AQUIFER MAPPING STUDY UPDATE – RE-EVALUATION OF THE GROUNDWATER USE SCENARIOS

Submitted To:

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EXECUTIVE SUMMARY

The Town of Gibsons (the Town) obtains all its potable water from a high-quality artesian aquifer situated below the Town and extending beyond the Town boundary into the Sunshine Coast Regional District (SCRD). The aquifer has been mapped as a single aquifer across several watersheds and is referred to as Aquifer 560 by the province. The watersheds include Charman Creek, Chaster Creek, Gibson Creek and Soames Creek, which defines the Study area for the project. The headwaters for all four watersheds originate along the south facing slope of Mount Elphinstone at an elevation of greater than 1,100 metres above sea level and all drain into the Strait of Georgia.

Reviewing the extensive drilling, groundwater monitoring, and aquifer mapping completed on behalf of the Town over the last decade, it is more likely that Aquifer 560 is a composite of three aquifer lobes. The aquifer material was deposited as coarse fluvial materials in drainage channels founded on bedrock which extend from the top of the present-day watersheds to the ocean. Glaciers inundated the region some 20,000 to 30,000 years ago depositing a thick glacial till blanket which formed the low permeability cap over the aquifer(s) which was subsequently covered with marine deposits as glaciers retreated.

The channel deposits appear to have formed a central basin beneath the Town which is considered by Waterline to be the "Gibsons Aquifer" lobe of Aquifer 560. This portion of Aquifer 560 is bounded by bedrock highs extending from Gospel Rock at Gibsons Harbour to Upper Gibsons on the west side, and along the west side of Gibson Creek east of the Town. Similar fluvial channel deposits appear to have formed beneath the Chaster Creek Valley to the west and the Soames Creek Valley to the east of the Town. Waterline has referred to these buried channel deposits as the Elphinstone and Soames Aquifer Lobes of Aquifer 560.

Aquifer 560 is a valued component of all watersheds in the study area is particularly important to both the Town and the SCRD. The Town has designated the Gibsons Aquifer portion of Aquifer 560 as natural or Eco-asset which requires careful management and maintenance as with any other valued municipal infrastructure needed for proper functioning of the Town. This approach provides an administrative responsibility to protect the aquifer from potential impacts that could influence the groundwater quality and deliverability of water supply. Groundwater monitoring and aquifer protection objectives were developed and summarized in the the Town's Official Community Plan (OCP). This approach has provided valuable operational information to guide the Town in expanding the groundwater supply to accommodate population growth for the Town.

Although there appears to be a common recharge area to Aquifer 560 at higher elevations, the lower portion of the aquifer lobes appear to be hydraulically disconnected from each other. This is an important finding as the Town and SCRD well fields located along the coast can be managed independently but the common recharge area must be managed jointly to ensure sustainability of the resource in each of the three well fields completed along the coast (Gibsons, Chaster, and Soames).

The Town applied for existing and new use license under the Water Sustainability Act (WSA) to the Ministry of Forests, Lands and Natural Resources (FLNR). Approval of the existing use license (# 500940) was confirmed in 2018 which allows for the diversion of 739,530 cubic metres per year (m^3/yr) from Aquifer 560. The new use WSA application (File # 20008793) requesting the groundwater diversion and use of 276,265 m3/yr remains under review by FLNR. Based on an estimated per capita water use amount of 0.523 cubic metres per day (m^3/c/d), a total groundwater volume of 1,015,795 m^3/yr or 2,783 cubic metres per day (m^3/d) is required to supply a population of 5,322 people projected out to 2026. Predictive modeling results indicate that the aquifer and existing wells and infrastructure can easily meet this water supply demand.

Several pumping scenarios were evaluated to determine the long-term sustainability of the Gibsons Aquifer to supply the Town out to 2050. Predictive modeling results indicate that the Gibsons Aquifer can likely also meet future demand as the population grows to approximately 10,000 people at full buildout. The groundwater modelling estimates also considered climate change impacts that could affect aquifer recharge and sea level rise that would increase the potential for saltwater intrusion. However, to meet the future projected demand at full buildout using the current groundwater demand of 0.404 m^3/c/d, the Town will need to make a new use application(s) under the WSA for an additional 1,257 m^3/d (458,805 m^3/yr) from the existing well field, beyond the existing approval and new use application currently under review.

Based on the results of the aquifer mapping study update, the following recommendations are provided for consideration by the Town:

- Continue to engage in discussions with the SCRD, FLNR and community stakeholders regarding aquifer monitoring and watershed management activities. This will be particularly important for the protection of the shared recharge areas located outside the Town of Gibsons in the SCRD. Further investigations should be completed in the upper reaches of the Chaster Creek and Gibsons Creek watersheds to assess the recharge characteristics of Aquifer 560 and its component aquifer lobes. This should be a joint effort between the Town and SCRD and include the installation of shallow and deep monitoring wells, a climate station, and infiltration studies.
- The Town should share the results of the current study with FLNR for use in updating previous aquifer mapping programs completed on behalf of the province.
- The Town should assess the artesian overflow from TW1 and TW4 that is currently being diverted to the stormwater outflow when those wells are not pumping. As discussed in 2013, some risks exist due to pressurization of the well casings if well heads are sealed but options should be assessed to make beneficial use of the water.
- The Town should install two shallow monitoring wells near TW3 in Lower Gibsons, to help characterize the competency of the confining unit and the Capilano aquifer.

TABLE OF CONTENTS

PAGE

LIST OF TABLES (IN-TEXT)

PAGE

LIST OF FIGURES (FIGURES SECTION)

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 Background

The Town of Gibsons (the Town) is a coastal community located on along the Strait of Georgia within the Sunshine Coast Regional District (Figure 1). The Town obtains all its potable water from a high-quality artesian aquifer situated below the Town and extending beyond the Town boundary, mapped as Aquifer 560 (ENV, 2022). It is located beneath several watersheds which drain into Georgia Strait, including Charman Creek, Chaster Creek, Gibson Creek and Soames Creek, which defines the Study area for the project (Figure 2). The headwaters for all four watersheds originate along the south facing slope of Mount Elphinstone at an elevation of greater than 1,100 metres above sea level (masl).

Hydrogeological conditions for Aquifer 560 were investigated by Waterline Resources Inc. (Waterline) as part of the 2013 Aquifer Mapping Study (Waterline, 2013). The study provided a comprehensive assessment and mapping of the aquifer, interactions with surface water (recharge conditions), and long-term groundwater yield projections. The 2013 study was foundational in protecting and managing groundwater and ensuring water security for future generations.

As Aquifer 560 is a valued component of the watershed, the Town has designated the aquifer as a natural asset which requires careful management and maintenance as with any other valued infrastructure. This approach provides an administrative responsibility to protect the aquifer from potential impacts that could influence the long-term sustainable yield and water supply for the Town. Groundwater monitoring and aquifer protection objectives were developed and summarized in the the Town's Official Community Plan (OCP; SMART, 2015). The OCP includes the following management and aquifer protection strategies:

- Development Permit Area (DPA) guidelines for protection of the aquifer recharge zone (well capture zone),
- Water regulation bylaws for maintaining the aquifer/aquitard system integrity from land development that could reach the aquitard or otherwise pollute the aquifer, and
- Water use and conservation policies for preventing overuse, excessive drawdown, and possible saltwater intrusion. This includes robust monitoring of the groundwater quality and quantity to establish the on-going health and sustainability of groundwater resources.

With ongoing support by Waterline, the Town has collected, and reviewed groundwater and surface water related data as part of these groundwater protection objectives since 2009. This long-term groundwater monitoring program has provided valuable operational information to guide the Town in expanding the groundwater monitoring network and has provided support for expanding the groundwater supply to accommodate population growth. Both initiatives have been completed in compliance with the provincial standards listed in the Water Sustainability Act (WSA; Government of BC, 2022).

The Town applied for existing and new use license under the Water Sustainability Act (WSA) to the Ministry of Forests, Lands and Natural Resources (FLNR). Approval of the existing use license (Conditional License # 500940) was obtained in 2018 which allows for the diversion of 739,530 cubic metres per year (m^3/yr.) of groundwater from Aquifer 560. The new use WSA application (File # 20008793) requesting the groundwater diversion and use of 276,265 m^3/yr. remains under review by FLNR. Based on an estimated per capita water use amount of 0.523 cubic metres per day (m^3/c/d), a total groundwater volume of 1,015,795 m^3/yr. or 2,783 cubic metres per day (m^3/d) is required to supply a population of 5,322 people projected out to 2026.

1.2 Objective and Scope of Work

The Town has requested Waterline to update the numerical groundwater model developed as part of the 2013 Aquifer Mapping Study. The objective of the current study is to integrate all new hydrogeological data collected by the Town since 2013, update the geological and numerical model, and assess the long-term sustainable supply from the aquifer to see if it can meet the projected demand in 2026 and beyond.

To meet these objectives, Waterline performed the following scope of work:

- Upgraded the 3-dimensional (3D) Leapfrog works model completed as part of the 2013 Aquifer Mapping Study with new geological information, groundwater level data, and topography,
- Integrated the new Leapfrog works model into the existing MODFLOW numerical groundwater flow model, confirming the model extent and recharge areas,
- Recalibrated the MODFLOW model for transient conditions using long-term monitoring data collected by the Town as part of the annual groundwater monitoring program,
- Based on the fully calibrated MODFLOW model, simulated predictive groundwater use scenarios (steady state and transient) using various pumping rates for the Town's water supply wells (TWs), capturing climate affected conditions, and
- Summarized the findings, providing comment on what groundwater related objectives have been accomplished and what is still required for protecting and maintaining the groundwater supply.

1.3 Previous Investigations

Data sources used for the 2013 Aquifer Mapping Study included creek mapping, surficial geology mapping, geophysical data collection and hydrogeological information from historical borehole logs. Since 2013, additional hydrogeological data has been collected, compiled and review by Waterline for the Study area, including:

- Publicly available drilling logs from the Ministry of Environment (ENV) groundwater wells database (ENV, 2022), including the 2020 updated description of Aquifer 560 completed by Advisian (2020),

- Development Permit Area 9 (DPA 9) hydrogeological and geotechnical data collected by proponents of new developments within the Town boundary,
- The Town's annual groundwater and surface water monitoring program results, including groundwater elevation data and groundwater use data from all operating TWs (Waterline, 2021) and the Provincial Groundwater Observation Well (OW) # 460,
- The Town's water supply well drilling and testing results for newly installed TW5 and TW6 (Waterline, 2019), and
- The Sunshine Coast Regional District (SCRD) Phase 2 Groundwater Investigations results for the Church Road, Mahan Road, and Maryanne West Park locations, completed by Associated Engineering Ltd. (AE, 2019) and Kalwij Water Dynamics Inc. (2021).

2.0 METHODOLOGY

2.1 Conceptual Site Model Update

A 3-dimensional (3D) conceptual model of the Study area was developed by Waterline for the 2013 Aquifer Mapping Study using the Leapfrog Works software *Version 1.8.0*. In 2021. This model was upgraded to the Leapfrog works software *Version 2021.1*, reusing the same geological data and stratigraphic relationships developed during the original mapping study. New geological information from numerous subsurface investigations completed since 2013, were integrated into the revised Leapfrog model. In total, including the 2013 Aquifer Mapping Study data, the upgraded Leapfrog works model contains 423 data locations (Figure 3), subdivided into three location types:

- 133 well locations, including TWs, monitoring wells, test pits, piles, excavations, and any other temporary boreholes,
- 15 resistivity profile locations interpreted from transient electromagnetic traces, and
- 275 field measurements taken within the Study area, completed at upper elevations of Mt Elphinstone, along the shoreline and from Chaster, Charman and Gibson Creeks.

Using this new data, changes were made to the stratigraphic sequences (thickness and distribution), which were reviewed, and validated through an iterative process. The geological descriptions from individual data locations were kept consistent with the 2013 model, standardized into the following stratigraphically recognized units. From oldest to youngest or deeper to shallower are:

1. The Bedrock (sedimentary and intrusive rocks),
2. The pre-Vashon formation (Aquifer 560),
3. The Vashon till formation (Aquitard 560), and
4. The Capilano formation (Unconfined Aquifer/Aquitard System).

Groundwater level data from georeferenced locations in the Study area were also reviewed by Waterline. Groundwater level contours were generated in the Leapfrog works software.

2.2 Numerical Groundwater Flow Model (MODFLOW) Update

As part of the 2013 study, Visual MODFLOW version 2011.1 was used to simulated groundwater flow in the aquifer. The model provides a graphical user interface for the finite difference code MODFLOW and operates using USGS MODFLOW-NWT engine and the WHS Solver Package available in Visual MODFLOW software (McDonald and Harbaugh, 1983).

Waterline updated the original MODFLOW model (Waterline, 2013) calibrated to current groundwater conditions, and then ran simulations to re-evaluate the groundwater flow regime of Aquifer 560 near the Town. As the aquifer conceptual model has not significantly changed, only minor adjustments were needed to provide an improved calibration result based on performance monitoring data from the Town's monitoring well network, collected over the past decade. A detailed summary of the model construction and calibration is provided in Appendix A.

3.0 RESULTS AND DISCUSSION

3.1 Geological Conditions

The Study area is characterized by bedrock outcropping near surface along the upper reaches of Mount Elphinstone, above 300-400 masl. A thin veneer (<1 m) of surficial sediments and or colluvium is covering the bedrock surface. A thicker sequence of surficial sediments was deposited below this elevation by glaciation, as the ice sheets expanded/retreated and by interglacial process and postglacial processes which include modern-day fluvial deposition operating during the last 30,000 years.

Although the stratigraphic sequence is the same, the formation thicknesses and distribution were updated using the additional data collected since the 2013 Study was completed. Isopach thickness maps of the different formations exported from the Leapfrog model are shown on Figure 4. A brief description is provided below:

- ***The Bedrock*** is mapped as sedimentary and or igneous rock across the Study area. Bedrock is the lowermost geological unit in the model. The bedrock surface structure is important as it was a controlling factor in sediment deposition. Bedrock surfaces in the Study area are irregular, reshaped by the various glacial and interglacial events. In Lower Gibsons, the "Bluff" and "Gospel Rock", are prominent bedrock features outcropping at the ground surface.
- ***The pre-Vashon formation*** is composed of sand and gravel, with trace silt. These sediments were deposited by marine (lower pre-Vashon) and fluvial (upper pre-Vashon) processes prior to the last glaciation. The upper sediments are composed of coarse sand and gravels and forms Aquifer 560. The formation extends deep beneath the Town in Upper Gibsons to Lower Gibsons and beyond the shoreline below Gibsons Harbour (Figure 2). The unit has a mean thickness of 28 m in the Study area, with the thickest sequence (106 m) mapped along a northwest to southeast trend beneath the Town. In the areas of Elphinstone and Soames, the pre-Vashon deposits are also locally extensive which appear to have formed as separate buried channels, deposited within the respective smaller

watershed. Although the unit is mapped as a continuous deposit, the bedrock topography suggests that the unit thins and may pinch out near bedrock highs resulting in hydraulically disconnected lobes of Aquifer 560.

- ***The Vashon till formation*** is mapped as a glacial till unit and forms a lower permeability or confining unit over Aquifer 560 which gives rise to artesian conditions observed in the Lower TWs and the Soames wells. Sediments consists of hard-packed silt, clay, sand, gravel, and stones. An erosional surface defines the contact with the underlying pre-Vashon sediments which is difficult to distinguish in driller's logs and drill cuttings. The main distinguishing feature is in the difficulty drilling and observed perforation rates. The Vashon till is regionally extensive and has a mean thickness of 39 m. The Vashon till is thickest across Upper Gibsons and thins significantly in Lower Gibsons where the TWs are located.
- ***The Capilano formation*** is a marine deposit that was laid down as glaciers retreated and flooded coastal areas along Georgia Strait to about 200 masl. The Capilano deposits are composed of stony till-like clay (Lower Capilano) with coarser-grained sand and gravel forming the Upper Capilano and the unconfined aquifer which blankets the Study area. The Capilano formation has a mean thickness of 18 m but varies locally from <1 m in Lower Gibsons and up to 51 m in Upper Gibsons.

3.2 Groundwater Flow Conditions

Waterline was able to update the 3D model of pre-Vashon formation using Leapfrog. The formation encompasses the extent of the mapped Aquifer 560 boundaries (Advisian, 2020). Although the pre-Vashon formation extends across the entire width of the Study area, bedrock ridges in the subsurface appear to separate the aquifer, creating channel and/or lobes of thicker permeable sediments. The three main channels are as follows:

- The Elphinstone Aquifer buried channel, which is situated entirely within the Lower Chaster Creek Watershed,
- The Gibsons Aquifer buried channel which extends from the Upper Chaster Creek Watershed, and incorporates Charman Creek, and the west side of Gibson Creek, and
- The Soames Aquifer buried channel which is largely located beneath the Soames Creek Watershed and extends into the Upper Gibson Creek Watershed.

Beneath the Town, the Gibsons Aquifer appears to be thickest due to deep erosion of the bedrock surface by glaciers. Figure 5 shows a northwest to southeast slice (A – A') through the Study area and the thickest part of the Gibsons Aquifer. Figures 6 and 7 show cross-sections southwest to northeast through Upper Gibsons (B – B') and Lower Gibsons (C – C'), respectively.

Groundwater levels in the Gibsons Aquifer range rom 38.4 masl (118.3 metres below ground level; mbgl) near the base on Mt. Elphinstone to 12.3 masl (2.4 metres above ground level, flowing artesian) in Lower Gibsons. Figure 8 presents a piezometric surface contour map of the groundwater elevation across the mapped pre-Vashon formation (Aquifer 560). As expected, groundwater flow is gravity driven and generally follows the drainage of the overlying creeks from the highest elevation towards the Strait of Georgia. It should be noted that the Gibsons Aquifer is only partially saturated in Upper Gibsons, (Figure 5). As the topography steepens from Upper to Lower Gibsons, the aquifer becomes fully saturated and the overlying Vashon till cover (Aquitard 560) causes a rise in groundwater pressure resulting in flowing artesian wells in Lower Gibsons (Figure 5).

Based on the age of the groundwater which ranges from 8-86 years (Doyle, 2013), aquifer recharge occurs rapidly due to the generally high permeability of glacio-fluvial and recent fluvial sediments that blanket the Study area. Despite the Aquitard 560 being mapped across much of the Study area, infiltration and aquifer recharge likely enters the aquifer(s) within the various drainages/creeks and "recharge windows" where the aquitard cover is absent or has been eroded by creek flow.

Although there is a general lack of geology/drilling data in the upper areas of the watersheds, the extensive braided network of surface drainage channels in the Upper Chaster Creek watershed suggest that this area could be the main recharge area to the Gibsons and Elphinstone Aquifers within the larger mapped Aquifer 560. The Upper Gibson Creek drainage likely also contributes some recharge to the Gibsons Aquifer but is more likely to be the main source of recharge to the Soames Aquifer.

3.3 Numerical Modelling Approach

All SCRD production well locations and TWs are located near the coast and appear to be separated by elevated bedrock in the subsurface. The data suggests that the aquifers may only be hydraulically connected at the higher elevations where creeks appear to drain Mt. Elphinstone in a radial pattern. This arrangement forms a common recharge area for all sub-surface channels which deposited the various "lobes" or buried channels described above. Recharge likely exists between the Elphinstone Aquifer Lobe and the Gibson Aquifer Lobe within the upper reaches of Chaster Creek; and the Soames Aquifer Lobe and the Gibsons Aquifer Lobe within the upper reaches of Gibson Creek. Although the Gibsons Aquifer is physically the same formation material as the Elphinstone and Soames Aquifers, Waterline does not expect that pumping wells in the discharge part of the system located near the coast would have a measurable interference effect.

The groundwater model was used to simulate the groundwater capture from each of the Town wells under full pumping conditions using the particle tracking feature in MODFLOW (Appendix A). Particles were placed near each well head and backwards tracking was activated in the model to show the axis of capture zone extending upslope from each well (Figure 9). The particle tracking simulation was completed over a 20-year pumping period and shows how groundwater is captured up the slope along the axis of the Gibsons Aquifer buried channel system (Figure 5). As the modelled capture zone extends upslope over a relatively narrow width, it does not appear to be in hydraulic communication with the Elphinstone and Soames Aquifer lobes, despite the apparent lateral continuity of the Pre-Vashon sediments mapped as Aquifer 560 (Figures 6 and 7).

4.0 GROUNDWATER USE SCENARIO UPDATE

4.1 Town of Gibsons Water Supply Wells

As of 2022, there are three active TWs (TW1, TW3 and TW4) which are licensed and connected to the Town's water distribution system. TW5 and TW6 were installed in 2019-20 and are currently inactive waiting for a WSA approval by FLNR. TW2 was converted to a monitoring well in 2018 and is not longer considered an active water supply well. A summary of the TW completion details is included in Table 1.

Table 1: Construction Details for The Town's Water Supply Wells

Well Name	Ground Elev. (masl)	Top of Casing Elev. (masl)	Top of Screen Elev. (masl)	Bottom of Screen Elev. (masl)	2021 Static Groundwater Elev. (masl)*	Proximity to the Gibsons Harbour (m)
TW1	13.50	13.92	-6.31	-9.36	14.34	120
TW3	18.50	16.60	-3.15	-6.20	19.47	310
TW4	13.50	12.62	1.15	-1.90	14.88	90
TW5	19.23	20.01	2.43	-2.37	21.06	330
TW6	107.27	108.18	-4.03	-14.63	23.76	920

Notes: *highlight* indicates active TWs; Elev. means elevation; masl means metres above sea level; * indicates that groundwater levels were measured in September 2021

Pumping tests were performed at each TW to assess the long-term sustainable well yield (Q_{20}) of individual wells, assuming continuous pumping for 20 years. The data collected was analyzed using various analytical solutions, considering well to well interference caused from pumping of adjacent wells only and not pumping of all wells simultaneously. A summary of the estimated Q_{20} values for the TWs is provided in Table 2.

Table 2: Summary of the Long Term Sustainable Well Yields (Q_{20})

Well Name	Tested Rate (m^3/d)	Q_{20} (m^3/d)	Reference
TW1	1345	1216	Piteau, 1997
		1095	
TW3	2620	1320	Town Records
		1273	
TW4	1123	1346	Piteau, 2000
		1145	
TW5	627	639	Waterline, 2019
		450	
TW6*	2091	***2091***	Waterline, 2019

Notes: m^3/d means cubic metres per day; ***italics*** indicates the long-term sustainable yield with well interference of the adjacent well only; * indicates the Q_{20} calculations suggested a higher untested rate of 4,168 m^3/d.

4.2 Groundwater Use Scenario Inputs

4.2.1 Groundwater Demand and Population Growth

In 2011, the Town's population was estimated at 4,450 people (OCP, 2015). Assuming an average population growth of 1.2%, the projected population in 2021 was expected to be 5,014 people. For comparison, assuming a per capita water use of 0.404 m^3/c/d, the total water usage by the Town (738,603 m^3 Waterline, 2021) indicates that the number of water users is around 5,000 people, which agrees with the 2015 OCP population growth predictions. However, with the accelerated development over the region, a medium population growth of 2.5% could be expected in the years to come as indicated in the OCP (2015) and should be considered for additional conservatism in estimating future groundwater demands.

A conservative per capita water use of 0.523 m^3/c/d was used to assess the aquifer performance and the long-term sustainability of groundwater supply. This value is 23% higher than current estimate of 0.404 m^3/c/d based on the total groundwater pumped in 2021 (September 2020 to September 2021) and the estimated population in the Town (Dave Newman, pers. comm, December 01, 2021). Although the Town will continue to be proactive in its management of the Gibsons Aquifer and related pumping system infrastructure, a conservative per capita water demand was applied to account for unforeseen infrastructure leaks and fire protection.

4.2.2 Domestic Groundwater Users and Sources of Additional Groundwater Use

Groundwater demand from private domestic users in the Study Area not connected to the Town's water distribution system was estimated to be 4 m^3/d. This is based on the Town's ongoing water metering program and the recent field verified survey completed by Waterline as part of groundwater licensing (Waterline, 2019).

As discussed in Waterline 2013, TW1 and TW4 are flowing artesian when not being pumped. The water is either directed to the storm Sewer (TW1) or to a fountain located in Lower Gibsons (TW4). Waterline measured an artesian overflow rate of 163 m^3/d and 107 m^3/d, respectively (Waterline 2013). These overflow rates were used to calculate the additional daily groundwater volumes extracted from the aquifer. TW3 and TW5, also located in Lower Gibsons, have been shut-in during non-use and therefore artesian pressures are contained in the well casing.

4.3 Climate Affects on Groundwater Use Scenarios

4.3.1 Changes to Total Precipitation (Rainfall and Snow Accumulation)

Climate change scientists have indicated that long-term weather patterns will change significantly in the following decades. In general, the BC coast will experience longer and drier summers, and cooler and wetter winters. Although annual rainfall could increase, the timing of precipitation events may be concentrated over shorter periods and will likely change the water budget parameters including runoff, evapotranspiration, and infiltration/recharge. Shorter recharge windows during the wetter winter months which could affect groundwater availability in the Gibsons Aquifer (Waterline, 2013).

Historical climate data is available from the Gibsons Gower Point Climate Station (Climate ID 1043152; Environment Canada, 2022) located 1.5 km west of the Town at an elevation of 34 masl. The data includes average monthly temperature and average monthly rainfall from 1981 to 2010 as well as recent climate averages from 2021. The data is summarized in Table 3.

Table 3: Climate Normals and Recent Climate Data from Climate Station ID No. 1043152

Climate Normal Data (1981-2010)													
Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Yr.**
Average Monthly Temperature (°C)	4.6	5.2	7.1	9.5	12.7	15.3	17.6	17.9	15.1	10.5	6.5	4.2	10.5
Average Monthly Rainfall (mm)	178.2	118.0	118.2	95.7	81.5	67.2	41.4	40.5	58.0	140.2	214.8	170.1	1323.6
Climate Data from 2021													
Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Yr.
Average Monthly Temperature (°C)	5.7	3.8	6.9	10.2	12.8	18.1	19.7	18.9	15.1	10.0	7.7	2.1	10.9
Total Rainfall (mm)	194.6	76.8	59.6	44.4	32.8	60.8	0.6	37.0	177.0	216.8	376.0	93.8	1,370.2

Notes: °C means degrees Celsius; mm means millimetres, Yr. means year.

In 2021, the precipitation from September to February was 29% greater than the climate normal, while precipitation from March to August was 50% lower than the climate normal (Table 3). Annual average temperatures were 0.4°C warmer as compared to climate normal from 1981-2010 (Table 3). To assess how changing contributions from rainfall could impact recharge to the Gibsons Aquifer, Waterline applied a 15% reduction to recharge across the Study area.

Climate change from increased temperatures will also reduce snow accumulation on the mountain block, decreasing the amount of water released during spring melt (Waterline, 2013). As a large component of recharge to the Gibsons Aquifer is thought to be contributed by snowmelt, snow accumulation was reduced by 30% to assess the potential impacts of reduced recharge from snow melt for each groundwater use scenario.

4.3.2 Changes To Sea Levels

Climate change is also predicted to cause sea level rise. All TWs are screened below sea level (Table 1) and located near the coast (< 1 km). As such, lowering the water level in a well below the mean sea level could cause a reversal of the hydraulic gradient from prolonged pumping inducing saltwater intrusion into the aquifer. As was done during the 2013 Aquifer Mapping Study (Waterline, 2013), Waterline incorporated a sea level rise of 1.0 m into the model which would effectively reduce the available drawdown at each TW by that same amount. It should be noted that climate change studies for the Strait of Georgia only predicts a 0.3 m rise along the coast and therefore using a 1.0 m rise is highly conservative.

Table 4 summarizes the current (2021 values) and climate-affected available safe drawdown elevations. This incorporates the 1 m of sea level rise and/or the 70% drawdown threshold limits for consideration as part of the groundwater use scenarios.

Table 4: Current and Climate Affected Drawdown - Town Water Supply Wells

Well Name	Current Condition (2021)			Climate Affected - Sea Level Rise		
	Total Available Drawdown to Top of Well Screen (m)	70% of Available Drawdown to Top of Well Screen (m)	Groundwater Elevation @ 70% Drawdown (masl)	Total Available Drawdown to Top of Well Screen (m)	70% of Available Drawdown to Top of Well Screen (m)	Groundwater Elevation @ 70% Drawdown (masl)
TW1	20.7	14.5	-0.1	19.7	13.8	0.6
TW3	22.6	15.8	3.6	21.6	15.1	4.3
TW4	13.7	9.6	5.3	12.7	8.9	6.0
TW5	18.6	13.0	8.0	17.6	12.3	8.7
TW6	27.8	19.5	4.3	26.8	18.8	5.0

Notes: masl means metres above sea level

4.4 Future Groundwater Use Scenarios

As indicated above, MODFLOW was used to predict drawdown in the Gibsons Aquifer for different pumping scenarios. The evaluation involved adjusting the pumping rates of individual wells such that the water level in the Gibsons Aquifer can be maintained at a safe level above the top of the well screen and/or sea level, whichever is higher. A safe level above the well screen was defined as 70% of the available drawdown or hydraulic head in the aquifer.

To accounting for some uncertainty in assessing future groundwater use, a variable population growth (1.2 to 2.5%) and water demand (0.404 to 0.523 m^3/c/d) were applied. The modelled groundwater use scenarios included the following:

- ***Scenario 1*** – Steady state simulation (constant pumping rates) to assess the total licensed groundwater volume for an estimated population of 5,322 residents in 2026 (4-years) using a population growth of 1.2% (OCP, 2015) and a per capita water demand of 0.523 m^3/c/d.
- ***Scenario 2*** – Transient state simulation to assess full buildout of the Town for the estimated population of 10,000 residents in 2050 (28-years) using a population growth of 2.5% and per capita water demand of 0.404 m^3/c/d. The transient model allowed Waterline to increase the pumping rate each year to simulate the changing water demand over the 28-year period.
- ***Scenario 3*** – Transient state simulation (same as Scenario 2) to assess full buildout of the Town for the estimated population of 10,000 residents in 2050 (28-years) using a population growth of 2.5% and per capita water demand of 0.523 m^3/c/d.
- ***Scenario 4*** – Steady state simulation (2022 to 2042) to assess simultaneous pumping from all TWs (cumulative drawdown effects), using the estimated Q_{20} pumping rates.

To simulate the different groundwater use scenarios, a combination of different pumping rates for the individual TWs were selected to optimize groundwater use and minimize drawdown effects of well-to-well interference. Model results and pumping rates for each scenario are provided in Appendix A. A summary of the groundwater use scenarios is included in Table 5.

Table 5: Summary of Future Groundwater Use Scenarios

Groundwater Use		**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**
Groundwater Use Simulation Type		**Steady State**	**Transient State**		**Steady State**
Population and Water Use	Population Growth (%)	1.2	2.5		-
	Total Population	5,322	10,000		-
	Date/Year Modeled from Present	2026	2050		2042
	Elapsed Time (Years)	4	28		20
	Water Use (m^3/c/d)	0.523	0.404	0.523	-
Water Demand (m^3/d)		**2,783**	**4,040**	**5,230**	**6,054**

Notes: m^3/d means cubic metres per day; m^3/c/d means cubic metres per capita per day

5.0 GROUNDWATER MODELLING RESULTS

The MODFLOW model was calibrated using transient groundwater level and pumping rates recorded from 2011 to 2021. Once calibrated, the numerical model was used to simulate both the steady state and transient state pumping scenarios presented in Table 5. The following conditions were considered:

- Pumping conditions with non-climate-affected recharge rates, denoted as series “a” simulation,
- Pumping conditions with an overall reduction in groundwater recharge by 15%, to simulate changes in rainfall denoted as series “b” simulation,
- Pumping conditions with a 30% reduction in mountain block recharge to simulate changes in snow accumulation denoted as series “c” simulation, and
- For series “a”, “b” and “c” simulations, climate-affected available drawdown from sea level rise was considered.

A total of 12 simulations were performed. The predicted drawdown in the aquifer is summarized in Table 6. Groundwater elevation charts for each scenario are included in Appendix B as Figures B1 to B12. For discussion of water use planning, a ranking system was developed to determine the potential risk to the Gibsons Aquifer for each groundwater use simulation. These included:

- A ***Low*** risk is assigned if the predicted groundwater elevations from pumping are above the 70% available drawdown elevation for both non affected and affected climate recharge conditions and sea level rise,
- A ***Moderate*** risk is assigned if the predicted groundwater elevation from pumping is below the 70% available drawdown elevation for both non affected or affected climate recharge conditions and sea level rise but remained above the mean sea level, and

- A ***High*** risk is assigned if the predicted groundwater elevation from pumping drops below the mean sea level elevation.

Table 6: Predicted Groundwater Levels for Each Groundwater Use Scenario

Scenario	Lowest Groundwater Elev. (masl)	Highest Groundwater Elev. (masl)	Groundwater Elev. Range for Lower Gibsons Wells (masl)	Groundwater Use Risk
Scenario 1_a	10.1	20.1	10.1 to11.5	***Low***
Scenario 1_b	9.7	19.7	9.7 to 11.1	
Scenario 1_c	10.1	20.0	10.1 to 11.5	
Scenario 2_a	6.9	16.2	6.9 to 8.4	***Low***
Scenario 2_b	6.0	14.9	6.0 to 7.3	
Scenario 2_c	6.8	16.1	6.8 to 8.3	
Scenario 3_a	2.6	13.5	2.6 to 3.9	***Moderate***
Scenario 3_b	1.2	12.0	1.2 to 2.6	
Scenario 3_c	2.5	13.4	2.5 to 3.8	
Scenario 4_a	-2.4	10.3	-2.4 to -0.7	***High***
Scenario 4_b	-3.6	9.0	-3.6 to -1.9	
Scenario 4_c	-2.5	10.2	-2.5 to -0.8	

Notes: Elev. means elevation; masl means metres above sea level; the Lower Gibsons Wells include TW1, TW2, TW3, TW4, and TW5

Notable observations include:

- The lowest predicted groundwater elevations were observed at TW1, while the highest predictive groundwater elevations were observed at TW6.
- For all predictive modelling a reduction in total recharge by 15% had the largest impact on drawdown levels in the Gibsons Aquifer.
- Pumping at TW5 was only simulated for Scenario 3 and Scenario 4, therefore drawdown observed under the Scenario 1 and Scenario 2 pumping conditions is strictly from pumping of the adjacent well (TW3).
- The 70% threshold limit was never exceeded at TW6, which is located at the highest elevation and furthest from the coast, for any pumping scenario, including climate-affected conditions.
- For Scenario 1 (5,322 residents to 2026, demand of 0.523 $m^3/c/d$), the risk to the Gibsons Aquifer under all pumping scenarios, including for recharge-affected and sea level rise conditions was low. The groundwater elevation at active and non-active TWs is above the 70% threshold limits for available drawdown to the top of the well screen.
- For Scenario 2 (10,000 residents to 2050, demand of 0.404 $m^3/c/d$), the risk to the Gibsons Aquifer under all pumping scenarios, including for recharge-affected and sea level rise conditions is considered low. The groundwater elevation at active TWs was predicted to remain above the 70% threshold limits for available drawdown to the top of the well screen.

- For Scenario 3 (10,000 residents to 2050, demand of 0.523 m^3/c/d), the risk to the Gibsons Aquifer under all pumping scenarios, including for recharge-affected and sea level rise conditions, is considered moderate.
  - Water levels in all TWs are predicted to remain above the mean sea level, however, all TW water levels are predicted to be drawn down below the 70% threshold except for the water level in TW6.
  - The TW6 pumping rate (2,091 m^3/d) used in the predictive modelling is the Q_{20} value from well testing.
- For Scenario 4 (pumping the five TWs simultaneously to 2042, using the Q_{20} rates), the risk to the Gibsons Aquifer under all pumping scenarios, including for recharge affected and sea level rise conditions was high.
  - The cumulative drawdown from continuous pumping over the 20-year period would result in sustained groundwater levels below sea level, except for TW6.
  - Because the Town's groundwater demand does not require operating the TWs at the Q_{20} rates simultaneously, it is possible that these rates could be sustained for shorter durations if required.

6.0 DISCUSSION OF GROUNDWATER USE SCENARIOS

The conceptual hydrogeological model for the Gibson Aquifer which was constructed using Leapfrog 3D was updated to include over a decade of groundwater monitoring data, drilling data and related test data. The conceptual model was used to update the numerical groundwater flow model using MODFLOW. The numerical model was successfully calibrated using observed groundwater levels and pumping responses for the active TWs recorded from 2009 to 2021. Predictive modelling of various groundwater use scenarios was performed to assess drawdown in the Gibsons Aquifer after pumping for 4 years and 28 years and to determine the risk from over pumping the TWs simultaneously for 20-years, testing the Q_{20} rates.

The risk to the Gibsons Aquifer from pumping groundwater to meet the Town's anticipated population growth and water demand to 2026 (Scenario 1), and for full buildout with a population of 10,000 in 2050 using the lower per capita demand of 0.404 m^3/c/d (Scenario 2) and including possible impacts from climate change, was low. Although there is a moderate risk to supply groundwater for full buildout of the Town to 2050 using a conservative water demand of 0.523 m^3/c/d (Scenario 3), there is the possibility to reduce the risk by:

1. Redirecting the approximately 270 m^3/d that is currently being diverted to the storm sewer into the Town's water system. This amount of water could potentially support an additional 525 residents, and
2. Increasing the pumping rate at TW6 above the tested rate of 2,091 m^3/d, further reducing the reliance on the Lower Gibsons TWs.

Cumulative pumping of all TWs at their maximum rated capacities or individual Q_{20} rates (Scenario 4) was determined to be high risk as it would result in excessive drawdown in the aquifer.

However, this practice could be considered for short periods during peak demand or when the per capita demand is higher due to water distribution leaks, fire suppression, etc.

Based on a population growth of 2.5%, full buildout of the Town is projected to occur by the year 2050. If the current groundwater demand of 0.404 m^3/c/d remains consistent, an additional groundwater license will be needed for a volume of 1,257 m^3/d (458,805 m^3/yr.). It is necessary to reassess the groundwater demand on an ongoing basis as part of the license conditions as indicated under Section 23 of the WSA (Government of BC, 2016) to prove beneficial use.

7.0 CONCLUSIONS

The Town's groundwater management framework includes promoting responsible water consumption through water metering, system maintenance, community awareness and engagement. This is in combination with efforts to characterize, protect and monitor the aquifer and overall watershed conditions in the Study Area. Unlike surface water which can be seen flowing in creeks and into the ocean, groundwater is buried deep beneath the Town and can easily be taken for granted. Groundwater systems provide natural filtration through geologic material which are recharged across large areas over a longer timeframe. This feature makes groundwater more resilient in times of drought as was observed during recent years by the SCRD who rely heavily on surface water. The Town's simple but novel approach of valuing and managing the Gibsons Aquifer as eco-infrastructure, just as it would manage and protect other infrastructure, is critical to its operation and has brought a deeper awareness of the need to protect this vital resource.

Since 2013, considerable progress has been made to better understand the movement and cycling of water in the Gibsons Aquifer. Updates to the conceptual model and re-evaluation of the groundwater use estimates were only possible due to the successful implementation of groundwater related policies by the Town.

The following summarizes the model updates:

- Although Aquifer 560 has been mapped as a single aquifer, the aquifer system(s) is more complex and requires refinement. The Town of Gibsons currently has the most comprehensive dataset from which to assess the depositional history and understand groundwater flow and recharge.
- The aquifer material was deposited as drainage channels extending from the coastal mountains to the ocean prior to the Vashon glacial period (pre-Vashon sediments). Glaciers inundated the region some 20,000 to 30,000 years ago depositing a thick glacial till blanket which formed the cap over the aquifer(s). The ice sheet during this period could have been over 2 km think in the present-day Georgia Strait. As the glaciers retreated, marine deposits referred to as the Capilano sediment, blanketed the area. These deposits formed locally unconfined aquifers near the surface which are connected to the creeks and largely disconnected from the deeper pre-Vashon aquifers including the Gibsons Aquifer.
- The pre-Vashon sediments beneath the Town of Gibsons are thick and have been deposited in a deep erosional channel. The channel appears to have created a central

basin situated beneath the Town which is considered by Waterline to be the “Gibsons Aquifer” lobe of what is referred to as Aquifer 560 by the province. This portion of Aquifer 560 is bounded by bedrock highs which extend from Gospel Rock at Gibsons Harbour to Upper Gibsons on the west side, and along the west side of Gibson Creek on the east side. Similar pre-Vashon channel deposits appear to have formed beneath the Chaster Creek Valley to the west and the Soames Creek Valley to the east which are thought to be the Elphinstone and Soames Aquifer Lobes of Aquifer 560, respectively.

- Although there appears to be a common recharge area at higher elevations, the lower portion of the aquifer lobes appear to be hydraulically disconnected from each other. This is an important finding as the Town and SCRD well fields located along the coast can be managed independently but the common recharge area must be managed jointly to ensure sustainability of the resource.
- After nearly a decade of collecting groundwater data in the Gibson Aquifer, the groundwater flow direction has remained relatively constant from the northwest to southeast.
- An interesting feature of the Gibsons Aquifer is that it is only partially saturated in Upper Gibsons. Despite having a confining unit (i.e., Vashon till cover) pumping test data indicate storativity values are in the unconfined aquifer range. As topography becomes steeper from Upper to Lower Gibsons, the aquifer becomes fully saturated, and wells are flowing artesian indicting a strongly confined system. Despite this, the Vashon till cover in Lower Gibsons is relatively thin and is highly vulnerable to penetration and breaching which could be catastrophic to containing groundwater if not managed carefully. The Town has implemented strict development guidelines (Development permit Area 9) in Lower Gibsons and the Gibsons Harbour to prevent breaching of the Gibsons Aquitard. Although somewhat unpopular for land developers, the strict requirements have allowed the Town to gather detailed information regarding the nature of the aquifer in Lower Gibsons as part of its Eco-Infrastructure management approach.
- The Gibson Aquifer conceptual model and numerical groundwater flow model was fully updated and calibrated using the performance monitoring data collected by the Town on an annual basis since 2013.
- Several pumping scenarios were evaluated to determine the groundwater availability to supply the Town into the future. Predictive modeling results indicate that there is a low risk from over pumping associated with the current groundwater demand for the Town of approximately 5000 people. In addition, predictive modeling indicates that the Gibsons Aquifer can also meet future demand as the population grows to approximately 10,000 people at full buildout of the Town. The groundwater modelling estimates also considered climate change impacts that could affect aquifer recharge and sea level rise that would increase the potential for saltwater intrusion.
- To meet the future projected demand for full buildout in 2050, using the current groundwater demand of 0.404 m^3/c/d, the Town will need to make an application(s) under the WSA for an additional 1,257 m^3/d (458,805 m^3/yr) from the existing well field, beyond the existing approval and new use application currently under review.

8.0 RECOMMENDATIONS

Based on the results of the aquifer mapping study update, the following recommendations are provided for consideration by the Town:

- Continue to engage in discussions with the SCRD, FLNR and community stakeholders regarding aquifer monitoring and watershed management activities. This will be particularly important for the protection of the recharge areas located outside the Town of Gibsons in the SCRD. Further investigations should be completed in the upper reaches of the Chaster Creek and Gibsons Creek watersheds to assess the recharge characteristics of Aquifer 560 and its component aquifer lobes. This should be a joint effort between the Town and SCRD and include the installation of shallow and deep monitoring wells, a climate station, and infiltration studies.
- The Town should share the results of the current study with FLNR for use in updating previous aquifer mapping programs completed on behalf of the province.
- The Town should assess the artesian overflow from TW1 and TW4 that is currently being diverted to the stormwater outflow when those wells are not pumping. As discussed in 2013, some risks exist due to pressurization of the well casings if well heads are sealed but options should be assessed to make beneficial use of the water.
- The Town should install two shallow monitoring wells near TW3 in Lower Gibsons, to help characterize the competency of the confining unit and the Capilano aquifer.

9.0 CERTIFICATION

This document was prepared under the direction of a professional geoscientist registered in the Province of British Columbia.

Waterline Resources Inc. trusts that the information provided in this document is sufficient for your requirements. Should you have any questions or concerns, please do not hesitate to contact the undersigned.

Respectfully submitted,

Waterline Resources Inc.
EGBC Permit No. 1000669

Original signed and stamped

Simon Wing, B.Sc., P.Geo.
Intermediate Hydrogeologist

Reviewed By:

Original signed

Darren David, M.Sc., P.Geo.
Principal Hydrogeologist

Original signed

Shermin Negari, M.Eng., P.Eng.
Hydrogeological Engineer

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11.0 LIMITATIONS AND USE

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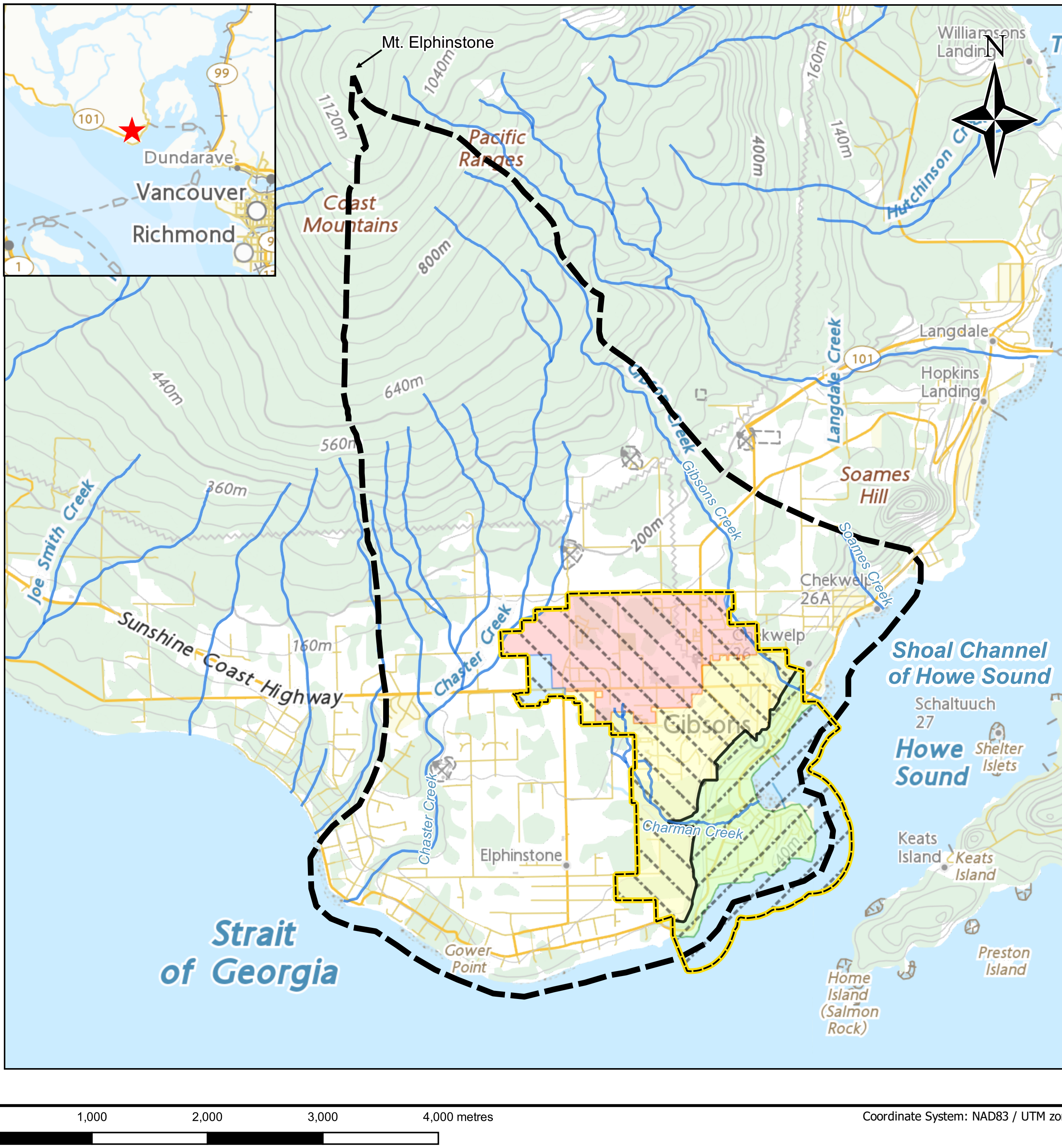
FIGURES



Sources:

Government of BC (Municipalities, 2016; FWA, 2017); Town of Gibsons (2016); Canada Base Map – Transportation (WMS).

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Aquifer Mapping Study Update –
Re-Evaluation of the Groundwater use Scenarios
Gibsons, British Columbia
Submitted to the Town of Gibsons

SITE LOCATION PLAN

Waterline

Prepared By: Waterline Resources Inc.	
Project Number: 1578-21-003	
Compiled By: jmusulak	
Date Issued: 2022-Mar-30	
Date Revised: --	

FIGURE 1

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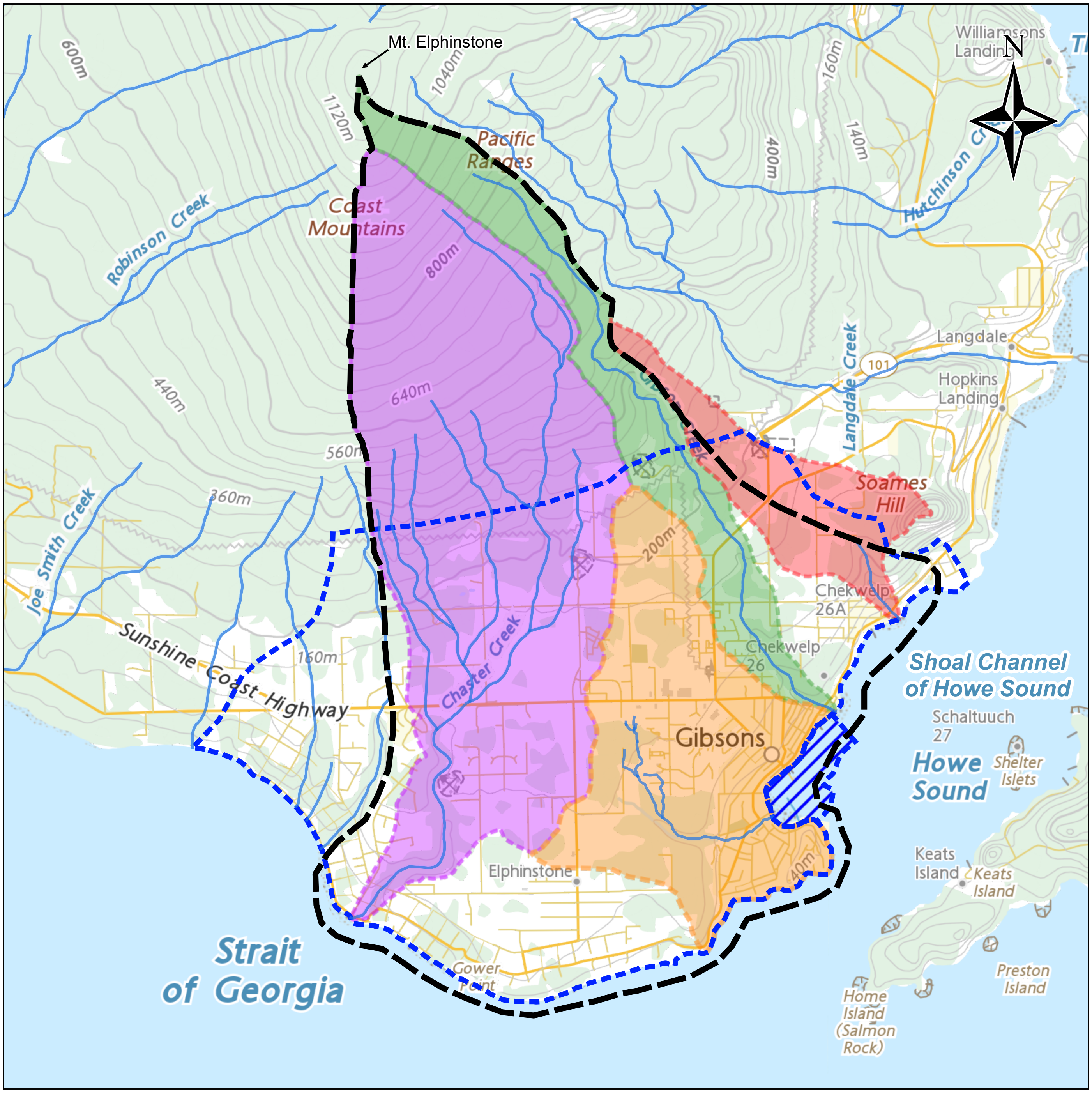

0 1,000 2,000 3,000 4,000 metres

Coordinate System: NAD83 / UTM zone 10N

Sources:

Government of BC (modified from MoE, 2020; Municipalities, 2016; modified from FWA, 2017);
Town of Gibsons (2016);
Canada Base Map – Transportation (WMS).

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- Study Area (Geological Model Boundary)
- Charman Creek Watershed
- Chaster Creek Watershed
- Gibson Creek Watershed
- Soames Creek Watershed
- Aquifer 560
- Aquifer 560 Inferred Area
- Watercourse

Aquifer Mapping Study Update –
Re-Evaluation of the Groundwater use Scenarios
Gibsons, British Columbia
Submitted to the Town of Gibsons

WATERSHED AND AQUIFER MAP

Waterline

Prepared By:	Waterline Resources Inc.
Project Number:	1578-21-003
Compiled By:	jmusulak
Date Issued:	2022-Mar-30
Date Revised:	--

FIGURE 2

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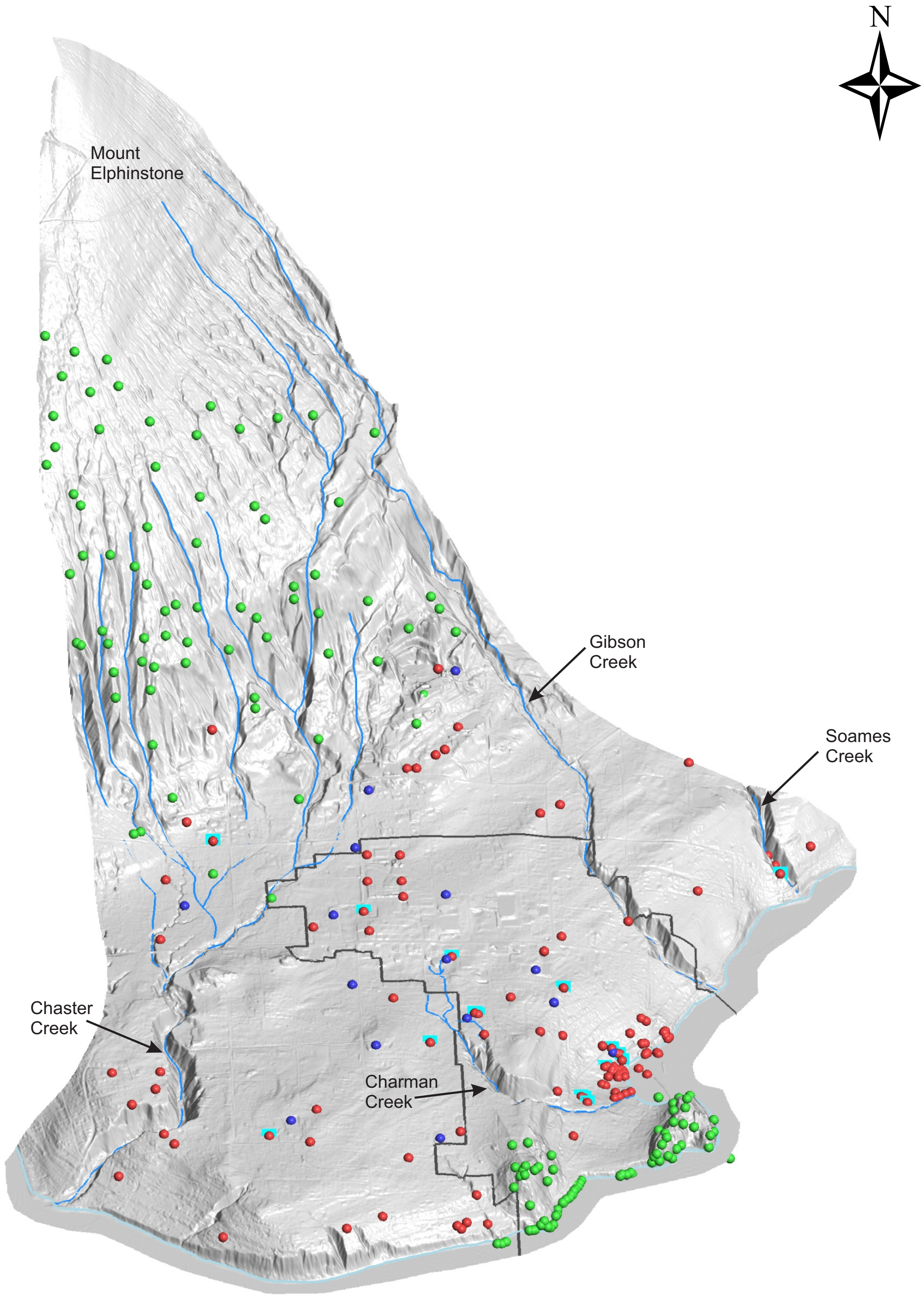


References: Town of Gibsons (2016, 2021).

Field Survey Location
Geophysics Location
Groundwater Well, Test Pit or Borehole Location
Water Level Location
Creek
Town of Gibsons Boundary
Coastline

PROJECT

Town of Gibsons Aquifer Mapping Update
Gibsons, British Columbia
Submitted to the Town of Gibsons

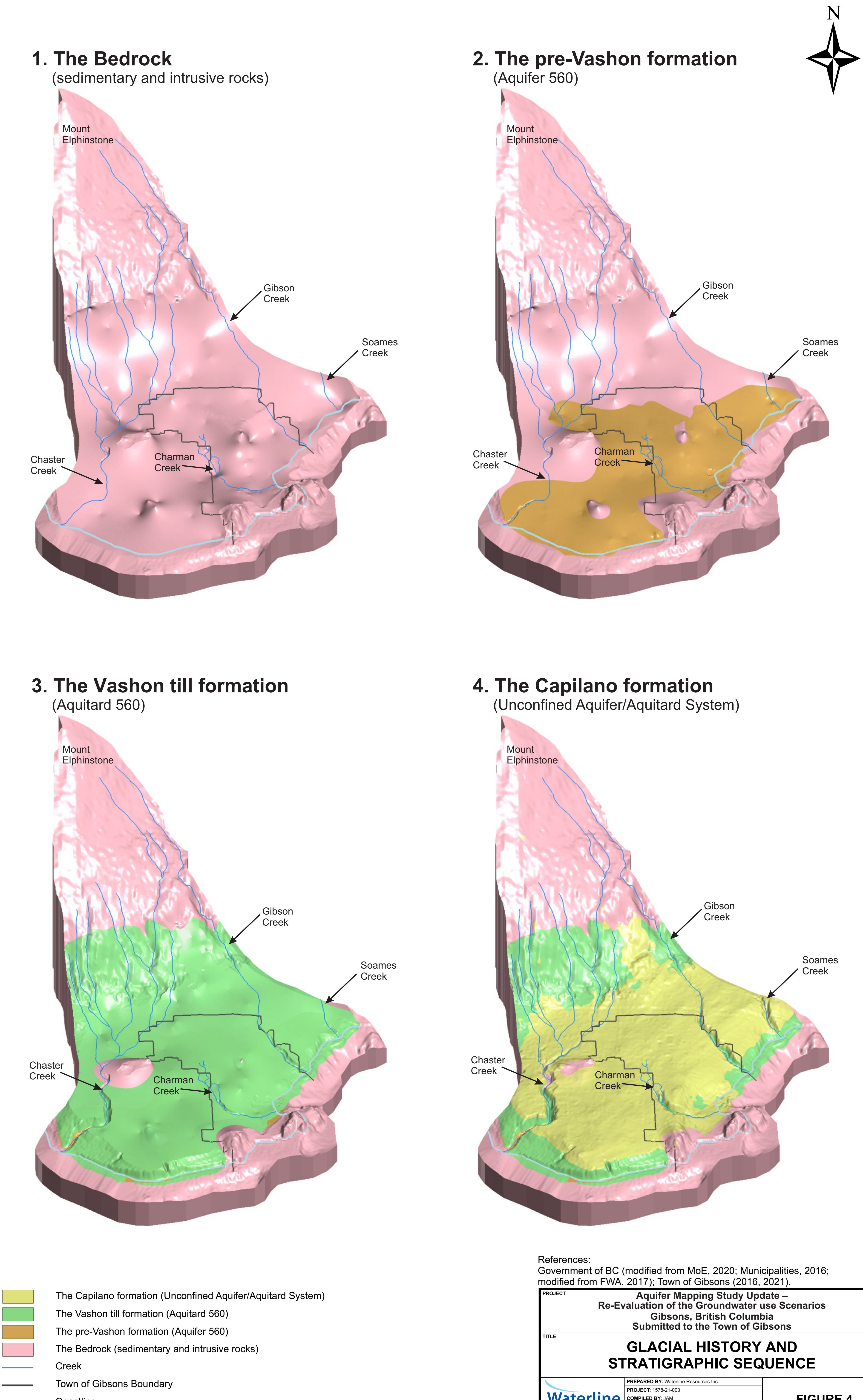
TITLE

DATA LOCATIONS FOR CONCEPTUAL SITE MODEL UPDATE

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: April 2022
REVISED: –

FIGURE 3



References:
Government of BC (modified from MoE, 2020; Municipalities, 2016; modified from FWA, 2017); Town of Gibsons (2016, 2021).

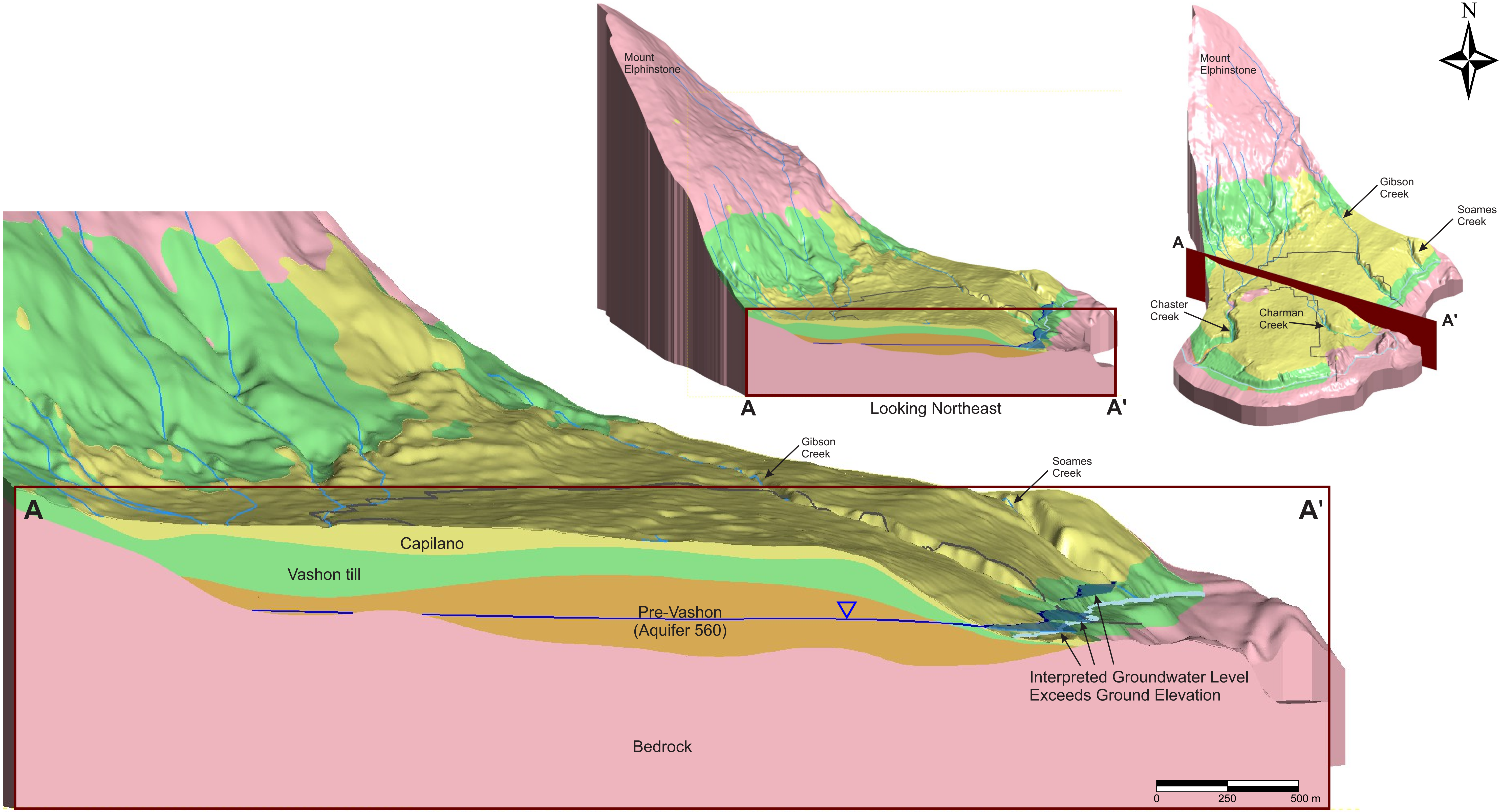
PROJECT
Aquifer Mapping Study Update – Re-Evaluation of the Groundwater use Scenarios
Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE
GLACIAL HISTORY AND STRATIGRAPHIC SEQUENCE

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: March 2022
REVISED: –

FIGURE 4



(yellow)	The Capilano formation (Unconfined Aquifer/Aquitard System)
(green)	The Vashon till formation (Aquitard 560)
(orange)	The pre-Vashon formation (Aquifer 560)
(pink)	The Bedrock (sedimentary and intrusive rocks)

▽	Intepreted Groundwater Elevation
—	Creek
—	Town of Gibsons Boundary
—	Coastline

References:
Government of BC (modified from MoE, 2020; Municipalities, 2016; modified from FWA, 2017); Town of Gibsons (2016, 2021).

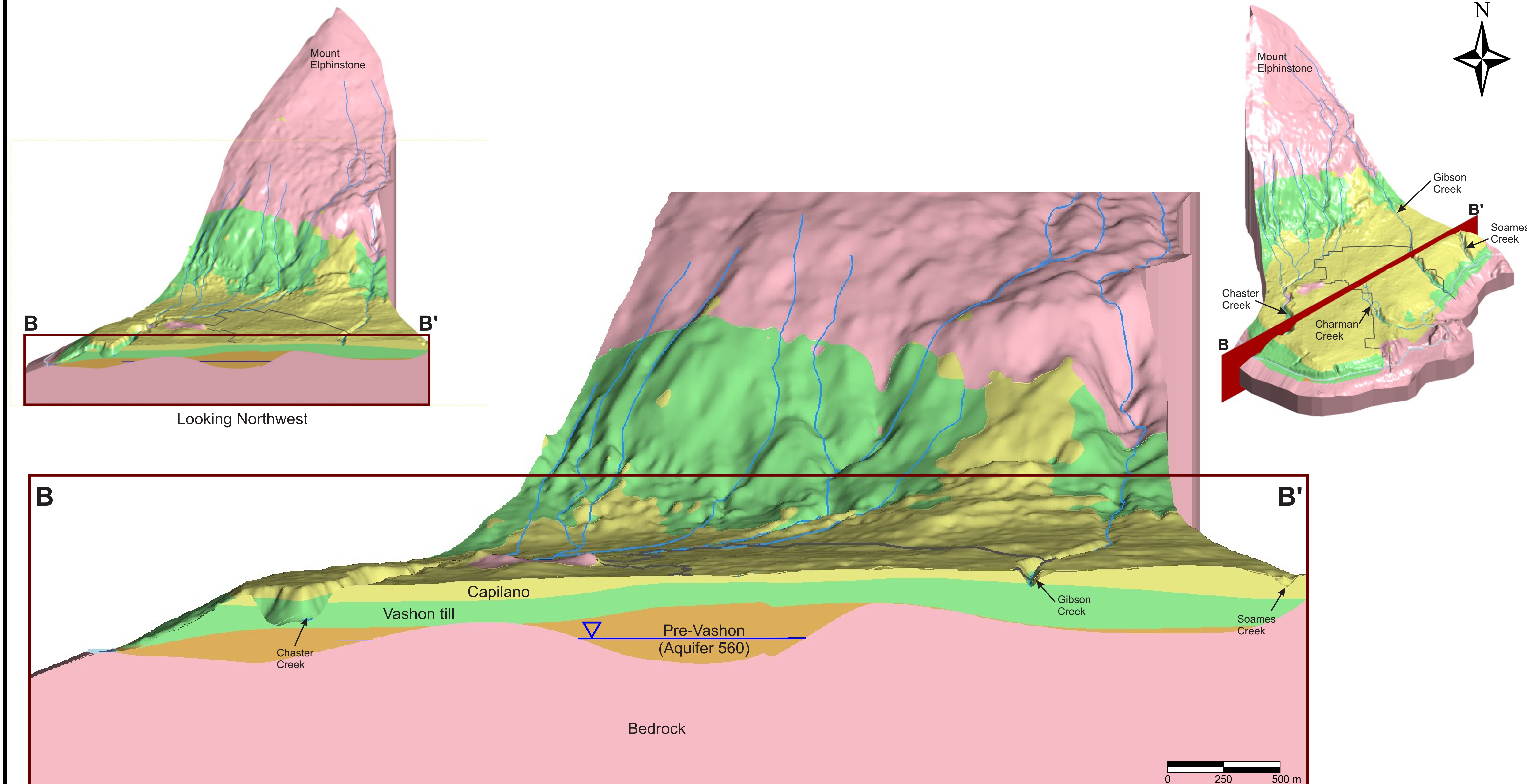
PROJECT
Aquifer Mapping Study Update – Re-Evaluation of the Groundwater use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons

TITLE
HYDROGEOLOGICAL CROSS-SECTION A-A' (NORTHWEST TO SOUTHEAST)

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: March 2022
REVISED: –

FIGURE 5



The Capilano formation (Unconfined Aquifer/Aquitard System)	Intepreted Groundwater Elevation
The Vashon till formation (Aquitard 560)	Creek
The pre-Vashon formation (Aquifer 560)	Town of Gibsons Boundary
The Bedrock (sedimentary and intrusive rocks)	Coastline

References:
Government of BC (modified from MoE, 2020; Municipalities, 2016; modified from FWA, 2017); Town of Gibsons (2016, 2021).

PROJECT

**Aquifer Mapping Study Update –
Re-Evaluation of the Groundwater use Scenarios
Gibsons, British Columbia
Submitted to the Town of Gibsons**

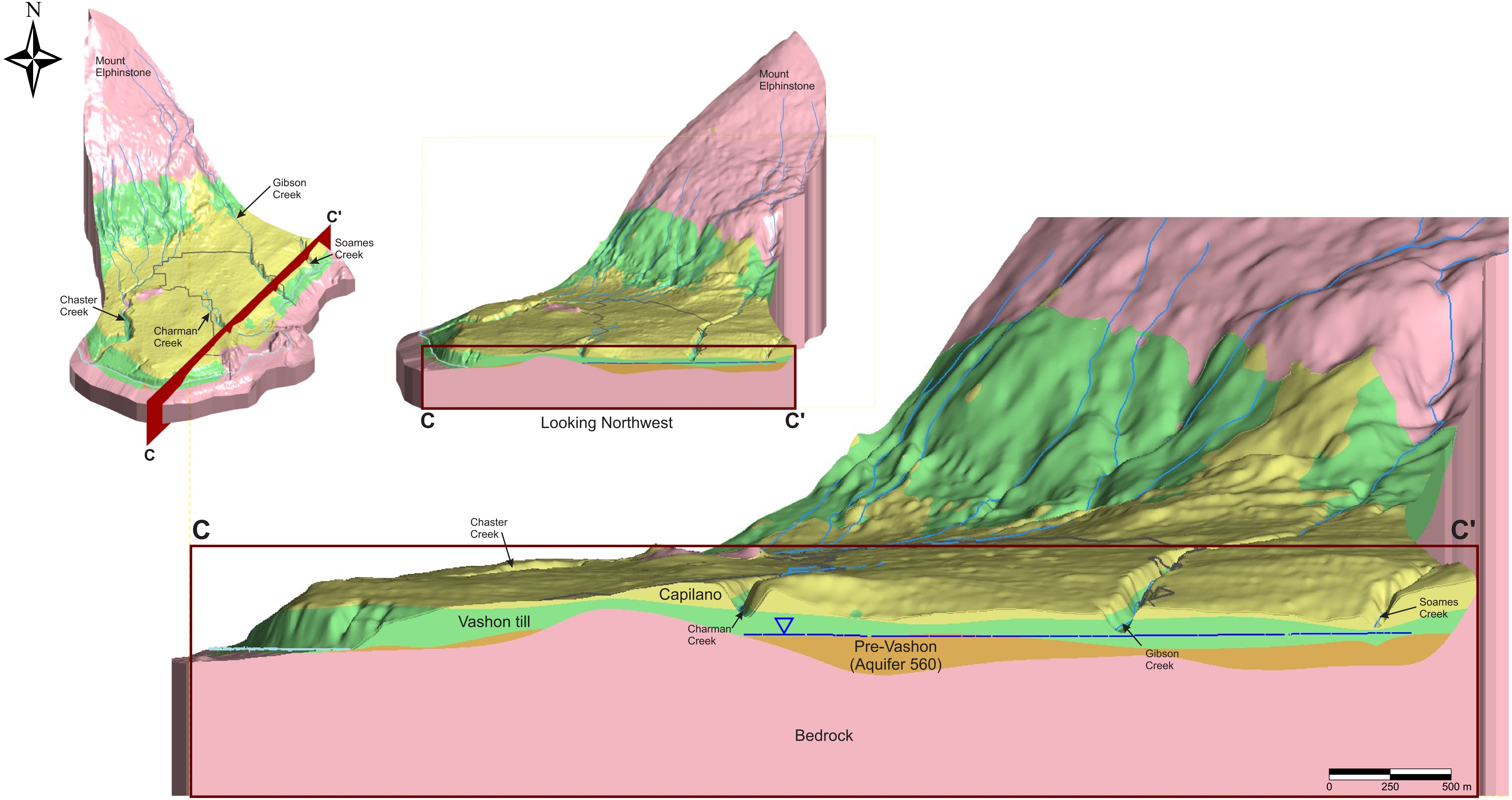
TITLE

HYDROGEOLOGICAL CROSS-SECTION B-B' (SOUTHWEST TO NORTHEAST)

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: March 2022
REVISED: –

FIGURE 6



	The Capilano formation (Unconfined Aquifer/Aquitard System)
	The Vashon till formation (Aquitard 560)
	The pre-Vashon formation (Aquifer 560)
	The Bedrock (sedimentary and intrusive rocks)

	Intepreted Groundwater Elevation
	Creek
	Town of Gibsons Boundary
	Coastline

References:
Government of BC (modified from MoE, 2020; Municipalities, 2016; modified from FWA, 2017); Town of Gibsons (2016, 2021).

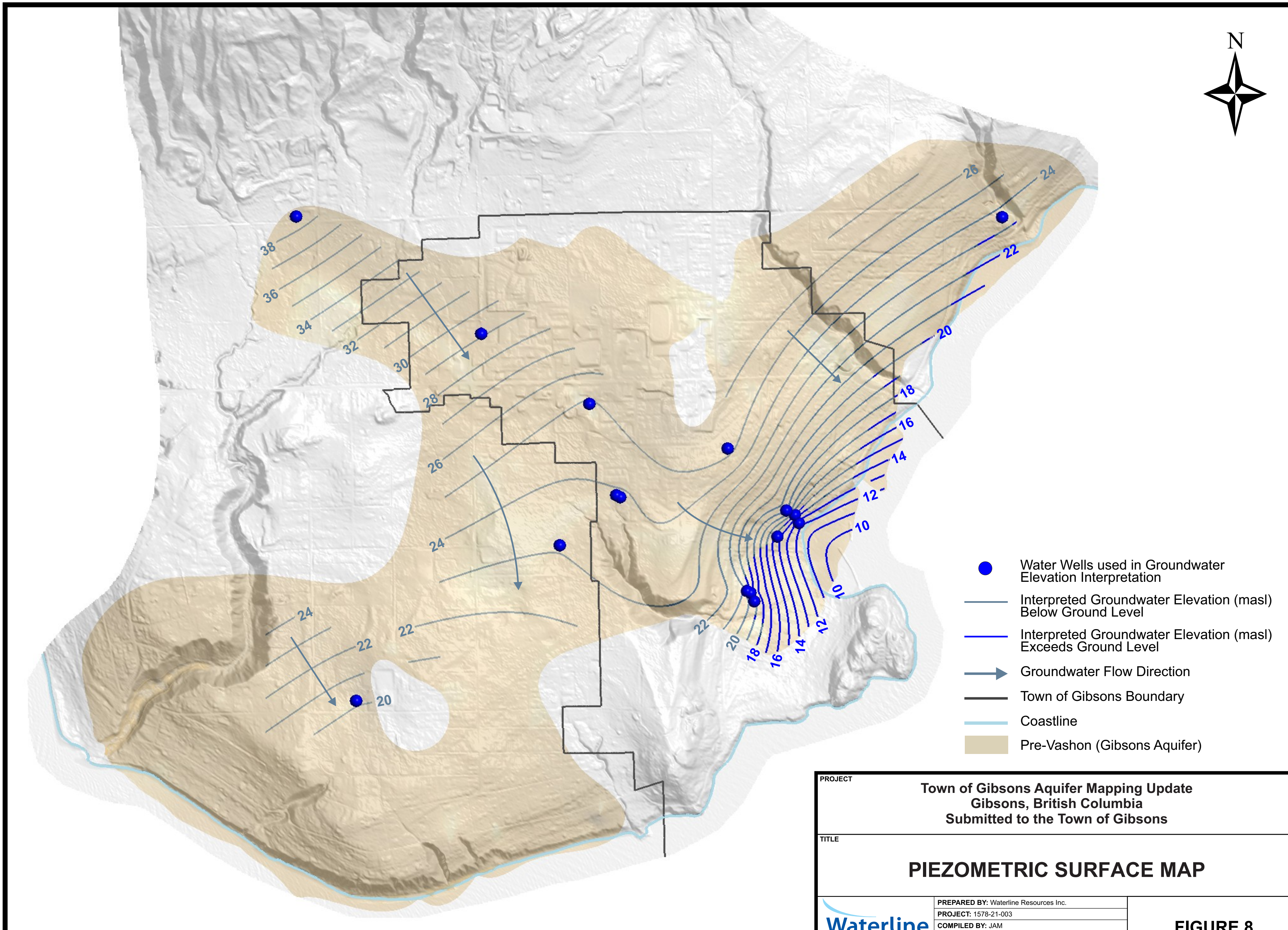
PROJECT
Aquifer Mapping Study Update –
Re-Evaluation of the Groundwater use Scenarios
Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE
HYDROGEOLOGICAL CROSS-SECTION C-C'
(SOUTHWEST TO NORTHEAST)

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: March 2022
REVISED: –

FIGURE 7



References: Town of Gibsons (2016, 2021).

PROJECT

Town of Gibsons Aquifer Mapping Update
Gibsons, British Columbia
Submitted to the Town of Gibsons

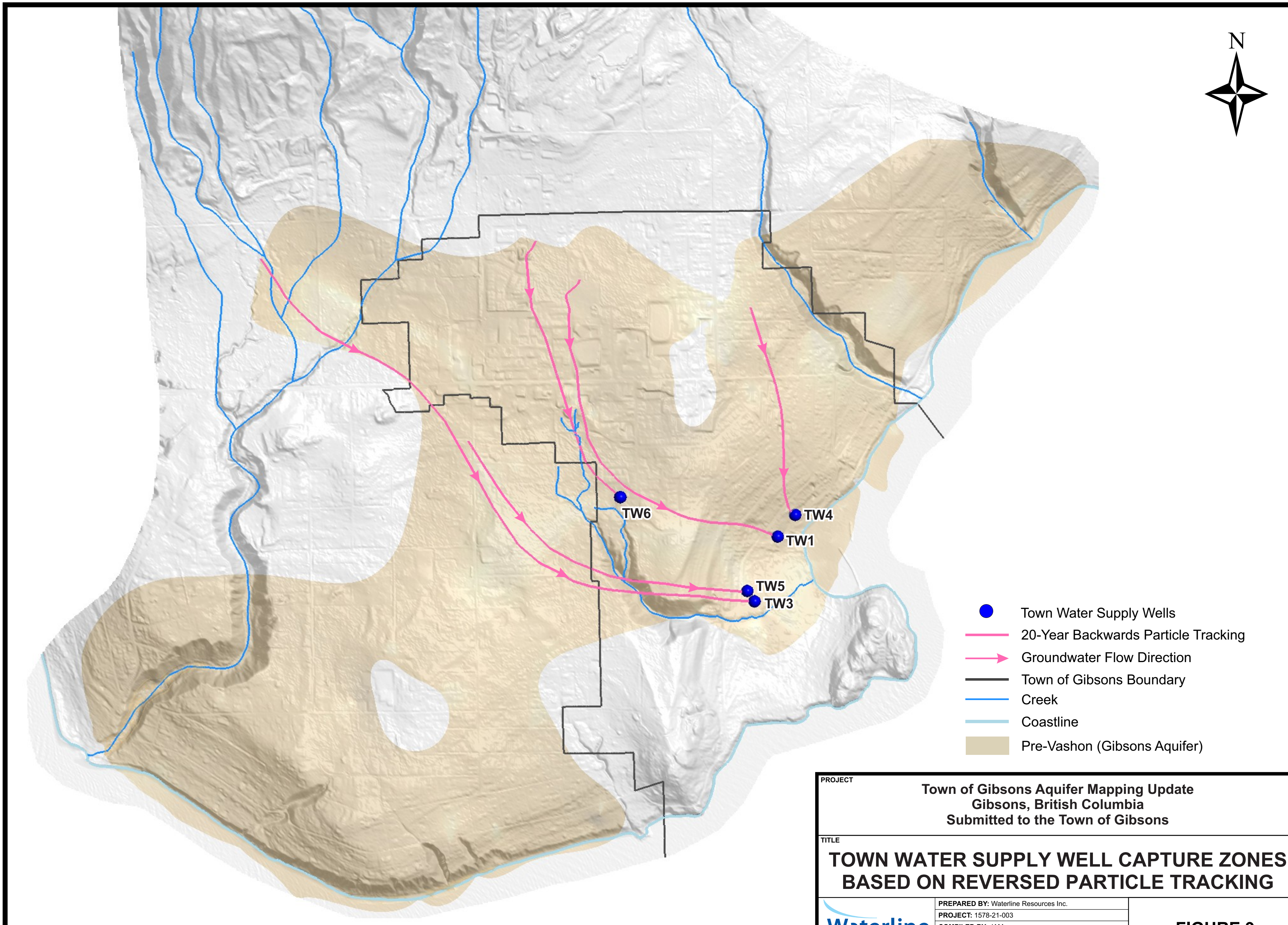
TITLE

PIEZOMETRIC SURFACE MAP

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: April 2022
REVISED: –

FIGURE 8



References: FWA (2017), Town of Gibsons (2016, 2021).

PROJECT

Town of Gibsons Aquifer Mapping Update
Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE

TOWN WATER SUPPLY WELL CAPTURE ZONES BASED ON REVERSED PARTICLE TRACKING

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: JAM
DATE ISSUED: April 2022
REVISED: –

FIGURE 9

Appendix A:
Methodology for Numerical Model Update

1.0 MODEL DOMAIN AND BOUNDARY CONDITIONS

During the 2021 update to the numerical groundwater flow model, the model domain remained unchanged as it was proposed and designed in the original model (Waterline, 2013), extending from the top of Mt. Elphinstone to the Town of Gibsons waterfront as shown below in Figure A1.

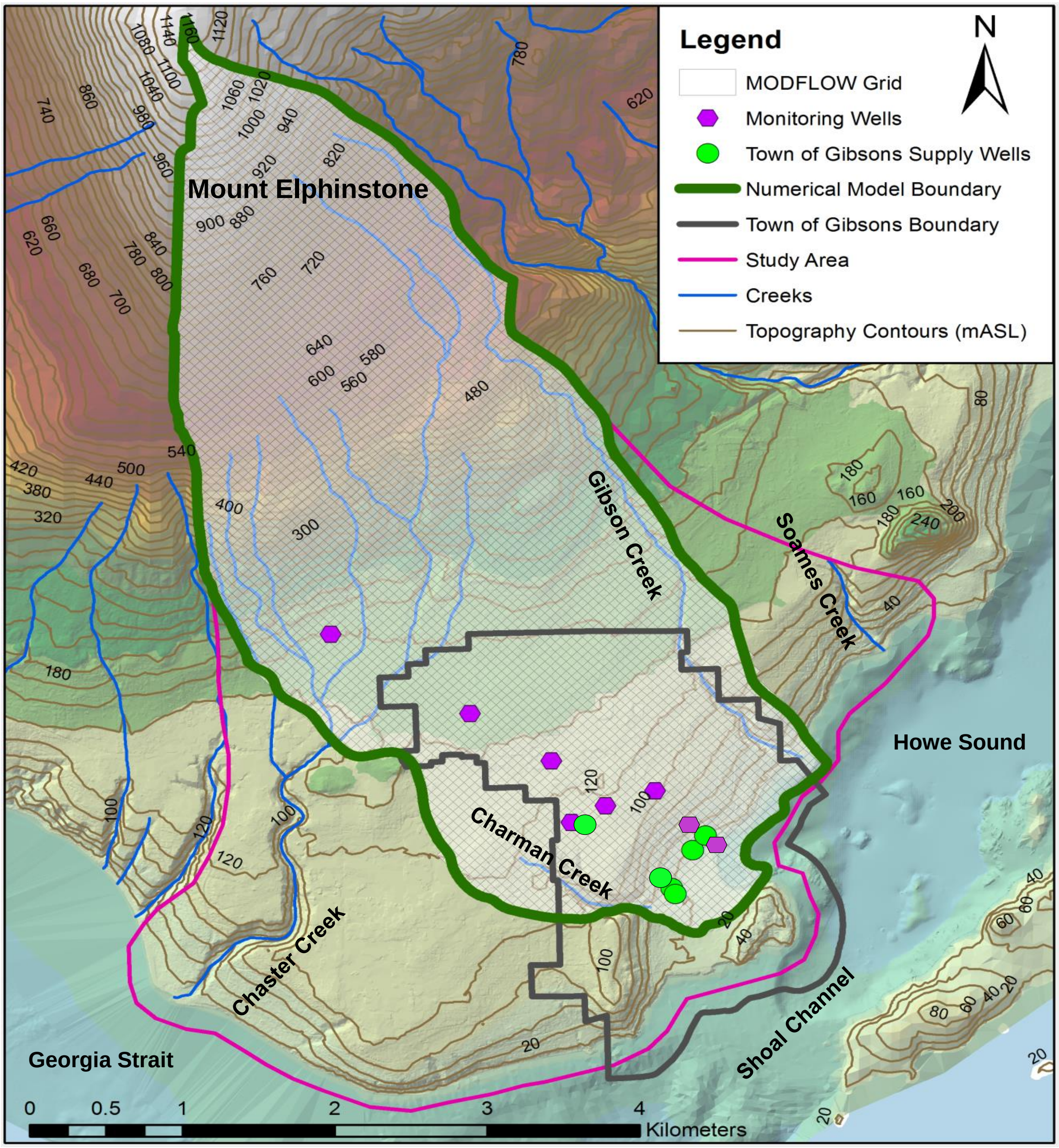


Figure A1: General Study Area and Model Domain Boundary

The new Town water supply wells (TW; TW5 and TW6) and monitoring wells (MW18-01 and MW18-02) were added as additional points. The numerical model grid was also modified by further refinement around the TWs. The model domain now consists of 172 rows, 127 columns and 5 layers orientated 45° to the northwest. This aligns with the principal direction of groundwater flow through the Gibsons Aquifer. These further grid refinement around the TW's facilitates more accurate flow distribution and groundwater head estimation at the pumping wells and their associated monitoring wells.

Like the previous model setup, three types of boundaries were included in the model, including:

- A no flow boundary around the perimeter of the domain (gray color; Figure A2) based on the geological and watershed constrains developed in Leapfrog works model. The updated model still suggests that the thickest pre-Vashon sediments are constrained in a northwest to southeast orientation. As such the capture zones for the TW's are oriented opposite to the direction of flow in a northwest direction.
- A constant head boundary at the shoreline in Lower Gibsons (red color; Figure A2). The Gibsons Aquifer is pressurized in Lower Gibsons, and it is assumed that the aquifer remains confined underneath the harbour.
- A constant flux boundary to represent the various recharge zones at different elevations, including:
    1. Mountain block recharge (magenta color; Figure A2),
    2. Direct infiltration of surface runoff water at the base of Mt. Elphinstone (green color; Figure A2),
    3. Indirect infiltration of precipitation over Upper Gibsons and part of Lower Gibsons (blue color; Figure A3), and
    4. No flux (white color; Figure A3) and was applied where the Gibsons Aquifer is known to be pressurized in Lower Gibsons.

The active TWs (TW1, TW3, TW4) and inactive TWs (TW5 and TW6) are also included in Figure A2 for reference.

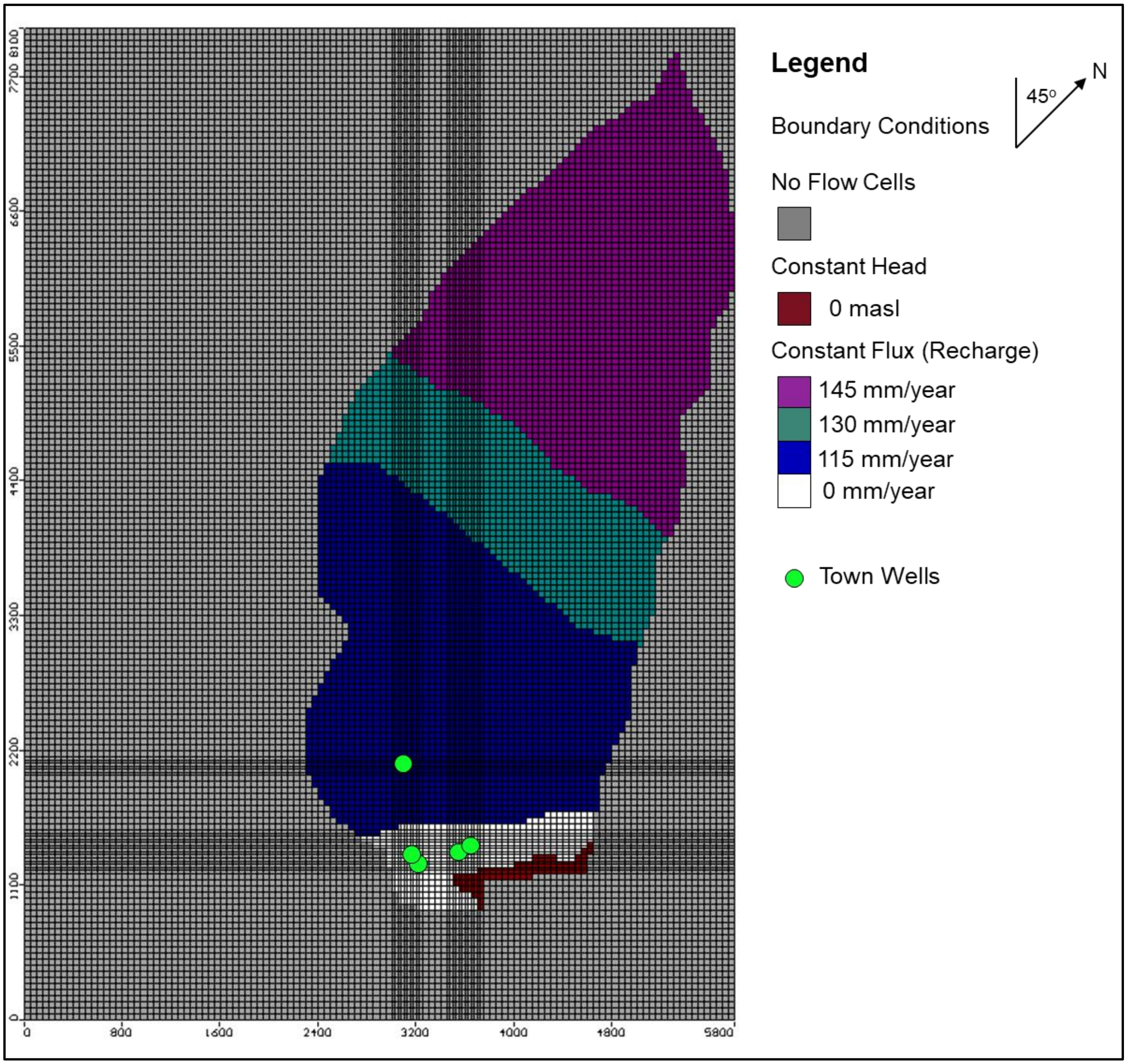


Figure A2: Hydraulic Boundary Conditions Details

2.0 HYDRAULIC CONDUCTIVITY DISTRIBUTION

Consistent with the distribution of surficial sediments and bedrock across the Study Area (from the Leadfrog works model), the distribution of hydraulic conductivities remained consistent with the 2013 Aquifer mapping study, including the testing results from TW5 and TW6. Figure A3 shows the distribution of hydraulic properties assigned to the modeled stratigraphy from shallowest to deepest (Layer 1 to Layer 5). The hydraulic conductivity parameters for each stratigraphic unit or combination of units are summarized in Table A1.

Table A1: Hydraulic Properties for the Stratigraphic Units in the Study Area

Color	Description	Hydraulic Conductivity (m/s)
Green	Vashon till/ Capilano	2.0E-6
Red	Fractured Bedrock	5.0E-7
Blue	Intact/competent Bedrock	5.0E-8
Teal	Marine Silt (lower pre-Vashon) / Fractured bedrock	5.0E-7
White	pre-Vashon sands and gravels	2.2E-4

Notes: m/s means metres per second

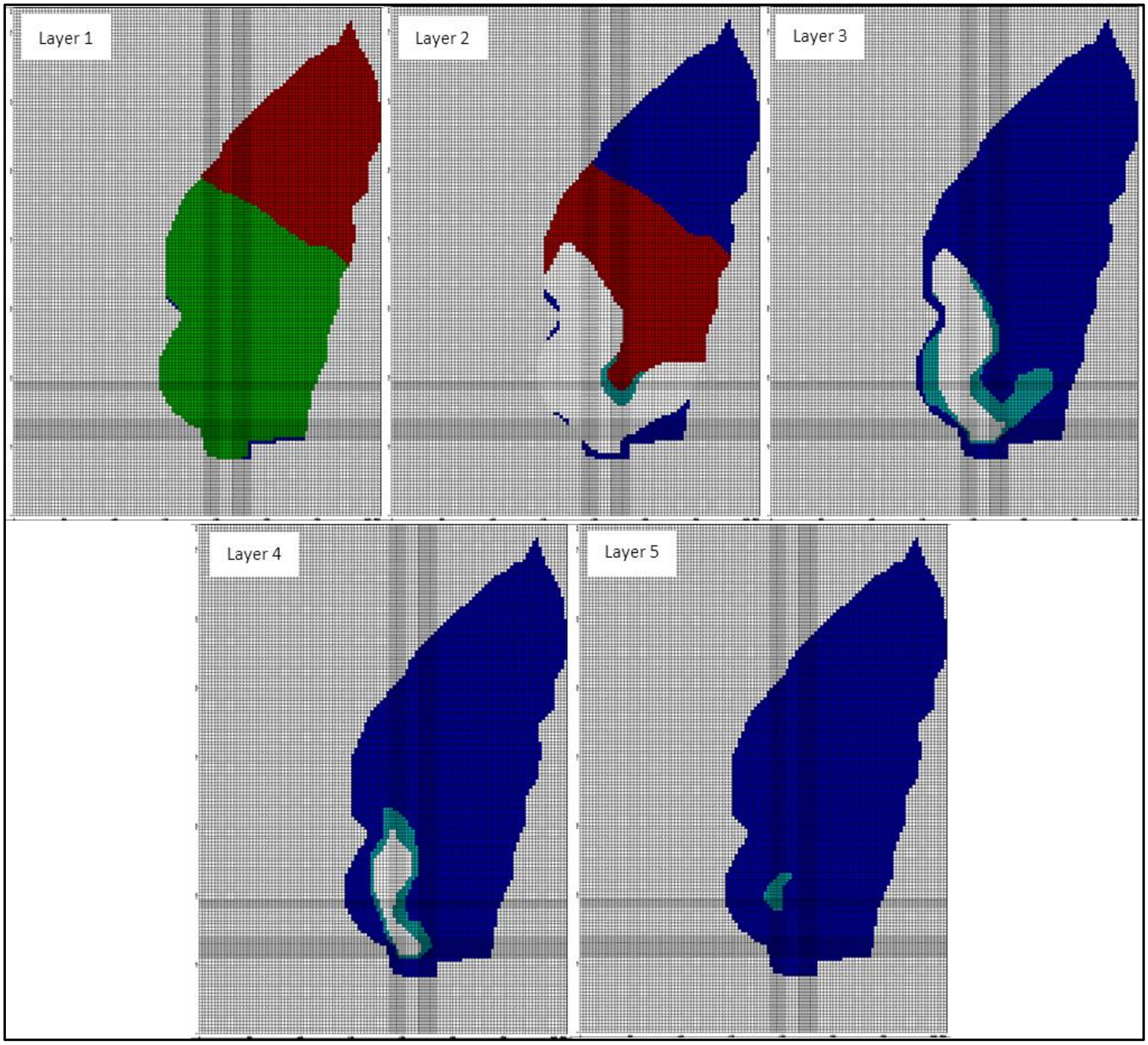


Figure A3: Distribution of Hydraulic Conductivities for the Study Area

3.0 CALIBRATION DATA

Groundwater level measurements from the TWs and monitoring wells, and the historical pumping rates for the active TWs, collected between 2009 and 2021, were compiled for model input and calibration. On an annual basis, Waterline had been:

- Collecting manual groundwater level measurements from accessible wells. For flowing wells (MW18-01, TW1, TW2, TW3, and TW4) a pressure gauge was used to measure the artesian pressure above the top of the well casing, which was then converted to a water elevation. Where a pressure gauge was not installed, the water level was calculated from the pressure transducer measurement and known hang depth,
- Downloading continuous (every 60-minutes) groundwater level readings from all monitoring wells. In select monitoring wells, continuous water levels were measured on a greater frequency (every 20-minutes) to capture changes in groundwater levels near the active TWs, and
- Compiling continuous groundwater level readings (daily maximum and minimum) and pumping rates measured from TW1, TW3, and TW4 using the Town's SCADA system.

4.0 CALIBRATION PROCESS

The model was calibrated for seven stress periods (SP1 to SP7) between 2009-2021. This was performed to maintain a better overall correlation between the pumping rate dynamics for active TWs (TW1, TW3 and TW4) and the recorded groundwater levels from the Gibsons Aquifer for that period. The chosen pumping rate for each period was the average rate, not including periods with no data or flow rates recorded as zero.

Built into the pumping rates for TW1 and TW4, was the overflow diversion rates documented by Waterline during the 2013 Aquifer Mapping Study, measured to be 163 cubic meters per day (m^3/d) and 107 m^3/d, respectively. In addition, a miscellaneous (Misc) daily diversion rate of 100 m^3/d was added to each stress period to account for pumping from other groundwater wells (private domestic and or commercial) completed in the Gibsons Aquifer, not monitored by the Town.

The modelled stress periods and corresponding pumping rates are summarized in Table A2. It should be noted that for each stress period, the pumping rates were assumed to be continuous, 24-hours a day, 7-days a week, 365-days a year.

Table A2: Numerical Model Stress Periods

Model Stress Periods						Pumping Rates						
Description	ID	Start Date	End Date	Length	Elapsed Time	TW1*	TW3	TW4*	TW5	TW6	Misc.	Total
				(days)	(days)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)	(m^3/d)
Steady-State Model	SP1	01-Jan-2009	01-Jan-2012	1,095	1,095	-338	-1,667	-271	0	0	-100	-2,376
TW3 Low Pumping Period	SP2	01-Jan-2012	14-Feb-2013	410	1,505	-304	-880	-224	0	0	-100	-1,508
TW1 & TW4 pumping segment (2012-2017)	SP3	14-Feb-2013	31-Dec-2016	1,416	2,921	-304	-880	-321	0	0	-100	-1,605
TW1 Low Pumping Period	SP4	31-Dec-2016	10-Aug-2019	952	3,874	-304	-880	-321	0	0	-100	-1,605
TW6 - 48 Hours Aquifer Test	SP5	10-Aug-2019	12-Aug-2019	2	3,876	-304	-880	-321	0	-2033	-100	-3,638
TW4 Low Pumping Period	SP6	12-Aug-2019	07-Jul-2020	329	4,205	-299	-880	-321	0	0	-100	-1,600
TW1&TW3&TW4 Increased Pumping Rates	SP7	07-Jul-2020	21-Sep-2021	441	4,646	-569	-880	-780	0	0	-100	-2,329

Notes: m^3/d means cubic metres per day; * indicates that the overflow diversion rates are included in the pumping rates; SP means stress period

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5.0 CALIBRATION RESULTS

The model calibration was achieved based on 81 historical measured heads which were collected between 2011 and 2021 at the pumping and monitoring wells. These manual head measurements were distributed across all the stress periods. The head calibration results are presented in a calibration graph, included as Figure A4.

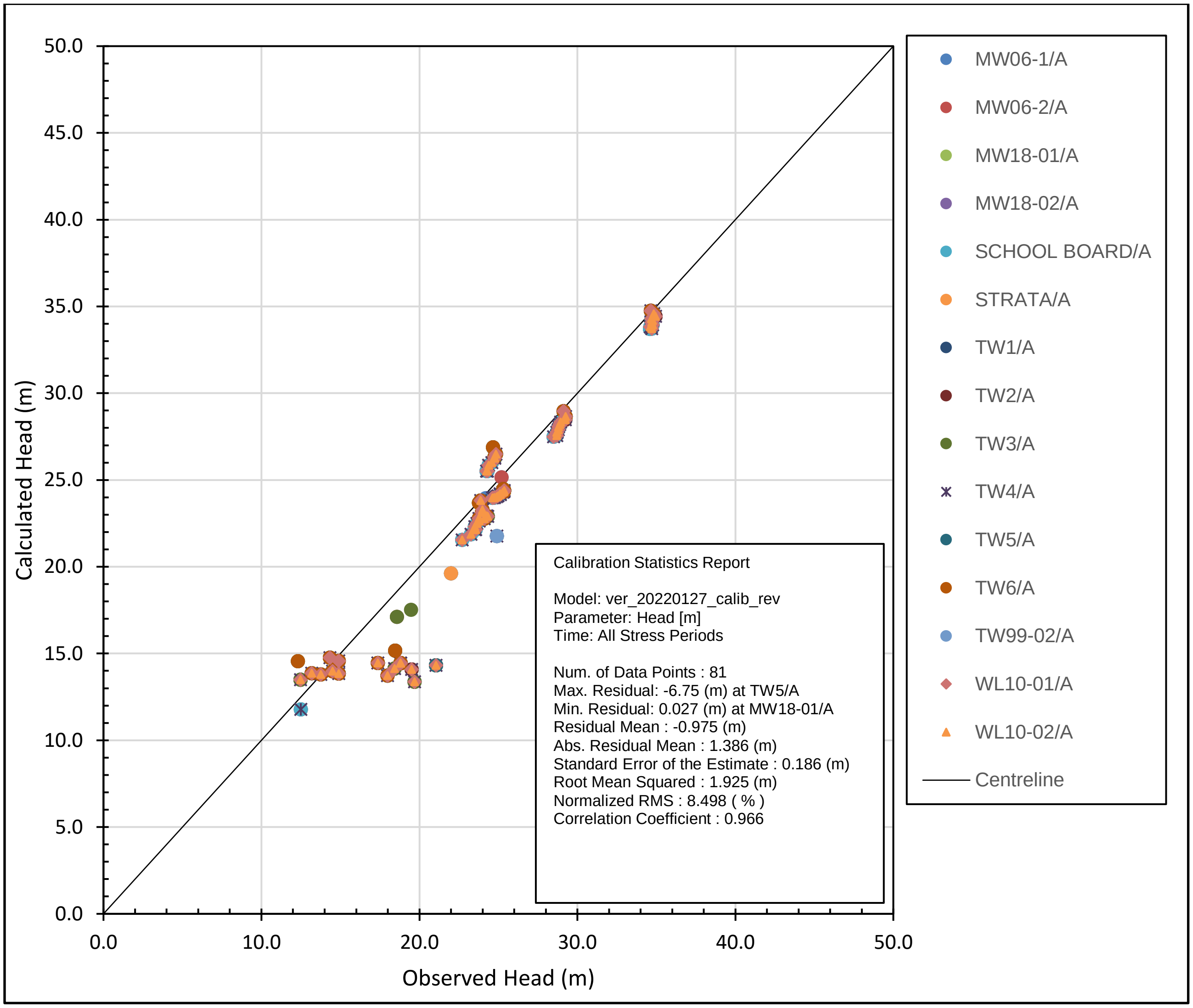


Figure A4: Head Calibration (Observed vs. Calculated)

The normalized root mean squared for all the measured heads value versus model predicted heads, calculated as 8.5% and is acceptable, given the size and complexity of the modelled area. In addition, it should be noted that the simulated water levels in the pumping center in the model do not account for well losses, daily diversion rate variability at the time of actual water level measurements. These factors also contribute to the observed discrepancies between the simulated and measured water levels in calibration process.

6.0 PARTICLE TRACKING SIMULATION

MODPATH/MODPATH-PLOT package in MODFLOW was used to compute and display three-dimensional particle path-lines. MODPATH/MODPATH-PLOT is a post-processing package developed by USGS that uses a semi-analytical particle tracking scheme to compute particle flow paths (cell by cell) until the particle is terminated by a boundary or internal source or sink. MODPATH is the code that calculates particle flow paths and MODPATH-PLOT graphically displays the results. Particles can be specified to track either forwards or backwards.

7.0 PREDICTIVE SIMULATION

The predictive modelling scenarios and the simulation results have been discussed in Sections 4.3 and Section 5.0 of the report, respectively. To achieve the desired groundwater demand for each groundwater use scenario, different pumping rates were chosen for each TW (active and inactive), with the modelled pumping rates summarized in Table A3.

Table A3: Summary of Groundwater Use Scenarios and Corresponding Daily Extraction Volumes

Groundwater Use		**Scenario 1**	**Scenario 2***	**Scenario 3***	**Scenario 4**
Population and Water Use	Total Population	5,322	10,000	10,000	-
	Water Use ($m^3/c/d$)	0.523	0.404	0.523	
Town of Gibsons Water Supply	TW1 (m^3/d)	432	600	799	1,095
	TW3 (m^3/d)	911	700	1,000	1,273
	TW4 (m^3/d)	687	700	1,000	1,145
	TW5 (m^3/d)	-	-	340	450
	TW6 (m^3/d)	753	2,040	2,091	2,091
Water Demand (m^3/d)		**2,783**	**4,040**	**5,230**	**6,054**
Additional Groundwater Extraction	TW1 Overflow (m^3/d)	163.3	163.3	163.3	163.3
	TW4 Overflow (m^3/d)	106.7	106.7	106.7	106.7
	Misc Use (m^3/d)	4.0	4.0	4.0	4.0
Total Daily Extraction Volume (m^3/d)		**3,057**	**4,314**	**5,504**	**6,328**

Notes: m^3/d means cubic metres per day; $m^3/c/d$ means cubic metres per capita per day; * indicates TW pumping rates are for full build-out or 10,000 people

The overflow diversion rates for TW1 and TW4 were kept constant from the calibration (Table A3). However, results from the Town's metering program and a recent field verified survey as part of groundwater licensing, suggested that well tag number (WTN) 74430 and 89798, were the only private domestic users near the Gibsons Aquifer. Based on Section 22.8 (b, i) of the WSA (Government of BC, 2022), which sets out precedence rights of 2.0 m^3/d per private dwelling, a lower miscellaneous use of 4 m^3/d was assumed for the predictive simulations (Table A3).

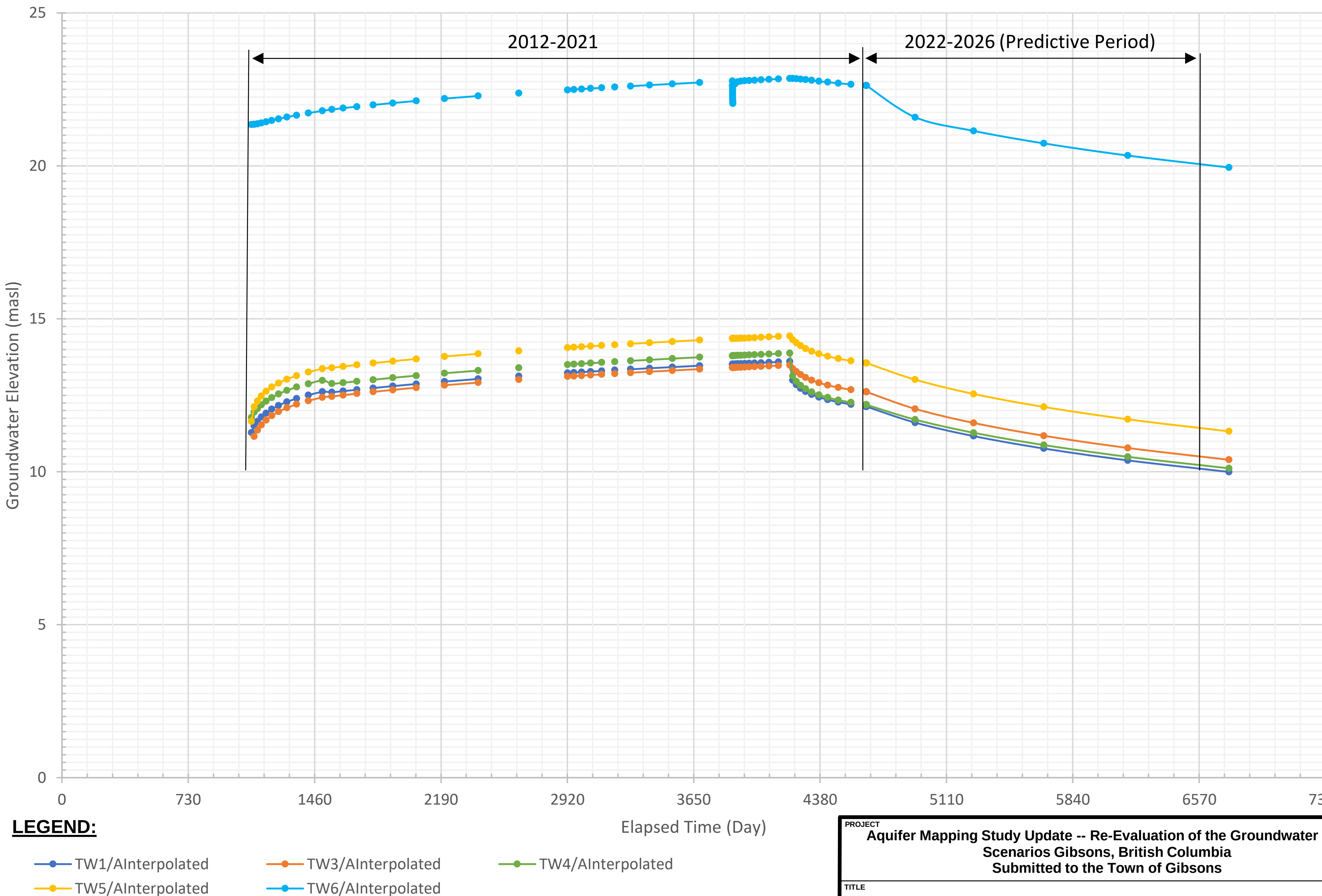
For the groundwater use scenarios 1 and 4, the pumping rates were simulated using a constant rate, where the pumping rates remained unchanged to assess the aquifer drawdown conditions. For the groundwater use scenarios 2 and 3, the pumping rates were simulated using a variable rate, to increase the annual pumping rate up to the total water demand rate, mimicking the changing water demand for the population growth period. The variable pumping rates used for the transient simulation are summarized below in Table A4.

Table A4: Summary of the Population Projections for 10,000 People (Full Build-out of the Town) and the Corresponding Town Well Pumping Rates

Groundwater Use Scenario		Projected Population (2022 to 2050)																											
		Yr. 1	**Yr. 2**	**Yr. 3**	**Yr. 4**	**Yr. 5**	**Yr. 6**	**Yr. 7**	**Yr. 8**	**Yr. 9**	**Yr. 10**	**Yr. 11**	**Yr. 12**	**Yr. 13**	**Yr. 14**	**Yr. 15**	**Yr. 16**	**Yr. 17**	**Yr. 18**	**Yr. 19**	**Yr. 20**	**Yr. 21**	**Yr. 22**	**Yr. 23**	**Yr. 24**	**Yr. 25**	**Yr. 26**	**Yr. 27**	**Yr. 28**
		5,139	5,268	5,400	5,535	5,673	5,815	5,960	6,109	6,262	6,418	6,579	6,743	6,912	7,085	7,262	7,443	7,629	7,820	8,016	8,216	8,421	8,632	8,848	9,069	9,296	9,528	9,766	10,000
Scenario 2 Pumping Rates	TW1 (m^3/d)	400	400	400	400	450	450	450	450	500	500	500	500	550	550	550	550	600	600	600	600	600	600	600	600	600	600	600	600
	TW3 (m^3/d)	400	400	400	400	450	450	450	450	500	500	500	500	600	600	600	600	700	700	700	700	700	700	700	700	700	700	700	700
	TW4 (m^3/d)	400	400	400	400	450	450	450	450	500	500	500	500	600	600	600	600	700	700	700	700	700	700	700	700	700	700	700	700
	TW5 (m^3/d)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	TW6 (m^3/d)	876	928	981	1,036	942	999	1,058	1,118	1,030	1,093	1,158	1,224	1,042	1,112	1,184	1,257	1,082	1,159	1,238	1,319	1,402	1,487	1,574	1,664	1,755	1,849	1,946	2,040
	Total Cumulative Volume (m^3/d)	***2,076***	***2,128***	***2,181***	***2,236***	***2,292***	***2,349***	***2,408***	***2,468***	***2,530***	***2,593***	***2,658***	***2,724***	***2,792***	***2,862***	***2,934***	***3,007***	***3,082***	***3,159***	***3,238***	***3,319***	***3,402***	***3,487***	***3,574***	***3,664***	***3,755***	***3,849***	***3,946***	***4,040***
Scenario 3 Pumping Rates	TW1 (m^3/d)	450	450	450	450	500	500	500	500	550	550	550	550	600	600	600	600	650	650	650	650	700	700	700	700	799	799	799	799
	TW3 (m^3/d)	450	450	450	450	500	500	500	500	600	600	600	600	700	700	700	700	800	800	800	800	900	900	900	900	1,000	1,000	1,000	1,000
	TW4 (m^3/d)	450	450	450	450	500	500	500	500	600	600	600	600	700	700	700	700	800	800	800	800	900	900	900	900	1,000	1,000	1,000	1,000
	TW5 (m^3/d)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	218	340
	TW6 (m^3/d)	1,338	1,405	1,474	1,545	1,467	1,541	1,617	1,695	1,525	1,607	1,691	1,777	1,615	1,705	1,798	1,893	1,740	1,840	1,942	2,047	1,904	2,015	2,127	2,243	2,063	2,084	2,091	2,091
	Total Cumulative Volume (m^3/d)	***2,688***	***2,755***	***2,824***	***2,895***	***2,967***	***3,041***	***3,117***	***3,195***	***3,275***	***3,357***	***3,441***	***3,527***	***3,615***	***3,705***	***3,798***	***3,893***	***3,990***	***4,090***	***4,192***	***4,297***	***4,404***	***4,515***	***4,627***	***4,743***	***4,862***	***4,983***	***5,108***	***5,230***

Notes: m^3/d means cubic metres per day

Appendix B:
Output Charts from Numerical Modelling Update



PROJECT

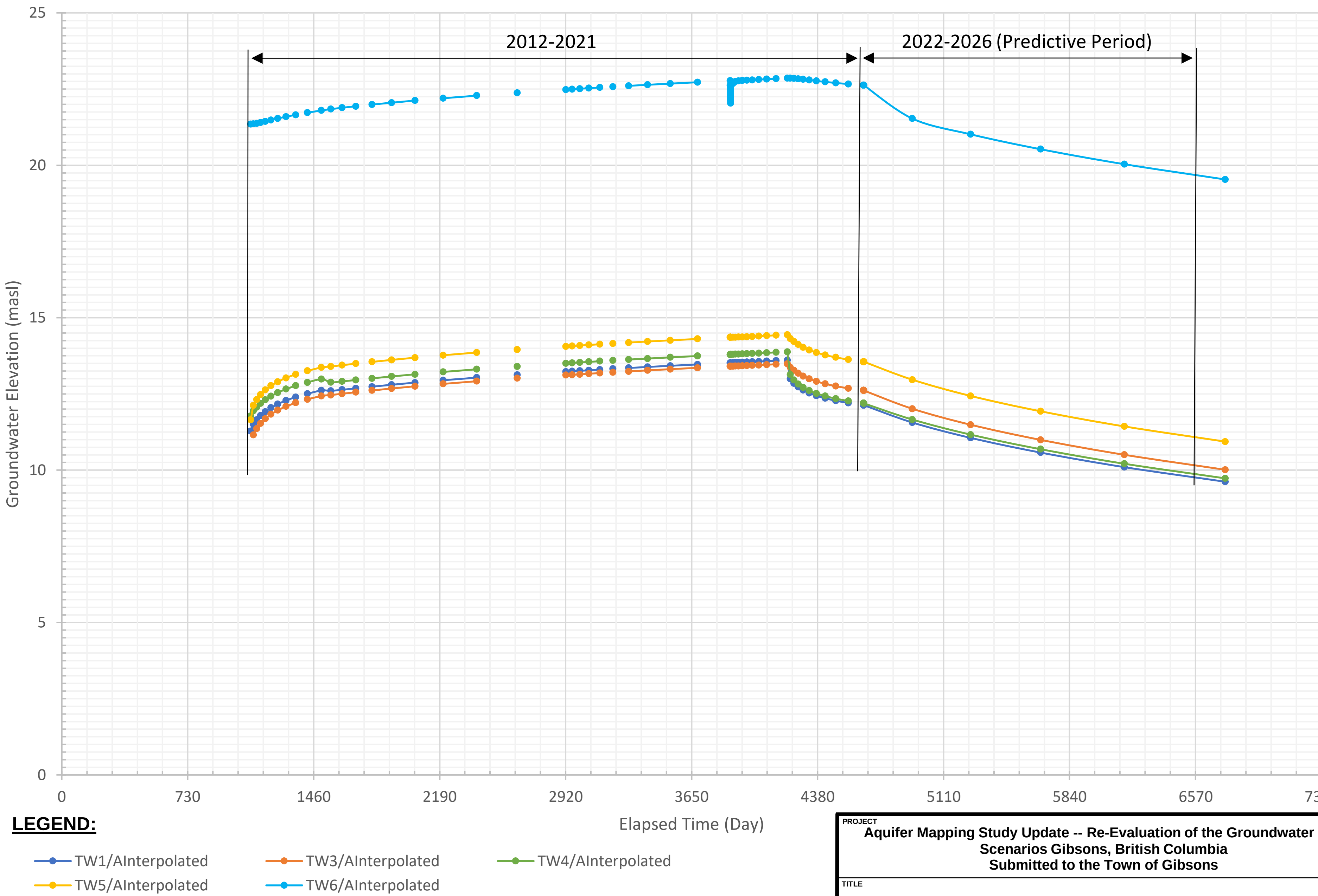
Aquifer Mapping Study Update -- Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE

SCENARIO "1a" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.	
PROJECT: 1578-21-003	
COMPILED BY: SN	**FIGURE B1**
DATE ISSUED: February 2021	
REVISED: -	



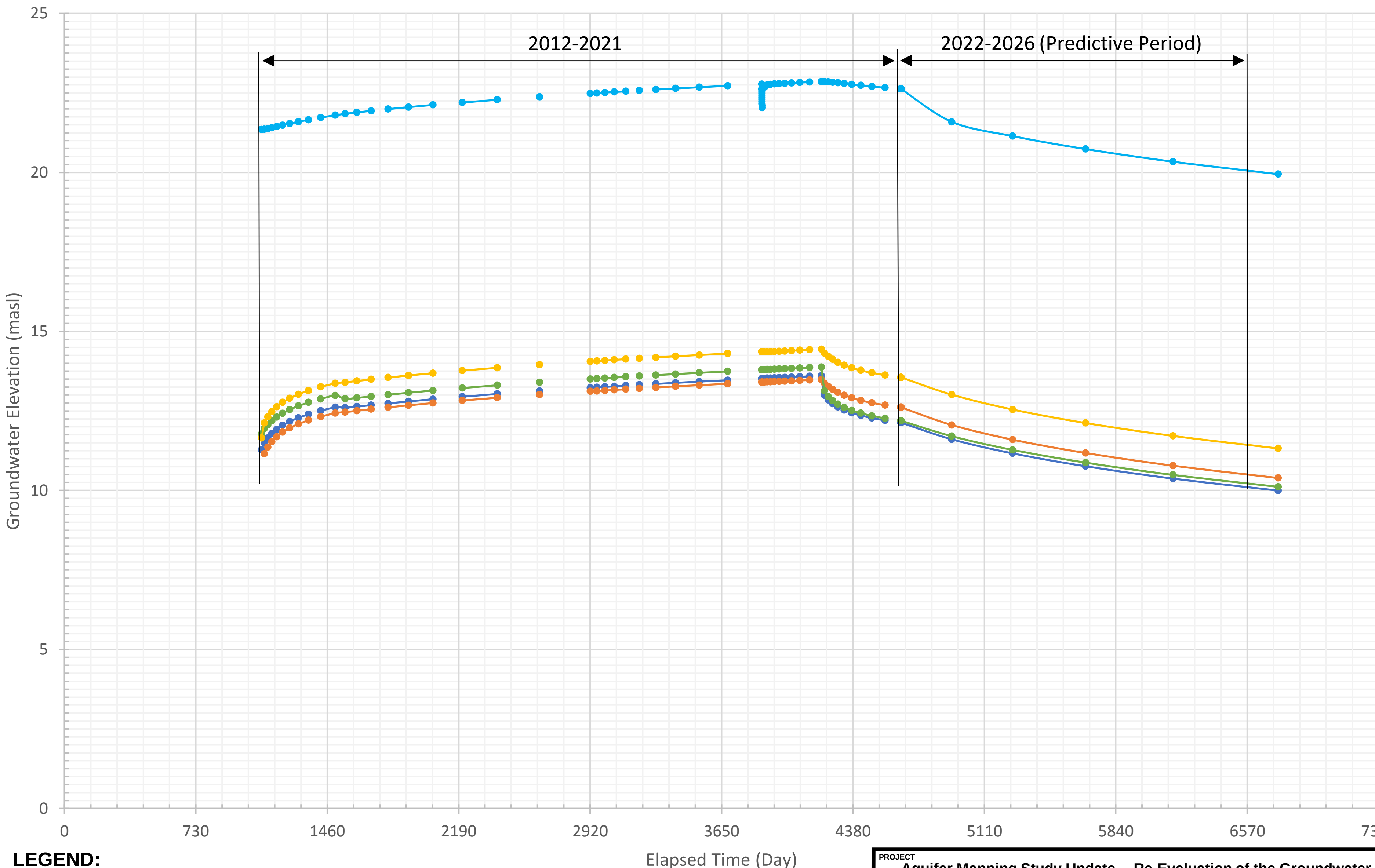
PROJECT
Aquifer Mapping Study Update -- Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE
SCENARIO "1b" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT:1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B2



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

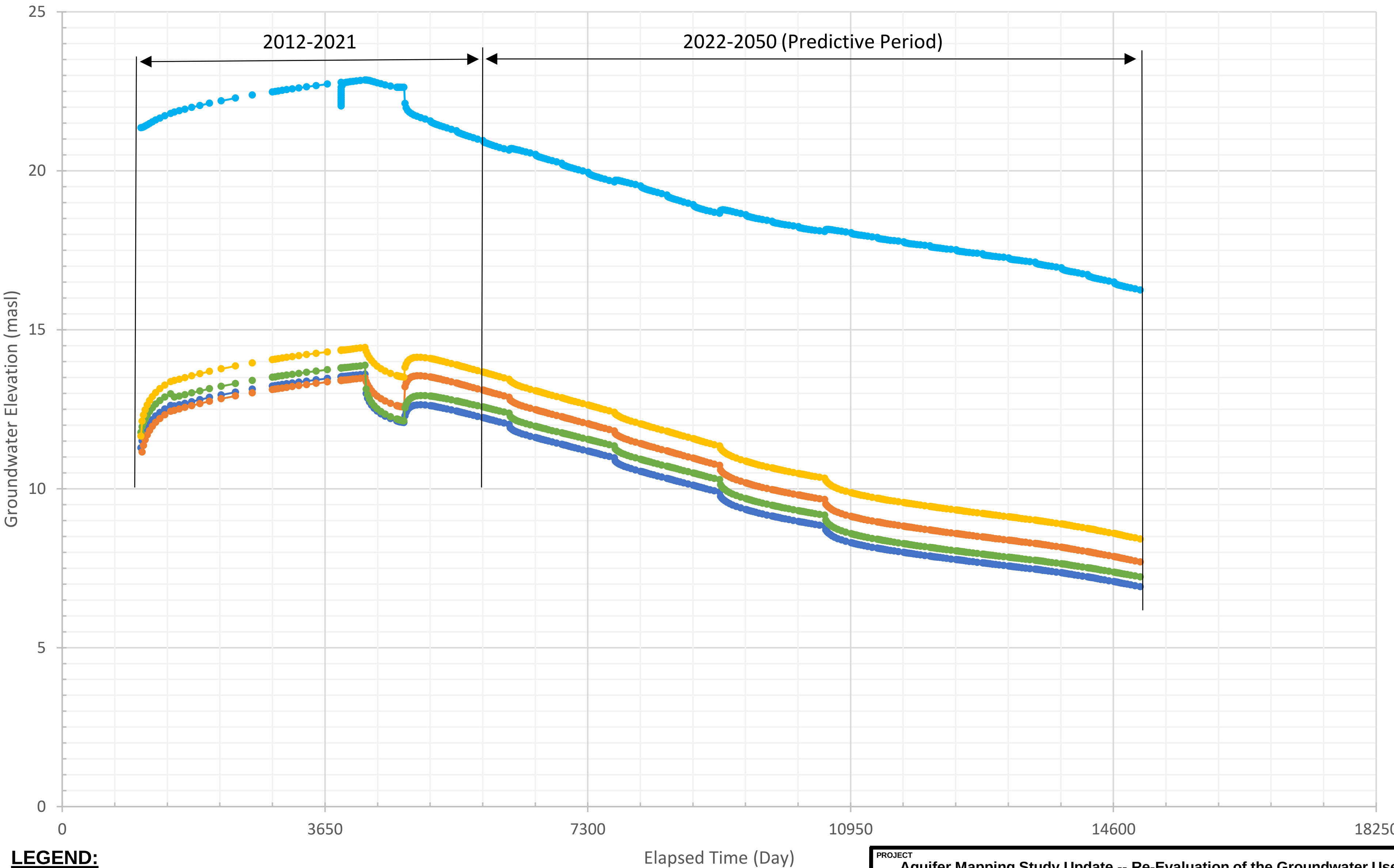
PROJECT
Aquifer Mapping Study Update -- Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE
SCENARIO "1c" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT:1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B3

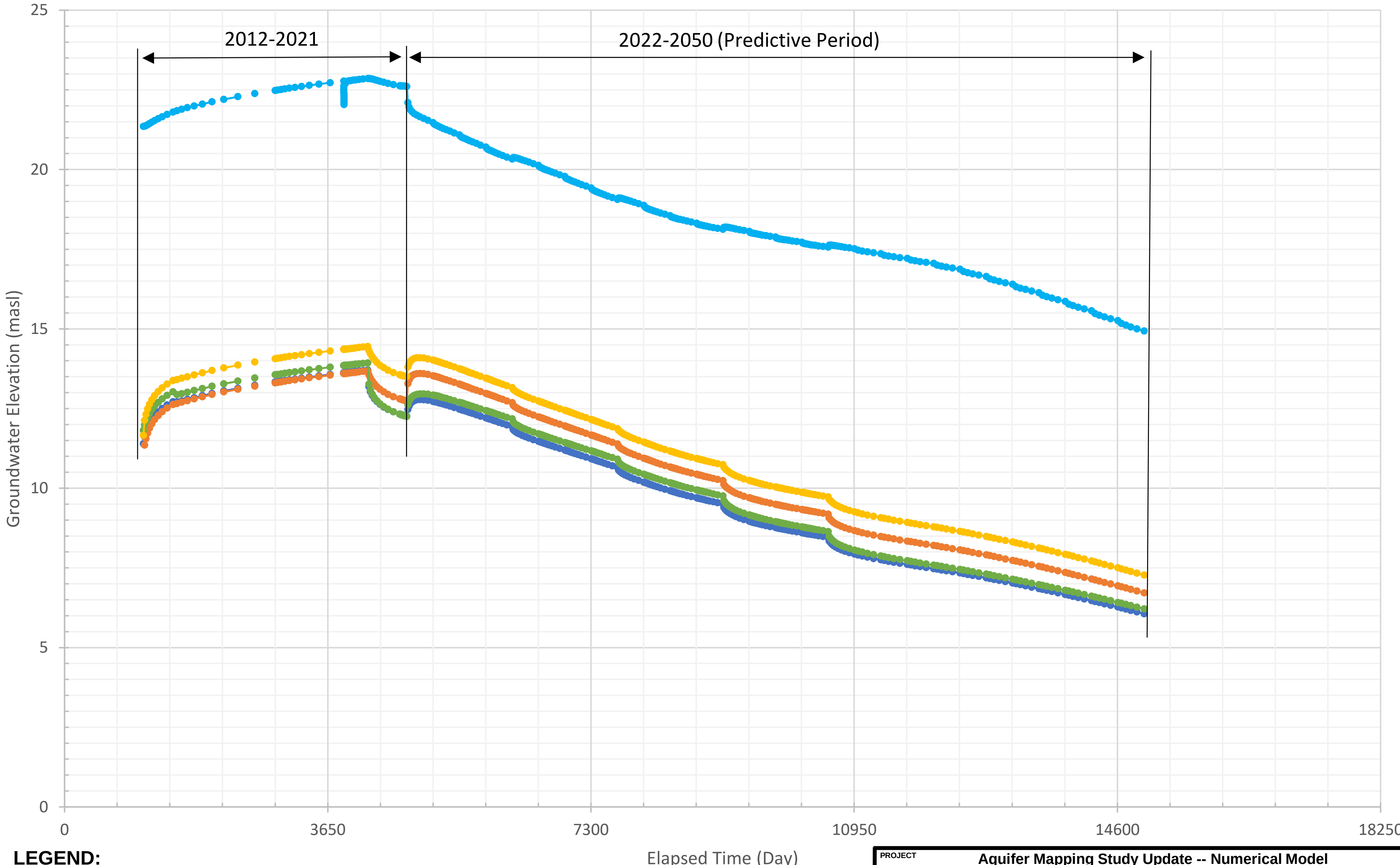


LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

PROJECT	Aquifer Mapping Study Update -- Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons
TITLE	**SCENARIO "2a" PREDICTION**

Waterline	**PREPARED BY:** Waterline Resources Inc. **PROJECT:** 1578-21-003 **COMPILED BY:** SN **DATE ISSUED:** February 2021 **REVISED:** -	**FIGURE B4**



LEGEND:

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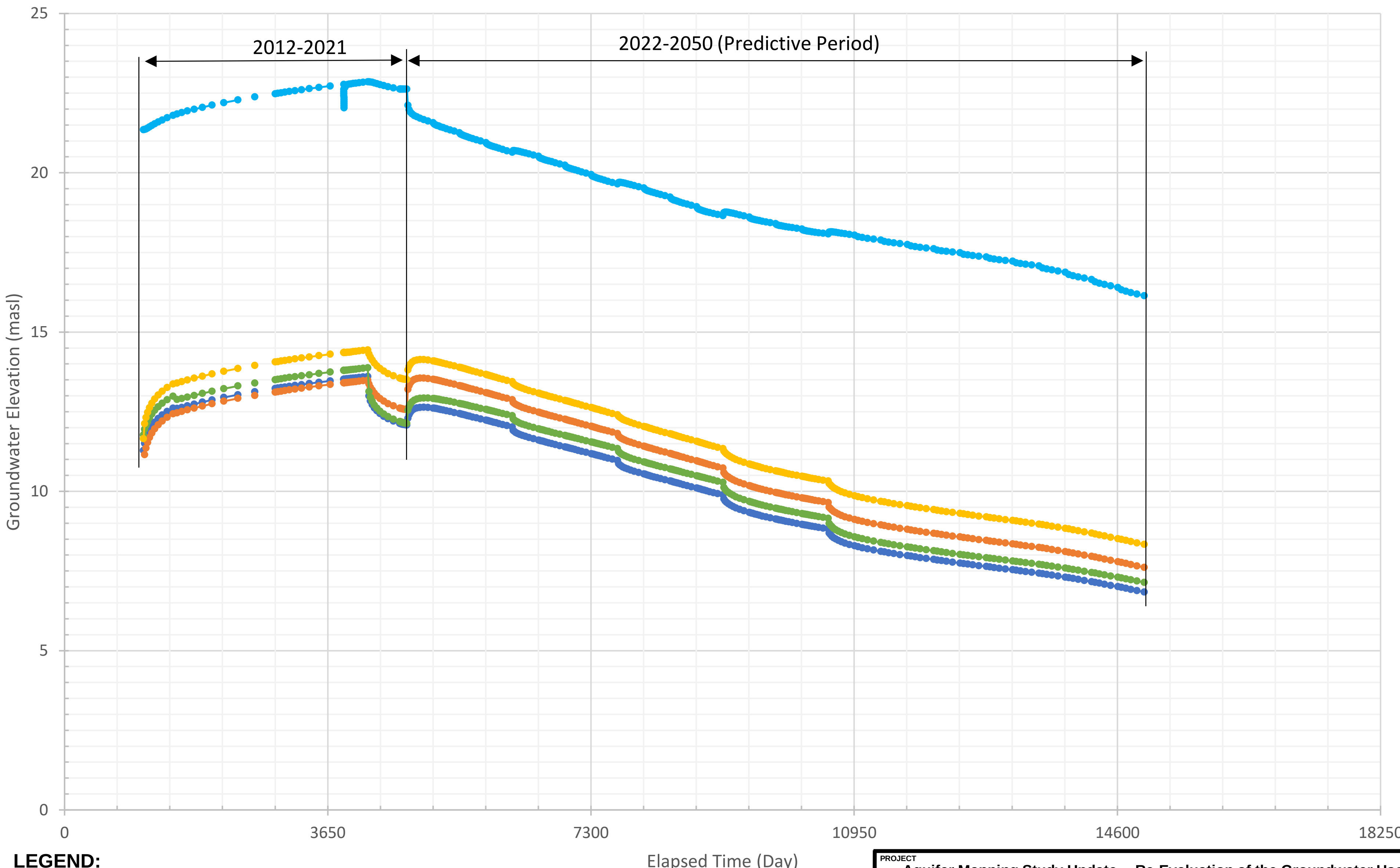
TW4/AInterpolated
TW5/AInterpolated
TW6/AInterpolated

PROJECT	**Aquifer Mapping Study Update -- Numerical Model and Groundwater Use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons**
TITLE	**SCENARIO "2b" PREDICTION**

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

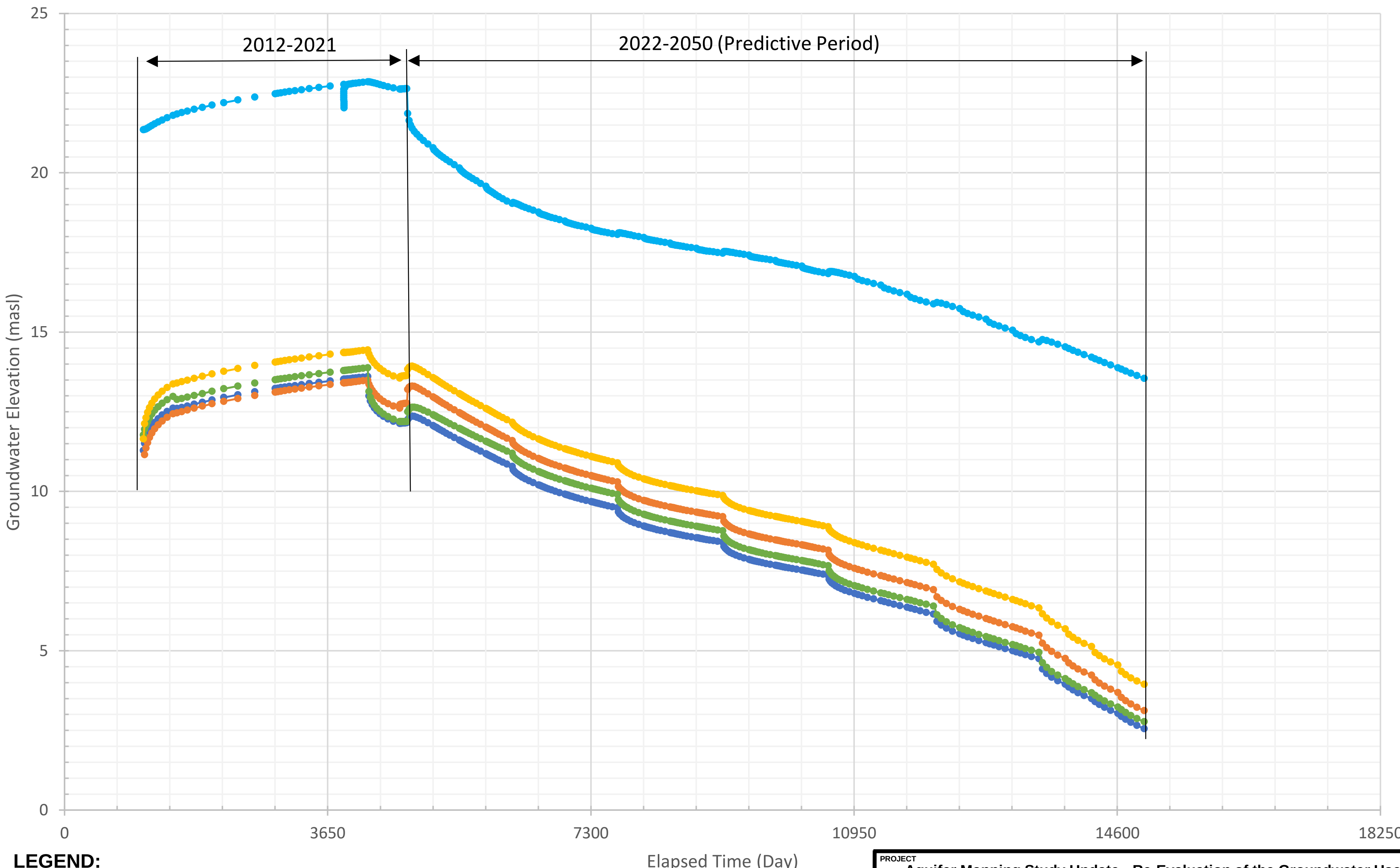
FIGURE B5



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

PROJECT	Aquifer Mapping Study Update -- Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons
TITLE	**SCENARIO "2c" PREDICTION**
Waterline	**PREPARED BY:** Waterline Resources Inc. **PROJECT:**1578-21-003 **COMPILED BY:** SN **DATE ISSUED:** February 2021 **REVISED:** -
	FIGURE B6



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

PROJECT

Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

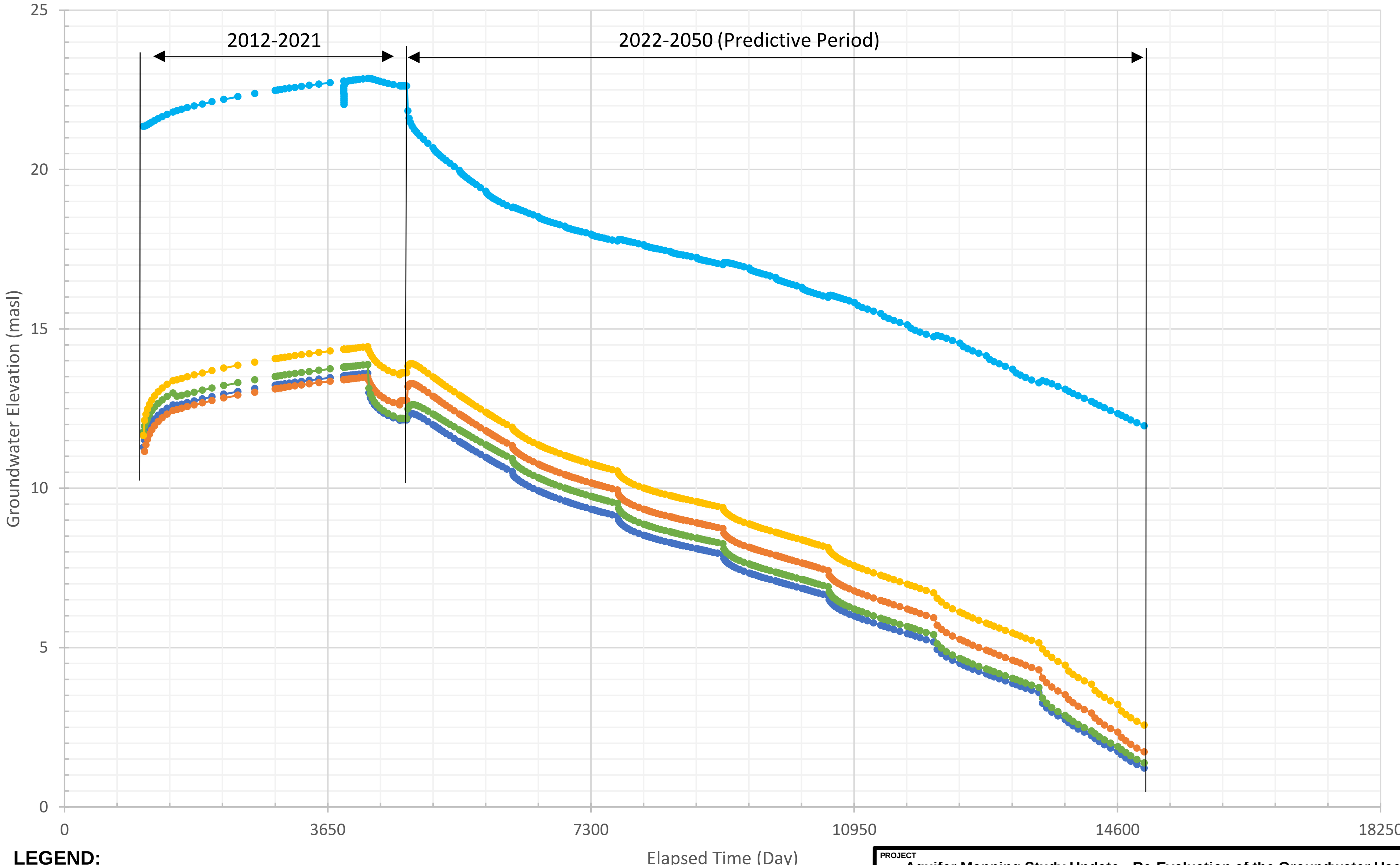
TITLE

SCENARIO "3a" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT: 1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B7



LEGEND:

TW1/AInterpolated
TW3/AInterpolated
TW4/AInterpolated
TW5/AInterpolated
TW6/AInterpolated

PROJECT

Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE

SCENARIO "3b" PREDICTION

PREPARED BY: Waterline Resources Inc.
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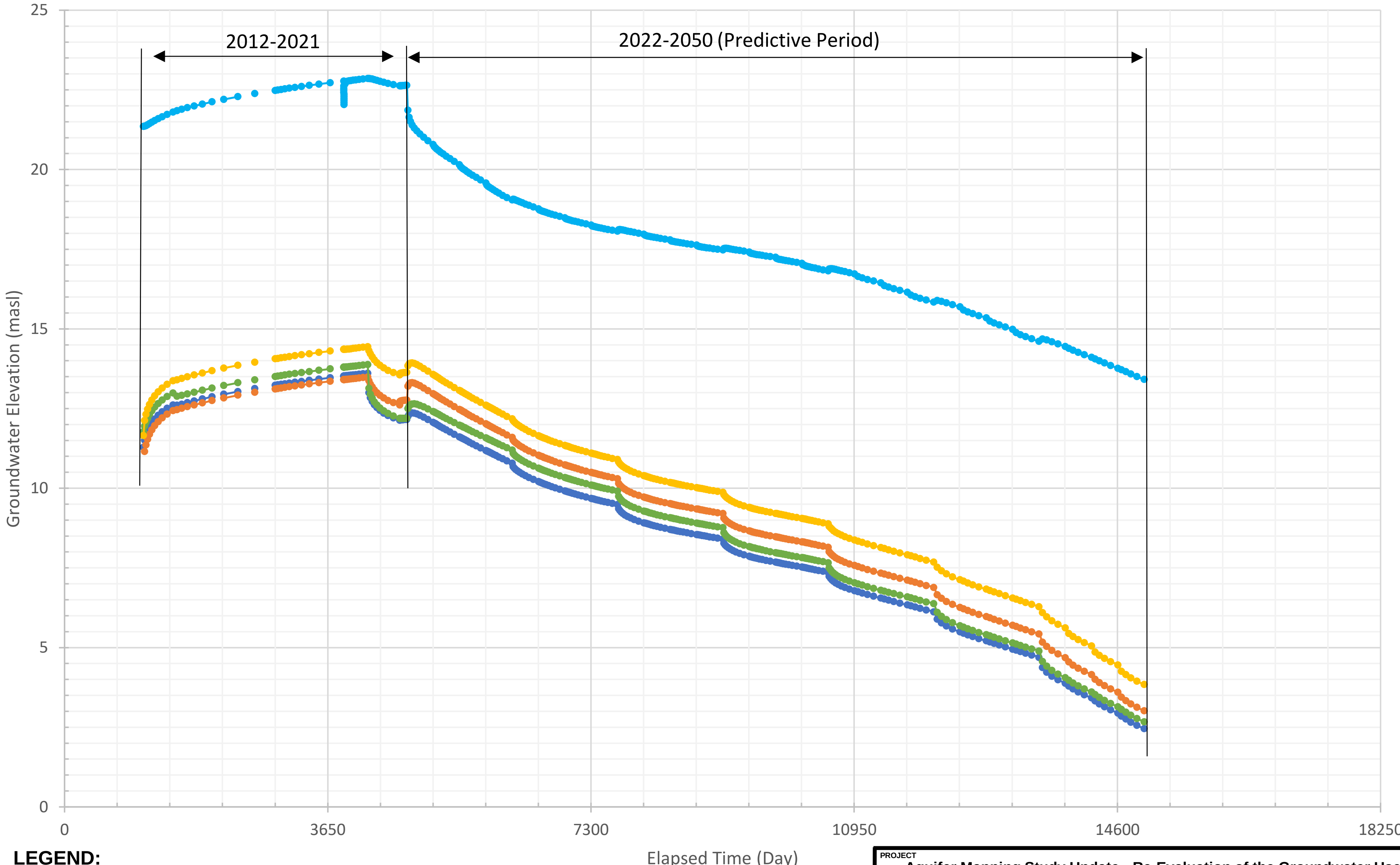
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B8



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

PROJECT

Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE

SCENARIO "3c" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
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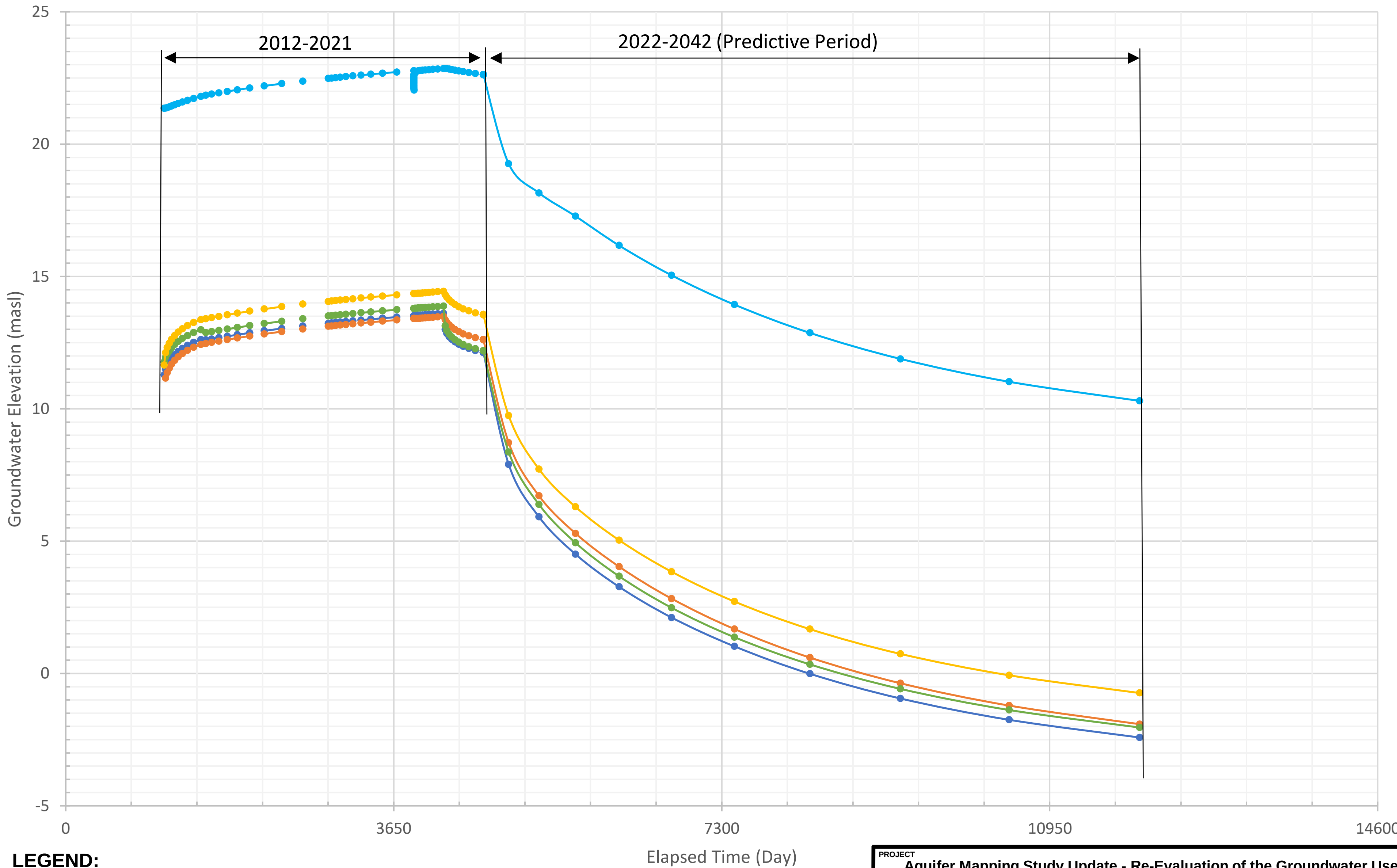
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B9



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

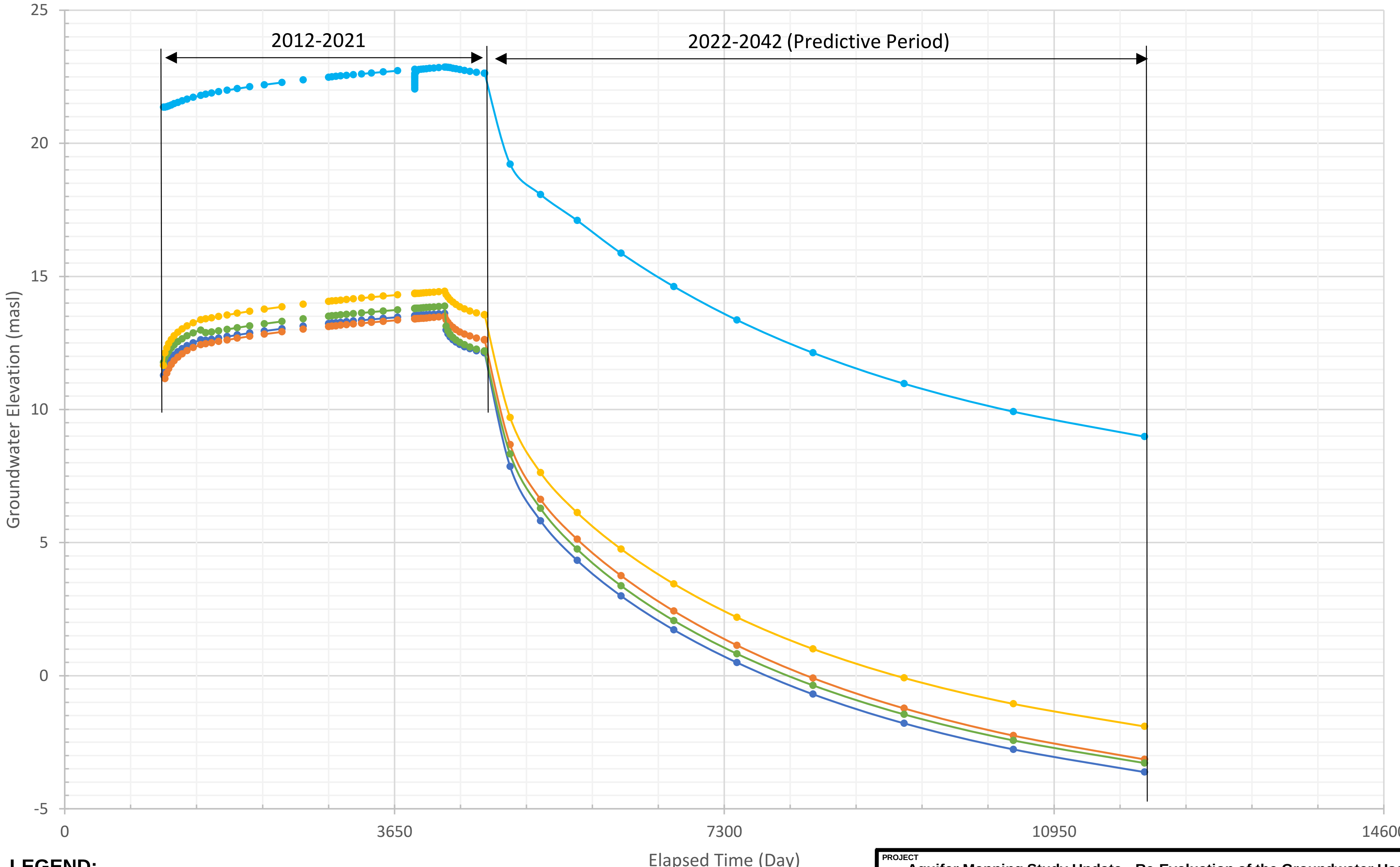
PROJECT
Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia
Submitted to the Town of Gibsons

TITLE
SCENARIO "4a" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT:1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
REVISED: -

FIGURE B10



LEGEND:

TW1/AInterpolated
TW3/AInterpolated
TW4/AInterpolated
TW5/AInterpolated
TW6/AInterpolated

PROJECT
Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons

TITLE
SCENARIO "4b" PREDICTION

Waterline

PREPARED BY: Waterline Resources Inc.
PROJECT:1578-21-003
COMPILED BY: SN
DATE ISSUED: February 2021
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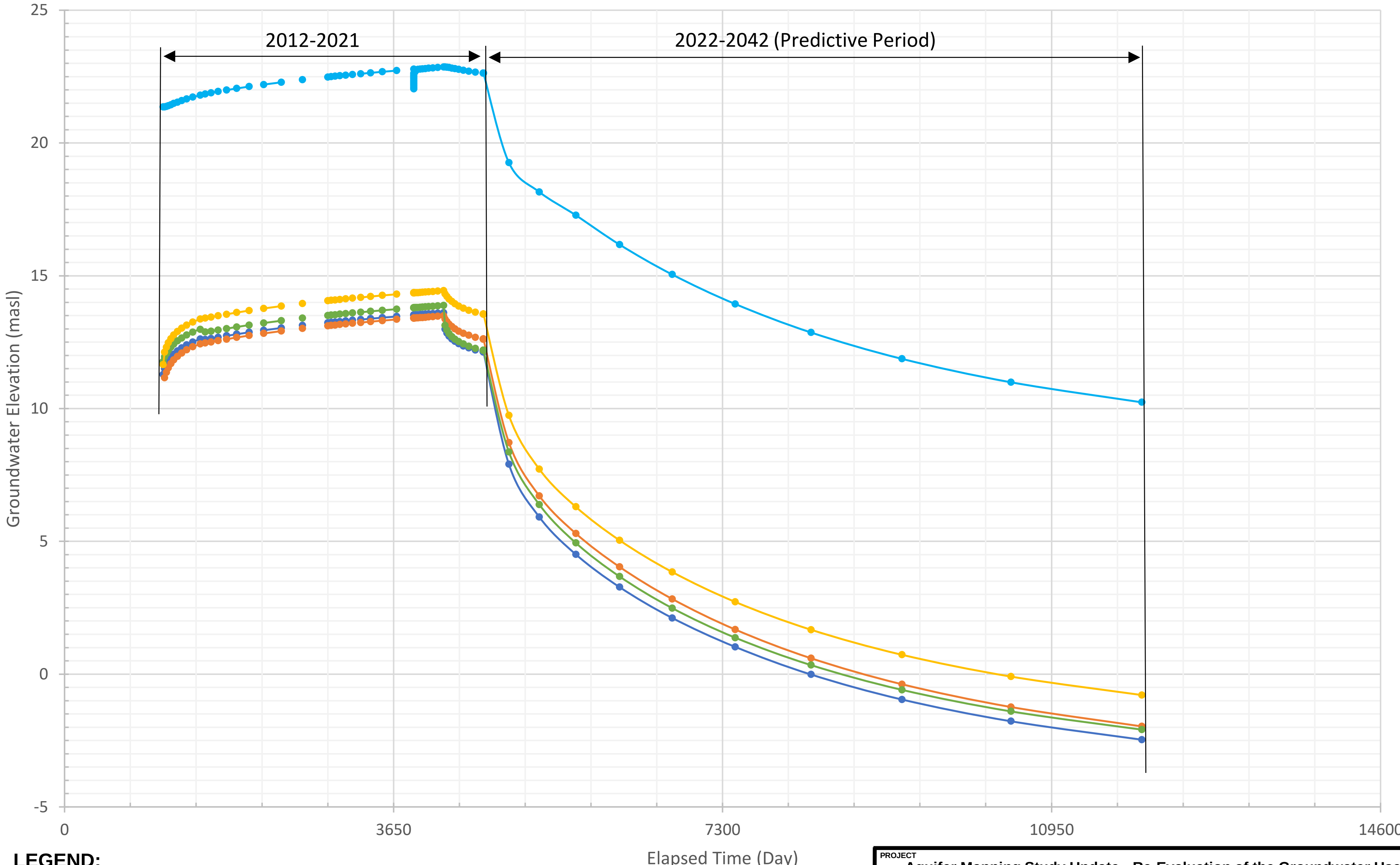
FIGURE B11



LEGEND:

- TW1/AInterpolated
- TW3/AInterpolated
- TW4/AInterpolated
- TW5/AInterpolated
- TW6/AInterpolated

PROJECT Aquifer Mapping Study Update - Re-Evaluation of the Groundwater Use Scenarios Gibsons, British Columbia Submitted to the Town of Gibsons		
TITLE SCENARIO "4c" PREDICTION		
Waterline	PREPARED BY: Waterline Resources Inc. PROJECT:1578-21-003 COMPILED BY: SN DATE ISSUED: February 2021 REVISED: -	FIGURE B12