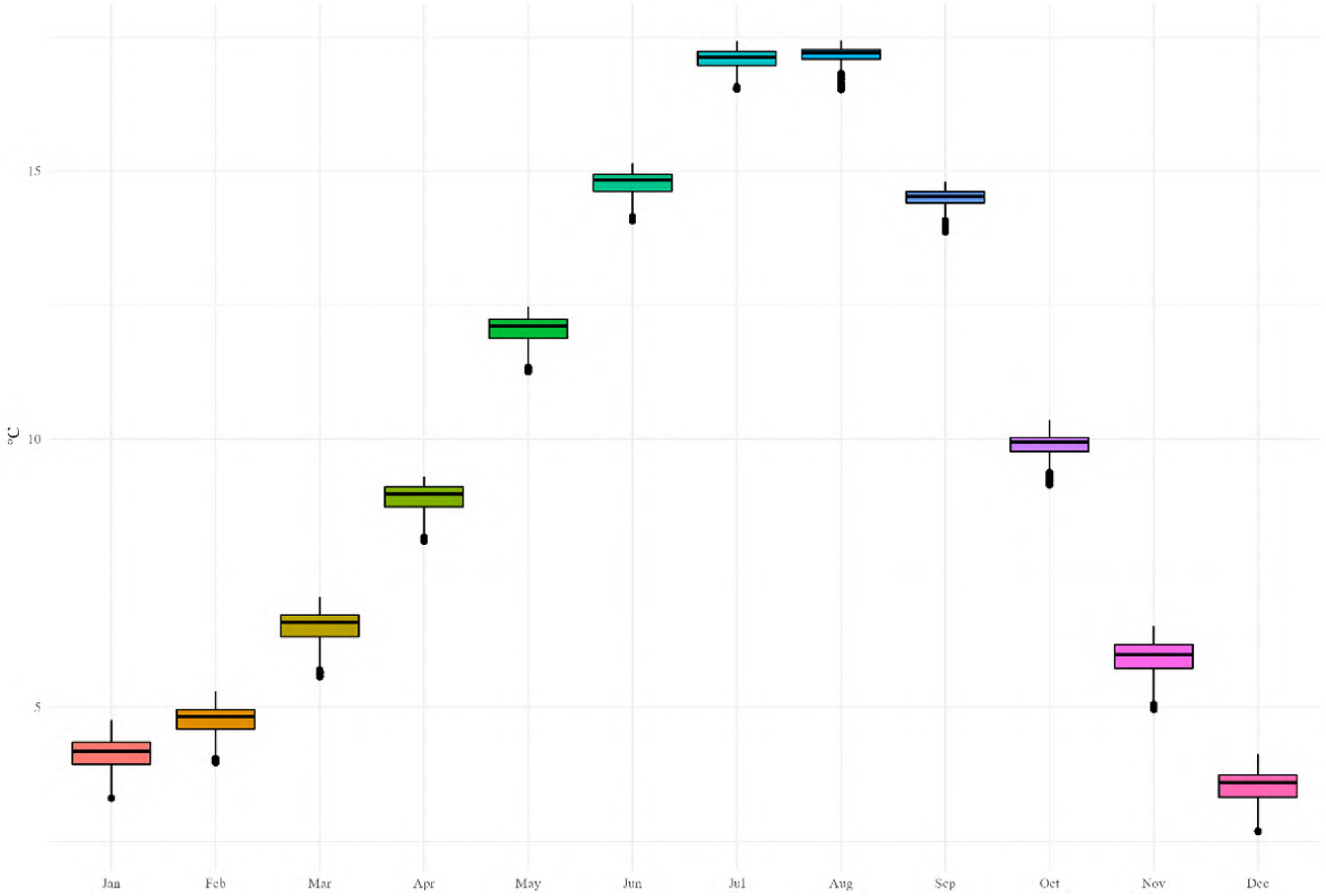


Figure 4: Monthly spread in temperature over Lake Weston and its surrounding watersheds

1.2.3 Radiation

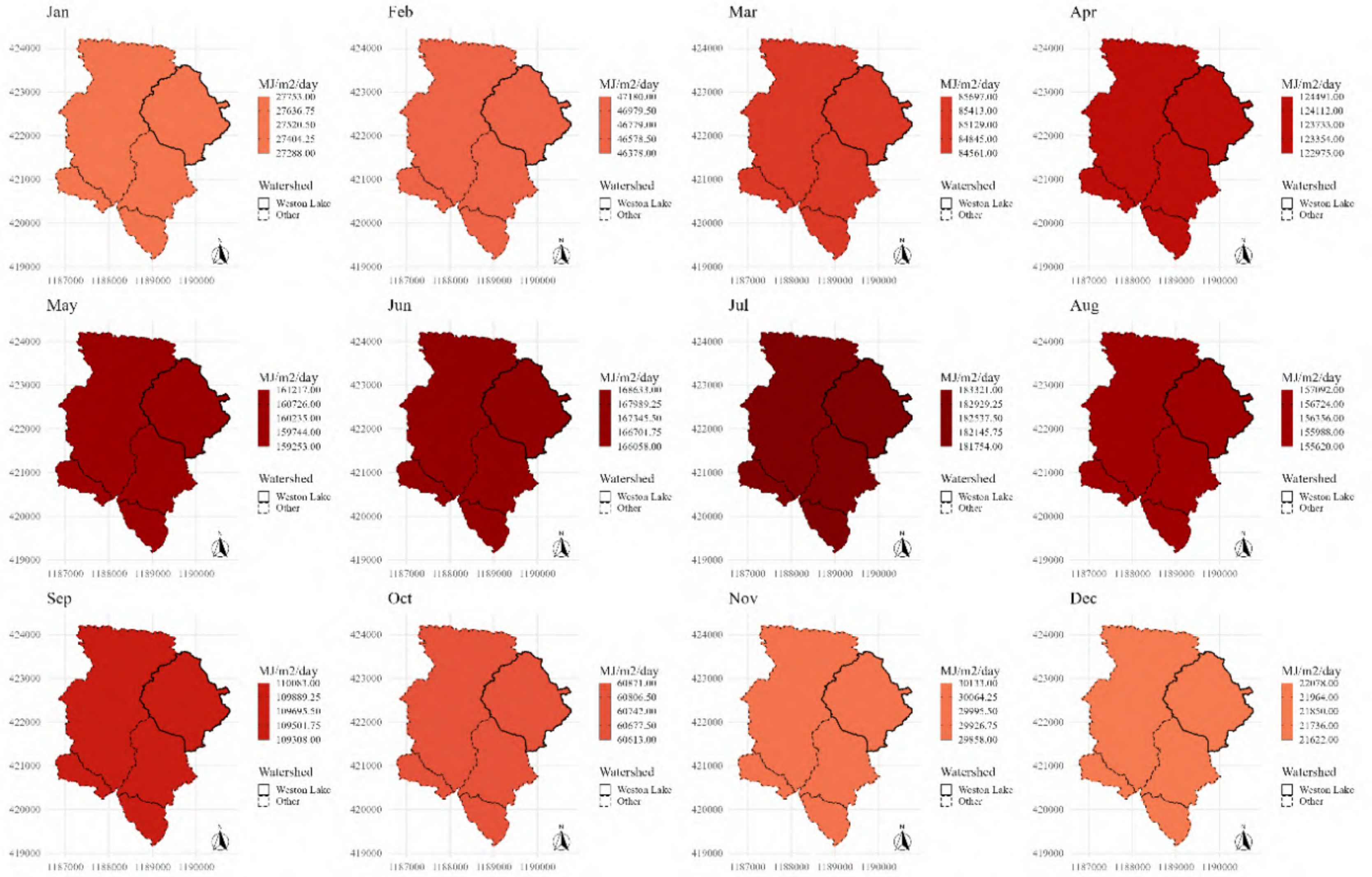


Figure 5: Radiation by month over Lake Weston and its surrounding watersheds

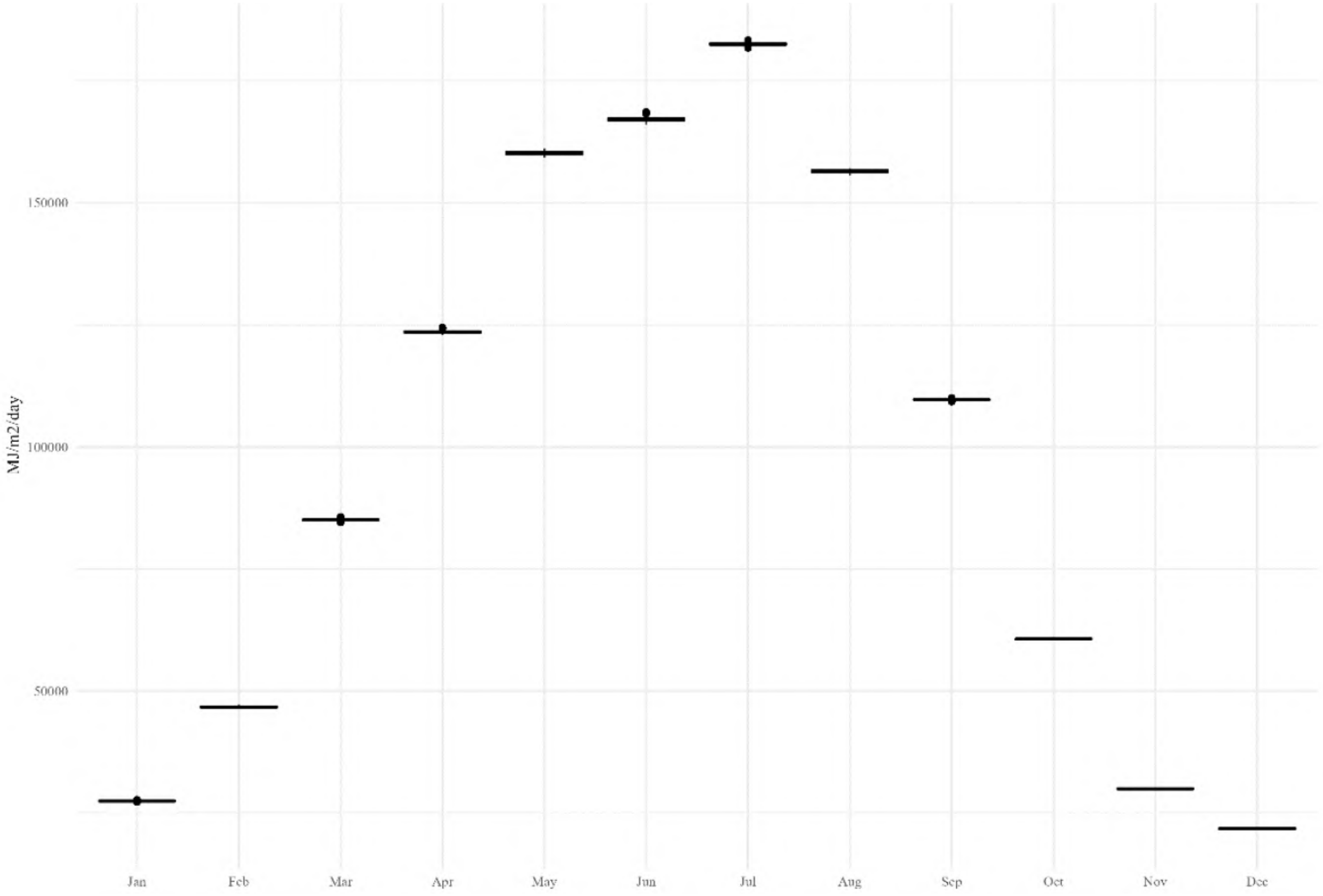


Figure 6: Monthly spread in radiation over Lake Weston and its surrounding watersheds

1.2.4 Potential Evapo-transpiration

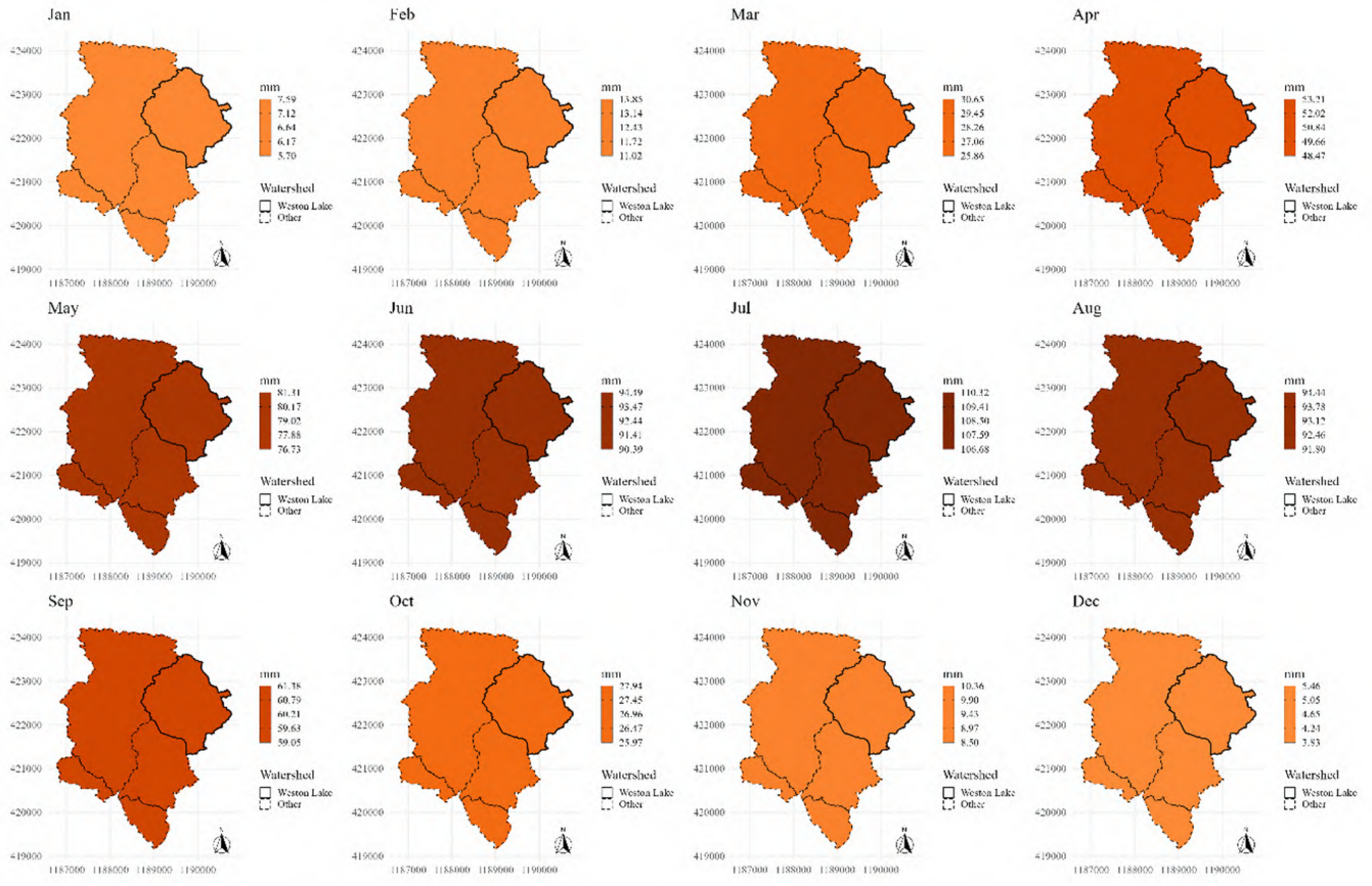


Figure 7: Potential evapo-transpiration by month over Lake Weston and its surrounding watersheds

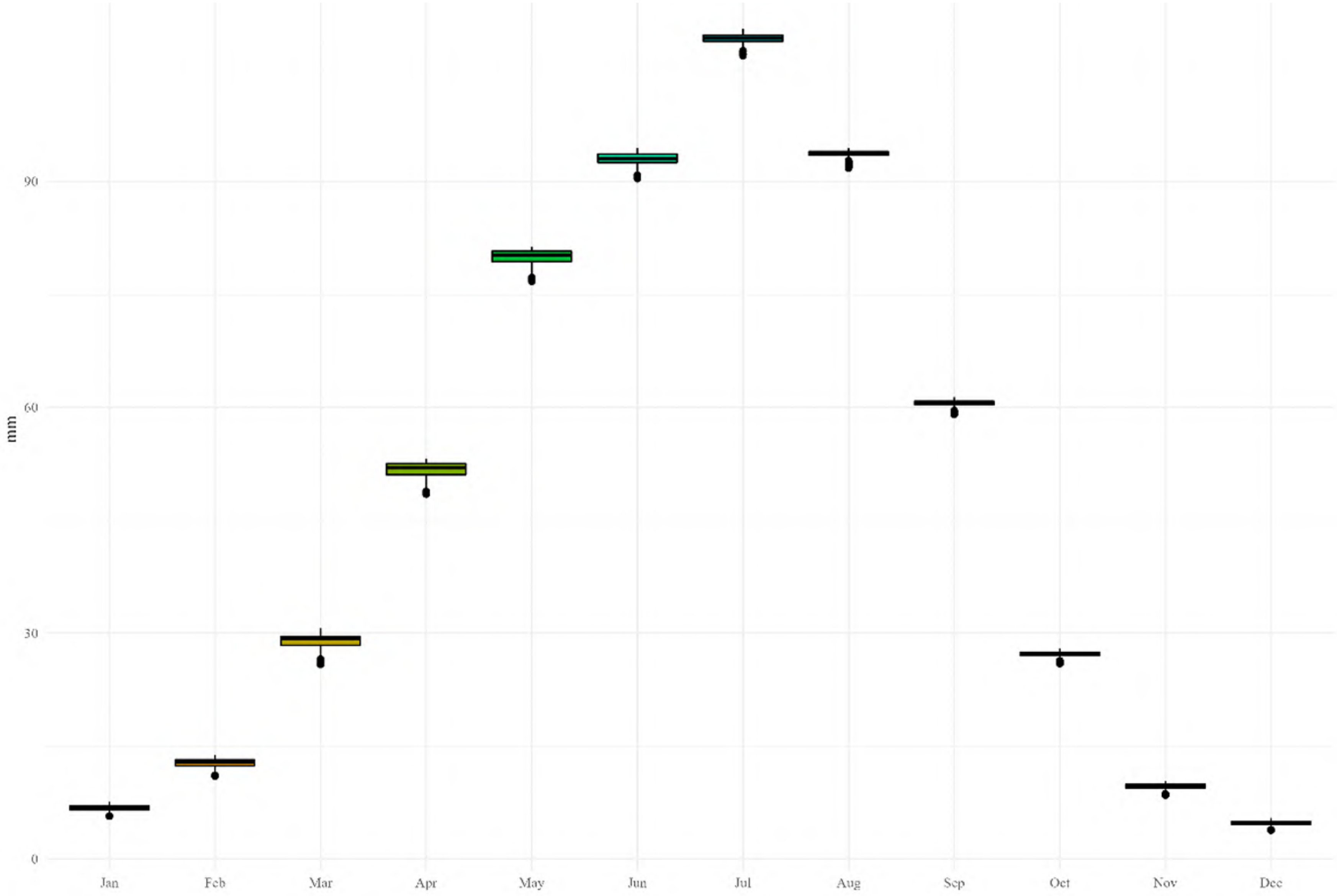


Figure 8: Monthly spread in potential evapo-transpiration over Lake Weston and its surrounding watersheds

1.2.5 Actual Evapo-transpiration

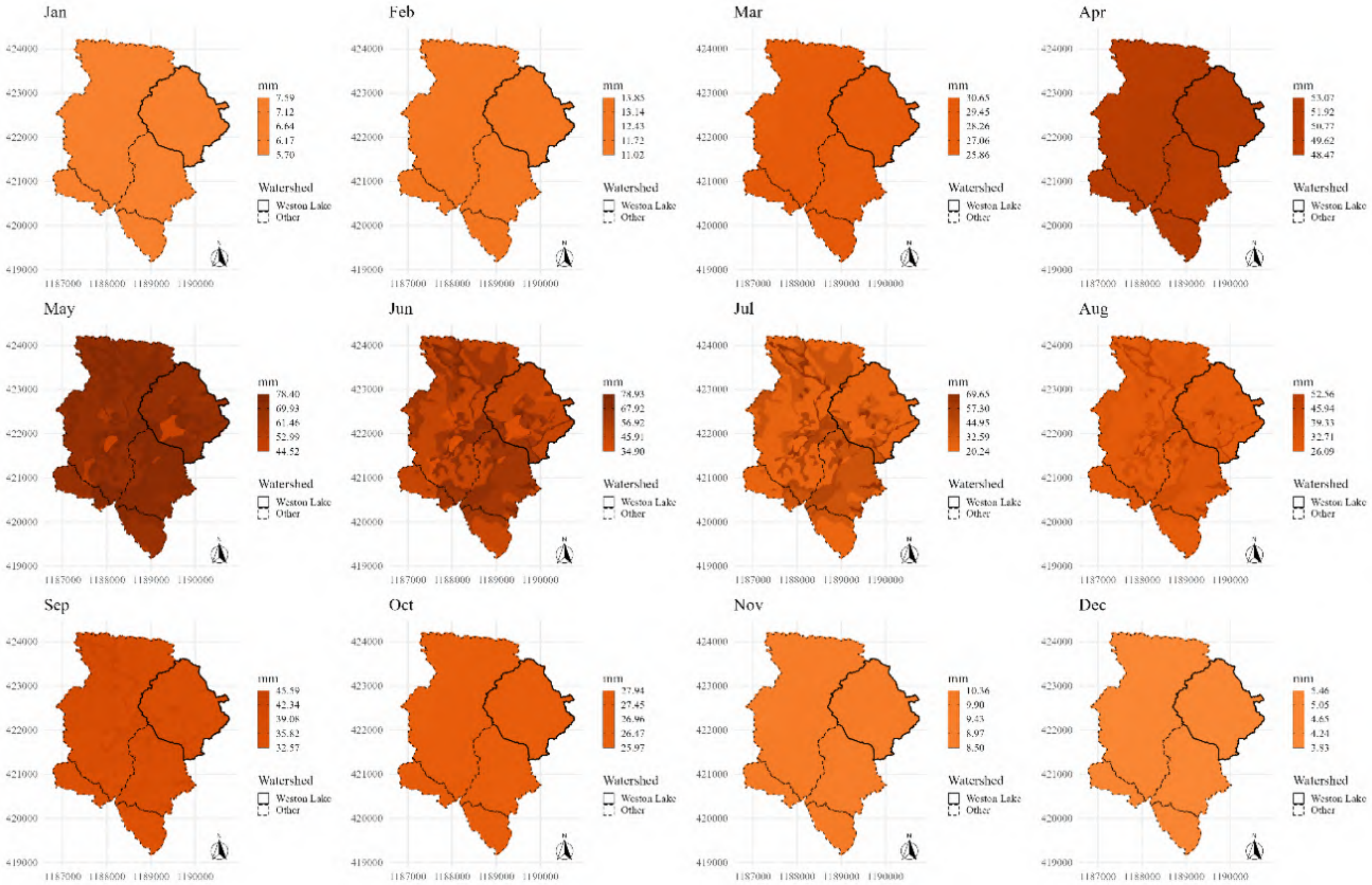


Figure 9: Actual evapo-transpiration by month over Lake Weston and its surrounding watersheds

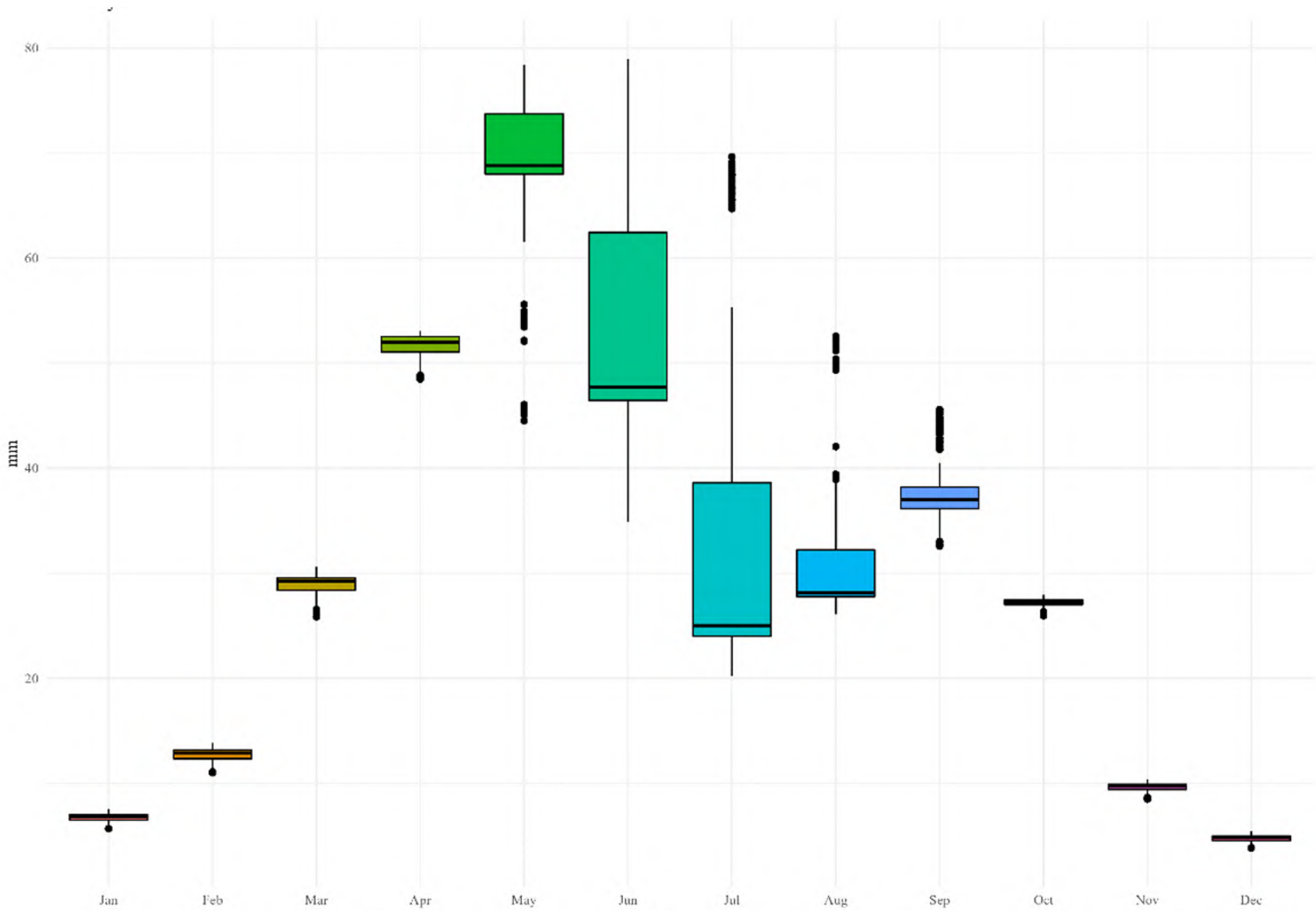


Figure 10: Monthly spread in actual evapo-transpiration over Lake Weston and its surrounding watersheds

1.2.6 Soil Storage

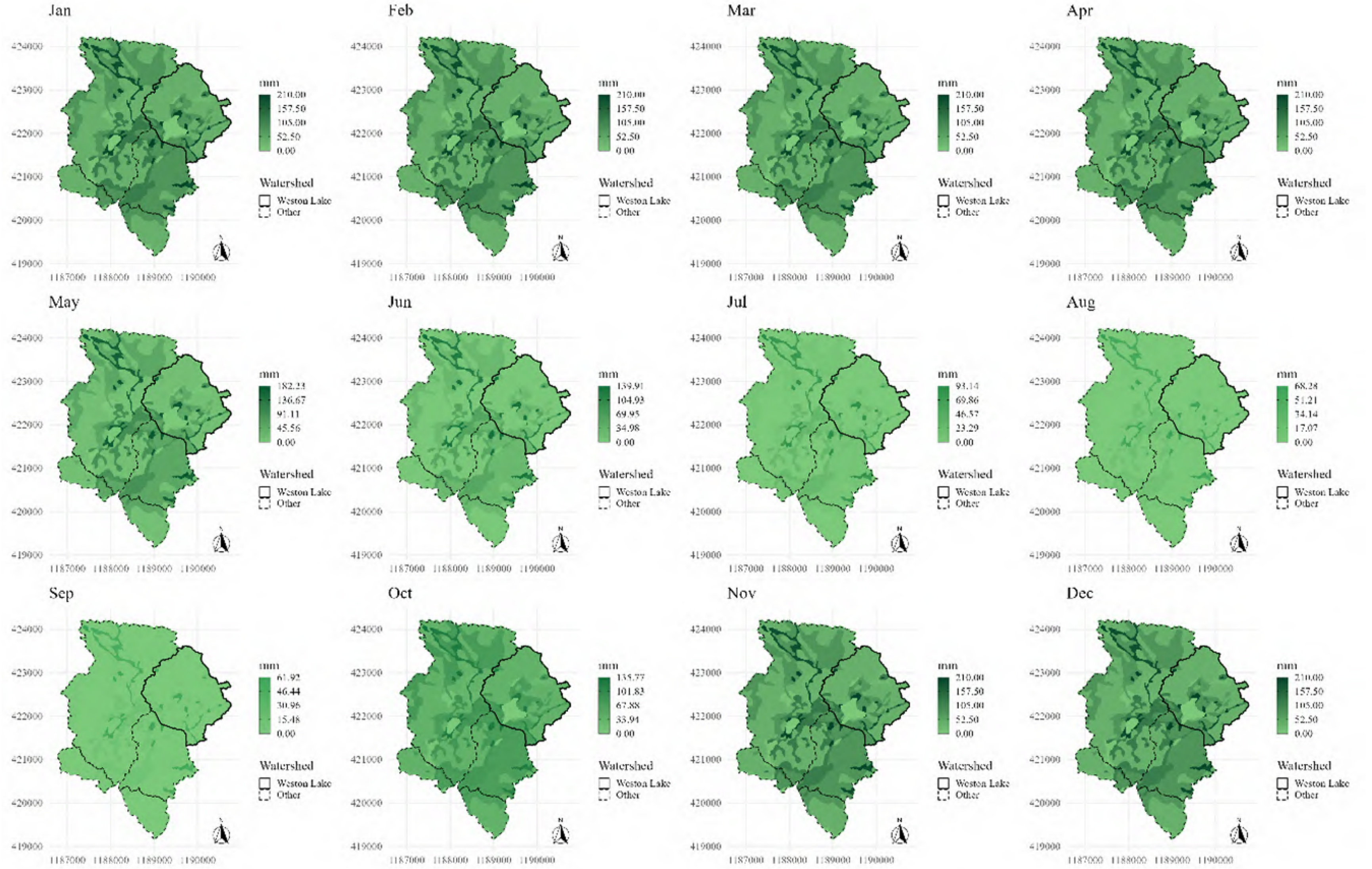


Figure 11: Soil storage by month over Lake Weston and its surrounding watersheds

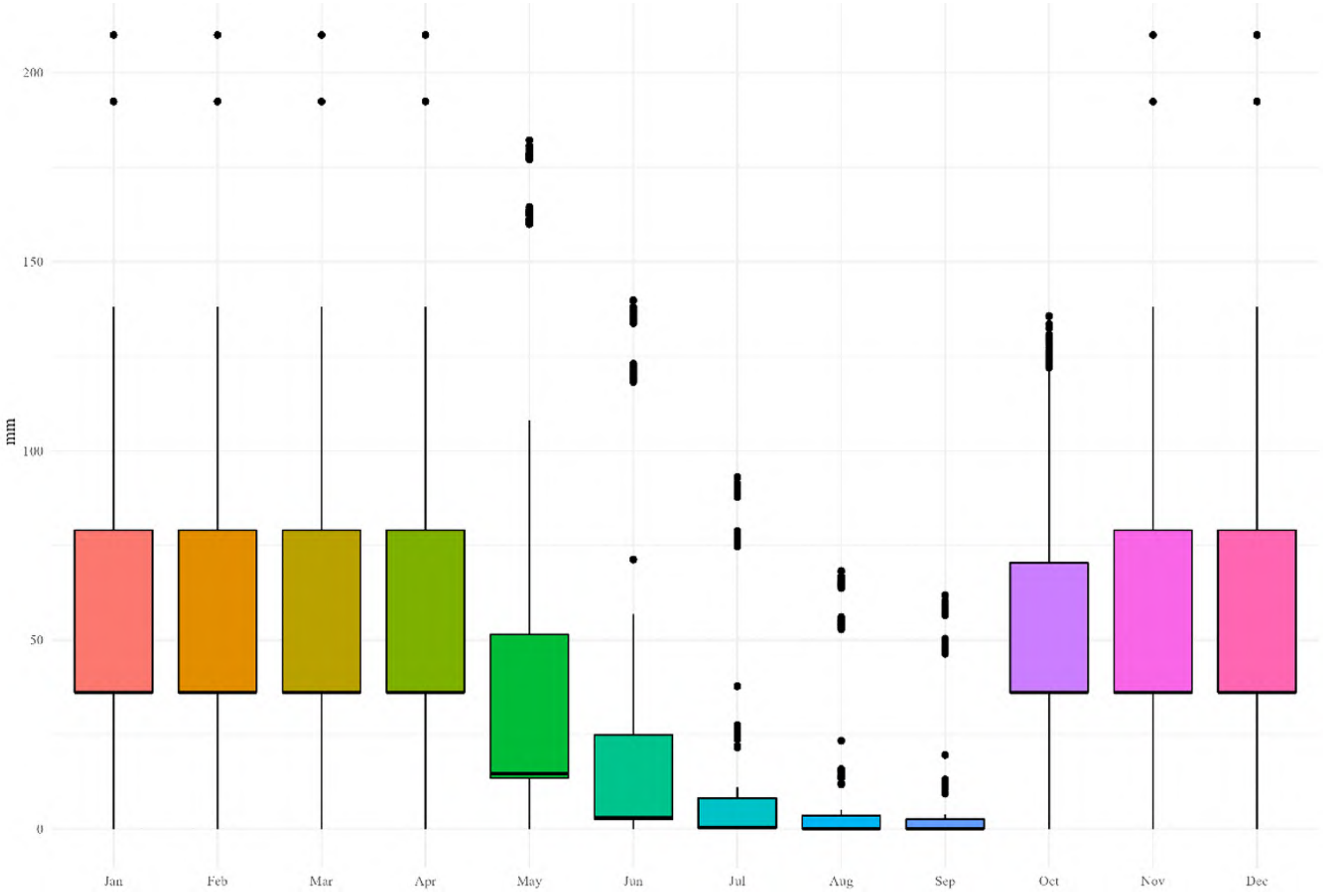


Figure 12: Monthly spread in soil storage over Lake Weston and its surrounding watersheds

1.2.7 Moisture Deficit

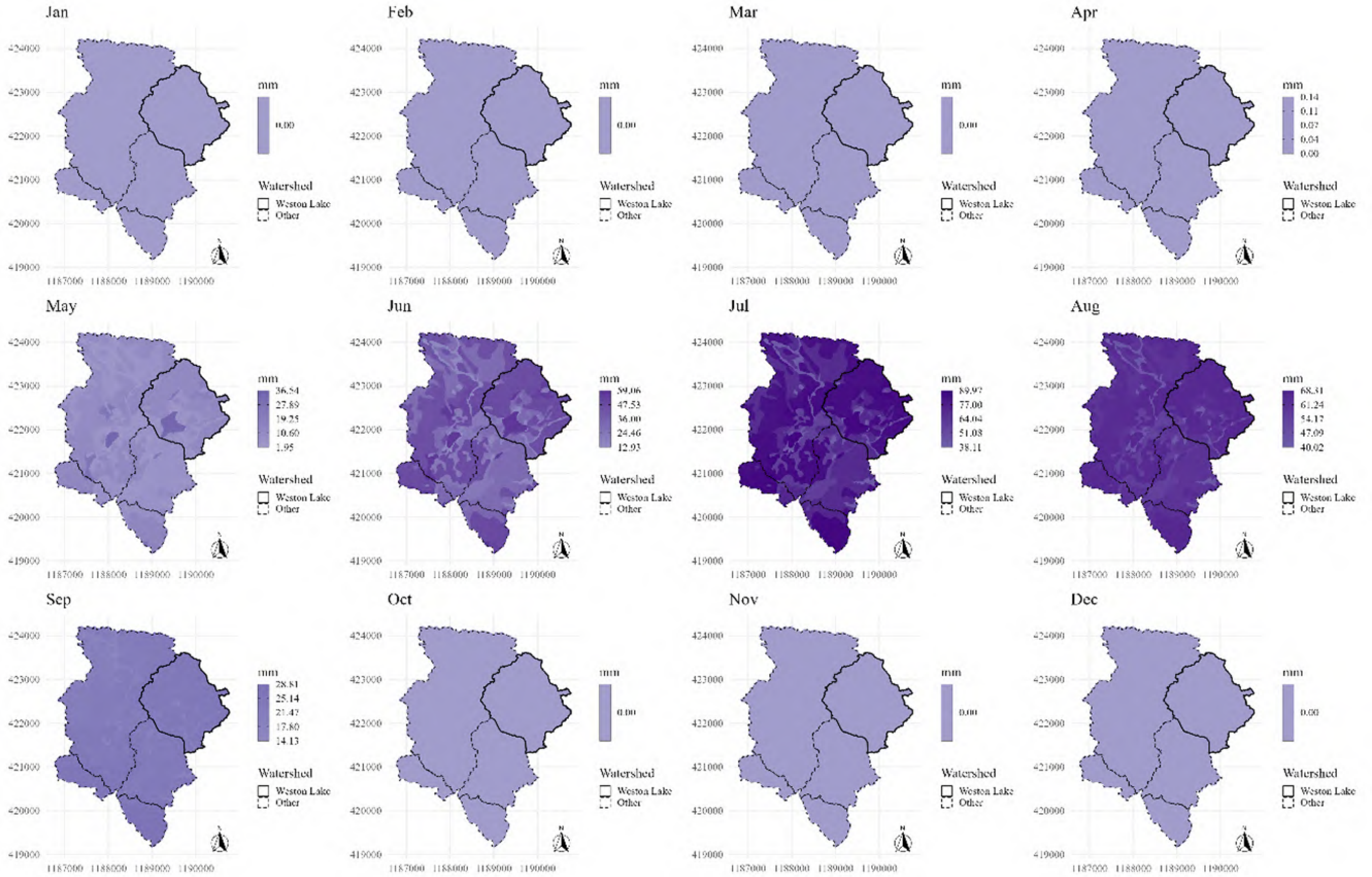


Figure 13: Moisture deficit by month over Lake Weston and its surrounding watersheds

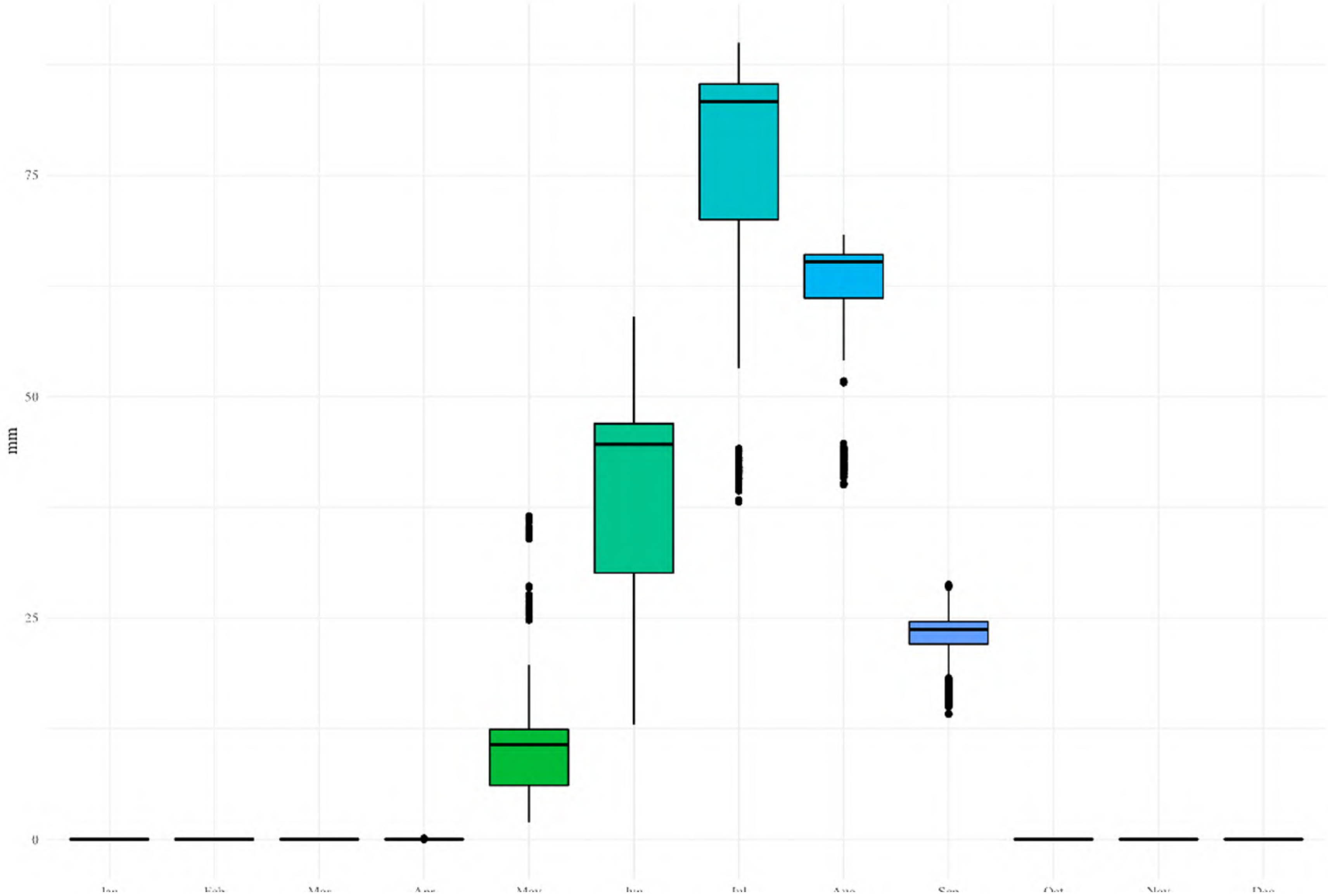


Figure 14: Monthly spread in moisture deficit over Lake Weston and its surrounding watersheds

1.2.8 Moisture Surplus

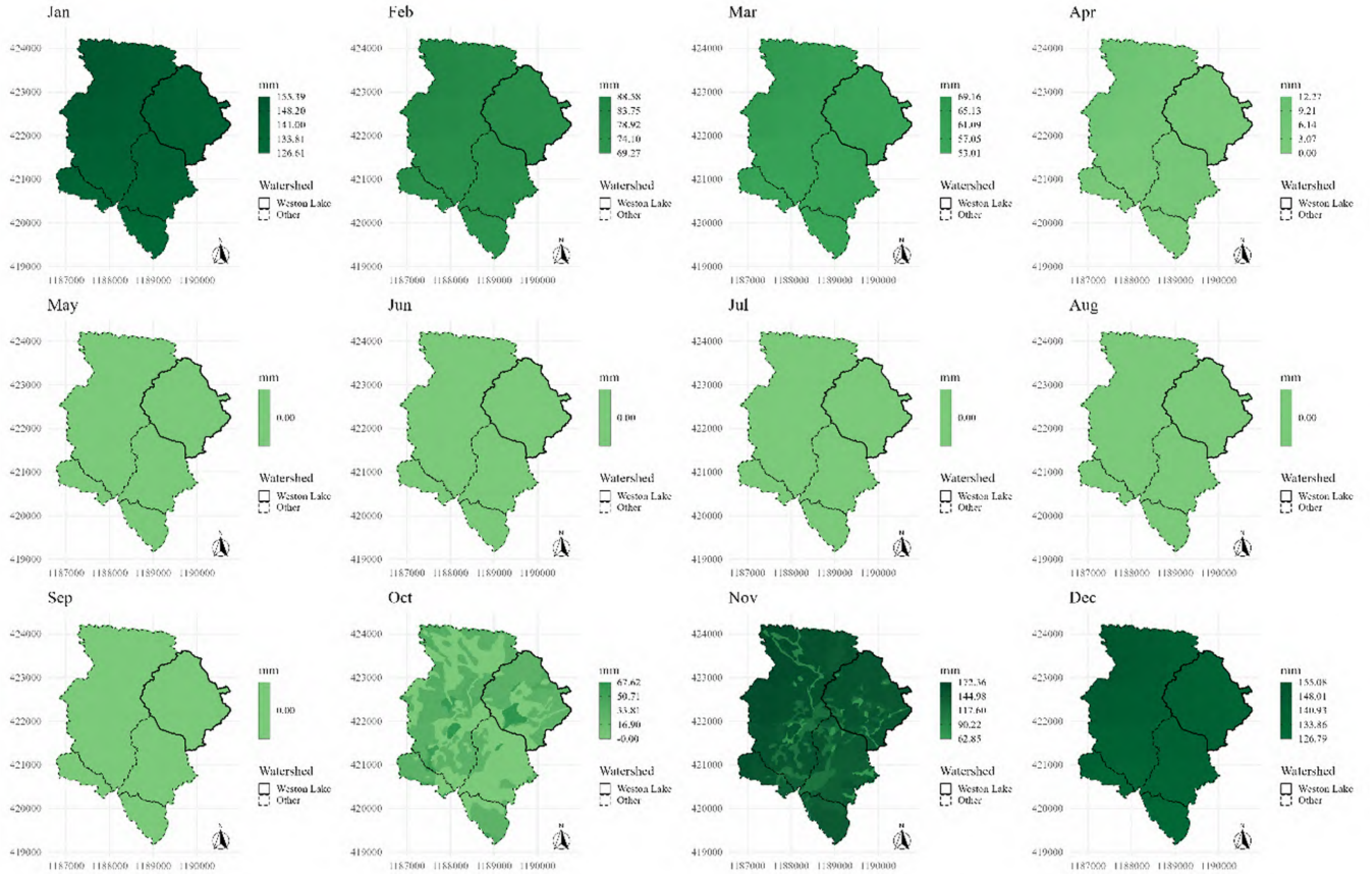


Figure 15: Moisture surplus by month over Lake Weston and its surrounding watersheds

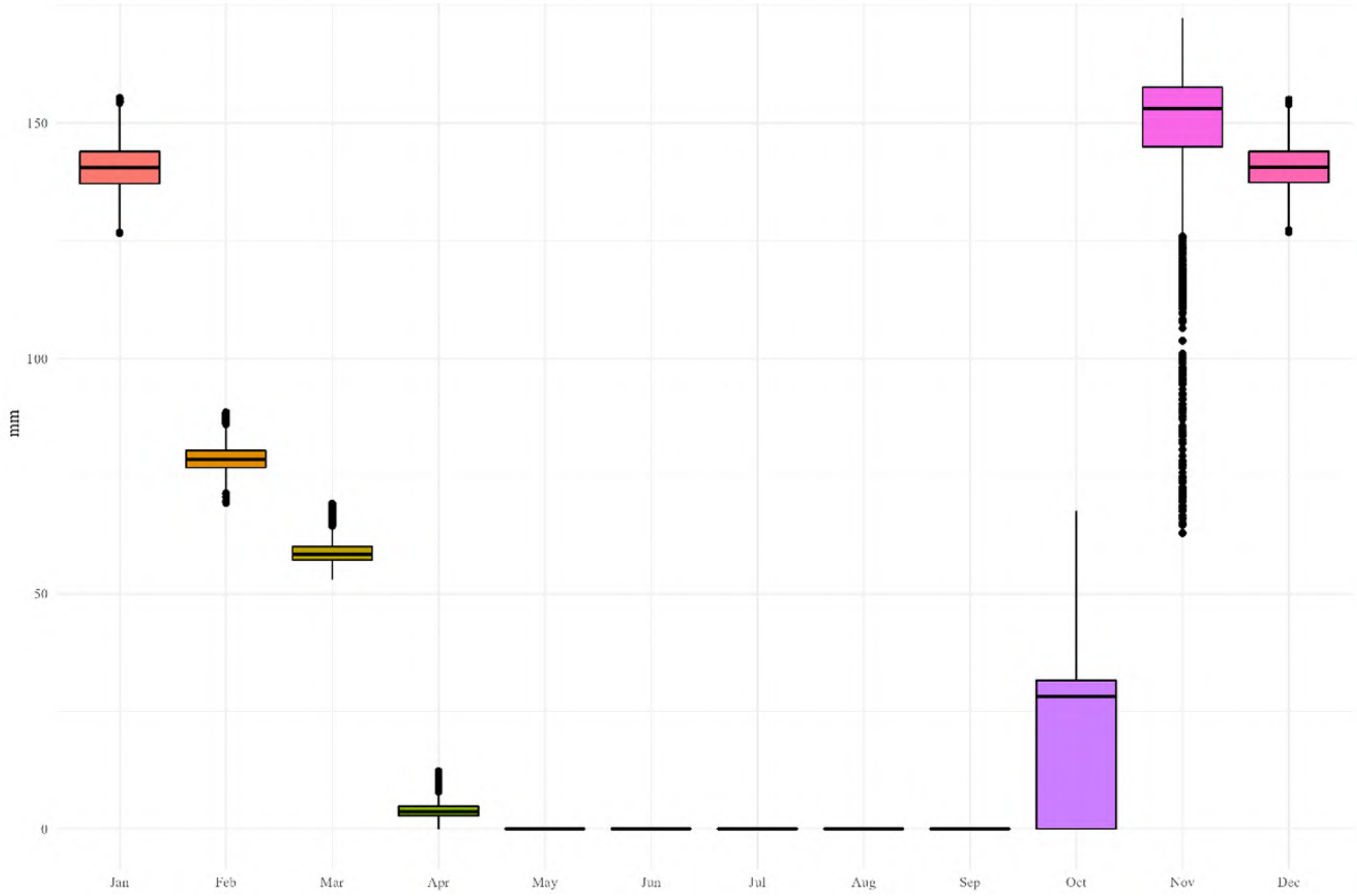


Figure 16: Monthly surplus in moisture deficit over Lake Weston and its surrounding watersheds

1.2.9 Groundwater recharge

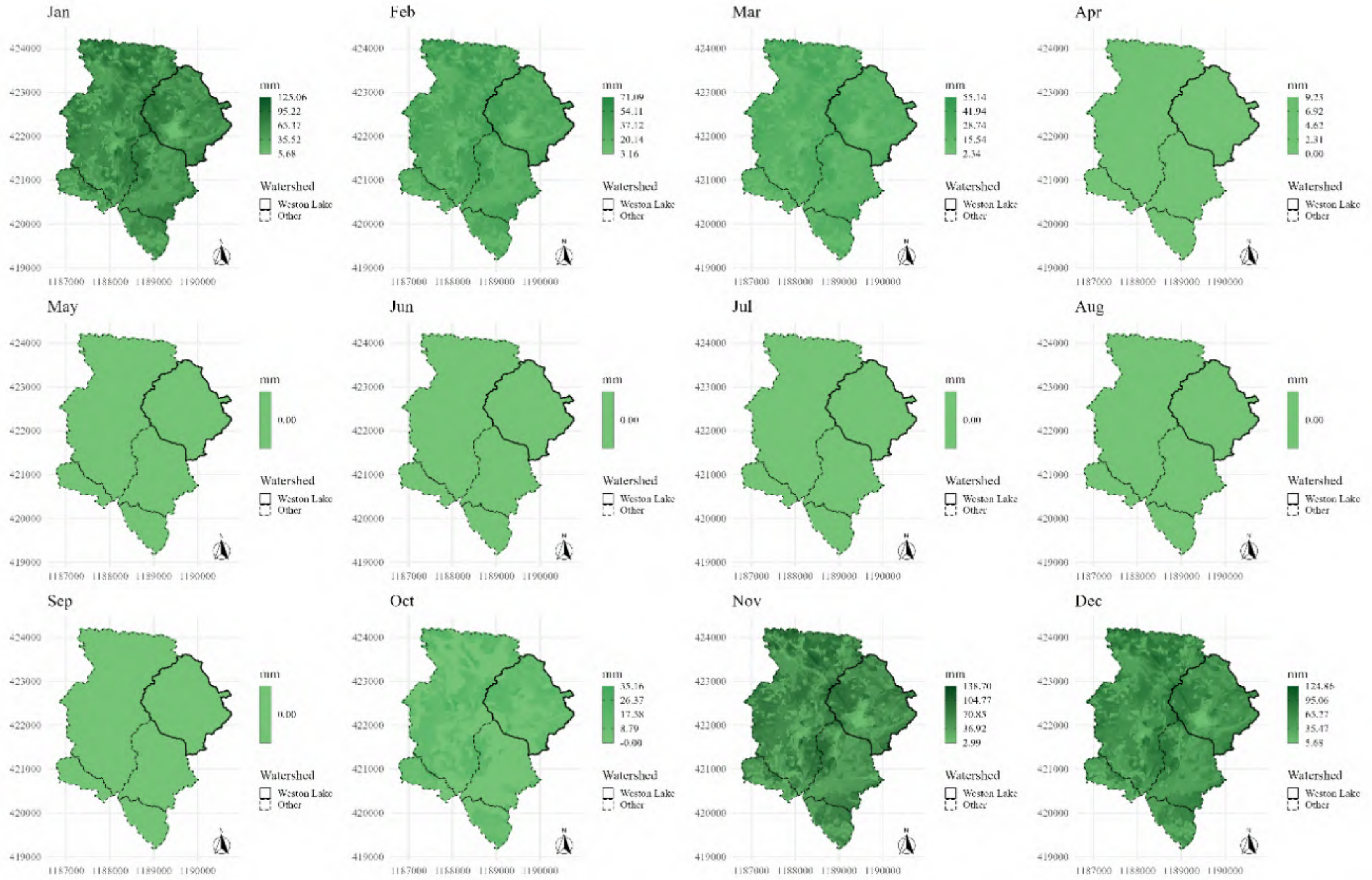


Figure 17: Groundwater recharge by month over Lake Weston and its surrounding watersheds

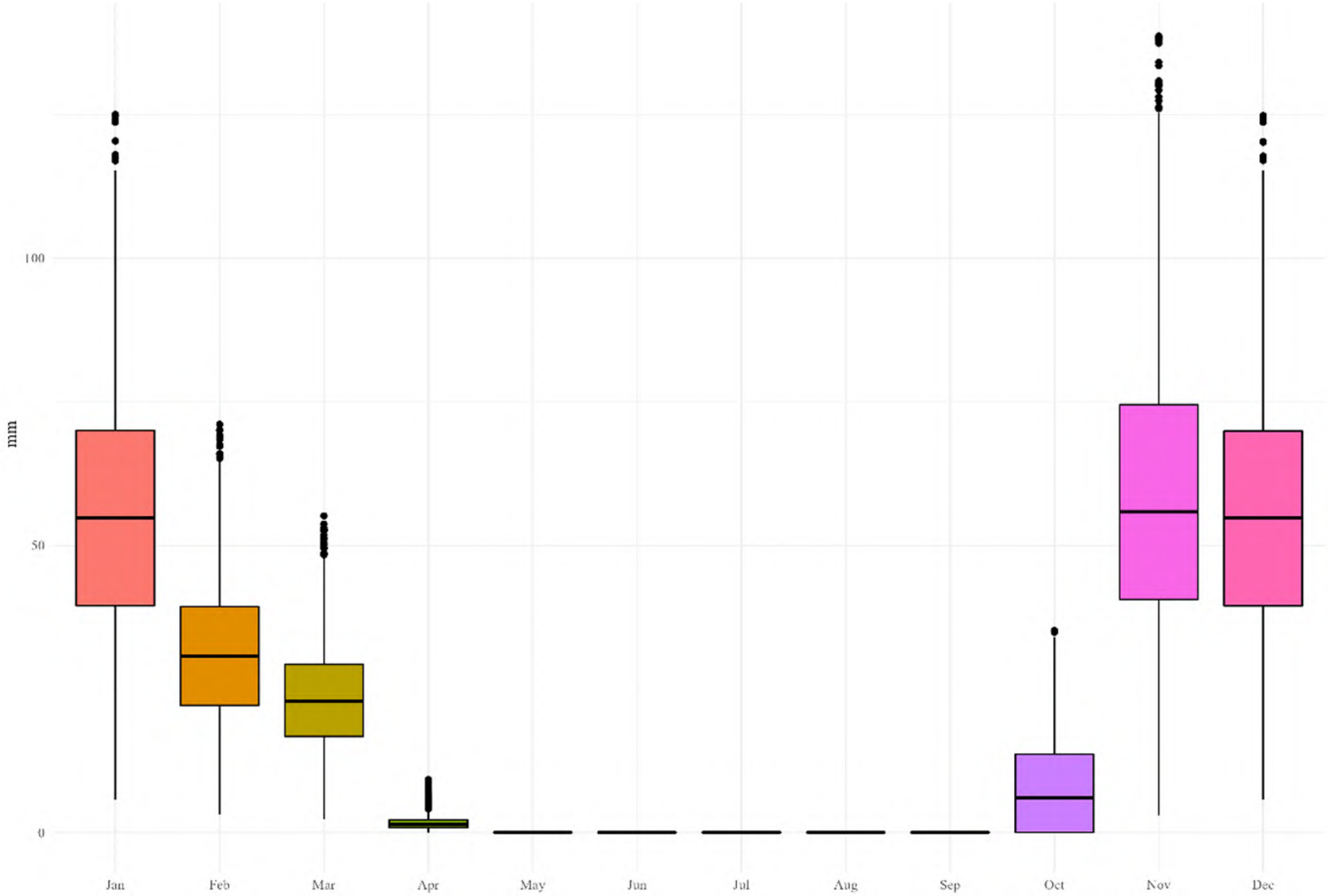


Figure 18: Monthly spread in groundwater recharge over Lake Weston and its surrounding watersheds

1.2.10 Surface runoff

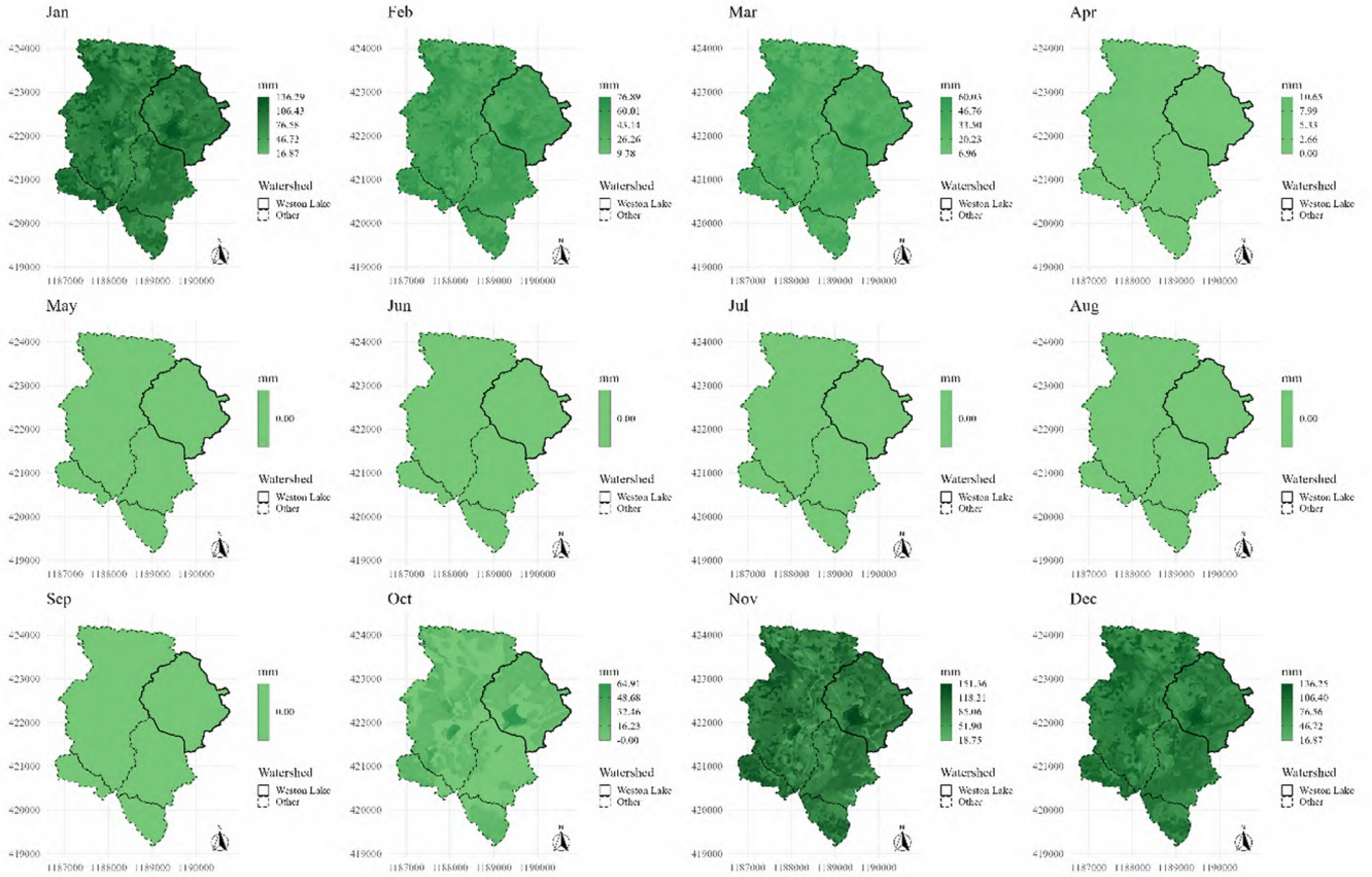


Figure 19: Surface runoff by month over Lake Weston and its surrounding watersheds

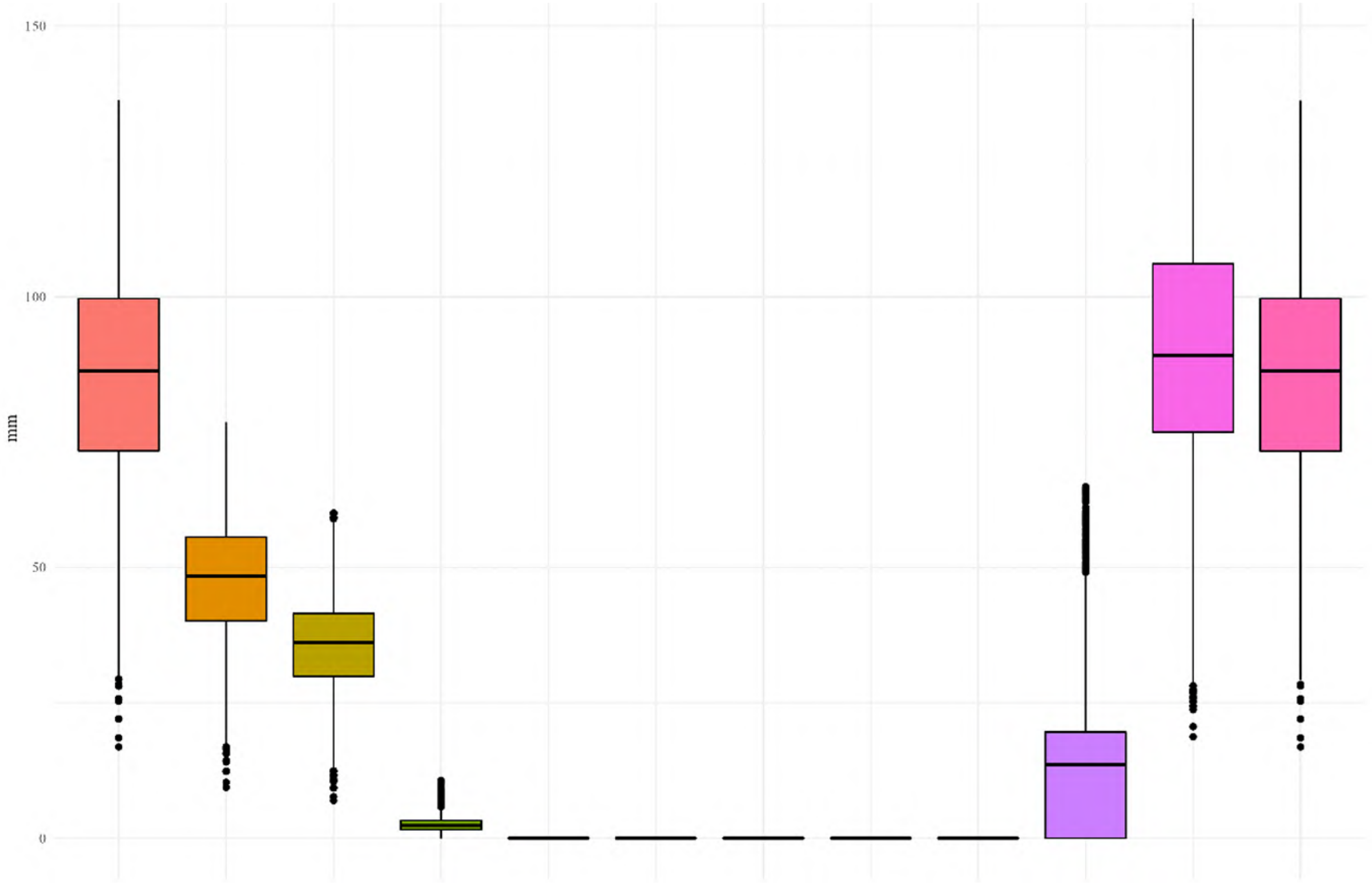


Figure 20: Monthly spread in surface runoff over Lake Weston and its surrounding watersheds

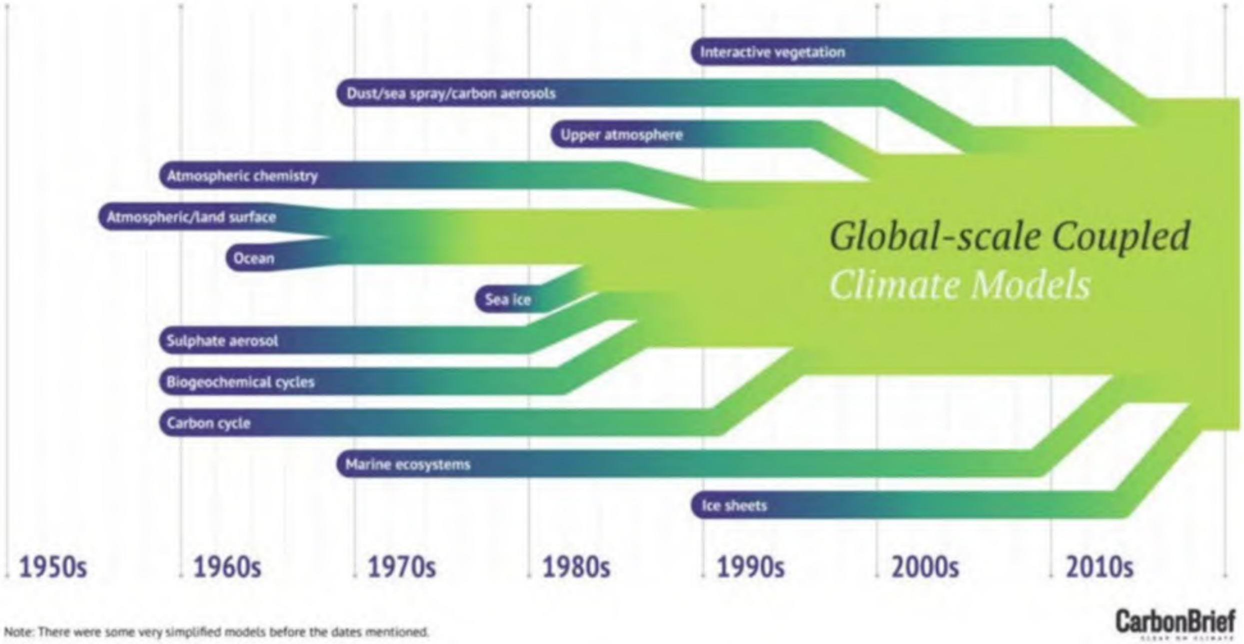
APPENDIX 4

Climate Change Analysis

APPENDIX 4: CLIMATE CHANGE ANALYSIS

1.1 Introduction to Climate Models and their Evolution

Mathematical models that simulate climate, known as climate models, are commonly used to understand the Earth's climate. These climate models are a conceptualization of the physics of the atmosphere, oceans, and the cycling of chemicals between living things and their environment. These models have increased in complexity over time, with different components affecting the Earth's climate being integrated to form coupled systems. The coupled General Circulation Models (GCMs), also called Global Climate Models simulate climate variables considering the circulation of air and water in the atmosphere and oceans, as well as the transfer of heat.



Note: There were some very simplified models before the dates mentioned.

Figure 1: Improvement of climate change models over time (source: McSweeney and Hausfather, 2018)

Processes that affect climate change are challenging to estimate and model. Additionally, human responses to climate change, through decisions regarding policy, land-use and climate mitigation add uncertainty as they affect how future climate change mitigation will unfold. When modelling climate, then, it is useful to consider multiple greenhouse gas emission scenarios, ranging from low to high emissions. As there is no single climate future, such projection scenarios can be used to illustrate a range of possible futures, depending on how human and natural systems respond to climate forcing.

Integrated Assessment Models (IAMs) are tools that model emissions scenarios by analyzing how various kinds of social and economic decisions will impact climate change. Combining insights from GCMs and IAMs, the climate research community has developed a set of 4 “shared socio-economic pathways” (SSPs) – models of climate forcing that each represent different projected human responses to climate change. These SSPs are named SSP 2.6, SSP 4.5, SSP 7.0 and SSP 8.5. Each SSP serves as a representation of future climate forcing under certain conditions of mitigation, thereby reflecting different degrees of optimism regarding the human response to climate change. SSP1- 2.6 considers aggressive mitigation measures, which ensure that climate warming by 2100 does not exceed the 2-degree mark. In contrast, SSP5 - 8.5 reflects a status quo scenario with no mitigation measures. The other scenarios fall in between these two extremes. The SSPs thus enable the GCMs to model a range of possible climate change scenarios, offering greater insight into the breadth of potential impacts that climate change can have on the earth system.

1.2 Defining Applicable Models and Scale

GCMs undertake the momentous task of modelling the climate across the entire earth. Large volumes of climate data, usually in gridded raster form, have become available in recent years, including interpolated historical data from weather stations and future predictions from General and Regional Circulation Models. However, the spatial resolution of global climate model outputs is often too coarse to provide sufficient local detail on climate. To analyze climate impacts locally thus requires a process of “downscaling” projected climate data.

One way this is achieved is through Regional Climate Models (RCMs), which are similar to GCMs, but aim to model the climate over a limited area of the Earth, leading to greater spatial detail. Since RCMs are not available for most parts of the earth, however, another common process is to use “statistical downscaling”. This involves establishing an empirical relationship between locally observed and globally modelled climate. This relationship is then used to further downscale projected climate data to model local changes.

Two tools that offer statistically downscaled climate data are ClimateNA and ClimateBC (Wang et al., 2016), encompassing western North America and British Columbia, respectively. Both are stand-alone software packages that provide monthly historic and climate change data, downscaled to any grid scale through a combination of bilinear interpolation, elevation adjustment, and application of the PRISM high-resolution 1971-2000 baseline climatology. The scale-free downscaling method employed can better account for local variations in elevation, as well as considerably improve statistical accuracy compared to downscaling using regular climate grids (Wang et al., 2016). The program was updated with historical monthly data for the years 1901- 2018 in June 2019 to improve its accuracy.

The software includes the option to downscale climate data from 13 GCMs, all of which were part of the Coupled Model Intercomparison Project 6 (CMIP6), included in the IPCC Sixth Assessment Report (IPCC, 2014). The tool offers data from a subset of 13 models including in CMIP6 which were selected following an evaluation of all 44 CMIP6 GCMs, using a number of criteria to select only those models that best characterized climatic patterns across North America (Mahony et al., 2022). The tool provides projection data from each individual model, as well as an aggregate of climate data across all 13 models – a useful reference dataset, as there is evidence that combining knowledge across multiple models can improve accuracy over single-model forecasts (Tebaldi and Knutti, 2007). We chose to use the entire 13-model ensemble rather than a single model subset since we were interested in a single representative projection that could characterize the entire possible range of project climate change in the study area (Mahony et al., 2021).

The variables for ClimateBC provides include temperature, precipitation, solar radiation, as well as several derived climate variables for historic and future periods. Projected climate data are available for four future periods: 2030s (2021-2040), 2050s (2041-2060), 2070s (2061-2080), and 2090s (2081-2100). These projected years are available for all four SSP scenarios – SSP 2.6, SSP 4.5, SSP 7.0 and SSP 8.5.

1.3 Study Area and Data Selection

GW Solutions used ClimateBC version 7.21 (Wang et al, 2016, updated in 2022) to gather statistically downscaled, monthly, climate variables for 2030, 2050 and 2070. To estimate the climate of these time-periods, GW Solutions gathered projected data averaged across all 13 GCMs in the ClimateBC tool – a 13-model ensemble[1].

ClimateBC reads a digital elevation model (DEM) to interpolate monthly, seasonal, or annual climate variables. The climate data are then downscaled to the resolution of the provided DEM. GW Solutions used a 20m-by-20m resolution DEM raster file (*.asc) of the Lake Weston watershed study area as the input. The outputs were raster files of monthly climate variables, clipped to the boundaries of the study area. The monthly climate variables for which data were gathered include:

Variable Name	**Description**
Tave01 – Tave12	January - December mean temperatures (°C)
PPT01 – PPT12	January - December precipitation (mm)
Rad01 – Rad12	January - December solar radiation (MJ m^{-2} d^{-1})

1.4 Data Analysis Methodology

Once gathered, all the climate data for each projection year (2030, 2050 and 2070) were compared against averages of current observed climate data, or “climate normals”, for the period 1981-2010. The comparison process involved the creation of raster files that showed the cell-by-cell change between the observed “normal” period and climate projections

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[1] The models included in this ensemble average are ACCESS-ESM1.5, BCC-CSM2, CanESM5, CNRM-ESM2-1, EC-Earth3, GFDL-ESM4, GISS-E2.1, INM-CM5.0, IPSL-CM6A-LR. MIROC6, MPI-ESM1.2-HR, MRI-ESM2.0, and UKESM1 (Mahony et al., 2022)

for all three time-periods. These changes were then mapped to show the spatial variation in the projected changes for all the climate variables.

Additionally, water budget calculations were performed using inputs from each climate change scenario and were also compared to the water budget outputs from the normal periods. This allowed a comparison of not just raw input climate data, but also an estimation of how important water balance variables – like monthly available moisture surplus – are projected to change with climate change.

Comparisons between projected future data and climate normals were performed for all four SSP scenarios under consideration – SSP 2.6, 4.5, 7.0 and 8.5. Maps showing the results of these comparisons for each SSP, and each year were generated to examine the spatial variation of change for each climate variable. Moreover, summary charts showing average changes across the Lake Weston watershed were also calculated for all climate variables. These summary charts depict changes by month and included data from all SSPs to illustrate how the magnitude of impact changes under each SSP.

All the analysis and visualization were completed in the R programming language. The maps and charts produced during this analysis are presented in section 1.6.

1.5 Generalized Interpretation of Climate Change Results

The projected data from the 13-model ensemble predict a significant increase in precipitation during the winter, and a smaller yet still considerable increase in spring and fall precipitation. The magnitude of increase is greatest during the December to February period. The data also predict a decrease in summer precipitation. These patterns are consistent across all the SSP scenarios, and indeed the magnitude of these changes is higher the more pessimistic the SSP is.

Solar radiation is projected to increase during the summer months and decrease during the fall and spring periods, remaining relatively unchanged during the rest of the winter. Interestingly, the magnitude of change is projected to be the strongest within the 2030s period, suggesting that the most meaningful shifts in radiation patterns will happen within the next 2 decades. As with precipitation, the magnitude of change is higher with more pessimistic SSPs. Additionally, all SSPs and year periods seem to project a slight increase in radiation during March alone, amid an otherwise reduced-radiation Spring.

Average temperatures are projected to increase in all months for 2030, 2050 and 2070 across all SSP scenarios, with the highest increases being in July and August. Even under the most optimistic scenario (SSP 2.6), temperatures are projected to rise by nearly 2 degrees Celsius in July and August by 2070. In contrast, under SSP 8.5 the projected increase in July and August is nearly 5 degrees.

Finally, available moisture surplus is projected to increase considerably during the winter months of December to February, while also increasingly slightly during the fall months of October and November. Additionally, surplus is projected to decrease during the spring period, especially in March. As with the others, the magnitude of these patterns is exacerbated under less optimistic SSPs.

These patterns are consistent with changes expected under climate change globally. Increasing temperatures, particularly during the summer months, combined with higher solar radiation and lower summer precipitation will mean a reduced potential for groundwater recharge during the summer. The current hydrological regime, however, already operates within a pattern of excess water during the winter months and low precipitation during the summer. The impact of climate change on this system appears to be a reduction in the available window or annual time period for groundwater recharge.

Precipitation is projected to occur in higher magnitudes within a smaller time period (primarily December to February). This combined with reduced solar radiation during months leads to an excess of moisture surplus during the winter, increasing the possibility of flash flooding since the capacity for groundwater infiltration at any given time cannot be exceeded upon saturation. Furthermore, reduced precipitation and higher temperatures during the summer reduces the potential for groundwater recharge during the months when groundwater uptake is greatest. The projected decline in moisture surplus during March illustrates a reducing temporal window within which moisture surplus can recharge aquifers. Overall, these patterns will adversely affect the sustainability of the groundwater system by leading to a pattern of excess water when it is not needed and water deficits during periods when it is necessary.

1.6 Analysis Results

Figures 2 to 57 present the model-predicted changes between climate normals (1981-2010) and the predicted climate variables for 2030, 2050 and 2070. While maps and charts were calculated for all climate and water budget variables, only the most important variables have been shown here, namely: average temperature, precipitation, radiation, and available moisture surplus. These were selected since temperature, precipitation and radiation are the three primary inputs that have the greatest impact on the water cycle, as they affect the availability of water as well as the rate of water loss through evapotranspiration. Moisture surplus was selected from among the water budget variables as it is the primary parameter of interest that can enable the calculation of available surface runoff and groundwater recharge.

1.6.1 SSP 2.6

1.6.1.1 Average Temperature

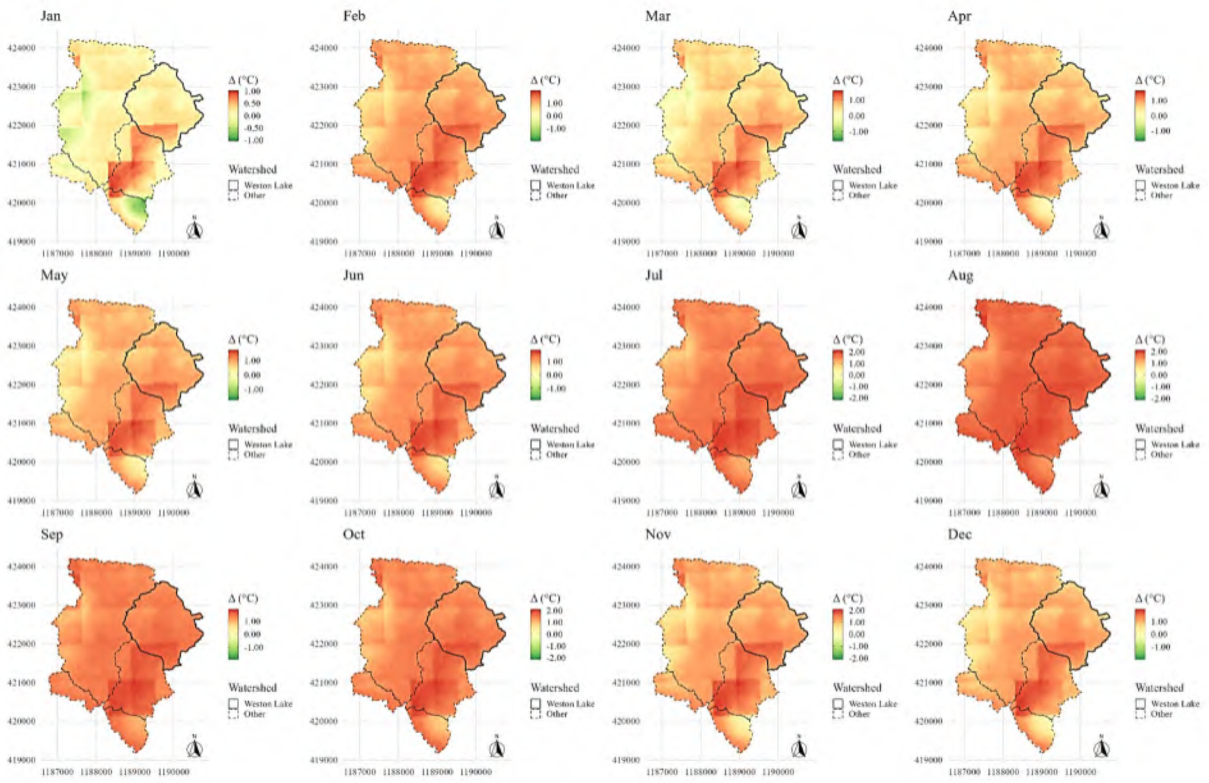

Figure 1: Monthly change in average temperature between year 2030 and present normals, SSP 2.6

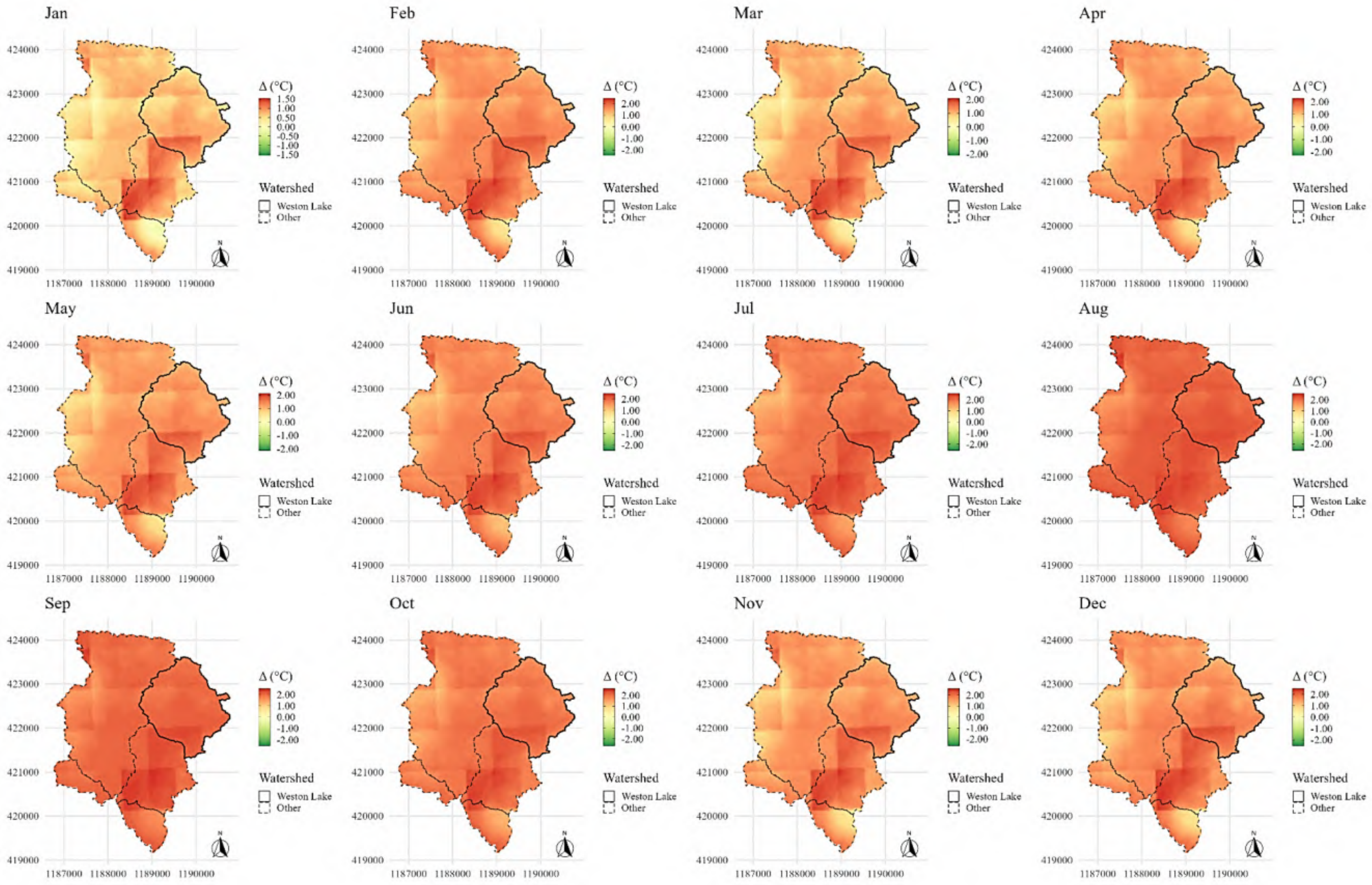

Figure 2: Monthly change in average temperature between year 2050 and present normals, SSP 2.6

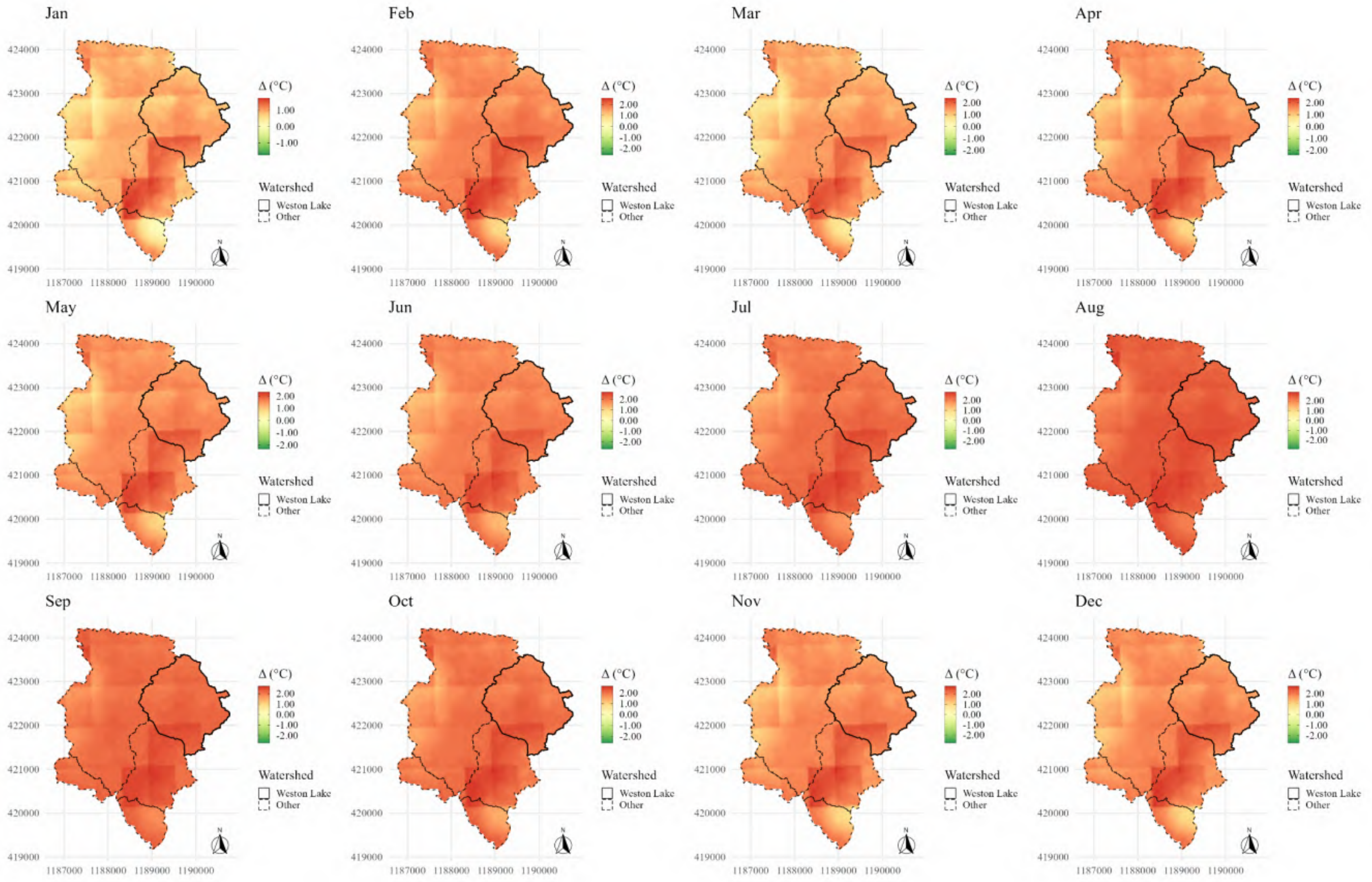

Figure 3: Monthly change in average temperature between year 2070 and present normals, SSP 2.6

1.6.1.2 Precipitation

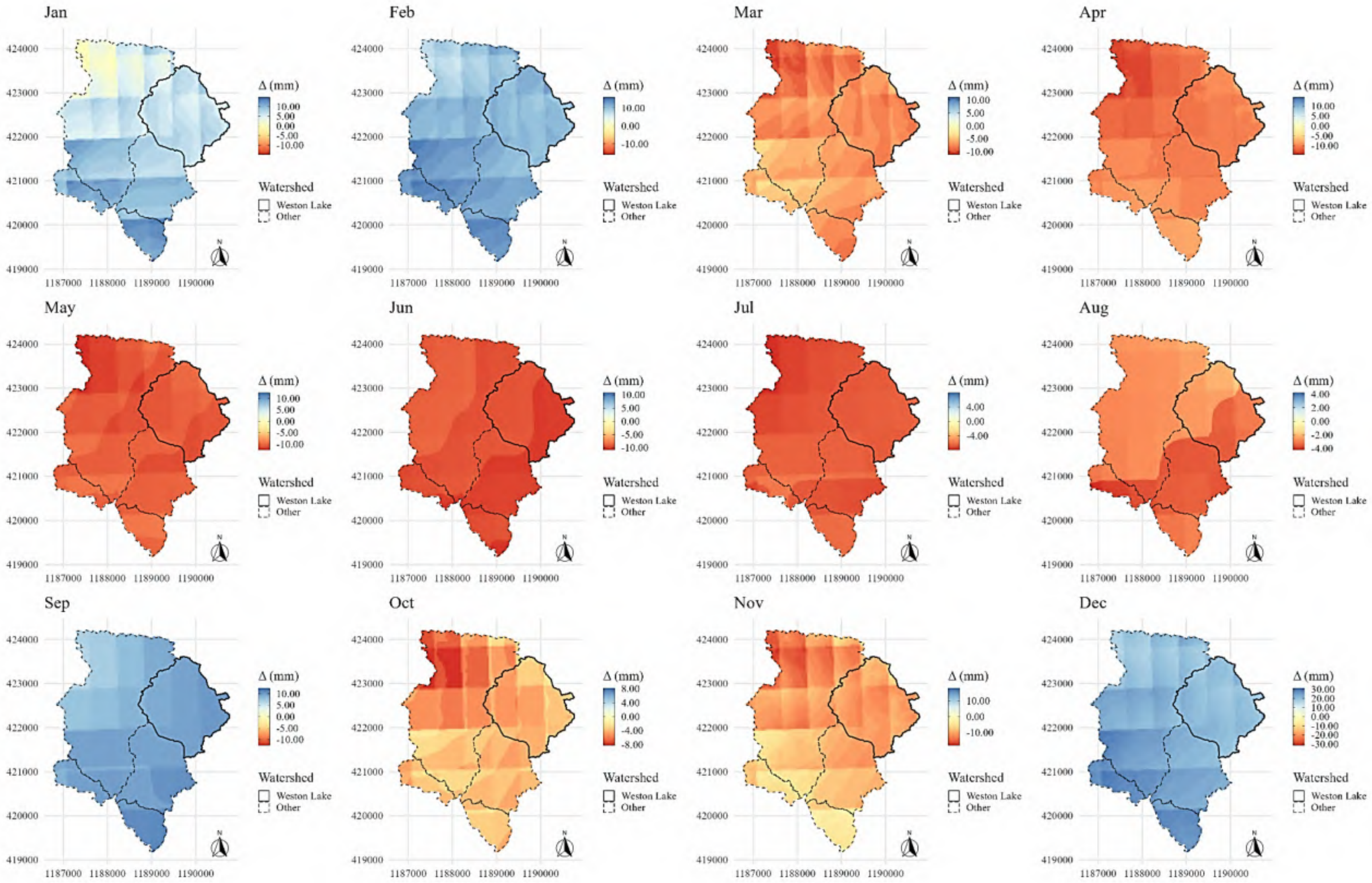

Figure 4: Monthly change in precipitation between year 2030 and present normals, SSP 2.6

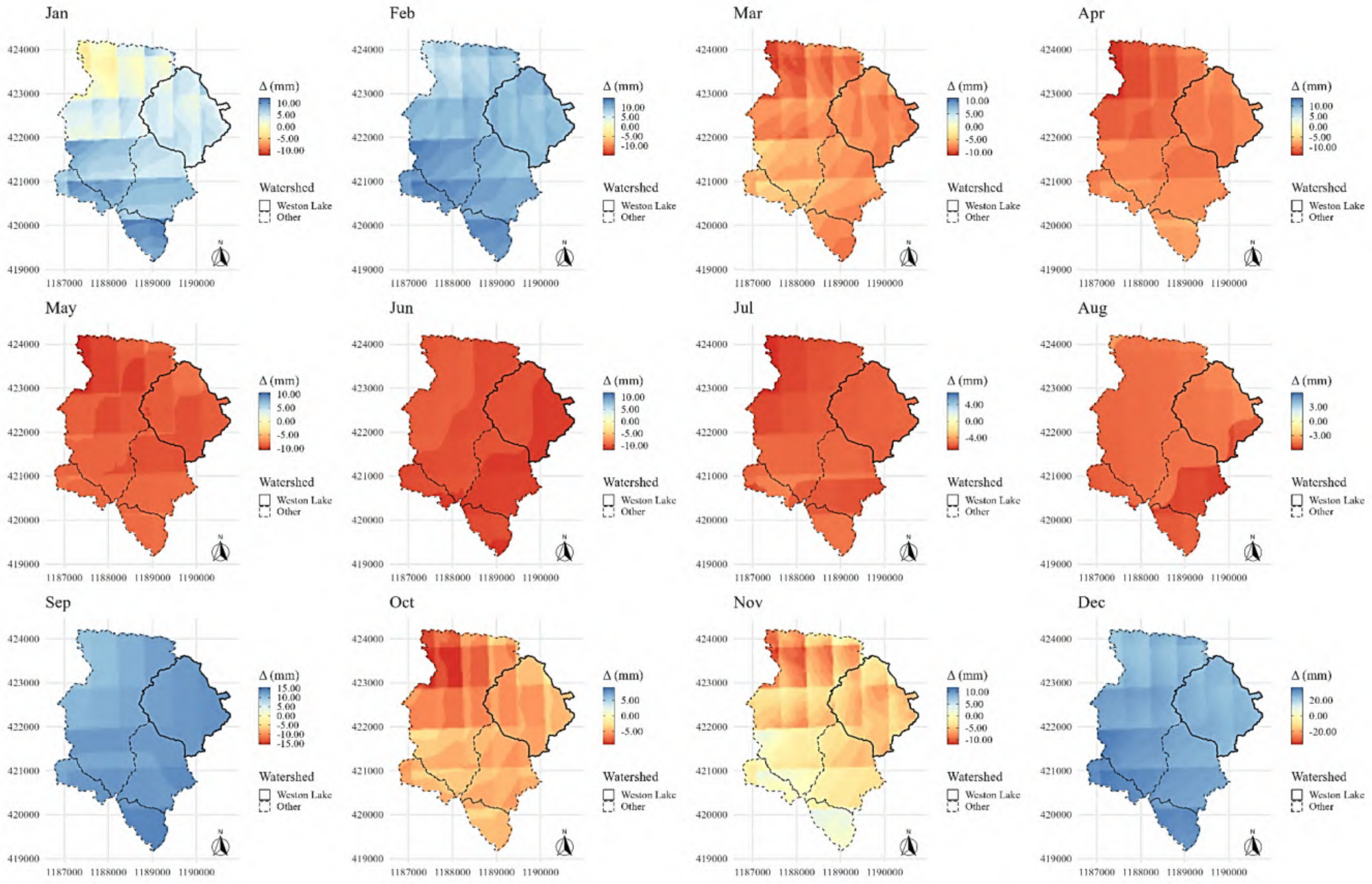

Figure 5: Monthly change in precipitation between year 2050 and present normals, SSP 2.6

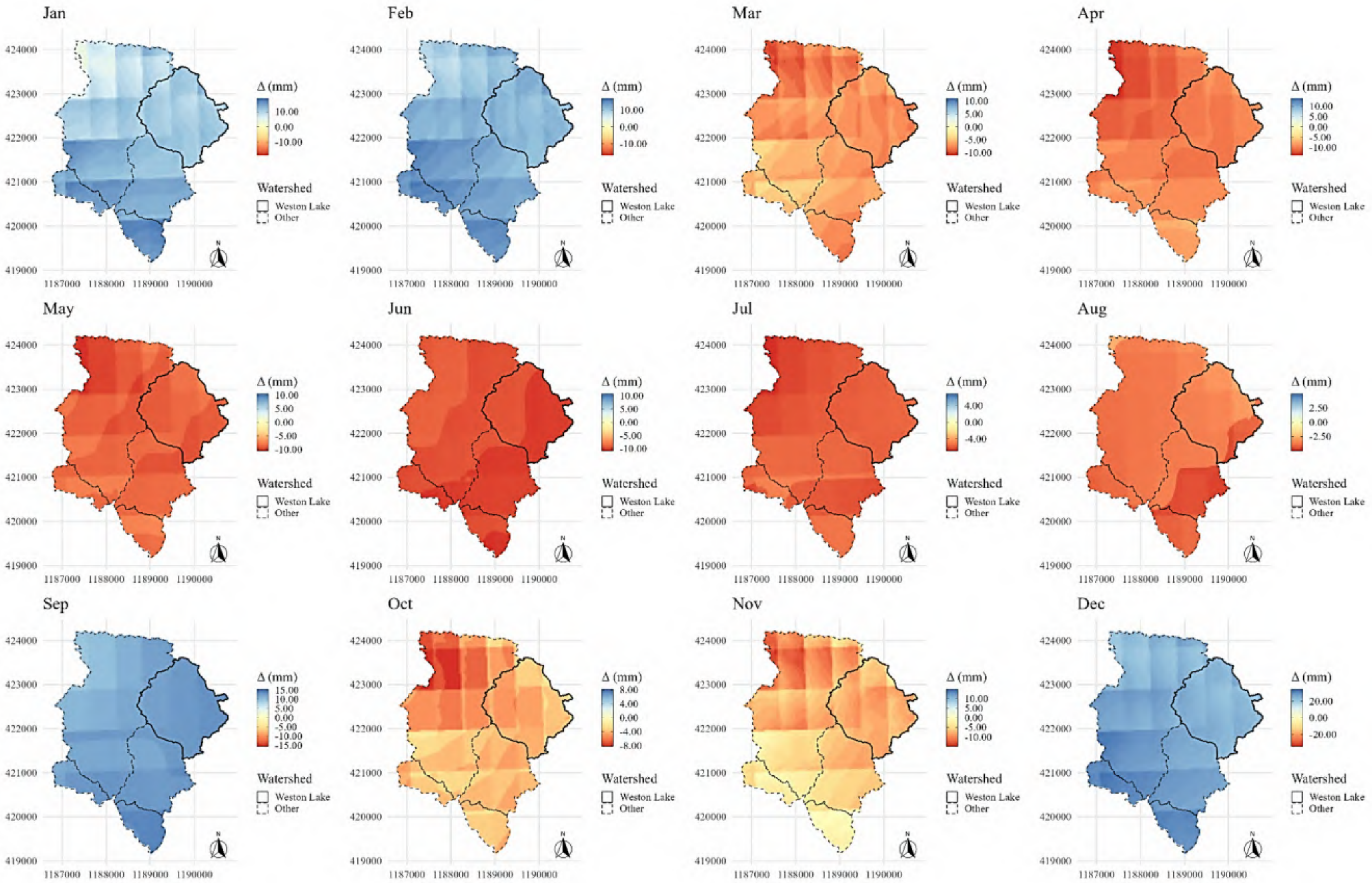

Figure 6: Monthly change in precipitation between year 2070 and present normals, SSP 2.6

1.6.1.3 Solar Radiation

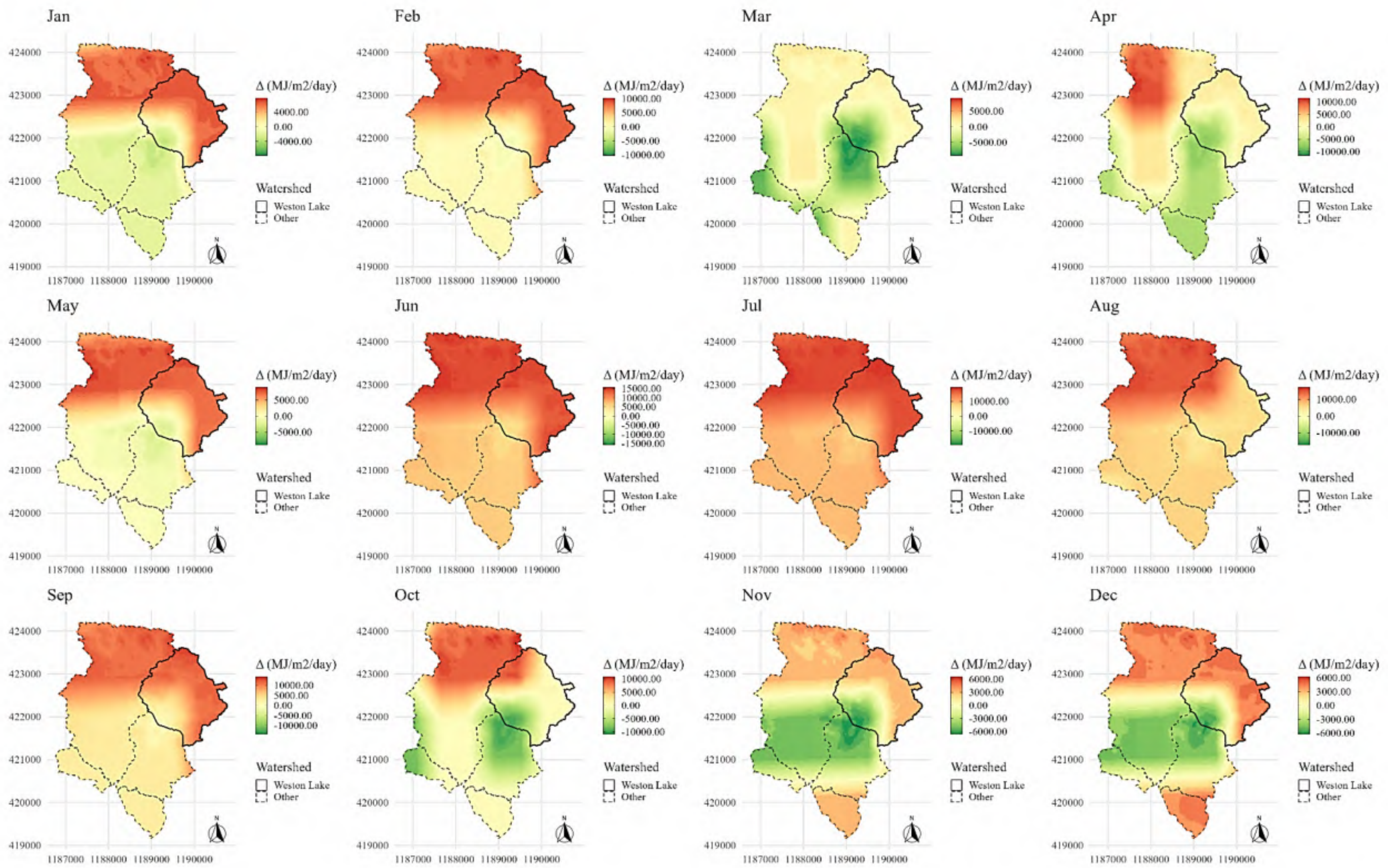

Figure 7: Monthly change in radiation between year 2030 and present normals, SSP 2.6

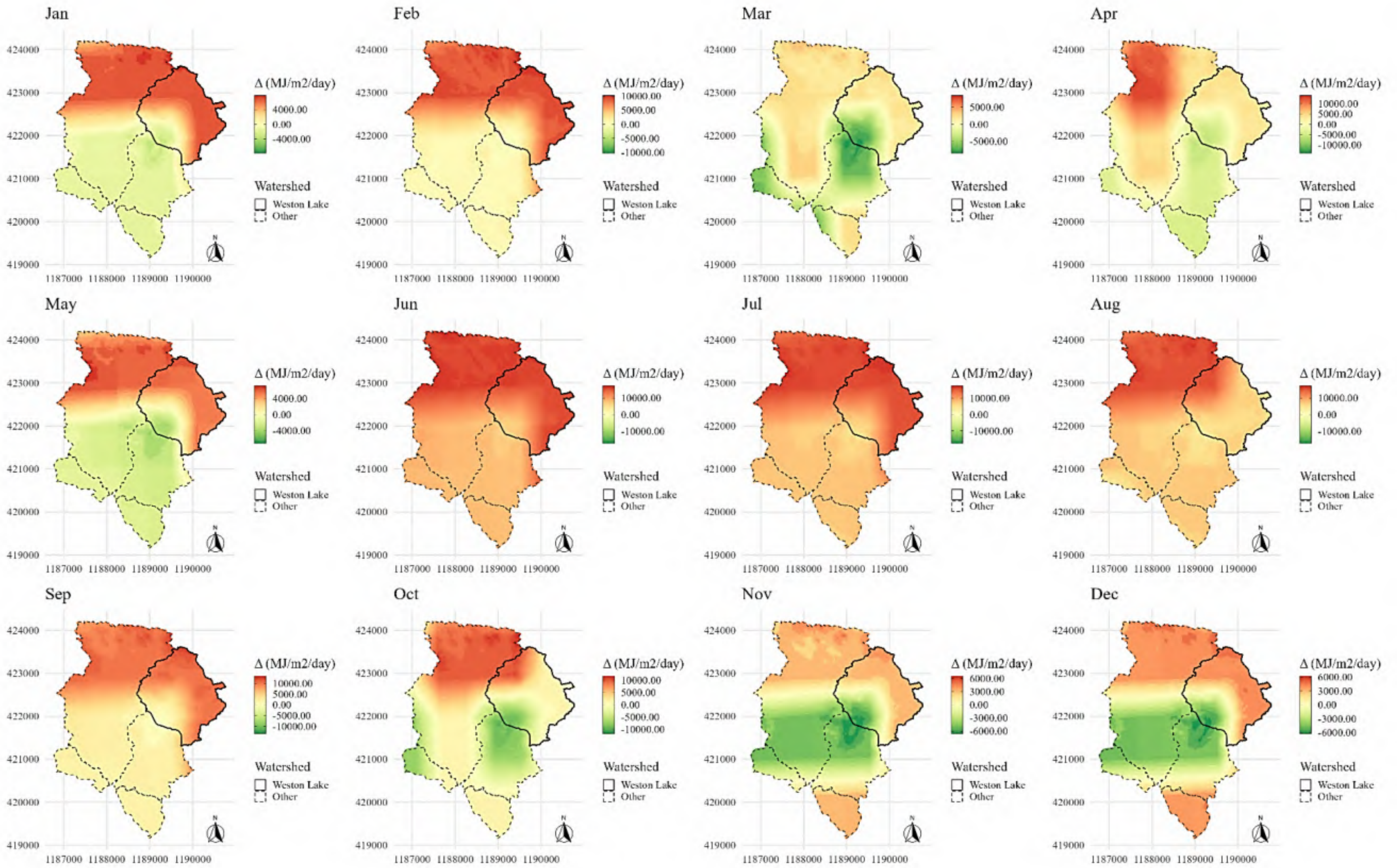

Figure 8: Monthly change in radiation between year 2050 and present normals, SSP 2.6

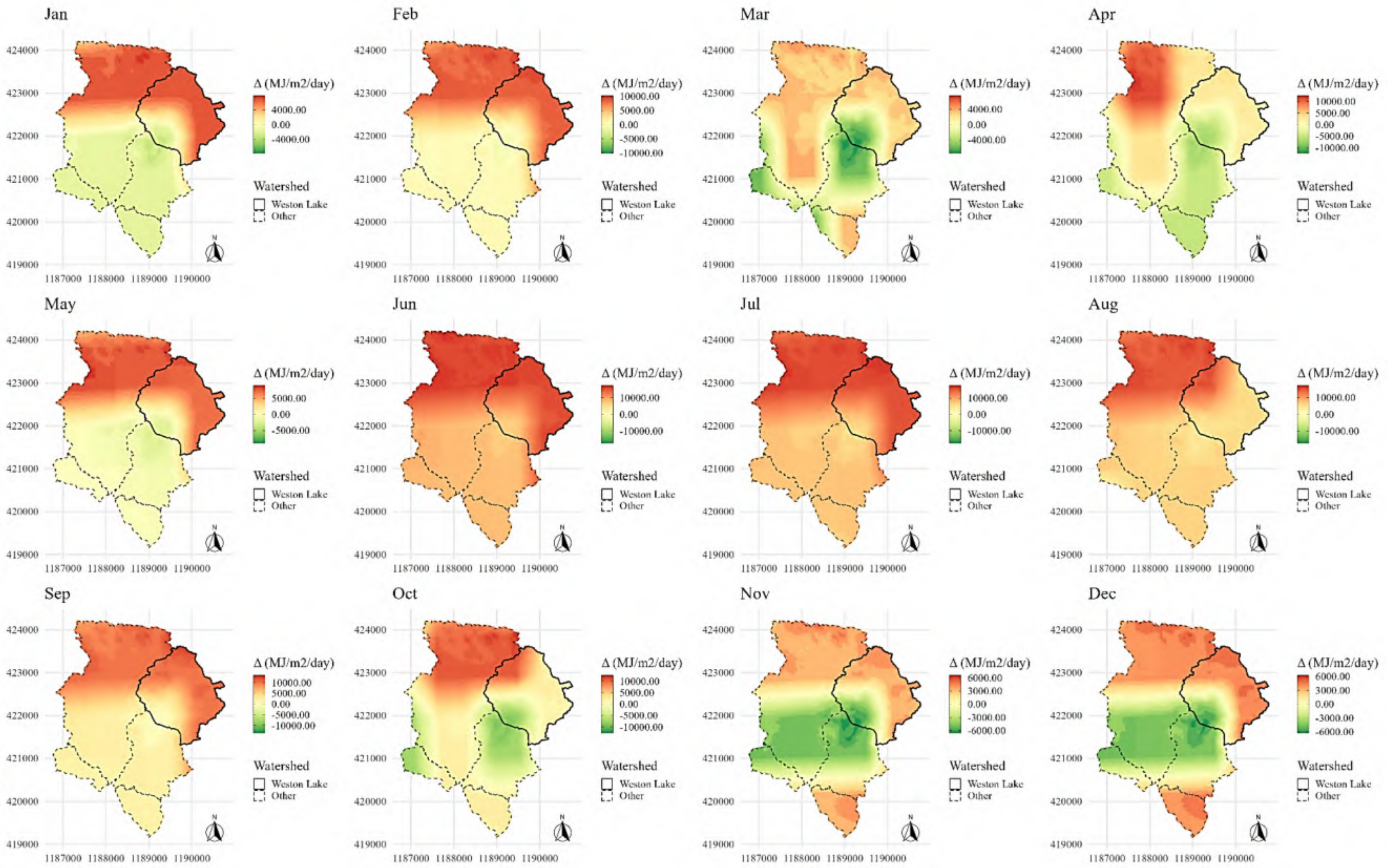

Figure 9: Monthly change in radiation between year 2070 and present normals, SSP 2.6

1.6.1.4 *Available Moisture Surplus*

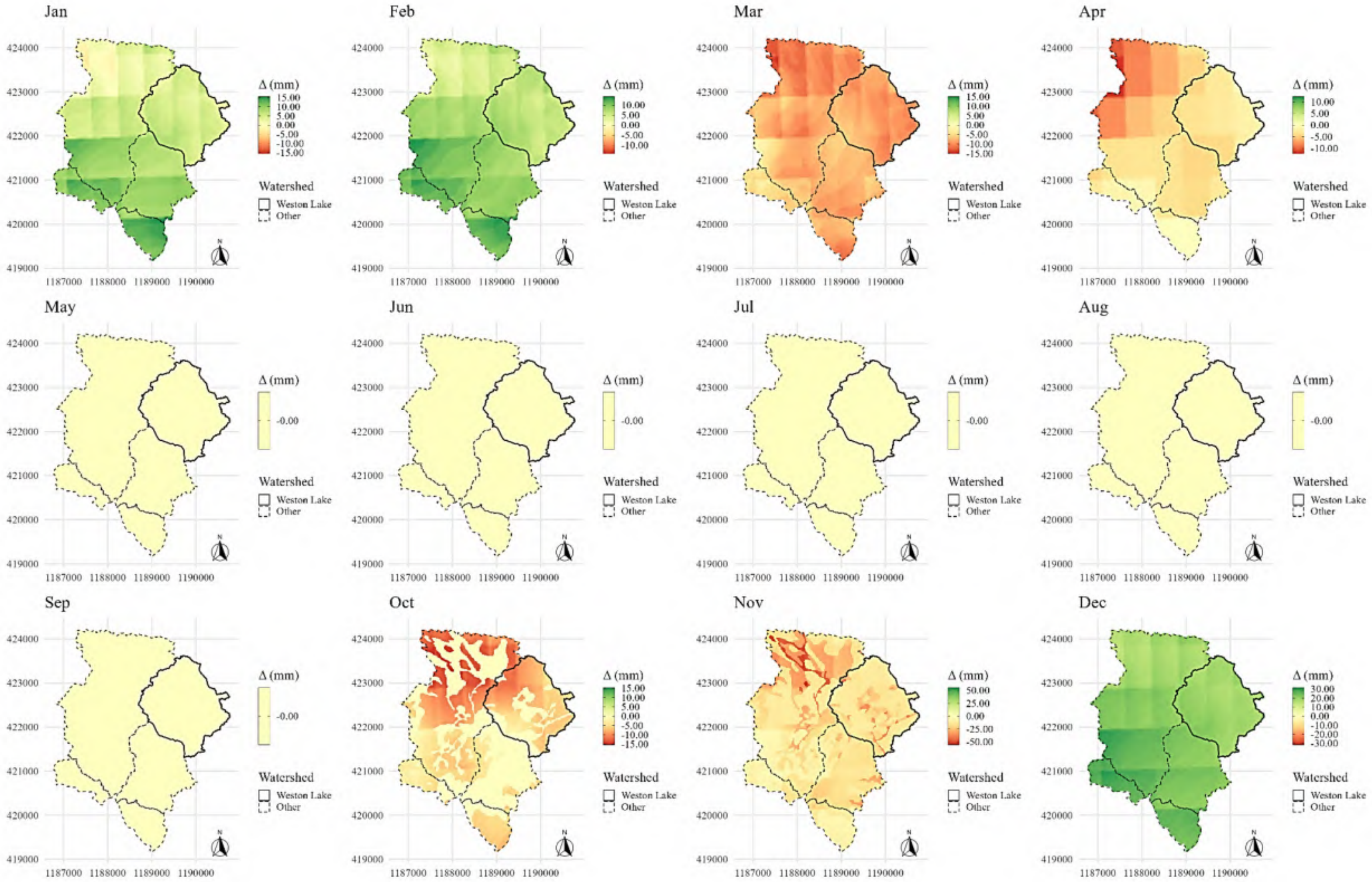

Figure 10: Monthly change in available moisture surplus between year 2030 and present normals, SSP 2.6

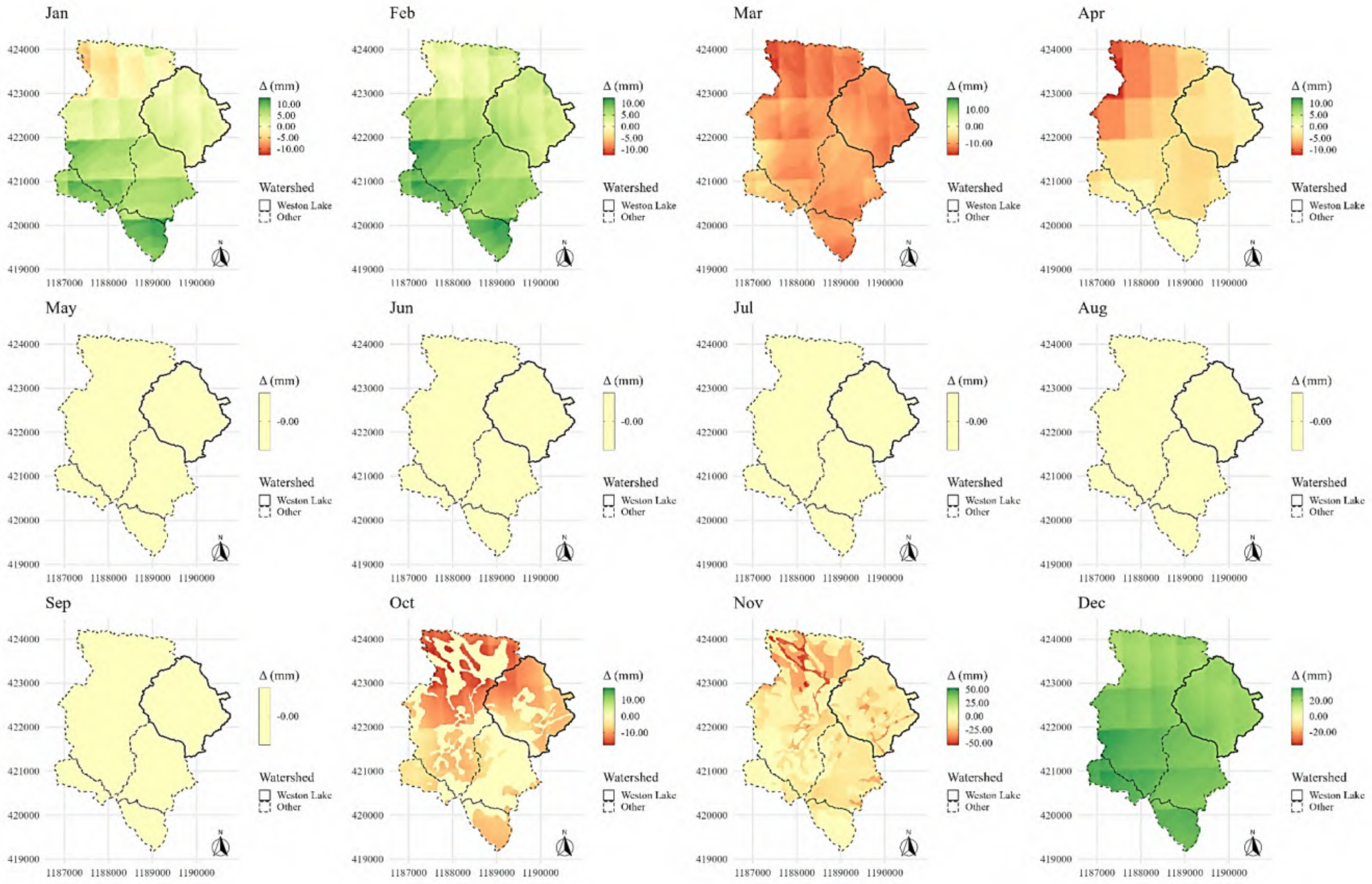

Figure 11: Monthly change in available moisture surplus between year 2050 and present normals, SSP 2.6

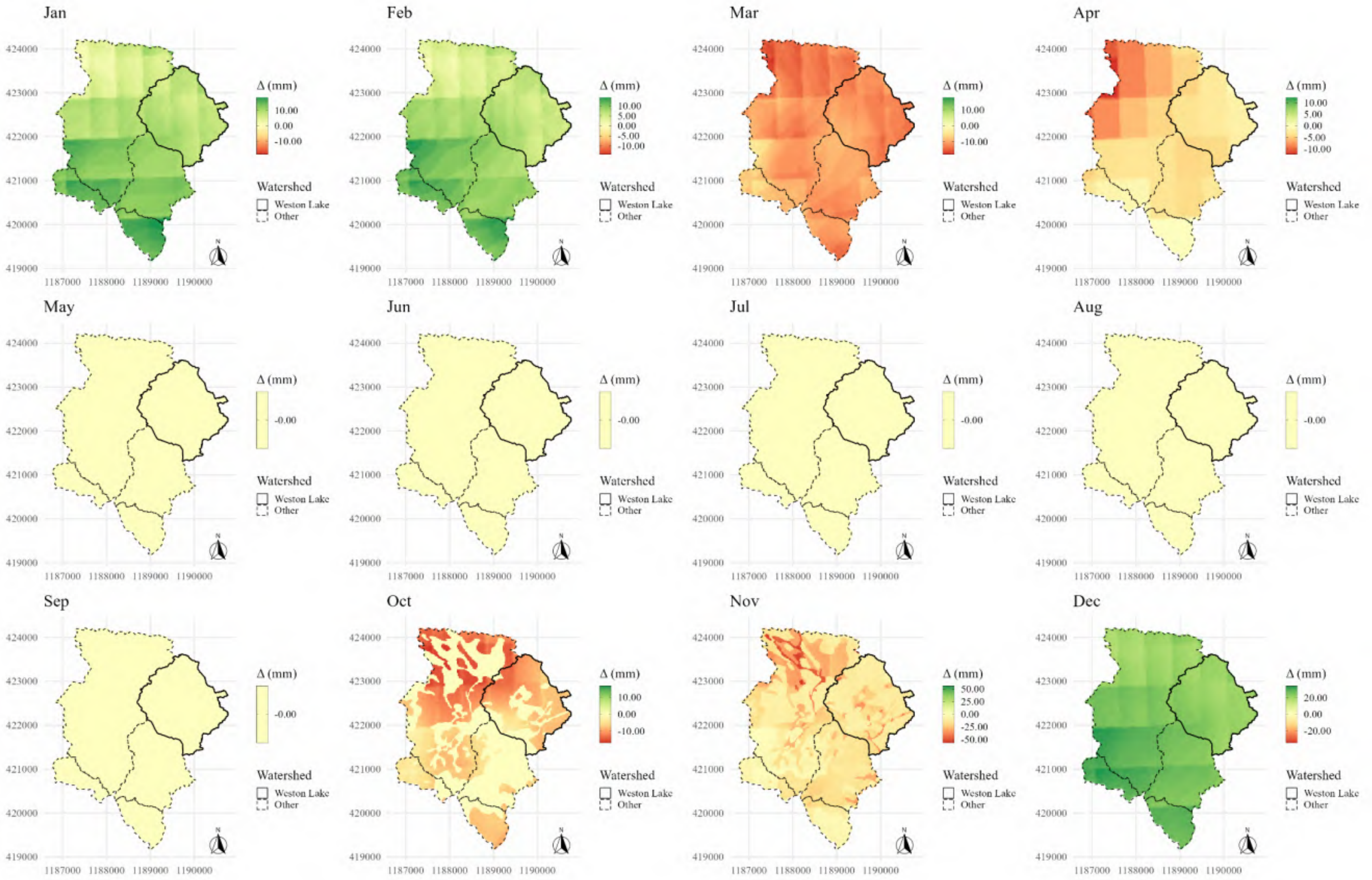

Figure 12: Monthly change in available moisture surplus between year 2070 and present normals, SSP 2.6

1.6.2 SSP 4.5

1.6.2.1 Average Temperature

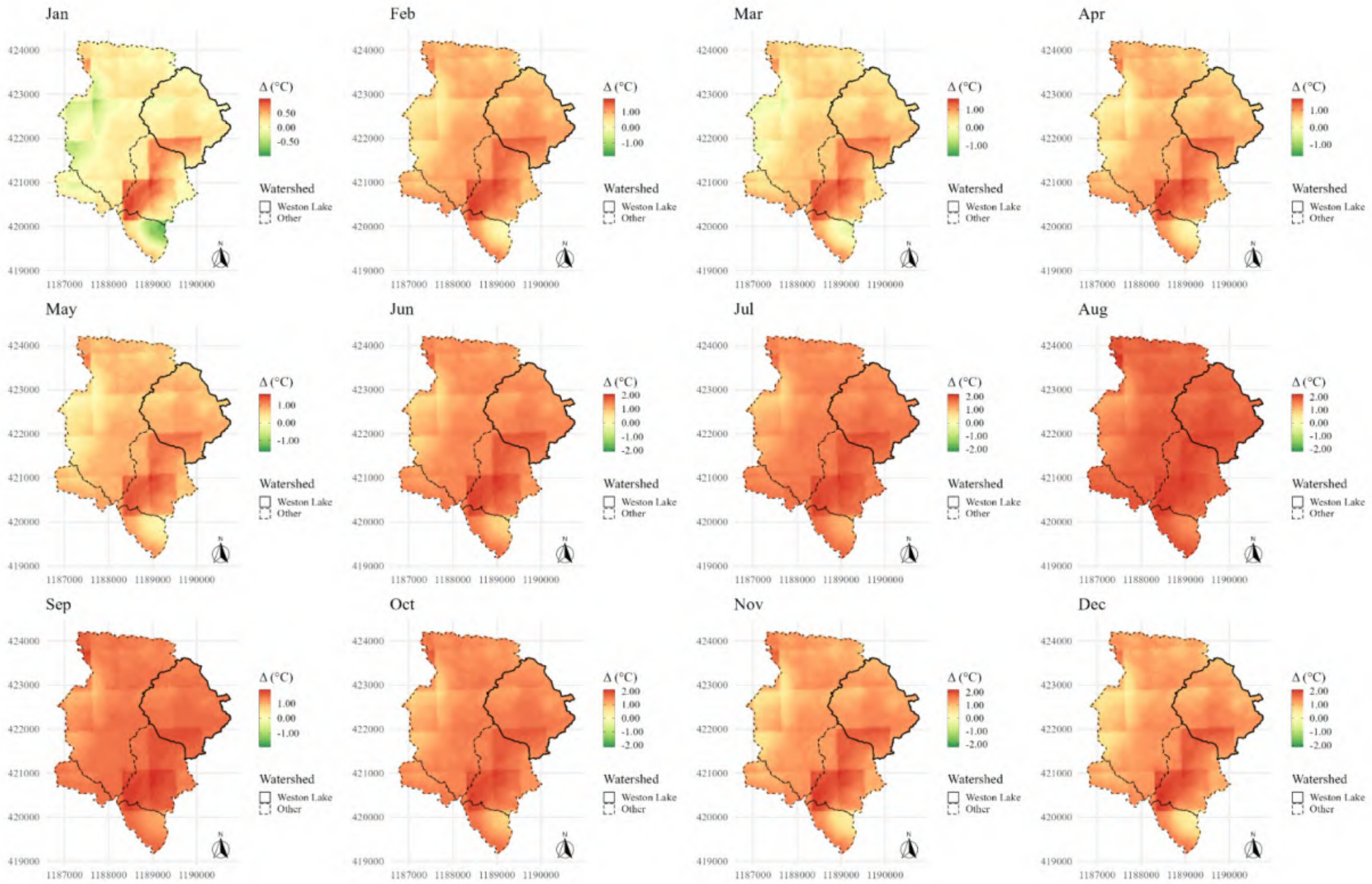

Figure 13: Monthly change in average temperature between year 2030 and present normals, SSP 4.5

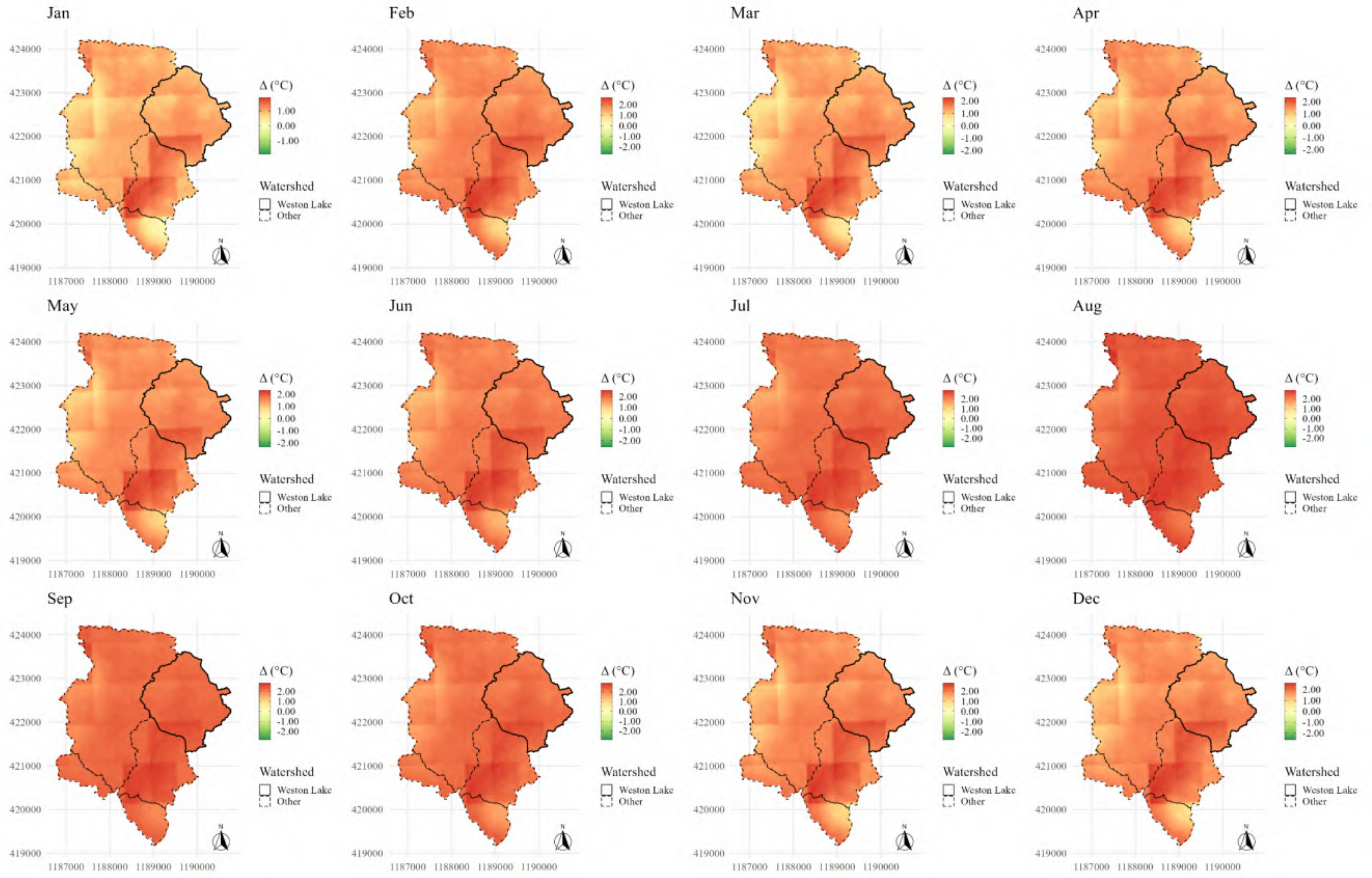

Figure 14: Monthly change in average temperature between year 2050 and present normals, SSP 4.5

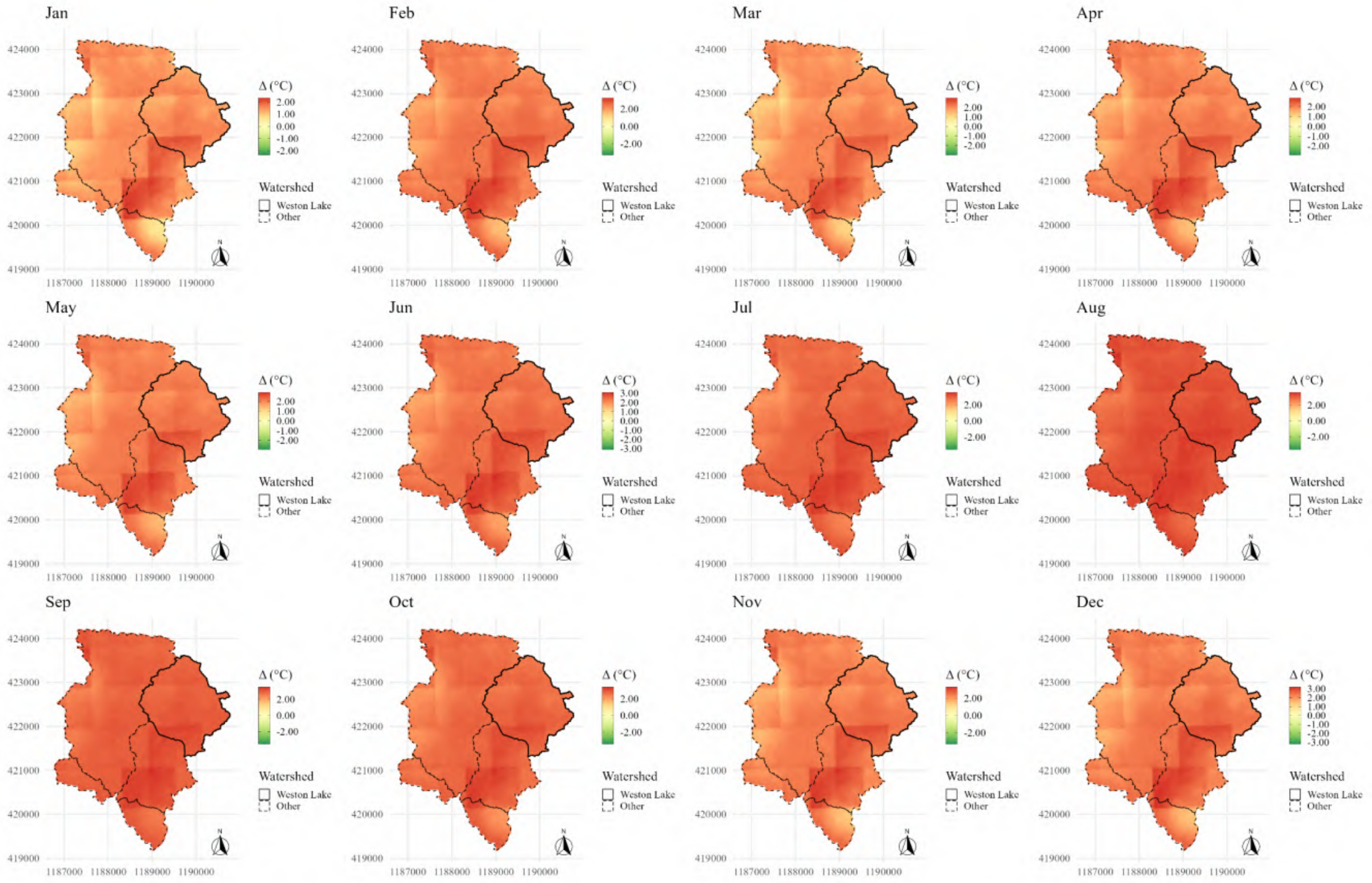

Figure 15: Monthly change in average temperature between year 2070 and present normals, SSP 4.5

1.6.2.2 Precipitation

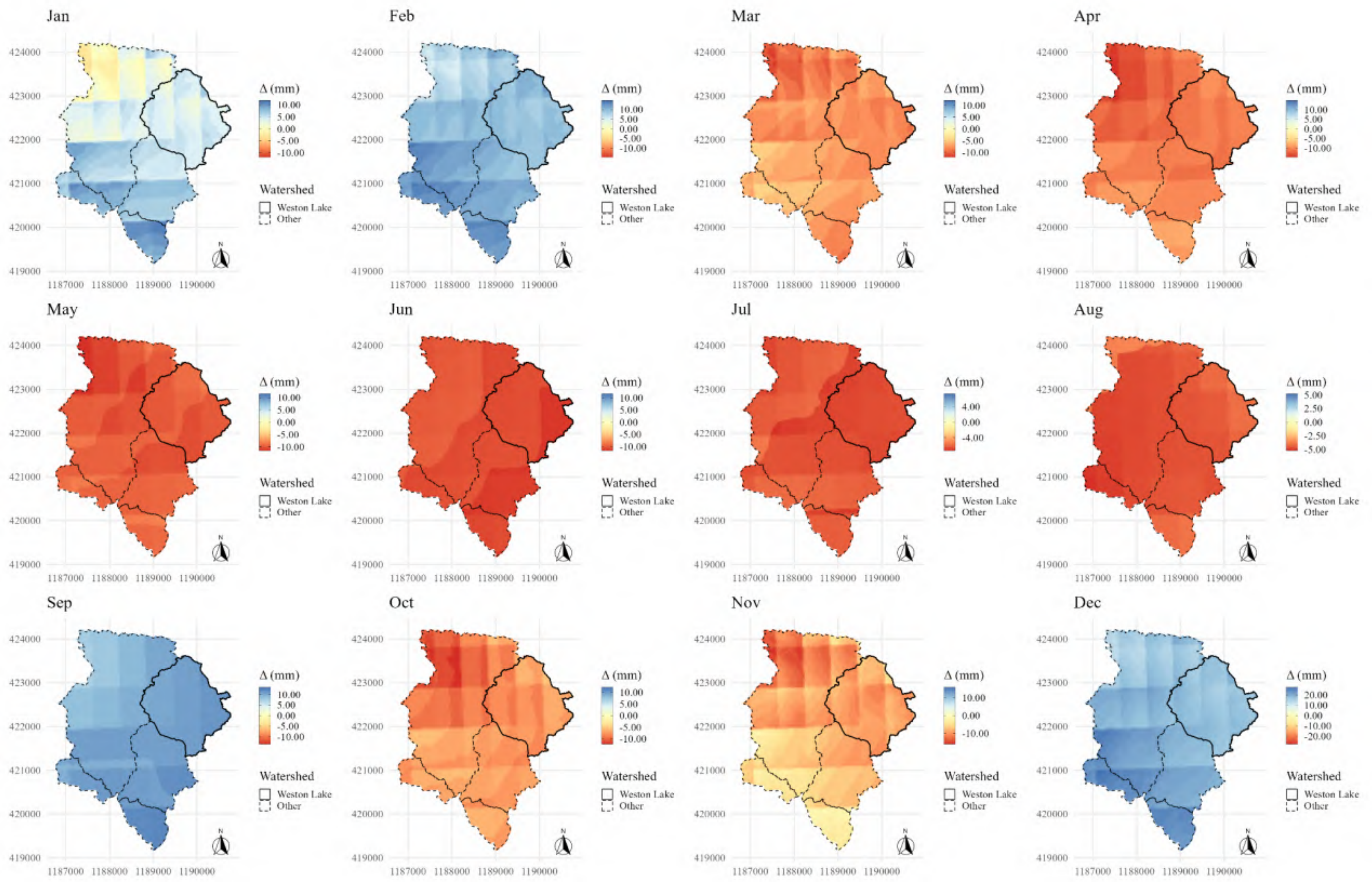

Figure 16: Monthly change in precipitation between year 2030 and present normals, SSP 4.5

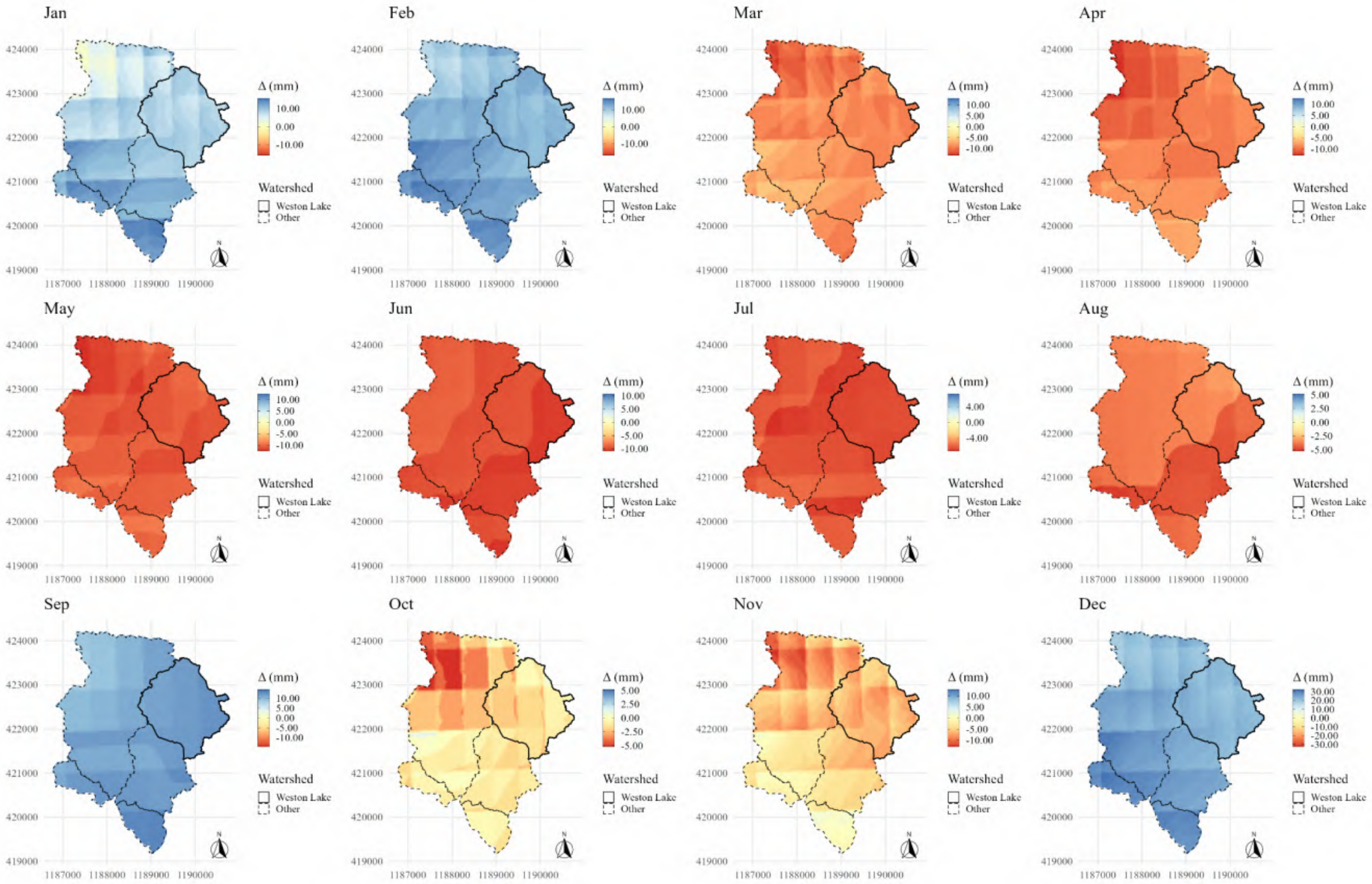

Figure 17: Monthly change in precipitation between year 2050 and present normals, SSP 4.5

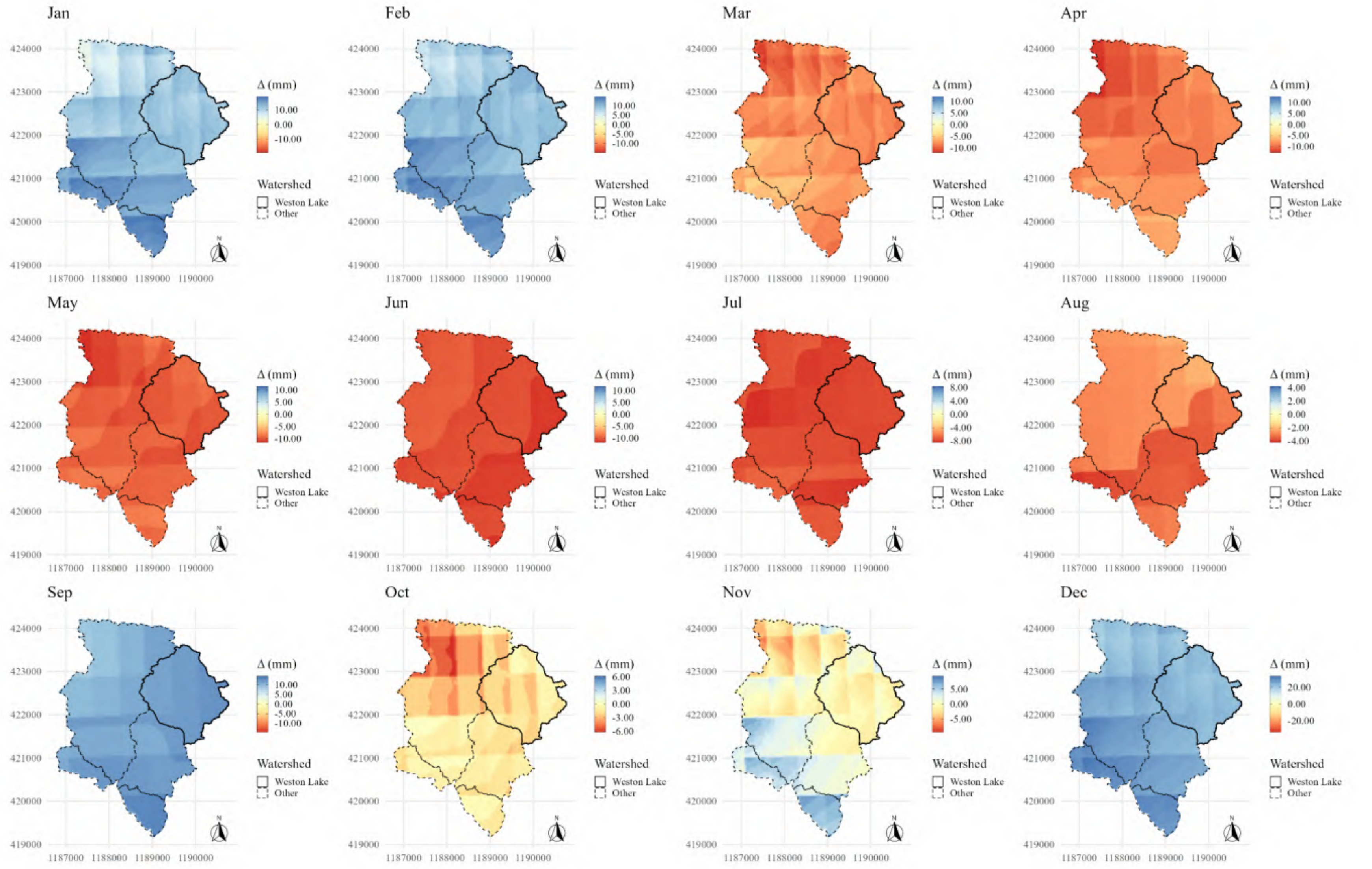

Figure 18: Monthly change in precipitation between year 2070 and present normals, SSP 4.5

1.6.2.3 Solar Radiation

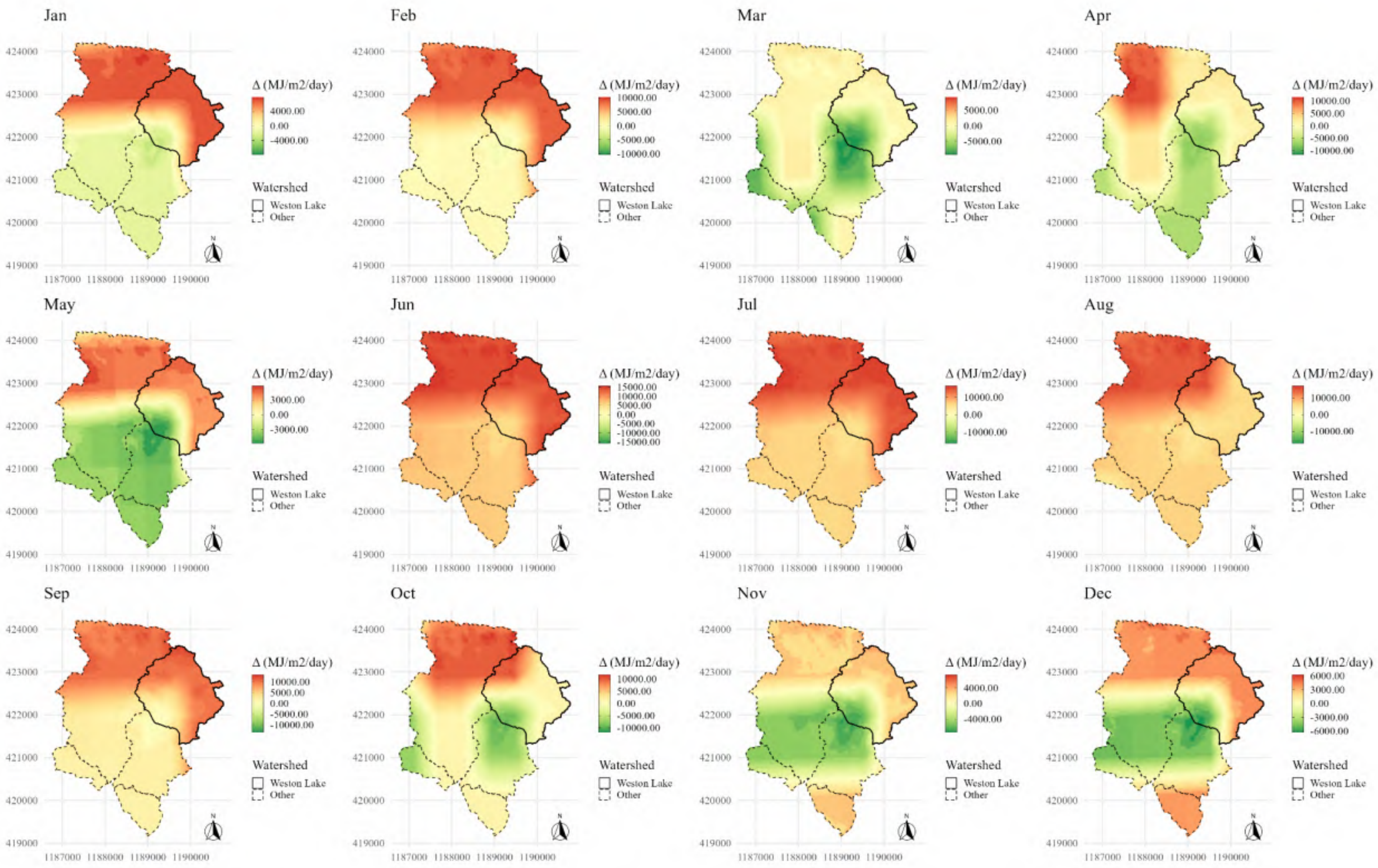

Figure 19: Monthly change in radiation between year 2030 and present normals, SSP 4.5

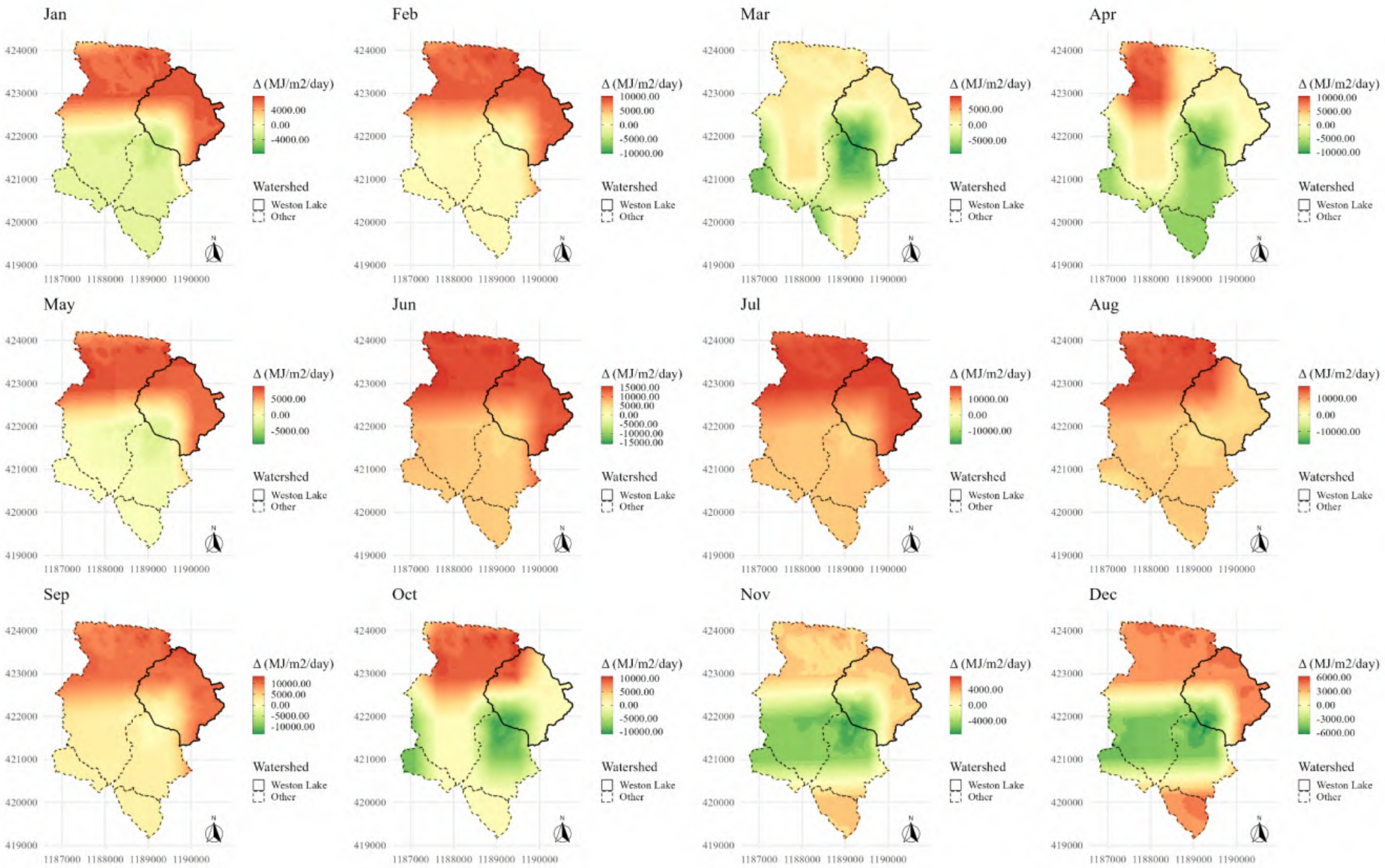

Figure 20: Monthly change in radiation between year 2050 and present normals, SSP 4.5

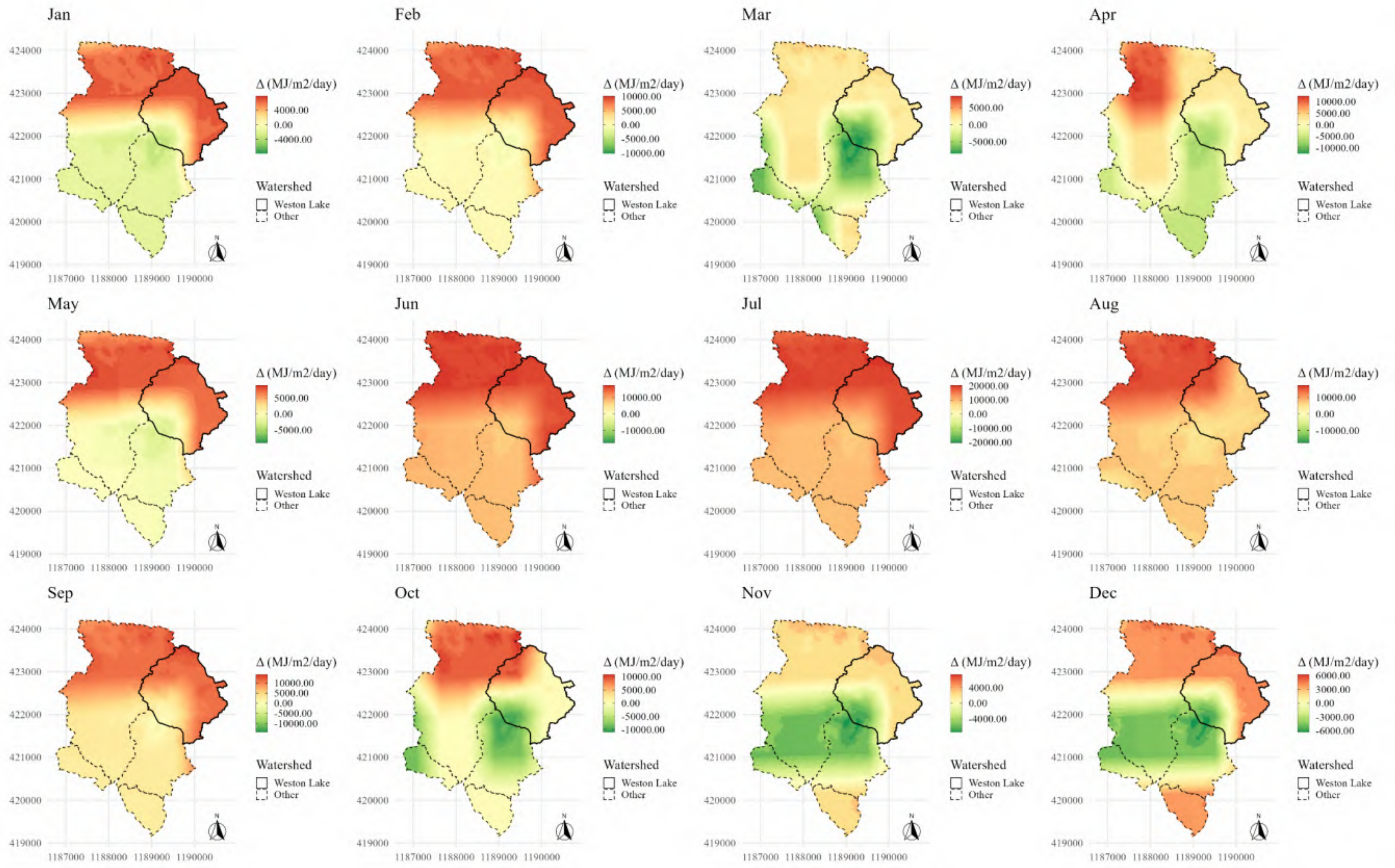

Figure 21: Monthly change in radiation between year 2070 and present normals, SSP 4.5

1.6.2.4 *Available Moisture Surplus*

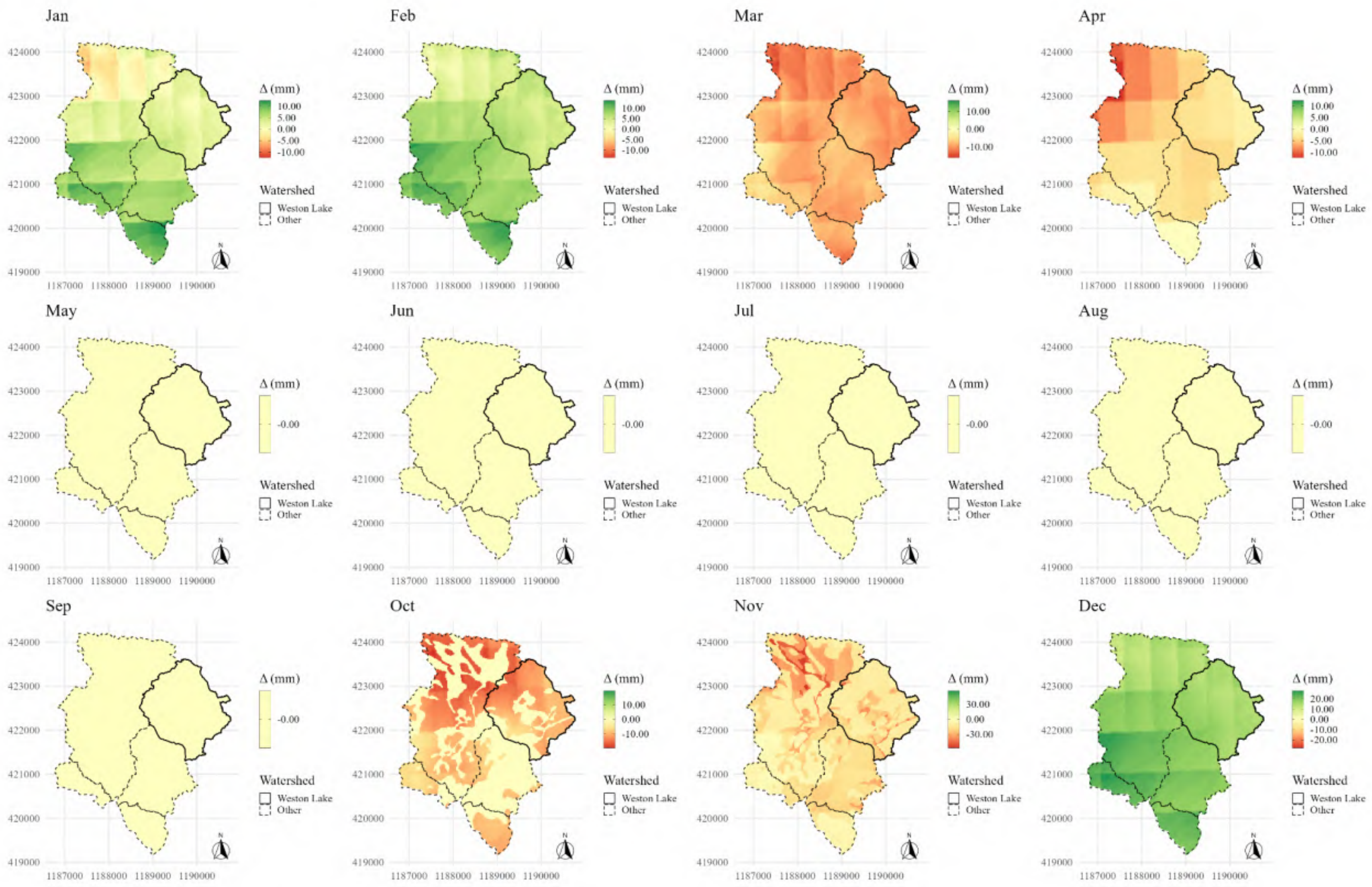

Figure 22: Monthly change in available moisture surplus between year 2030 and present normals, SSP 4.5

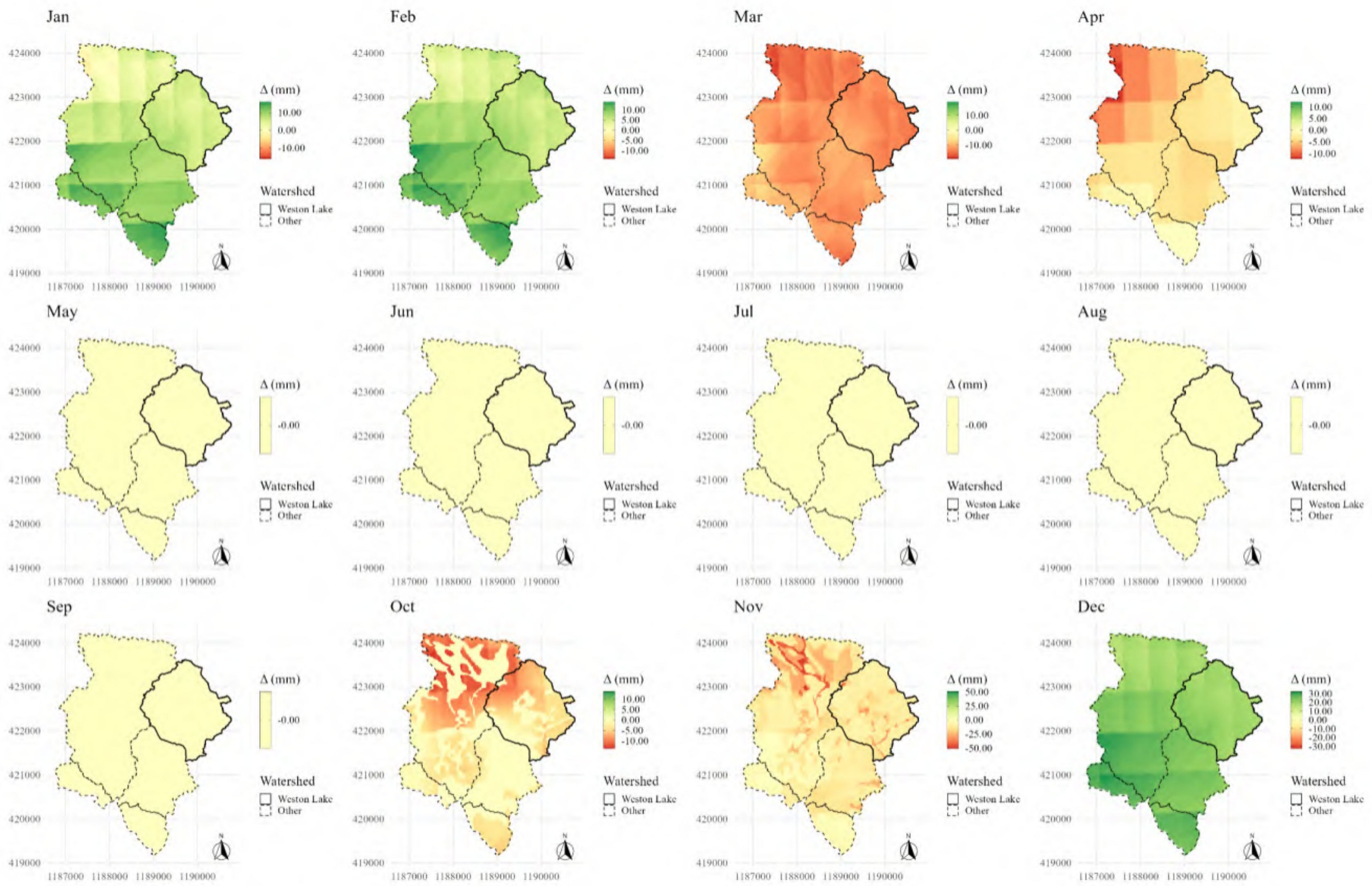

Figure 23: Monthly change in available moisture surplus between year 2050 and present normals, SSP 4.5

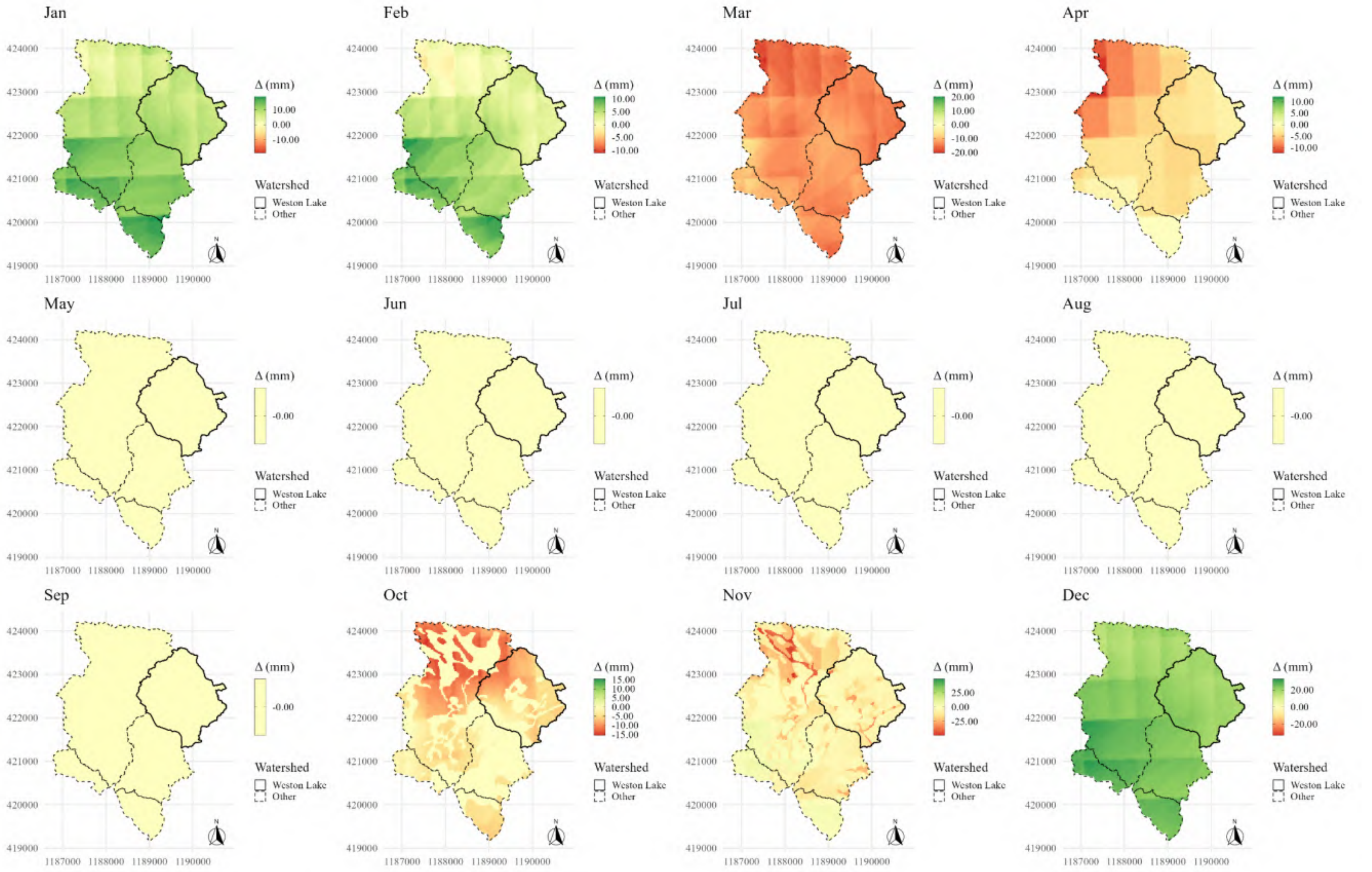

Figure 24: Monthly change in available moisture surplus between year 2070 and present normals, SSP 4.5

1.6.3 SSP 7.0

1.6.3.1 Average Temperature

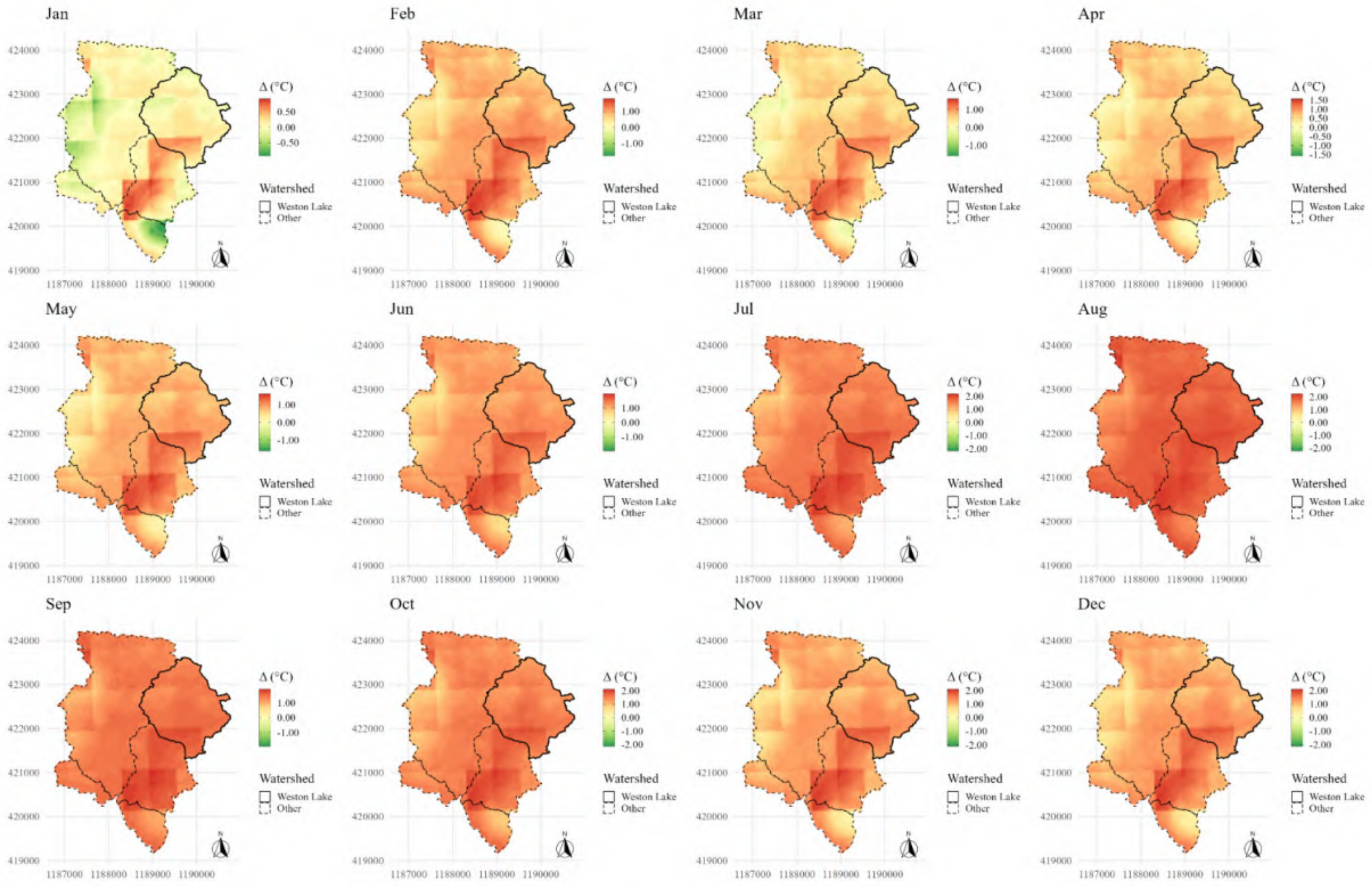

Figure 25: Monthly change in average temperature between year 2030 and present normals, SSP 7.0

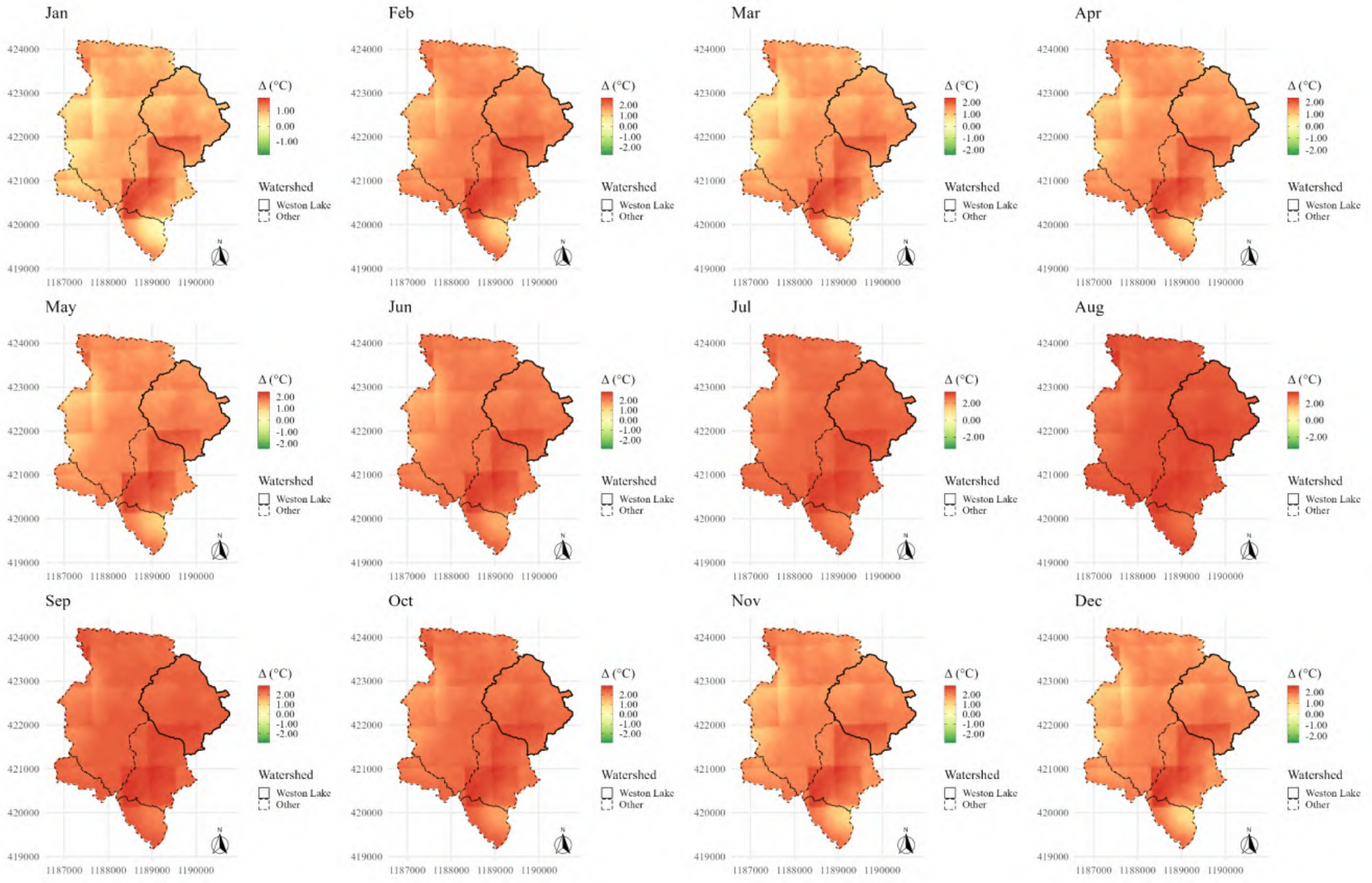

Figure 26: Monthly change in average temperature between year 2050 and present normals, SSP 7.0

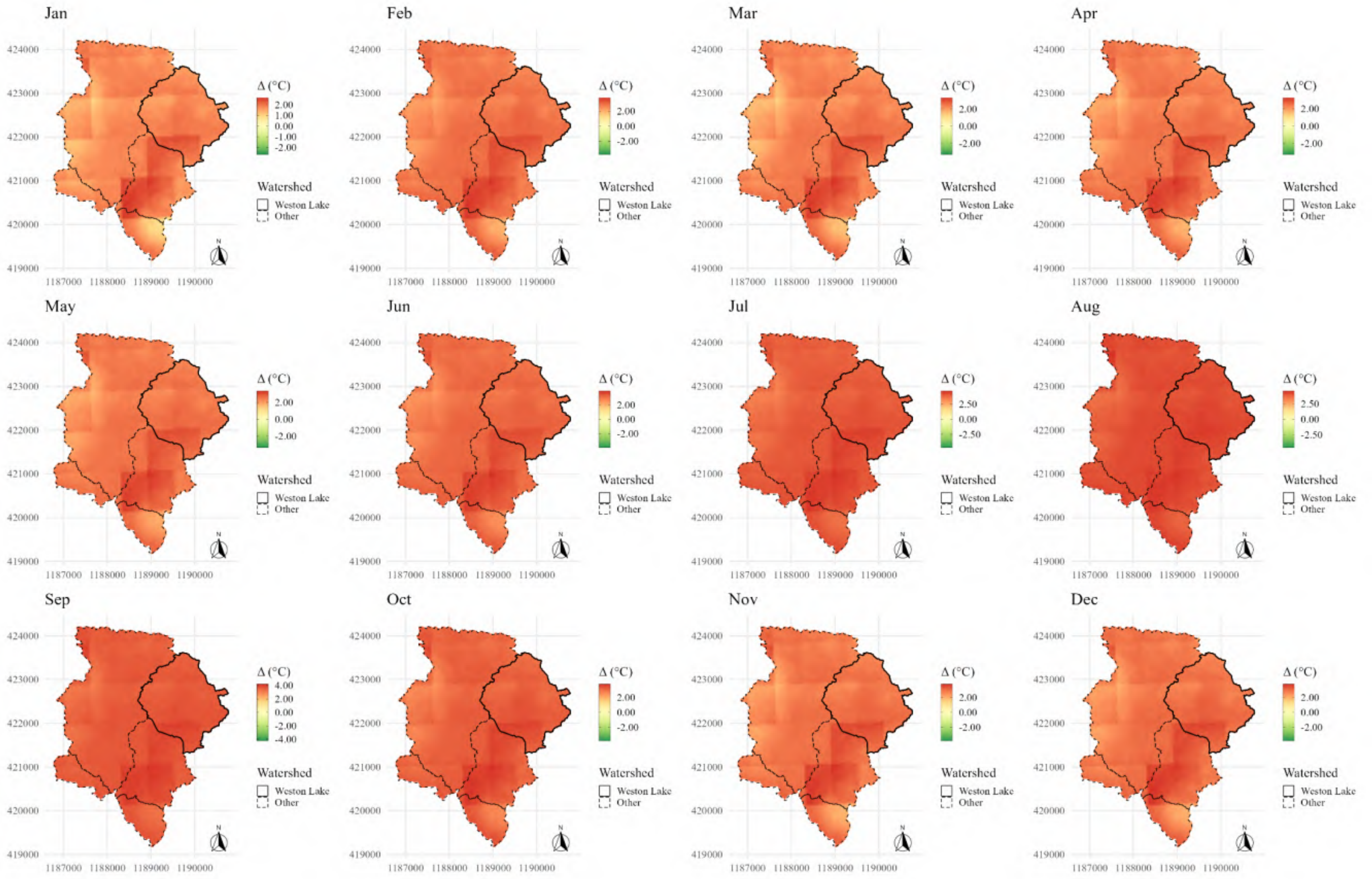

Figure 27: Monthly change in average temperature between year 2070 and present normals, SSP 7.0

1.6.3.2 *Precipitation*

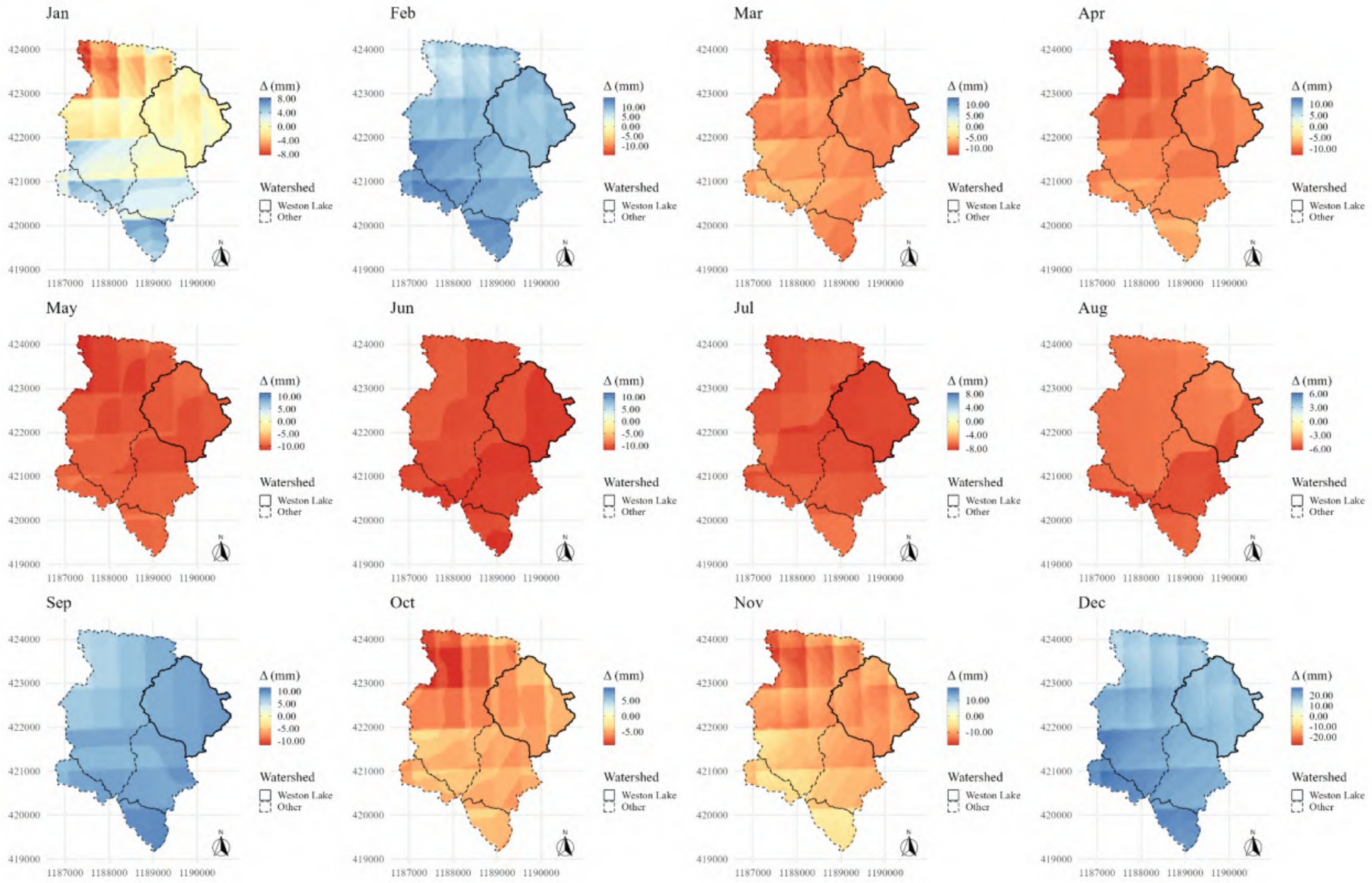

Figure 28: Monthly change in precipitation between year 2030 and present normals, SSP 7.0

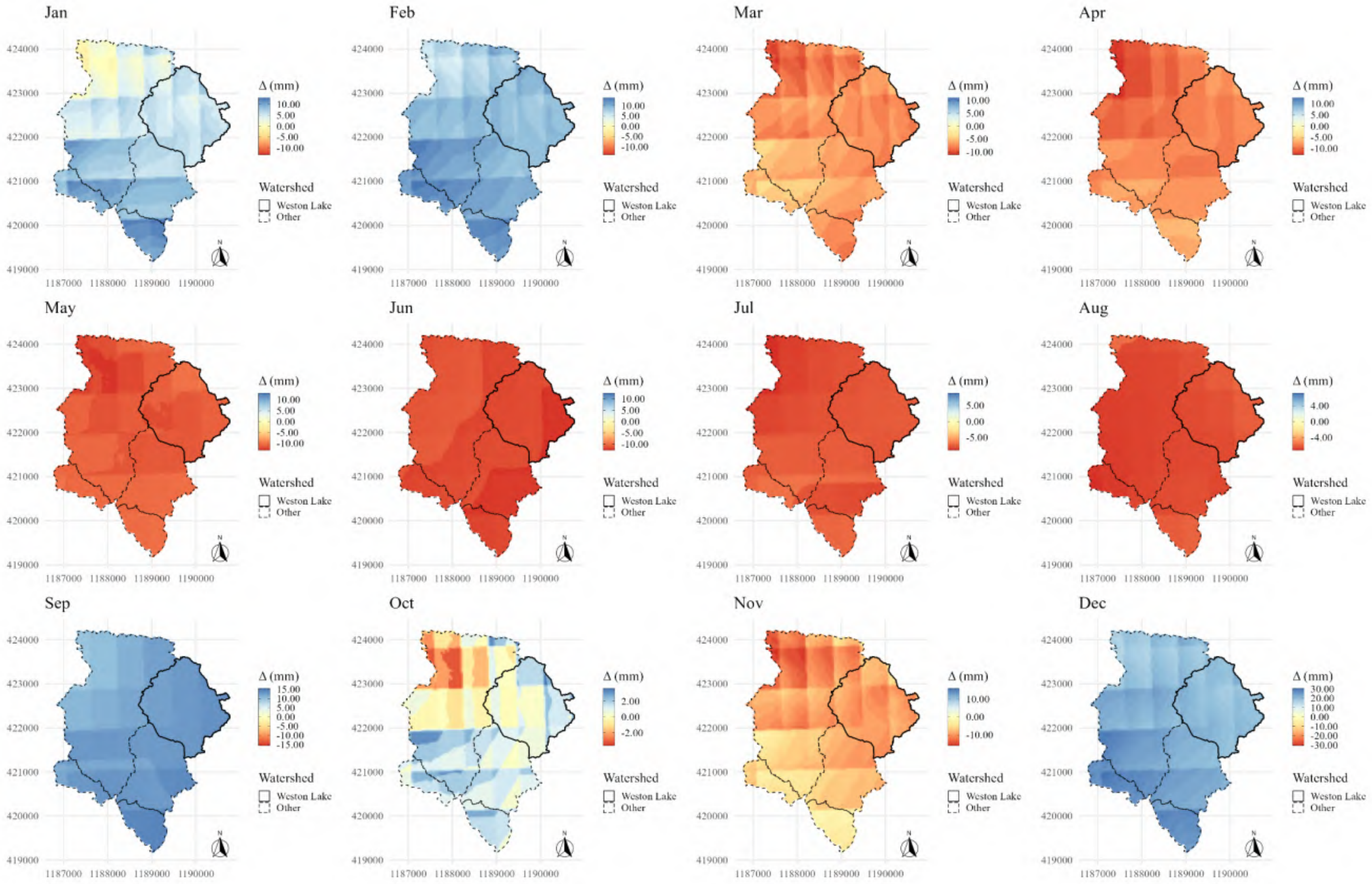

Figure 29: Monthly change in precipitation between year 2050 and present normals, SSP 7.0

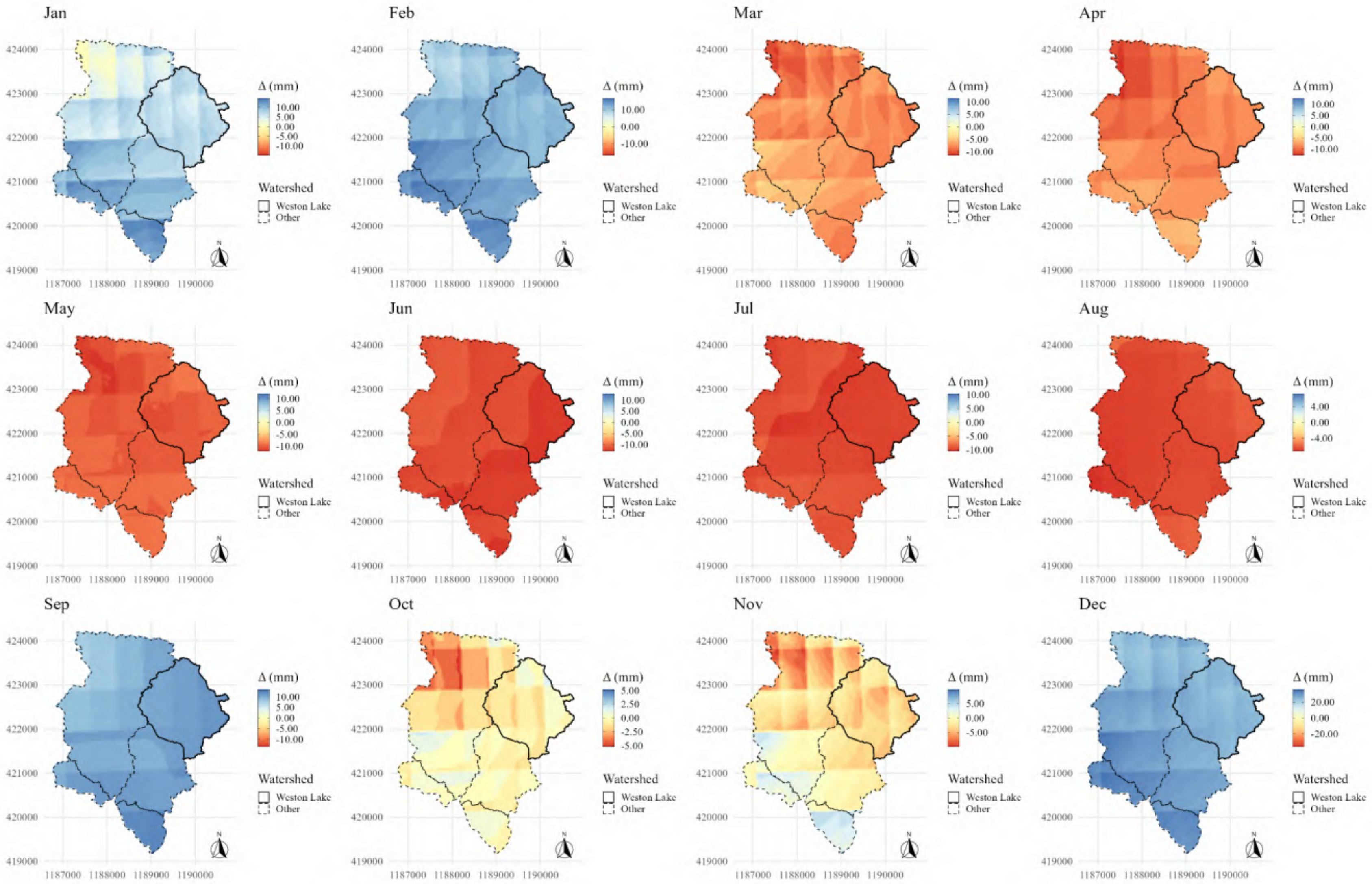

Figure 30: Monthly change in precipitation between year 2070 and present normals, SSP 7.0

1.6.3.3 *Solar Radiation*

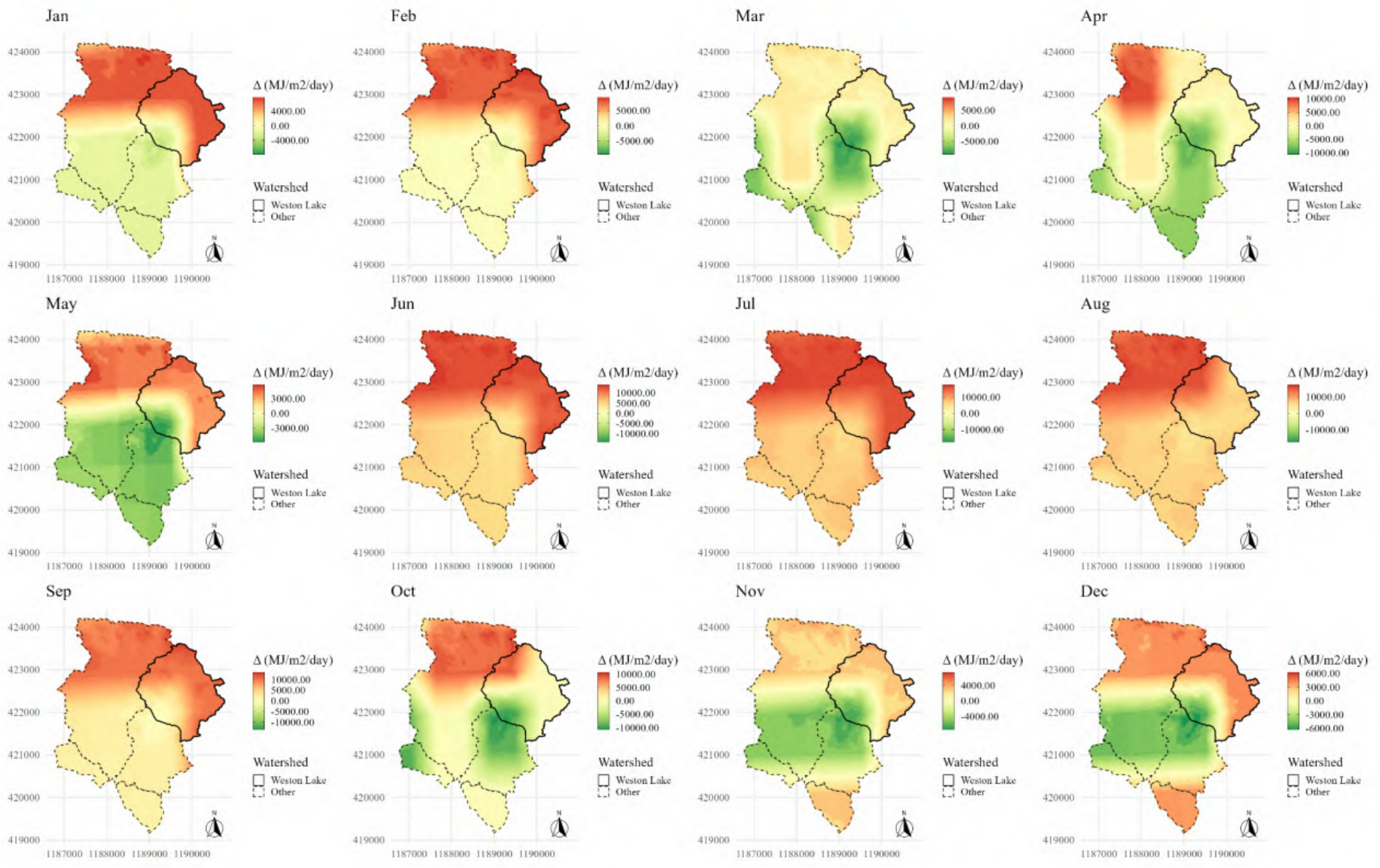

Figure 31: Monthly change in radiation between year 2030 and present normals, SSP 7.0

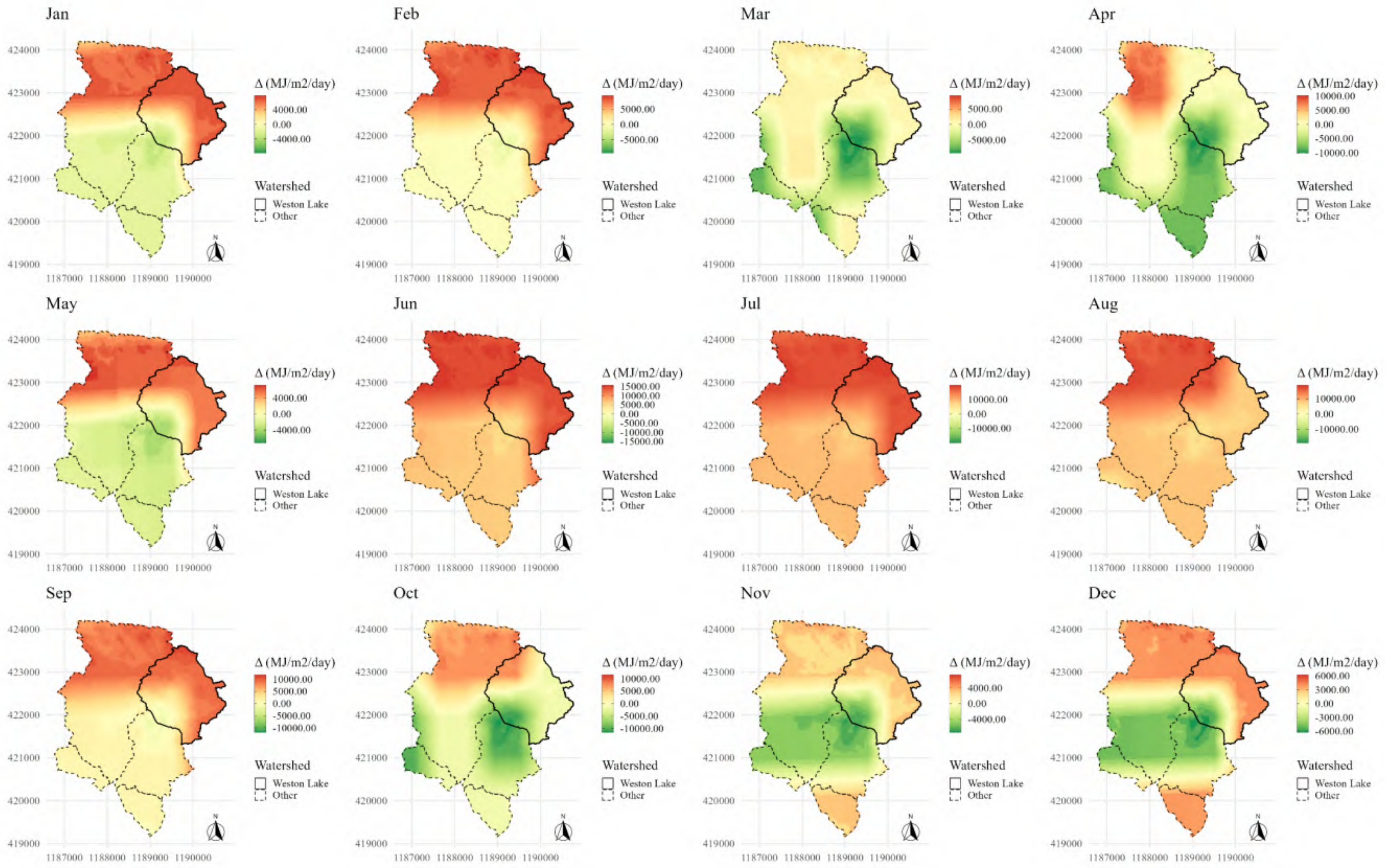

Figure 32: Monthly change in radiation between year 2050 and present normals, SSP 7.0

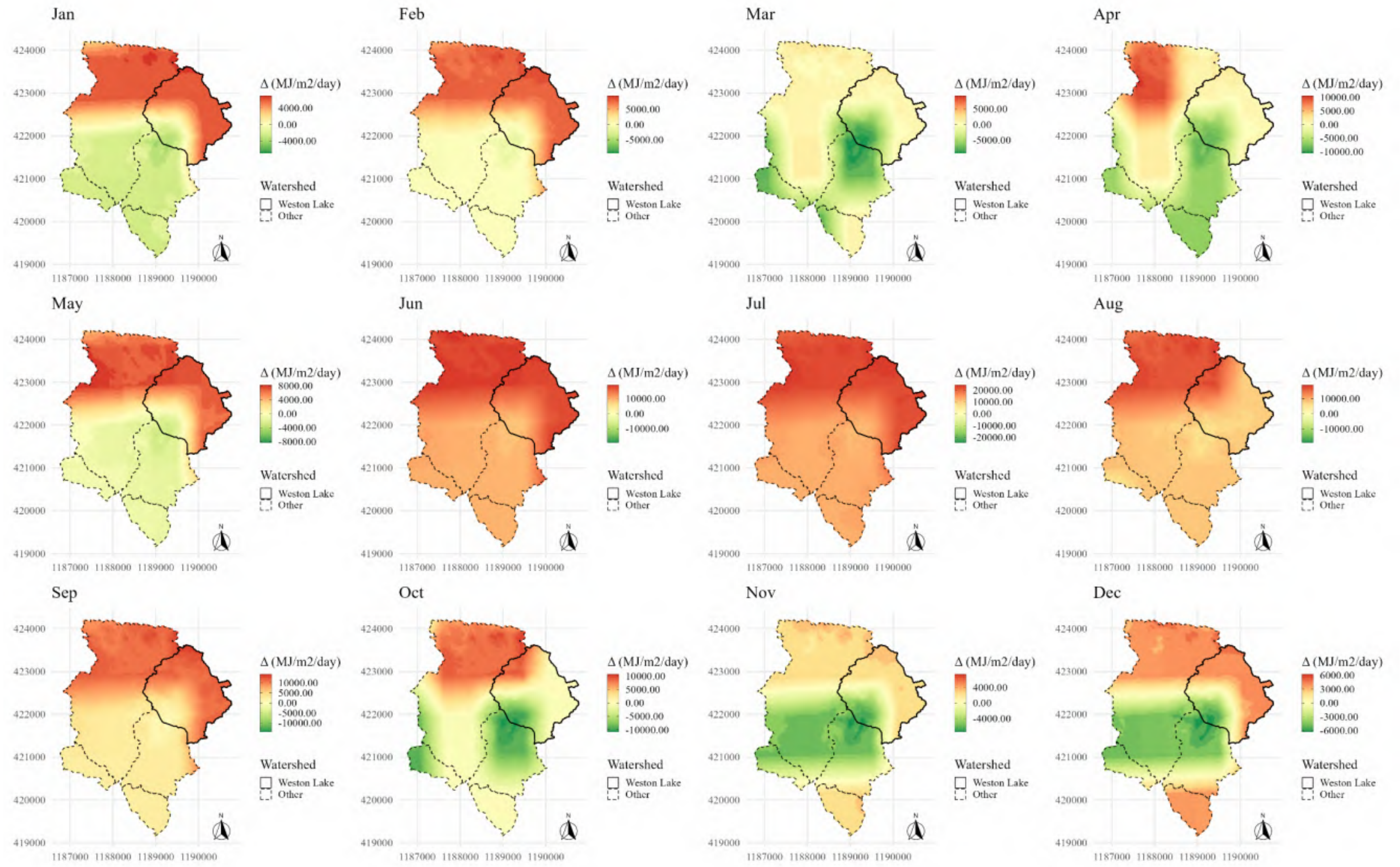

Figure 33: Monthly change in radiation between year 2070 and present normals, SSP 7.0

1.6.3.4 Available Moisture Surplus

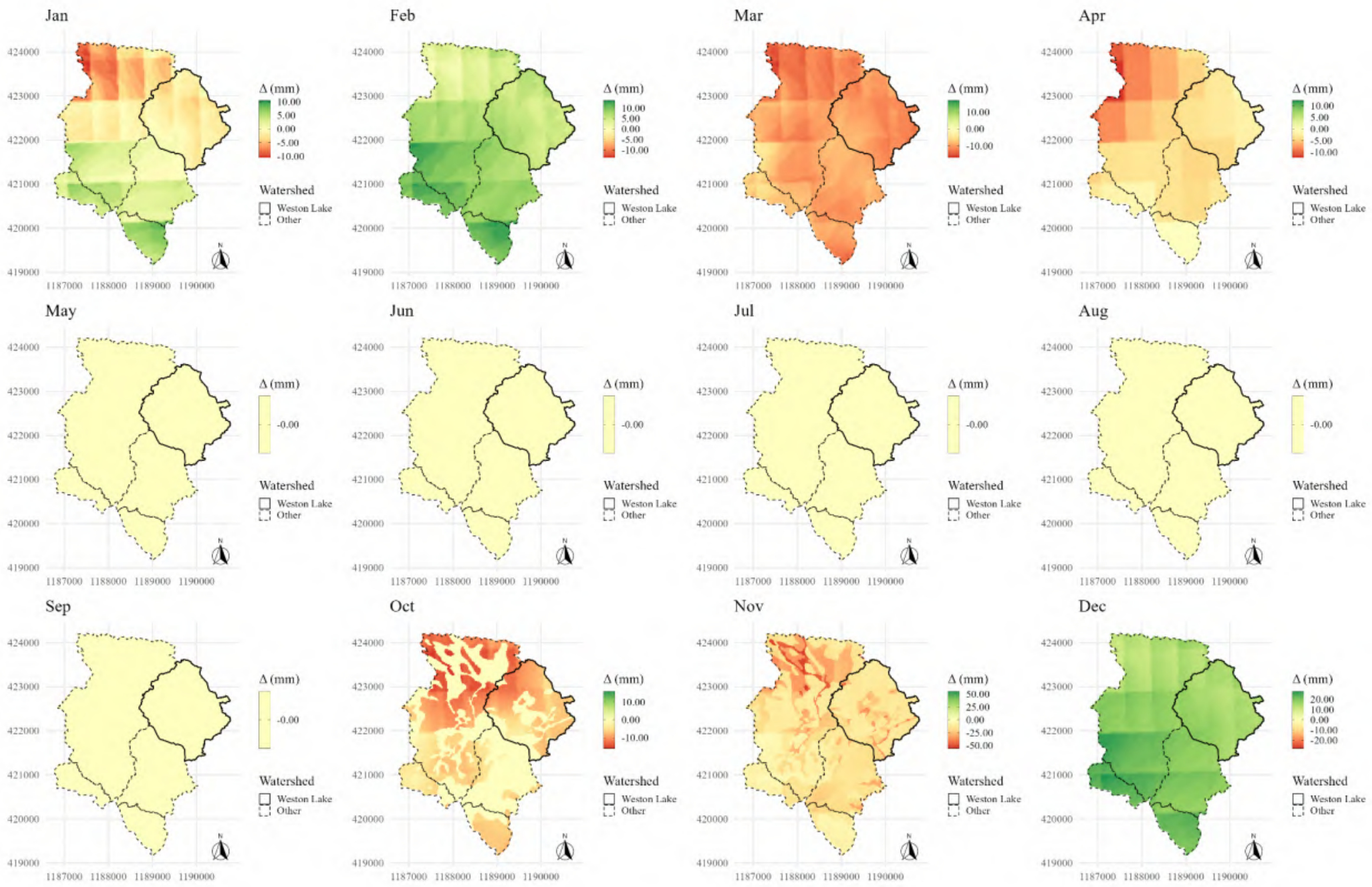

Figure 34: Monthly change in available water surplus between year 2030 and present normals, SSP 7.0

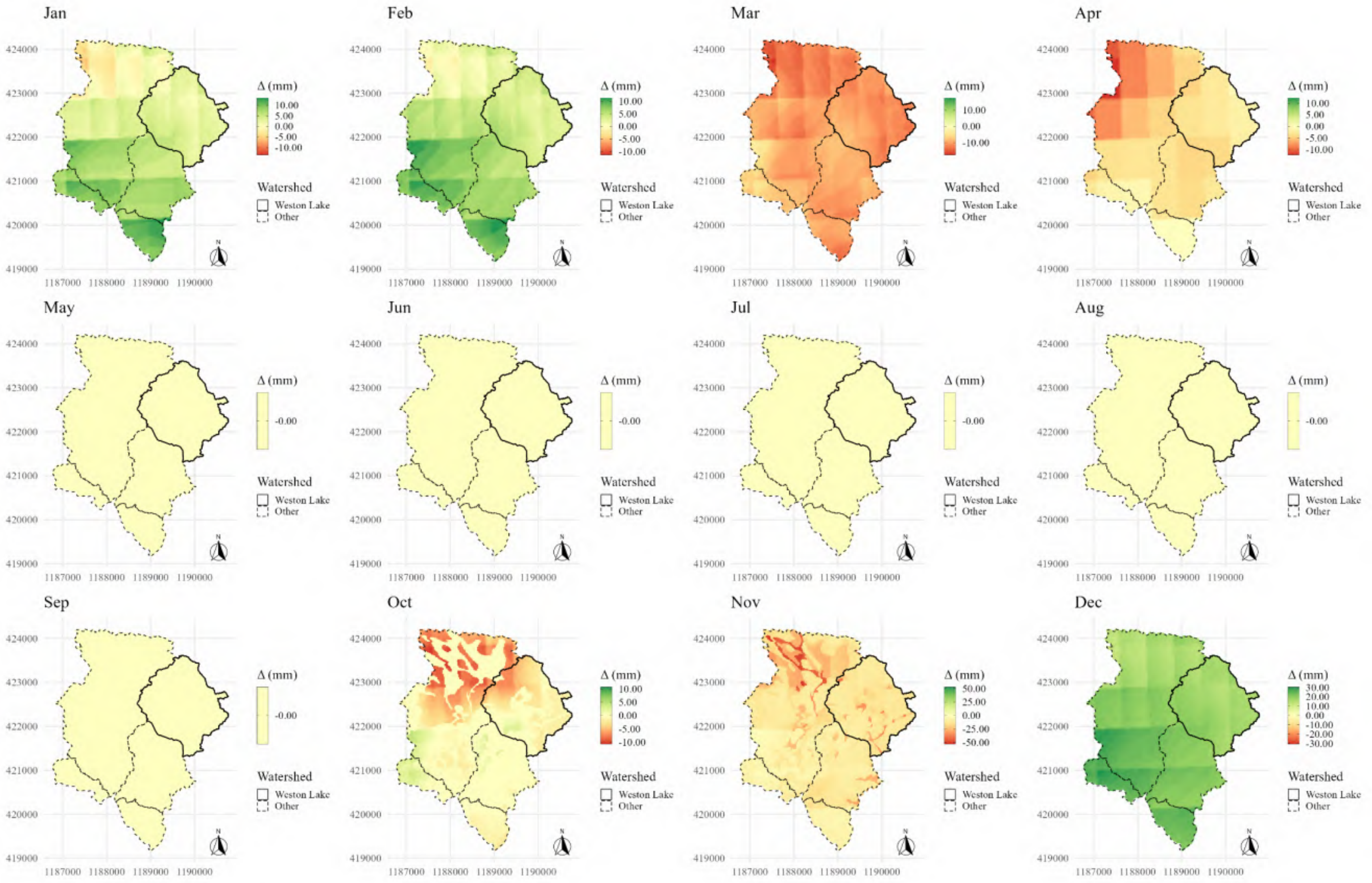

Figure 35: Monthly change in available water surplus between year 2050 and present normals, SSP 7.0

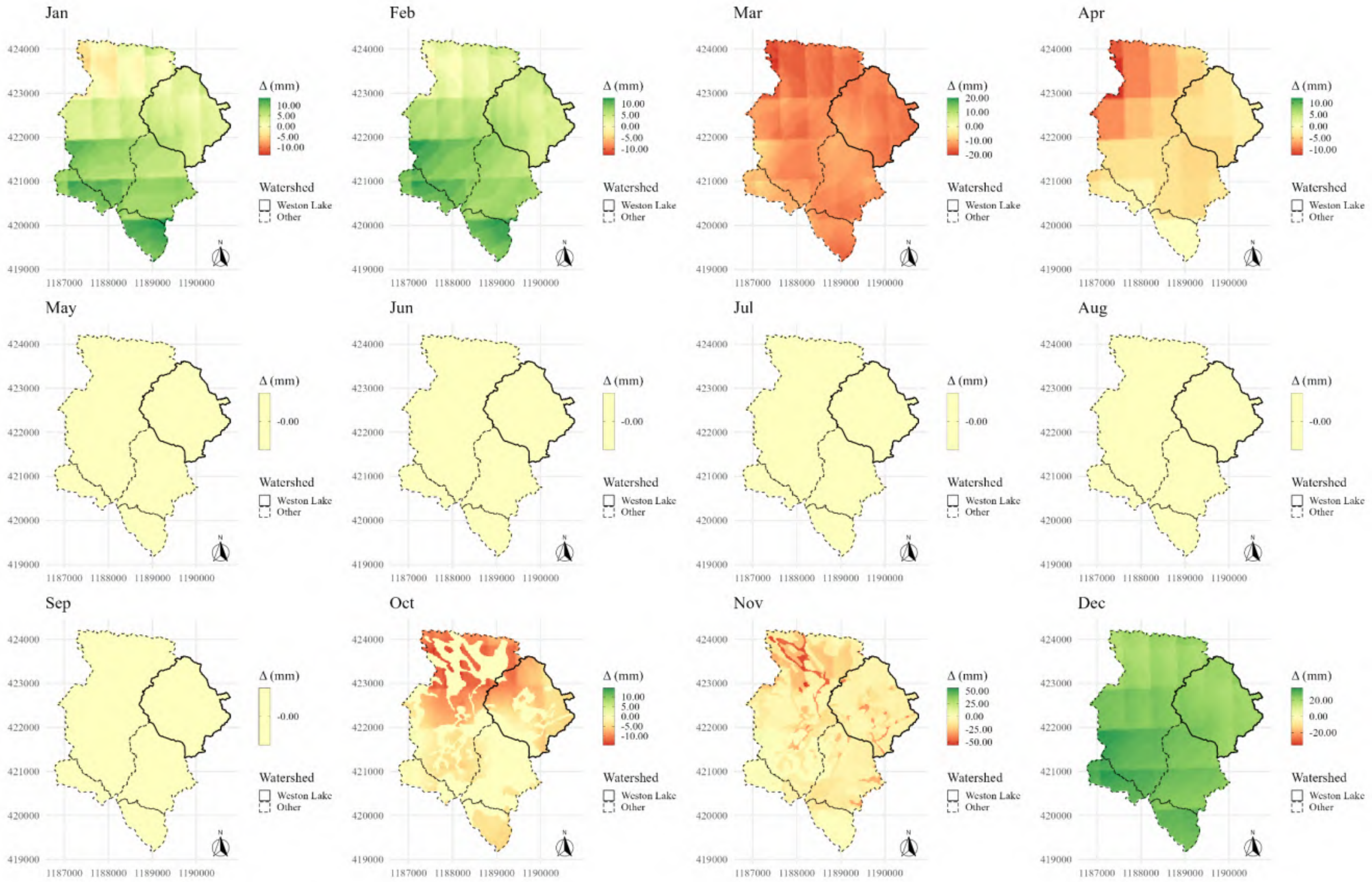

Figure 36: Monthly change in available water surplus between year 2070 and present normals, SSP 7.0

1.6.4 SSP 8.5

1.6.4.1 Average Temperature

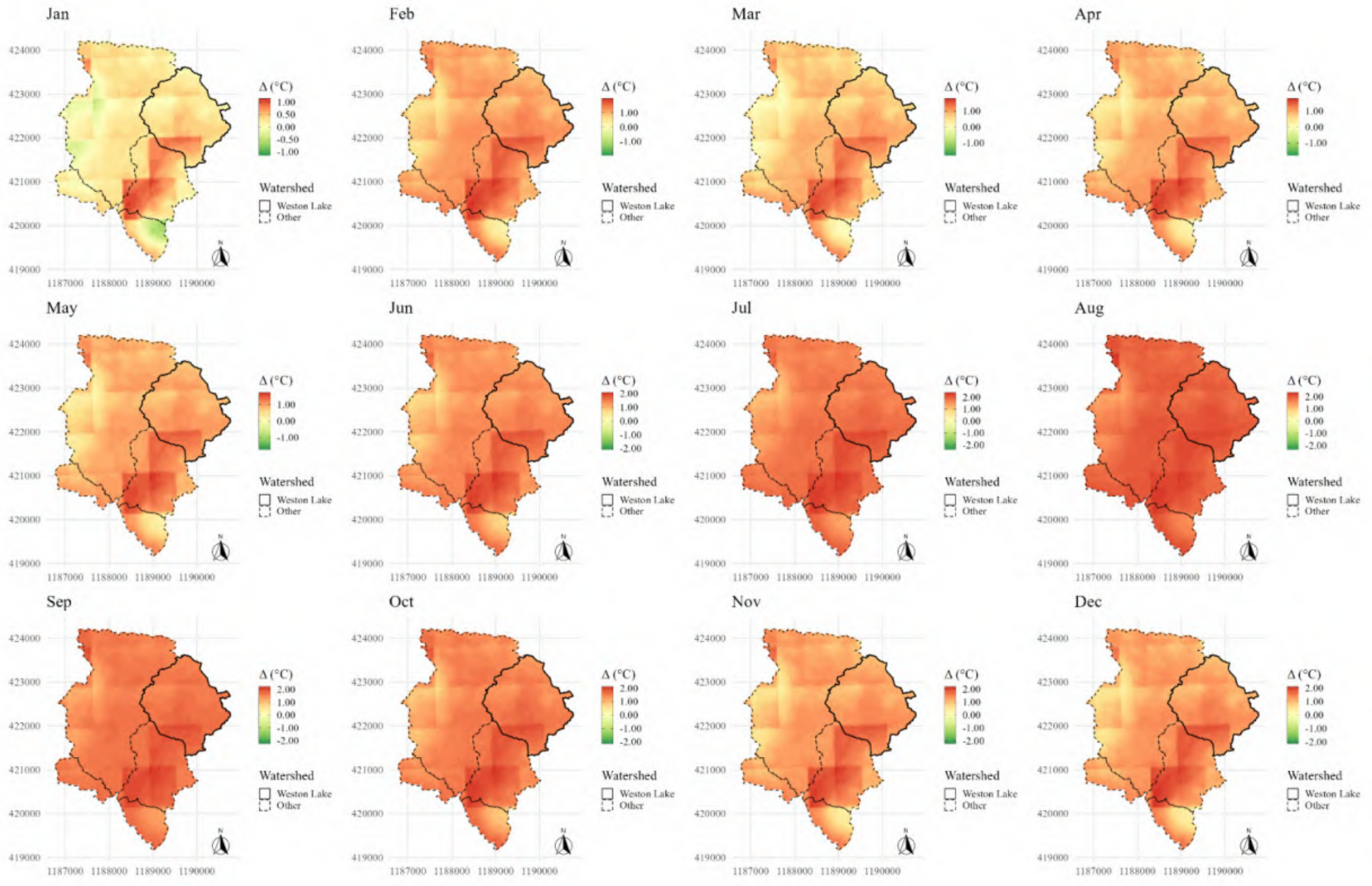

Figure 37: Monthly change in average temperature between year 2030 and present normals, SSP 8.5

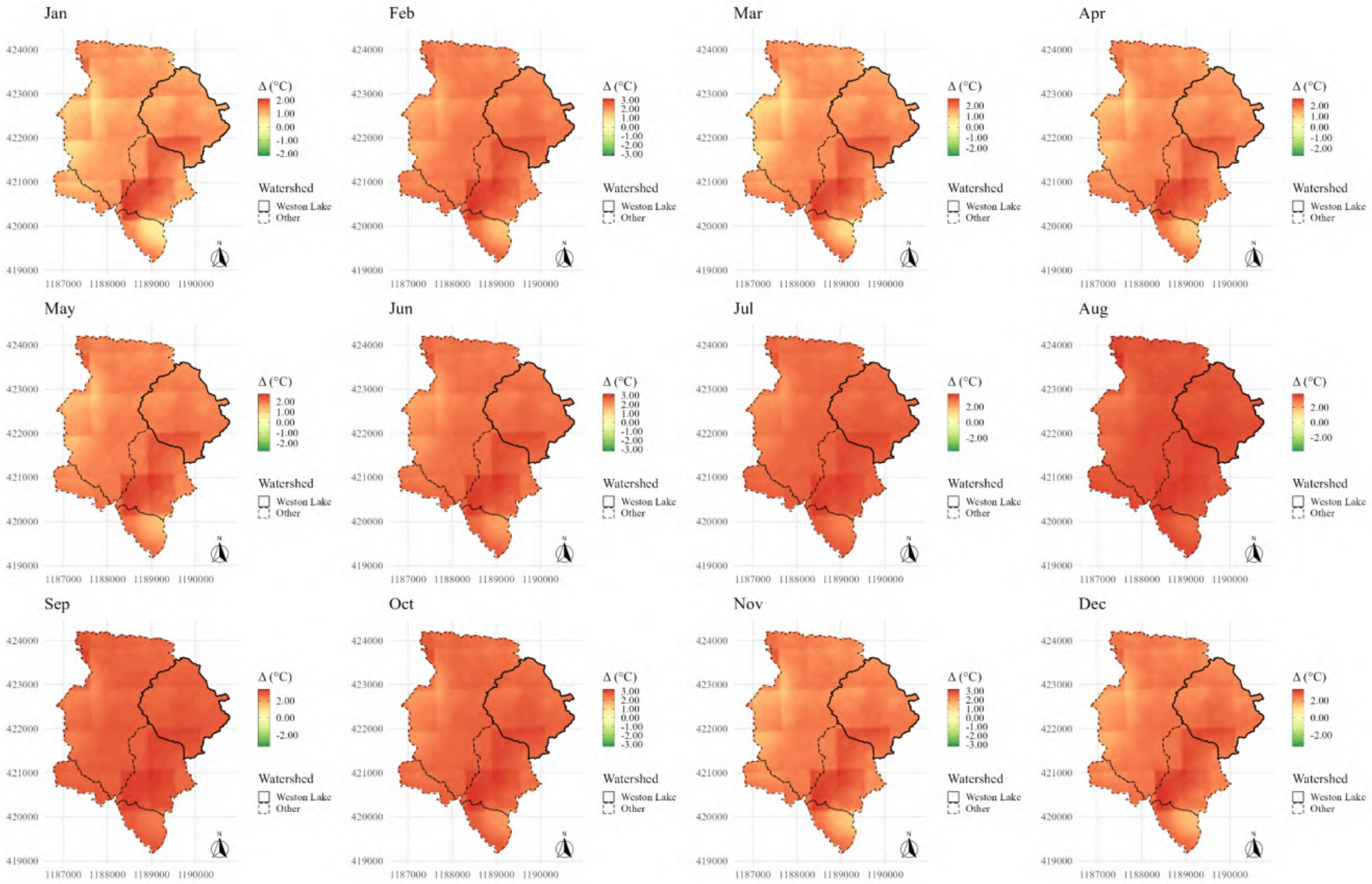

Figure 38: Monthly change in average temperature between year 2050 and present normals, SSP 8.5

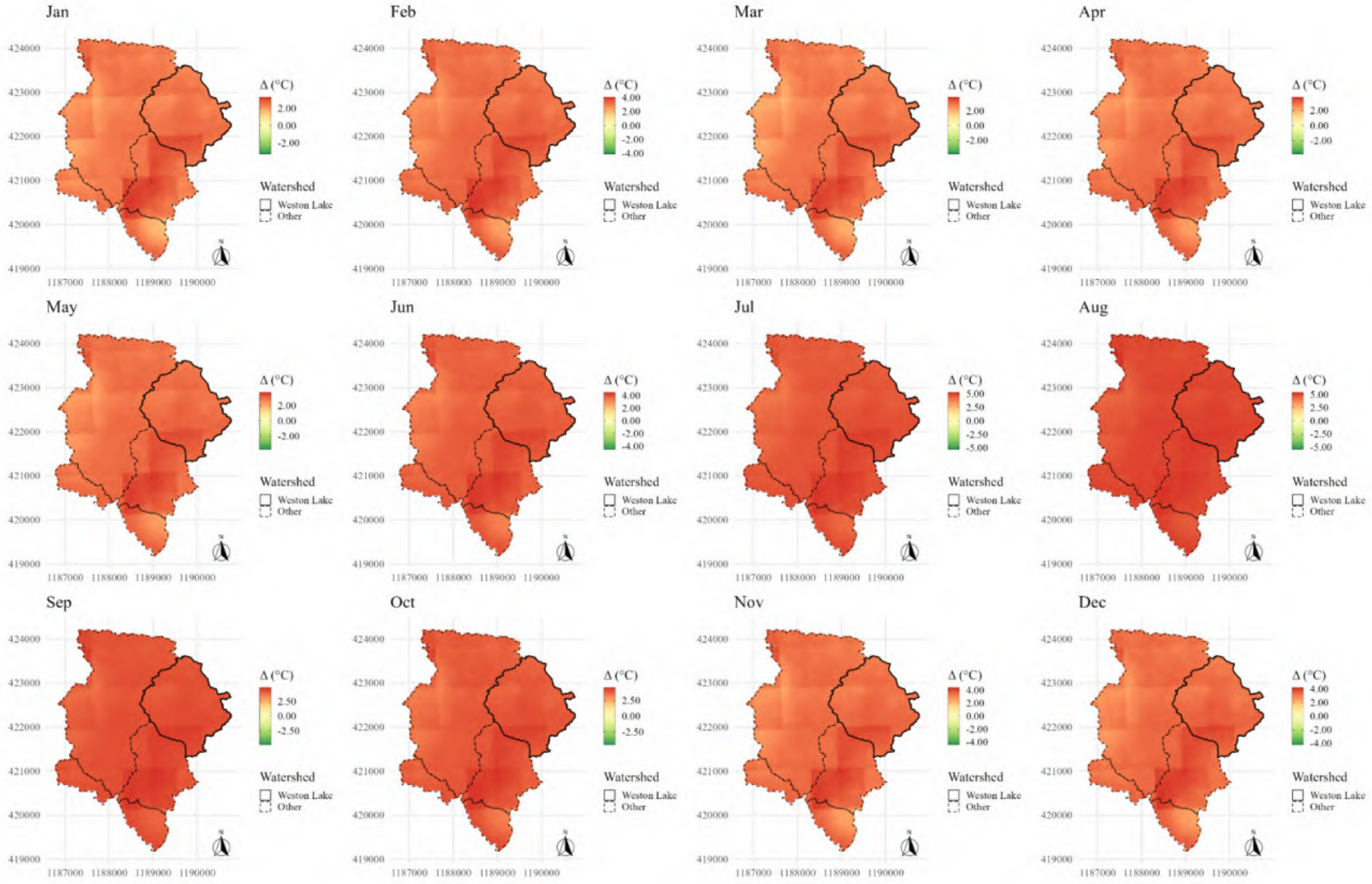

Figure 39: Monthly change in average temperature between year 2070 and present normals, SSP 8.5

1.6.4.2 *Precipitation*

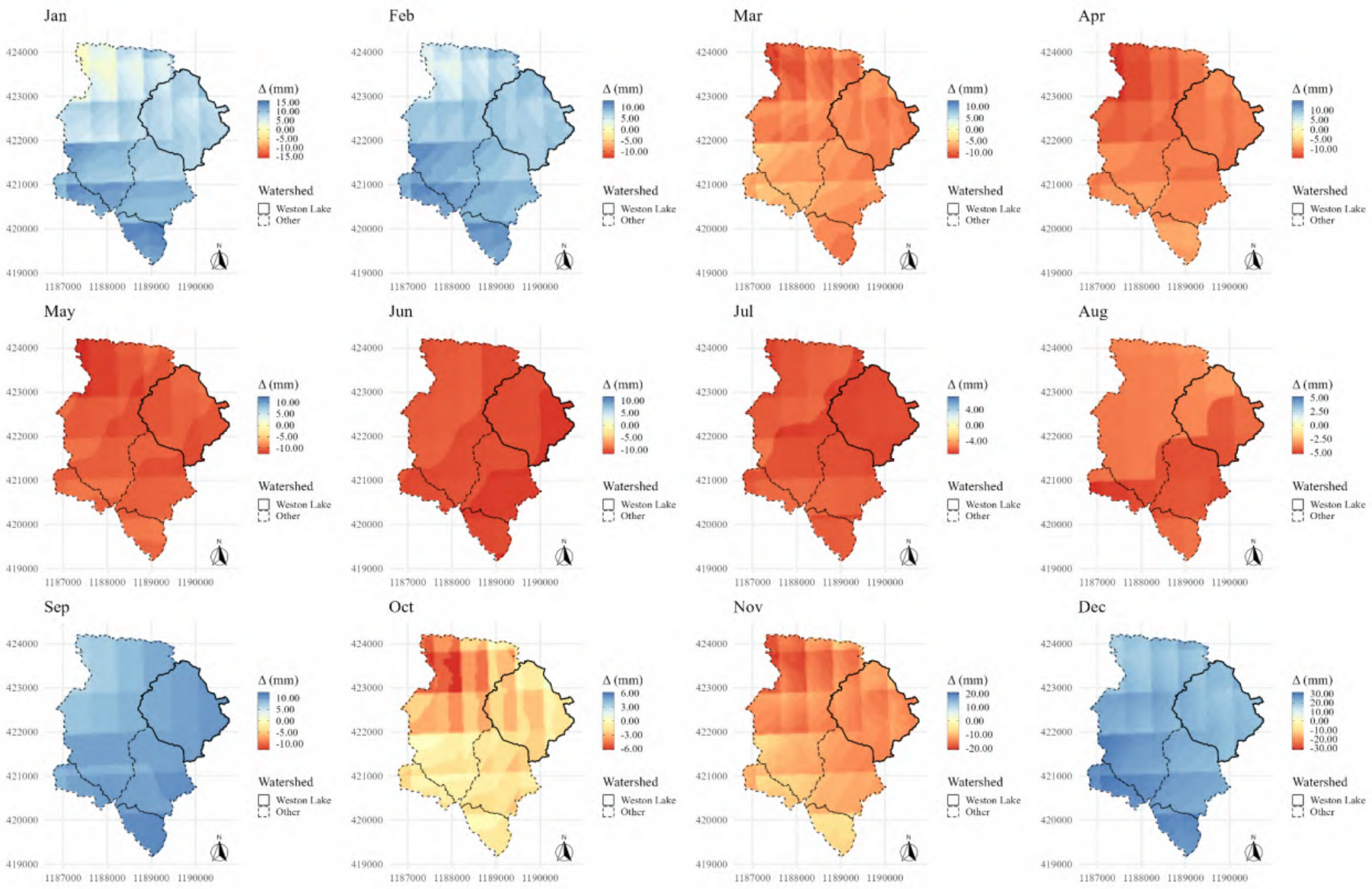

Figure 40: Monthly change in precipitation between year 2030 and present normals, SSP 8.5

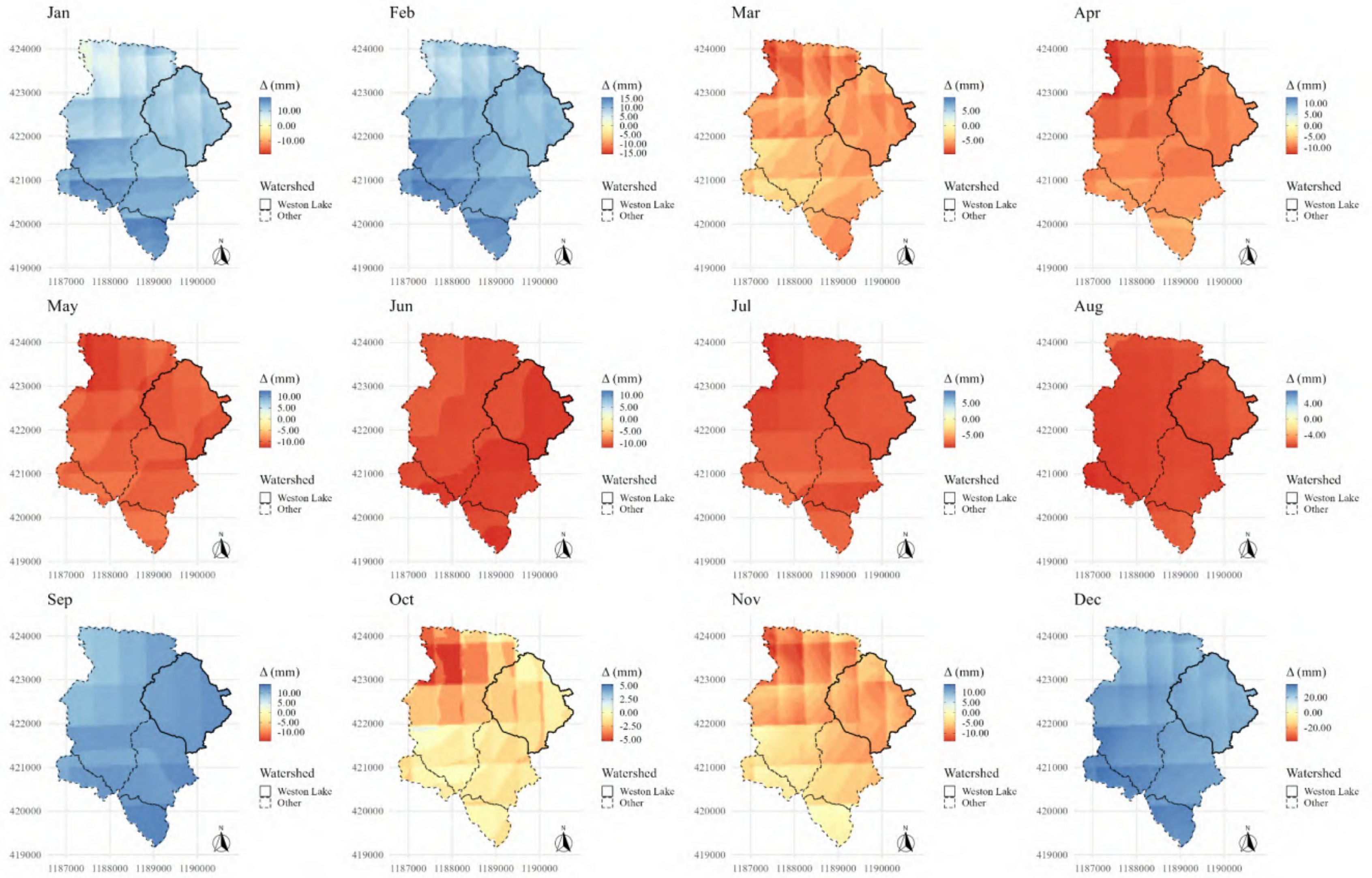

Figure 41: Monthly change in precipitation between year 2050 and present normals, SSP 8.5

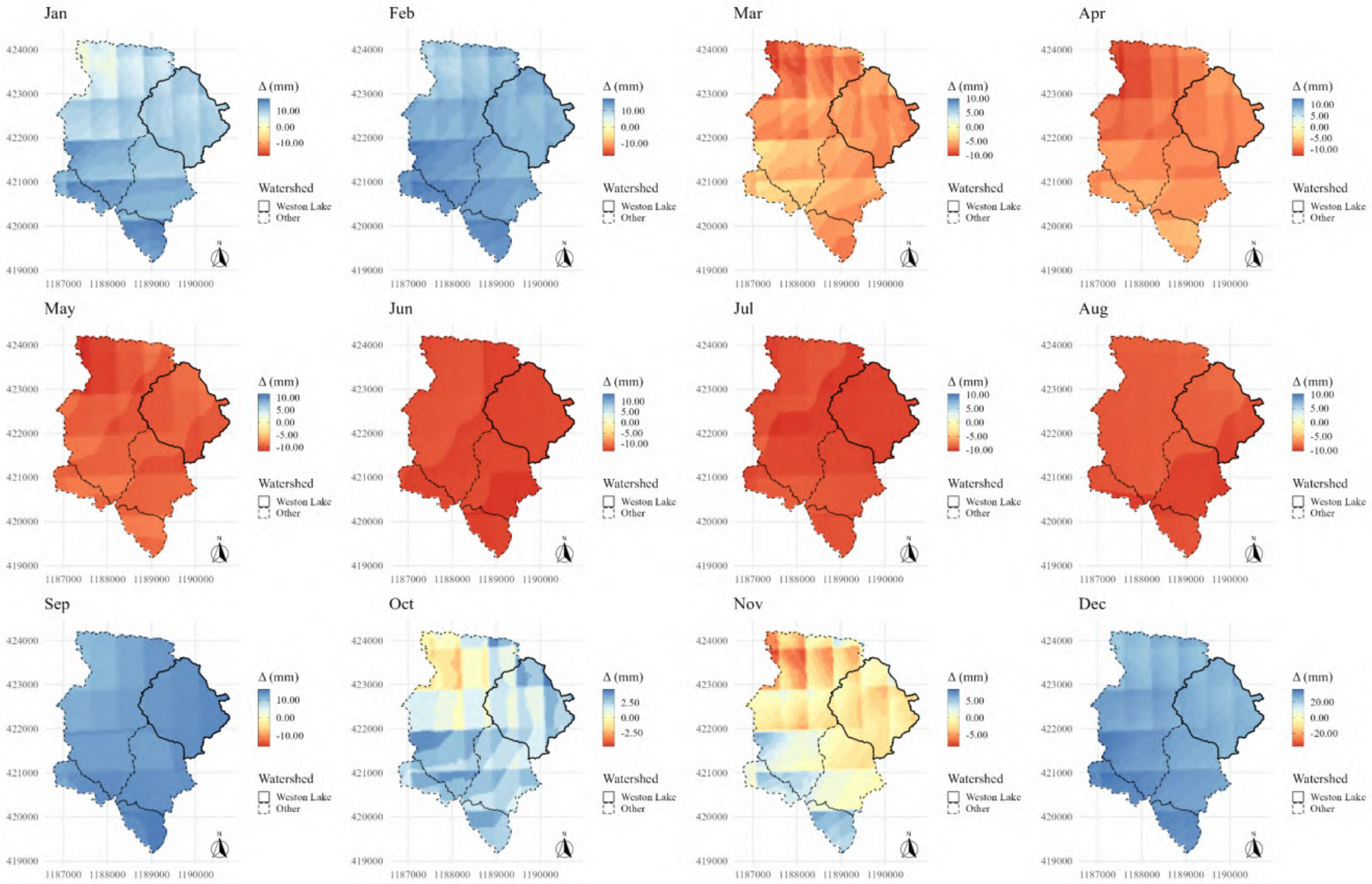

Figure 42: Monthly change in precipitation between year 2070 and present normals, SSP 8.5

1.6.4.3 *Solar Radiation*

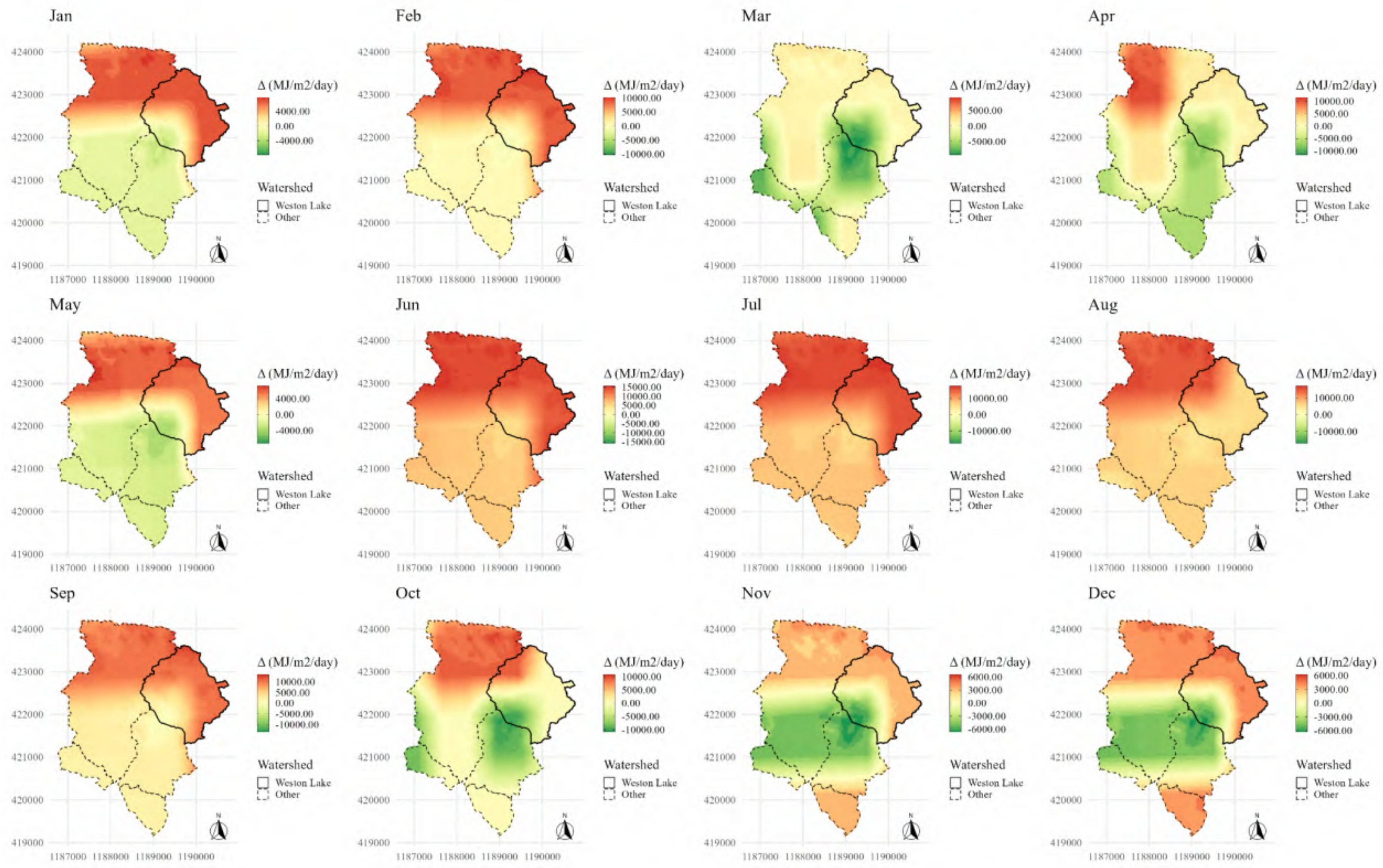

Figure 43: Monthly change in radiation between year 2030 and present normals, SSP 8.5

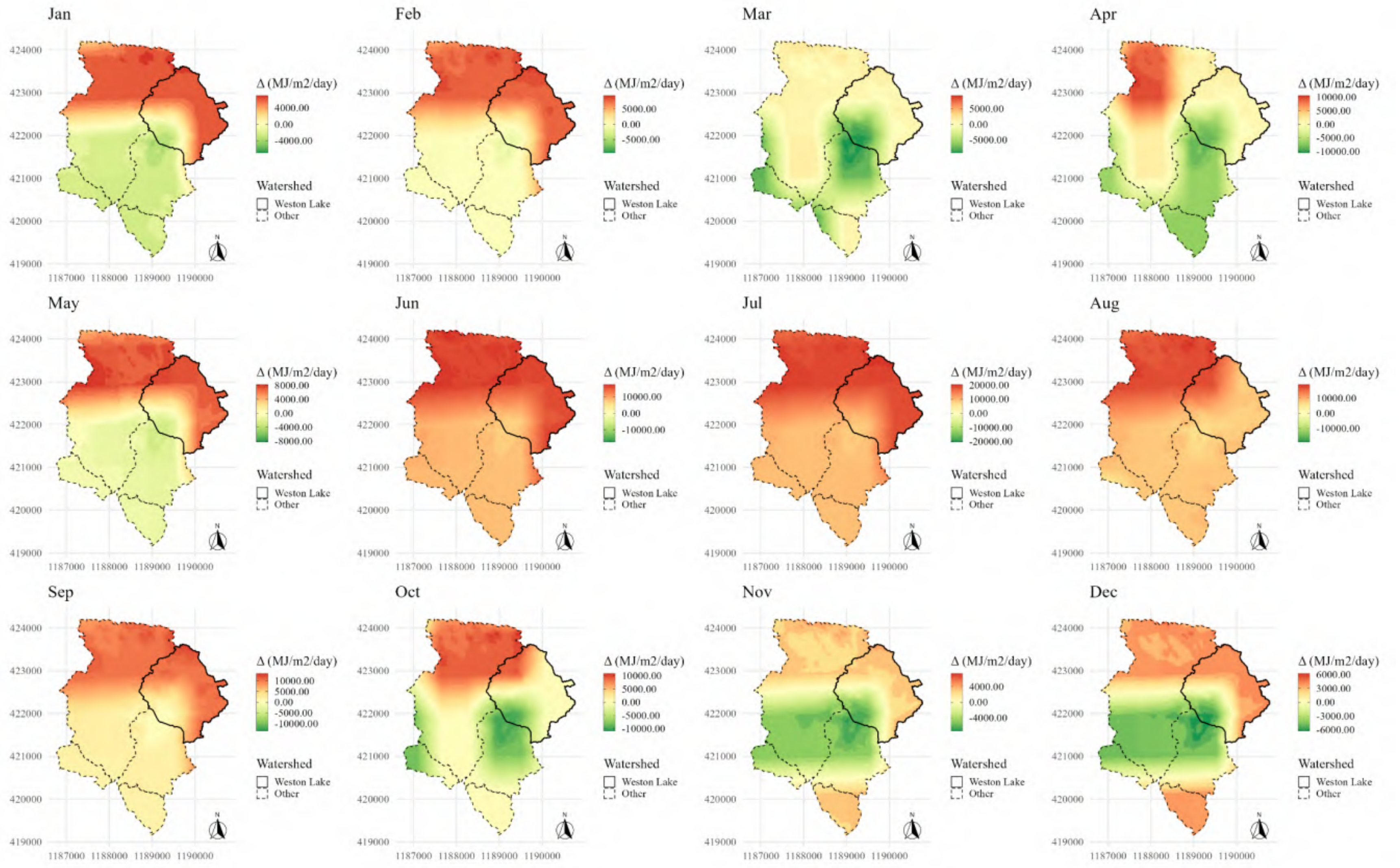

Figure 44: Monthly change in radiation between year 2050 and present normals, SSP 8.5

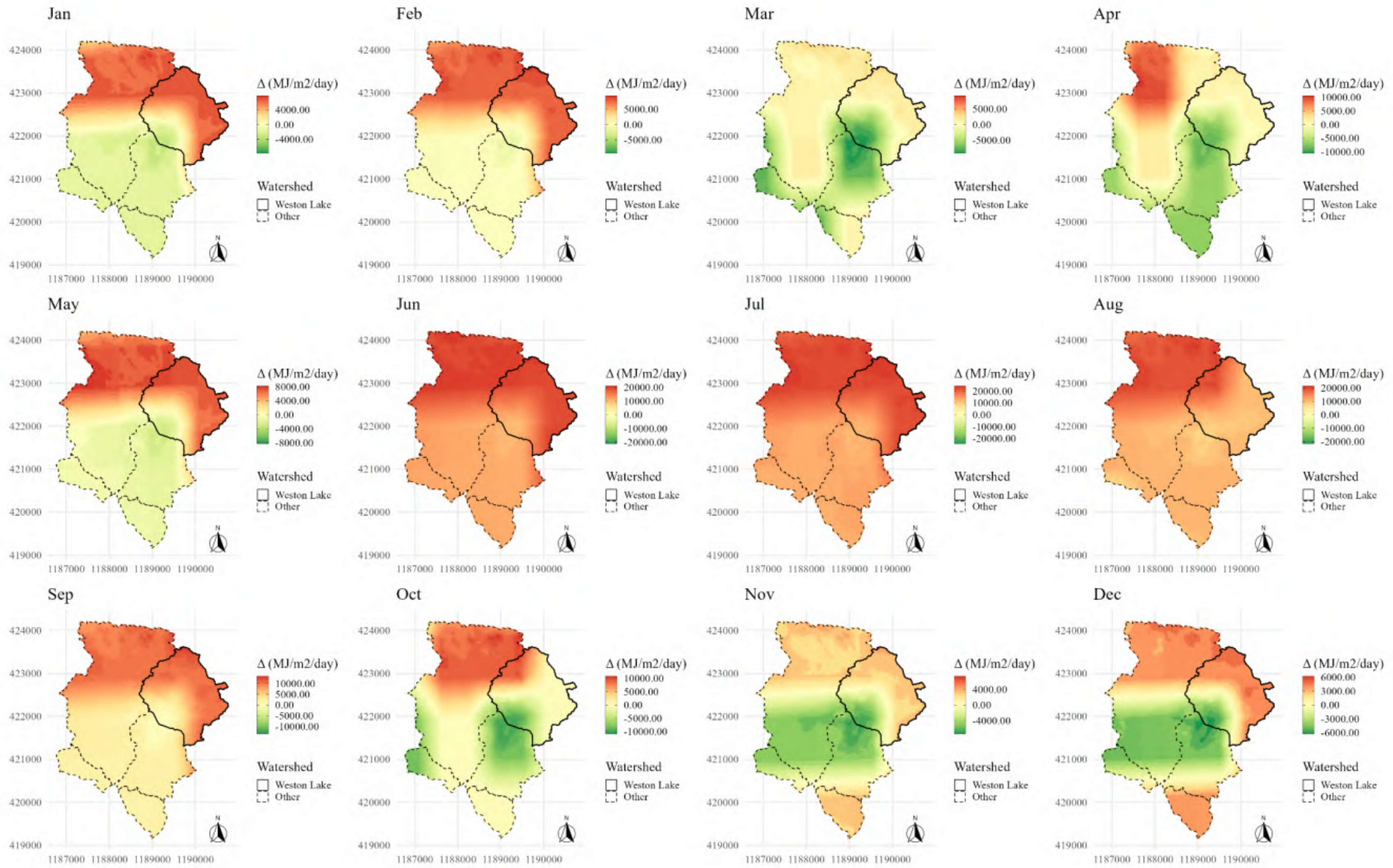

Figure 45: Monthly change in radiation between year 2070 and present normals, SSP 8.5

1.6.4.4 Available Moisture Surplus

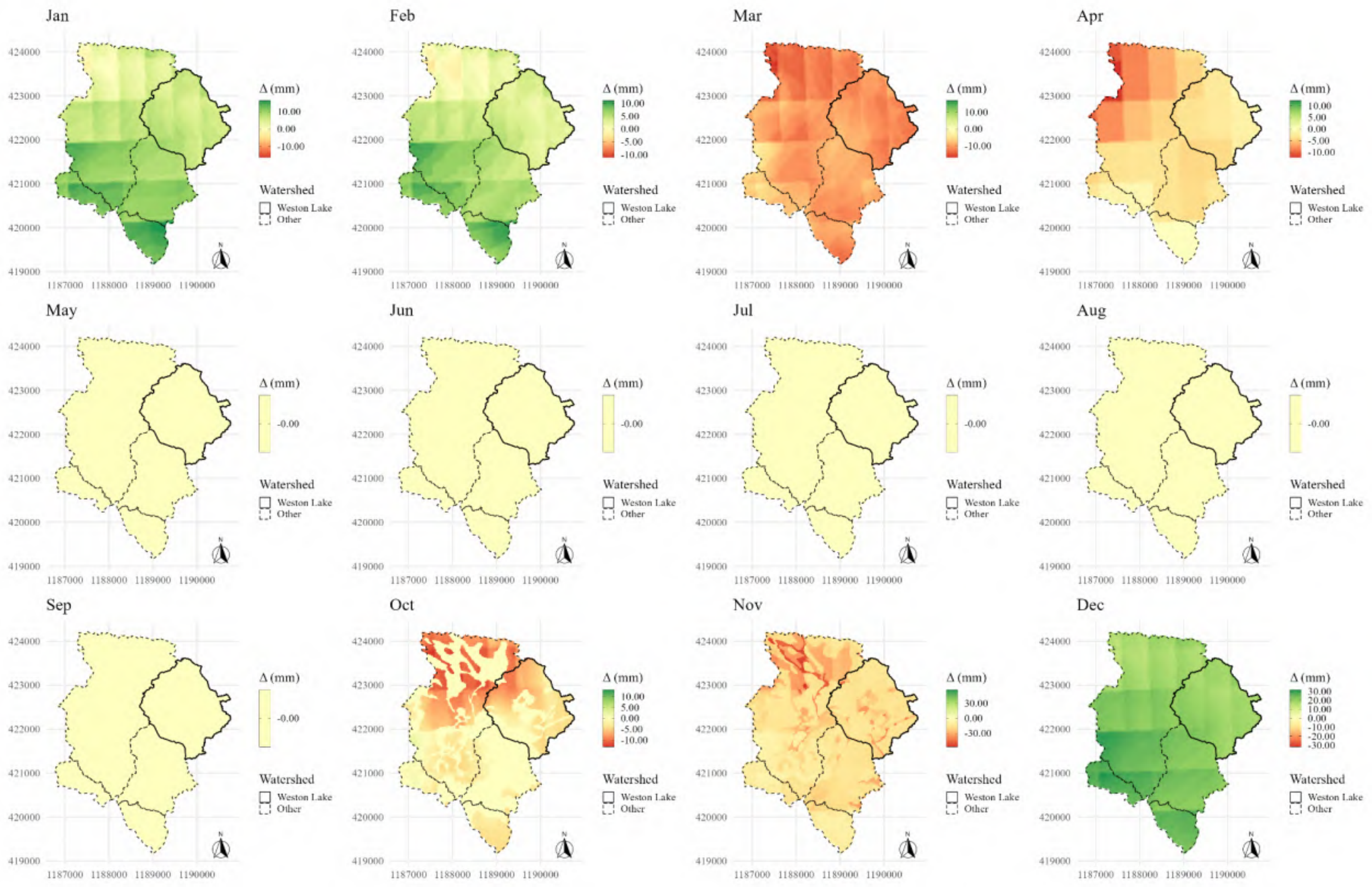

Figure 46: Monthly change in available moisture surplus between year 2030 and present normals, SSP 8.5

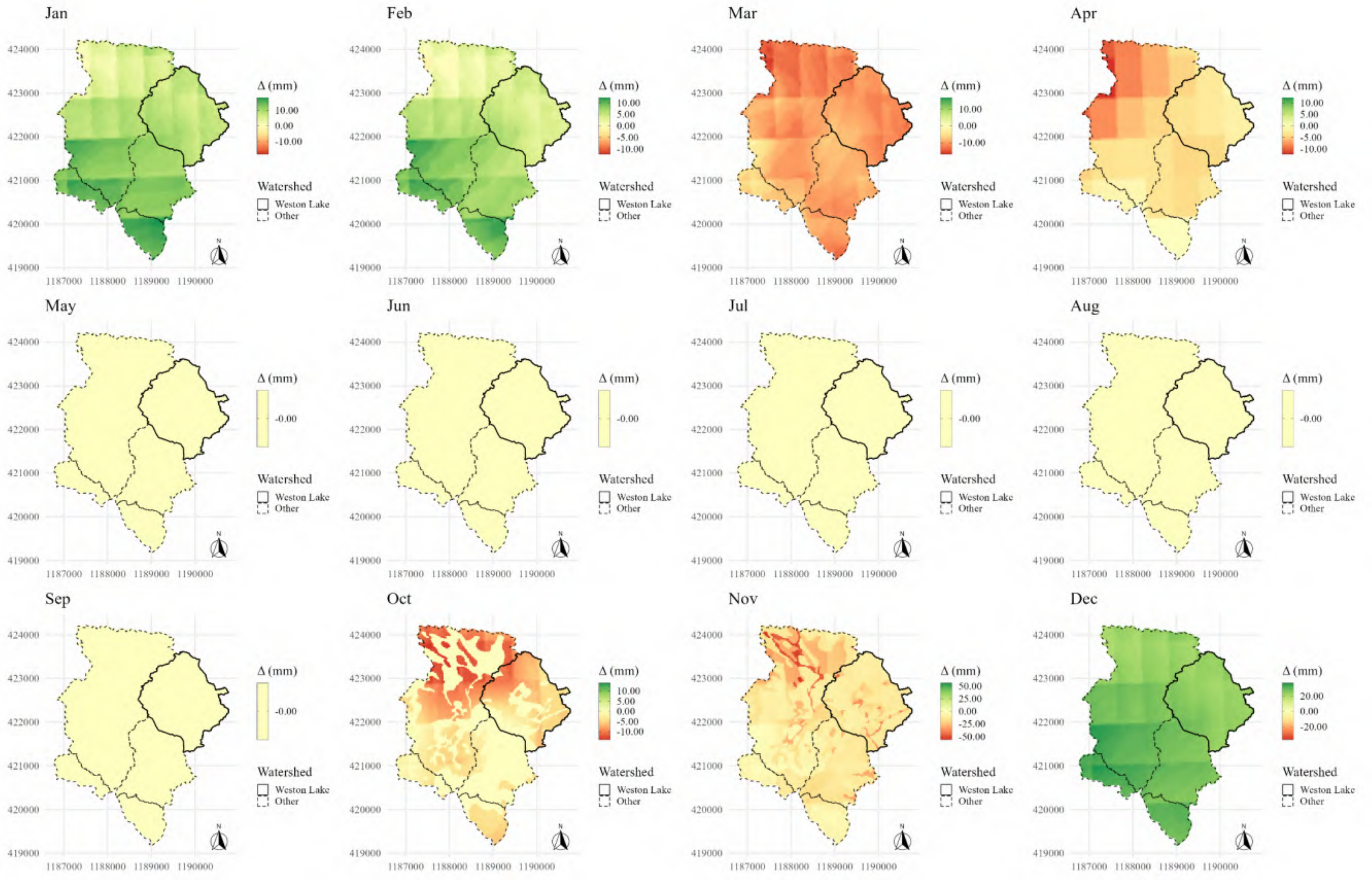

Figure 47: Monthly change in available moisture surplus between year 2050 and present normals, SSP 8.5

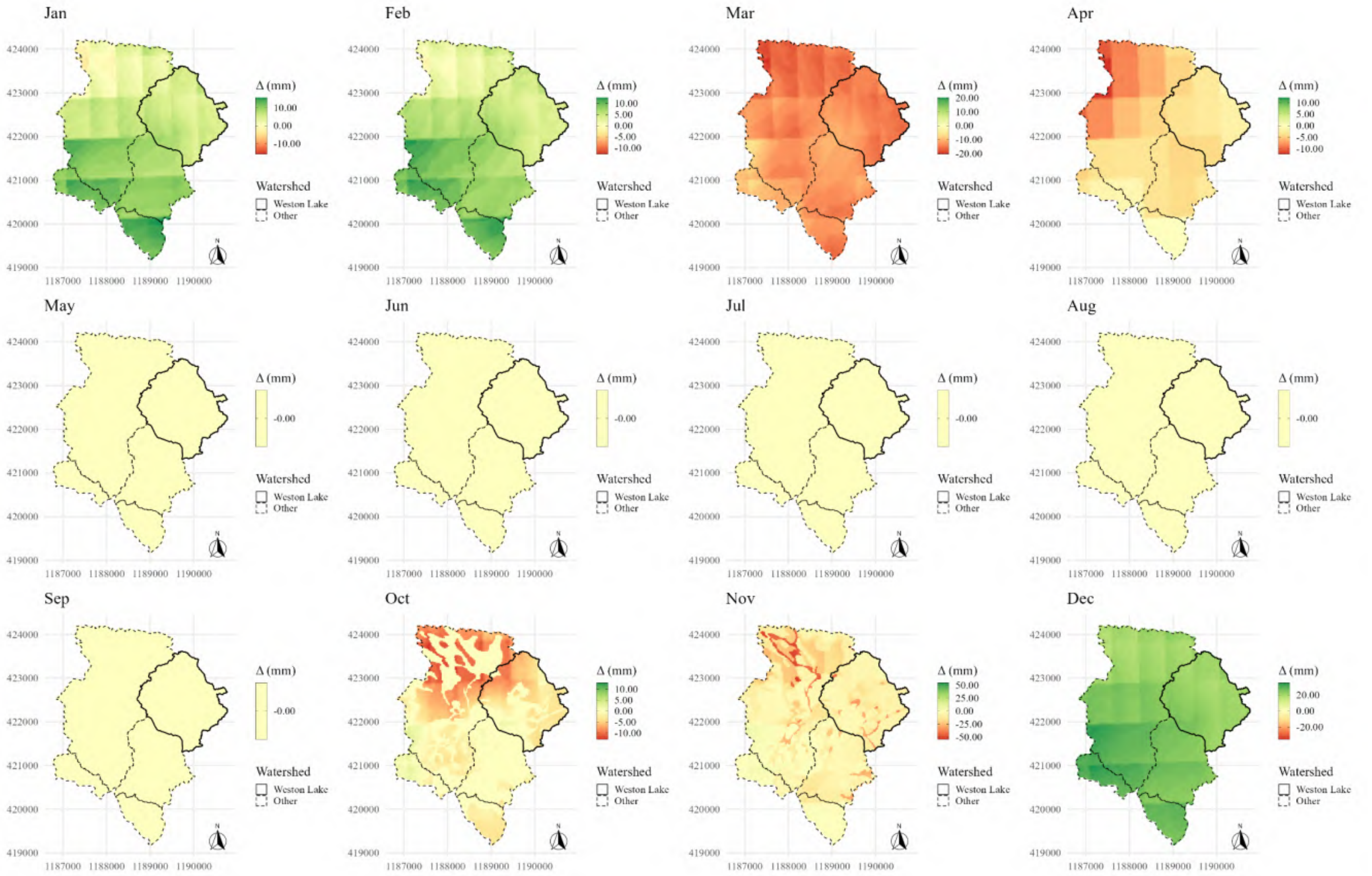

Figure 48: Monthly change in available moisture surplus between year 2070 and present normals, SSP 8.5

1.6.5 Lake Weston Watershed Summary Charts

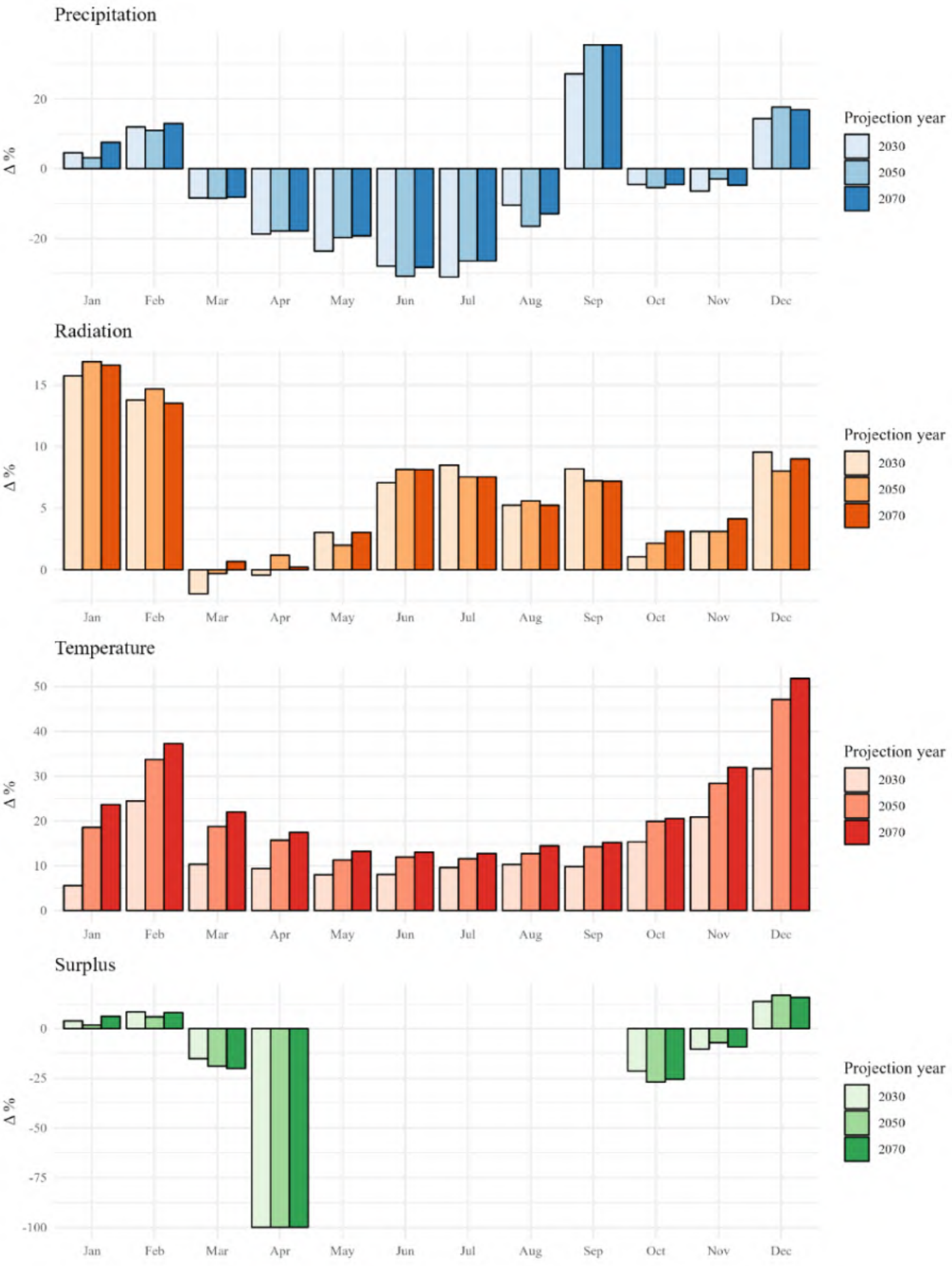

Figure 49: Percentage change relative to climate normal, summarized by month for the Lake Weston watershed, SSP 2.6

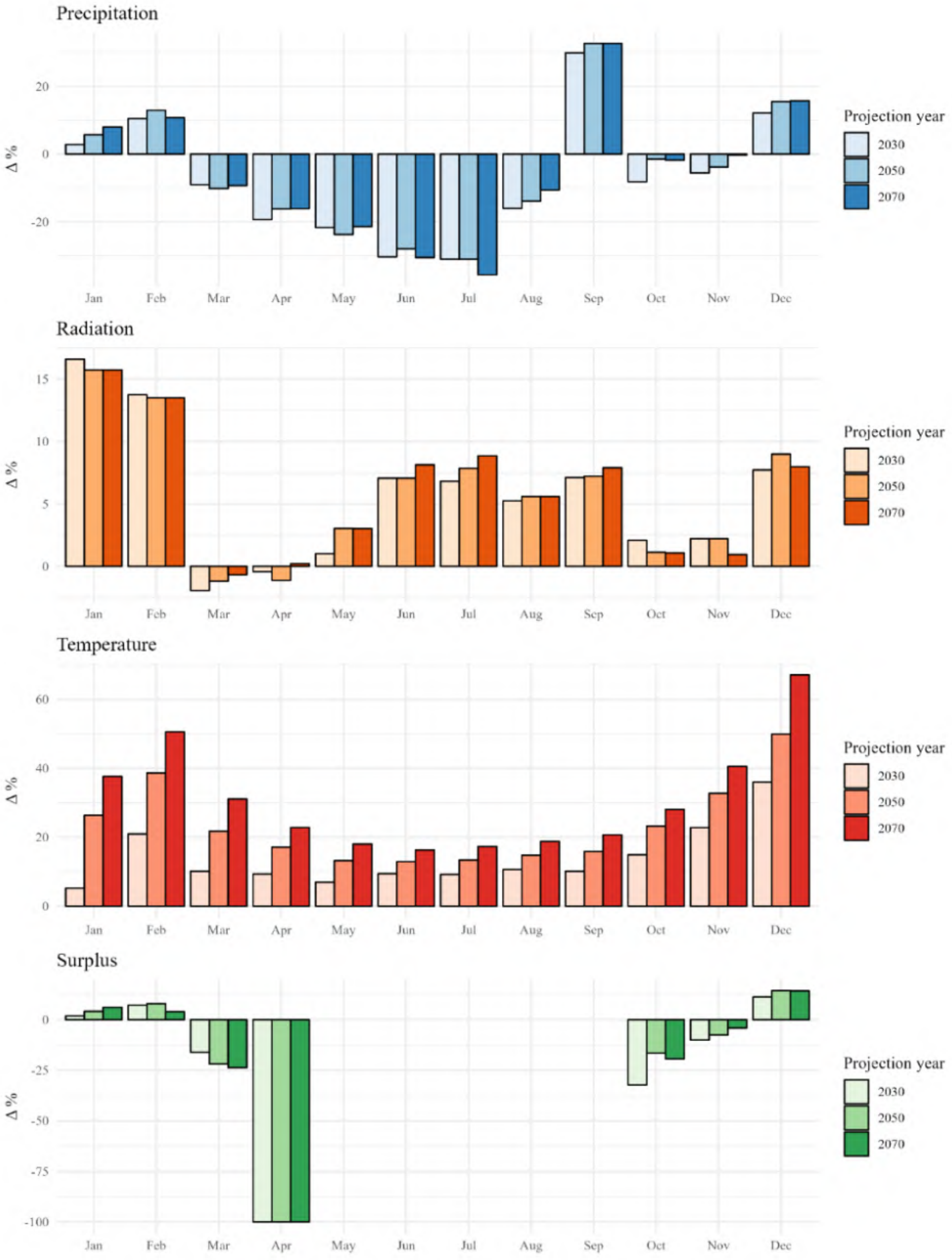

Figure 50: Percentage change relative to climate normal, summarized by month for the Lake Weston watershed, SSP 4.5

Figure 51: Percentage change relative to climate normal, summarized by month for the Lake Weston watershed, SSP 7.0

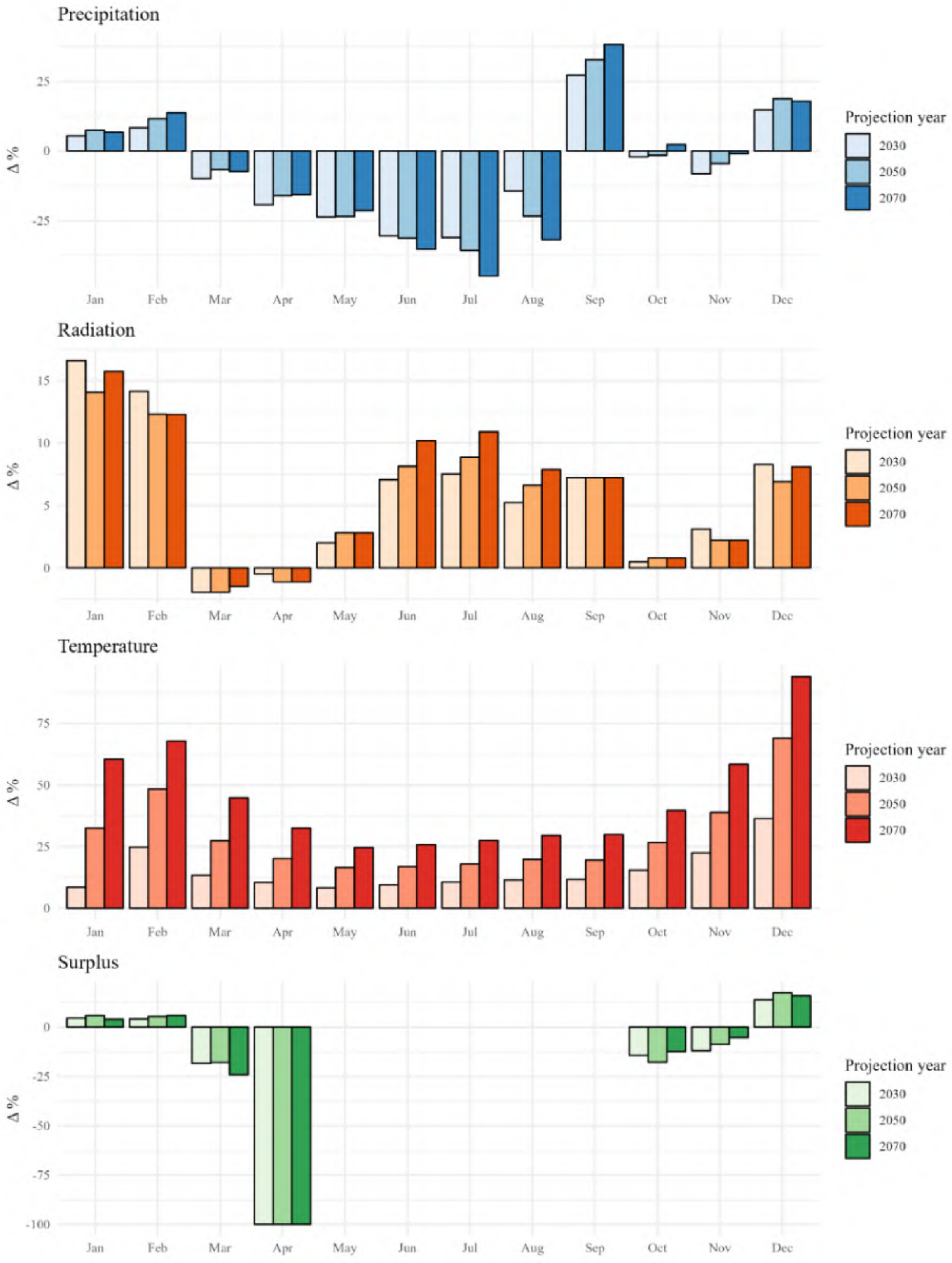

Figure 52: Percentage change relative to climate normal, summarized by month for the Lake Weston watershed, SSP 8.5

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APPENDIX 5

Water Rights Licences: Points of diversions (accessed February 2022)

APPENDIX 5: WATER RIGHTS LICENCES: POINTS OF DIVERSIONS

POD NUMBER	STATUS	FILE NUMBER	LICENCE NUMBER	PRIORITY DATE	PURPOSE	SOURCE	QUANTITY	UNIT	QUANTITY DESCRIPTION	PRIMARY LICENSE NAME
PD33584	Active	300787	C037411	2/22/1971	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33586	Active	250393	F041199	6/24/1963	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33592	Active	277651	F047416	2/29/1968	01A - Domestic	Lake Weston	4.54609	m3/day	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown	PRIVATE INDIVIDUAL NAME
PD33593	Active	277651	F047416	2/29/1968	01A - Domestic	Lake Weston	4.54609	m3/day	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown	PRIVATE INDIVIDUAL NAME
PD33592	Active	277651	F047416	2/29/1968	03B - Irrigation: Private	Lake Weston	5303.964	m3/year	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown	PRIVATE INDIVIDUAL NAME
PD33593	Active	277651	F047416	2/29/1968	03B - Irrigation: Private	Lake Weston	5303.964	m3/year	Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown	PRIVATE INDIVIDUAL NAME
PD33589	Active	290081	F045514	8/1/1969	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33585	Active	237701	F041041	7/27/1961	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33591	Active	305544	F047419	6/22/1971	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33589	Active	290081	F045514	8/1/1969	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD78964	Active	1002434	C120550	3/17/2005	02I12 - Misc Ind'l: Fire Protection	Lake Weston	0.08014	m3/sec	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33594	Active	346455	C120382	1/18/1946	00A - Waterworks: Local Provider	Lake Weston	58076.2998	m3/year	Total demand for purpose, one POD.	Capital Regional District (12780)

POD NUMBER	STATUS	FILE NUMBER	LICENCE NUMBER	PRIORITY DATE	PURPOSE	SOURCE	QUANTITY	UNIT	QUANTITY DESCRIPTION	PRIMARY LICENSE NAME
PD33597	Active	305338	C059393	4/26/1971	01A - Domestic	Garvey Spring	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33599	Active	285911	C035832	7/14/1969	01A - Domestic	Spencer Spring	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33594	Active	226409	C120292	7/2/1959	00A - Waterworks: Local Provider	Lake Weston	58076.2998	m3/year	Total demand for purpose, one POD.	Capital Regional District (12780)
PD33596	Active	226409	C120292	7/2/1959	00A - Waterworks: Local Provider	Lake Weston	0	m3/year		Capital Regional District (12780)
PD33599	Active	269377	F042626	5/31/1966	01A - Domestic	Spencer Spring	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33596	Active	226409	C120292	7/2/1959	08A - Stream Storage: Non-Power	Lake Weston	49339.2	m3/year	Total demand for purpose, one POD.	Capital Regional District (12780)
PD33594	Active	226409	C120292	7/2/1959	08A - Stream Storage: Non-Power	Lake Weston	0	m3/year		Capital Regional District (12780)
PD33595	Active	159262	F103906	1/25/1946	01A - Domestic	Lake Weston	4.54609	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33595	Active	231119	F103907	5/31/1960	03B - Irrigation: Private	Lake Weston	10114.536	m3/year	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33583	Active	310389	C040375	6/27/1972	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33587	Active	305153	F047418	4/21/1971	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33590	Active	267198	F040731	2/10/1966	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33599	Active	285910	F047417	7/14/1969	01A - Domestic	Spencer Spring	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33589	Active	290081	F045514	8/1/1969	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD70355	Active	1001808	C109036	11/24/1994	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME
PD33589	Active	285885	F045515	7/8/1969	01A - Domestic	Lake Weston	2.27305	m3/day	Total demand for purpose, one POD.	PRIVATE INDIVIDUAL NAME

APPENDIX 6

Glossary

APPENDIX 6: GLOSSARY

Term	Definition
Aquifer	An underground layer of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand) from which groundwater can be extracted using a water well.
Aquitard	An aquitard is a zone in the ground or bedrock that restricts the flow of groundwater from one aquifer to another, or from the surface to the subsurface. Aquitards are usually comprised of silt, clay, or non-porous (aka solid) rock of low hydraulic conductivity.
Bedrock Aquifer	In solid rock, groundwater is stored in the fractures, joints, bedding planes and cavities of the rock mass. Despite the potential for having voids, a rock can only act as an aquifer if those voids are saturated and connected via conduits such as fractures and faults.
Elevation	Elevation is given in meters above sea level. Ground elevations were projected/interpolated from a 1m Digital Elevation Model (DEM) provided by the Island Trust (ITC) for the current project.
Evaporation	Evaporation is the process by which water is transferred from surface water bodies (i.e.: lakes and rivers) to the atmosphere. The rate of evaporation is driven by air temperature, water temperature, wind speed and solar radiation. For this study, monthly average air temperature and maximum daylight hours per month have been used as indices for lake evaporation.
Evapotranspiration	Evapotranspiration is the process by which water is transferred from soil moisture to the atmosphere through either transpiration by plants or direct evaporation from leaves, standing

Term	Definition
	water on the ground or surface water bodies. The rate of evapotranspiration is driven by air temperature, wind speed, solar radiation and plant species or land cover.
Groundwater	Groundwater is water found in the soil or rock below the land surface where the pores and openings are filled entirely with water. The upper boundary of the groundwater zone is called the water table which is equivalent to the water level in shallow well.
Groundwater Recharge	Groundwater recharge is the process by which water flows from shallow soil moisture storage into groundwater in the subsoil.
Groundwater Storage	Groundwater storage is the capacity of subsoil (i.e.: below the root zone) to store water. This water is available to flow into surface water bodies through groundwater seepage (i.e.: springs or seeps).
Licenced Withdrawal Limit	The Licenced Withdrawal Limit is the maximum volume of water permitted to be withdrawn by water licence holders from surface water sources.
Precipitation	Precipitation is the total volume of rainfall and snowfall over a given time period. Precipitation is recorded as a depth, the total volume of precipitation falling across the watershed over a given time period is then calculated by multiplying the depth of precipitation by the watershed area.

Term	Definition
Soil Moisture Capacity And Soil Moisture Storage	The capacity of soil within the root zone of plants and trees to store water. The soil moisture capacity defines the total volume of water that can be stored in the soil while storage moisture storage is the amount of water in soil moisture at any given time. The soil moisture can transferred back to atmosphere via evapotranspiration and can pass into groundwater storage through groundwater recharge. When soil moisture storage is at the maximum soil moisture capacity all excess precipitation is surface runoff.
Surface Water	Surface water is water that can be seen on land and is usually freshwater. It includes lakes, rivers, streams, creeks, ponds, and wetlands. Surface waters are most often at least partially fed by groundwater.
Surface Water Runoff	Surface Water Runoff is the water available to flow into surface water bodies across the land surface and through shallow horizontal flow through soils (known as interflow) over a given time period. It is the excess water available from precipitation after all other hydrological processes are accounted for including evapotranspiration and replenishment of soil moisture storage. A portion of surface water runoff includes Direct Runoff which includes precipitation that runs off directly to surface water bodies. This is usually represented by a percentage of precipitation in a given period and is typically based on an estimate of the impervious area within a watershed.
Unconfined Aquifer	Where no aquitards overlie the aquifer, the aquifer is said to be "unconfined" and is vulnerable to impacts from human activities at the land surface, particularly if the water table is shallow.
Water Balance	The water balance is based on the law of conservation of mass in a closed system such that the volume of water entering the system must be equal to the amount of water leaving the system plus change of volume of water stored within the system. The water balance for this study considers precipitation as the only input to the closed system with lake outflow,

Term	Definition
	deep aquifer loss, evaporation and transpiration as outputs. Storage in the system includes lake storage, soil moisture storage and groundwater storage.
Water Budget	Comparison of the amount of surface water available in the watershed over-time (supply) and the amount of water required for use over time (demand). When the volume of water for demand is greater than the volume of water available in supply over a given time period, for this study a monthly time period is used, then the difference must be provided by storage.
Water Surplus	This term refers to a combination of surface water runoff and groundwater recharge which are the surplus or remaining water budget components following evapotranspiration.
Watershed	A watershed is the area of land that, due to its topography, collects water from precipitation and drains into a receiving surface water body (a river, a lake, a foreshore). Every piece of land is part of a watershed.
Well	A well is an excavation or structure created in the ground by digging, driving, or drilling to access liquid resources, usually water.

Appendix 2

Water Sustainability Project: Land Use Management for Watershed Protection *Weston Lake Water Availability and Climate Change Impact Assessment* - Charter v.1.1

Salt Spring Island Local Trust Committee

Date: March 23, 2021

Purpose: *The purpose of this project and associated charter is to define the Salt Spring Island Local Trust Committee's role in the commission of a study to quantify the volume of water in Weston Lake available for human use and the impacts that climate change is anticipated to have on that volume.*

Background: *Weston Lake on Salt Spring Island provides potable water to the Fulford Water System in Fulford Village. The Salt Spring Island Official Community Plan identifies the Island's villages as areas of potential residential and commercial growth. Islands Trust and the Capital Regional District, which manages the Fulford Water System, want to better understand the volume of water available for human use from Weston Lake and the impacts that climate change may have on that water availability.*

This project was identified in the 2020/21 work plan of the Salt Spring Island Watershed Protection Alliance (SSIWPA) and the Capital Regional District electoral area director has requested up to $30,000 from the Salt Spring Island Local Trust Committee to fund such a study. At its January 19, 2021 meeting the LTC endorsed this funding request using accumulated funds from its annual special property tax requisition to fund the coordination of freshwater policy on Salt Spring Island.

Objectives

- *A sustainable potential yield and storage analysis for Weston Lake that accounts for:*
    - *License allocations;*
    - *environmental flow needs; and*
    - *Climate change impacts*

In Scope

- *Provide up to $30,000 in funding;*
- *Assist CRD staff to:*
    - *Draft a cost-sharing agreement with CRD*
    - *Draft a Request for Proposals for qualified consultant to undertake the study;*
    - *Draft a Terms of Reference for the study;*
- *Provide relevant data to qualified consultant;*
- *Provide completed study to the LTC with implications for land use planning and options for next steps; and*
- *Manage communications related to release of project deliverables*

Out of Scope

- *Procurement process management;*
- *Contract management;*

Workplan Overview

Deliverable/Milestone	**Date**
Project charter endorsement	March 23, 2021
RFP distributed	Spring 2021
Qualified consultant selected	Spring 2021
Draft study provided for staff review	August 1, 2021
Final study released to LTC and general public	September 1, 2021

Project Team

Dale Green, CRD	Project Manager
Jason Youmans, IT	Project Liaison
William Shulba, IT	Technical Advisor
Barb Dashwood, IT	GIS Tech
Shannon Cowan, SSIWPA	Project Assistant

Budget

Budget Sources:

- Unspent special property tax requisition funds
- 2017 SSIWPA Constituency Grant

Fiscal	**Item**	**Cost**
2021/22	Weston Lake Water Availability and Climate Change Impact Study	$30,000
2021/22	Total	$30,000

Water Sustainability Project: Land Use Management for Watershed Protection
***Weston Lake Water Availability and Climate Change Impact Assessment* - Charter** v.1.1

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