Bear Brook Watershed Study – Water Resources Characterization Report

January 2025

Prepared for:

Ottawa

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Summary of Findings

The Bear Brook Watershed is an area that is rich in surface water and groundwater resources. The area exhibits complex hydrology due to the presence of varying soils including large expanses of clay and sands. Diverse landcover is found including urban, agricultural and natural systems. Key findings from the current existing conditions report include:

- **Watercourses**: The watershed includes approximately 1,700 km of mapped watercourses, with the majority classified as first-order streams.
- **Municipal Drains**: Many watercourses (approximately 14%) are designated as municipal drains, facilitating water conveyance in agricultural areas. The *Drainage Act* is being used increasingly in urban expansion areas to facilitate legal and sufficient outlet. Design standards for municipal drains do not necessarily address natural hazard concerns under the *Conservation Authorities Act*, leading to competing priorities and requiring increased collaboration between water resources managers.
- **Tile Drainage**: Approximately 17% of the Bear Brook Watershed is tile drained, predominantly on agricultural lands with clay soils. Tile drainage systems aid in runoff management, but they reduce water retention in soils, potentially lowering groundwater levels and contributing to downstream pollution through nutrient leaching.
- **Headwater Drainage Features (HDFs)**: Important for seasonal water storage, HDFs also provide habitat for various aquatic species. However, policies protecting these features vary, with specific policies employed in the City of Ottawa but unused in other areas of the watershed.
- **Surface Water Flow**: Flows in the Bear Brook River are dynamic and flashy; They vary significantly throughout the year, with spring freshets typically leading to annual peak flows. The watershed's ability to manage drought is heavily dependent on groundwater-fed baseflows. Recent data highlights the influence of climate variability, as above-normal rainfall in 2024, due to an active hurricane season, led to several flood events.
- **Water Budget Analysis**: The Bear Brook watershed model provides a detailed understanding of water inflows, outflows, and groundwater recharge. This analysis supports sustainable water resource management, particularly with respect to development planning in Ottawa. Maintaining watershed hydrology is emphasized.
- **Groundwater Quality and Drinking Water Protection**: Groundwater, a vital resource for drinking water and ecosystem health, is monitored to ensure compliance with safety standards. The Vars/Limoges municipal wells serve a significant population and are protected under Ontario’s Clean Water Act. The wells have delineated Wellhead Protection Areas (WHPAs) within which regulated activities prevent contamination.

This report underscores the need for integrated management approaches to balance water resource demands with ecological sustainability, particularly considering agricultural impacts, urban development pressures, and the uncertain future of weather and climate.

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Water Resources

Water resources, including surface water and groundwater features, are critical components of a watershed's hydrology. Understanding the flow, distribution, and quantity of water in these systems helps maintain a balance in the water cycle, which is crucial for sustaining ecosystems, agriculture, and human needs.

Capturing baseline conditions is an important step in the future components of the Watershed Planning Process. Scenario planning will be built upon these baselines, using different climate and land-use scenarios to predict potential impacts on water resources and related systems, such as natural hazards, natural heritage, and socioeconomic systems.

An understanding of the pre- and post-development hydrology and hydraulics of the Bear Brook River and its associated tributaries will be required to inform and support safe and sustainable development. This includes watershed implementation strategy recommendations, such as those associated with drainage, flood mitigation, design of erosion control and slope stability projects, groundwater recharge, baseflow targets, and drinking water systems.

The current report includes the characterization of surface water and groundwater features in the Bear Brook Watershed.

1. Surface Water Features

A comprehensive watercourse update was completed in 2024 on the Bear Brook Watershed. The purpose of this update was to increase spatial accuracy and confirm/correct flow direction of the existing watercourse network and identify any missing features visible through the evaluation of LiDAR derived hillshades.

Watercourses were defined as surface features with visible beds and banks that carry water for at least part of the year. They are represented as center lines and based on elevation data from LiDAR and aerial imagery. Several technical specifications were considered by a working group comprising of staff from the City of Ottawa, South Nation Conservation (SNC), Rideau Valley Conservation Authority (RVCA) and Mississippi Valley Conservation Authority (MCVA). The methodology for the development of this product is included in Appendix A.

The six major subwatersheds used in the Bear Brook Watershed Study were developed from watercourse and catchment data. The corrected watercourse product was compared to existing subcatchments derived from previous hydraulic modeling of the Bear Brook Watershed, which were developed through historical flood mapping exercises.

Where a discrepancy between the watercourse data and the hydraulic catchments existed, catchments were reevaluated using the ArcHydro suite of tools for ArcGIS to redefine the catchment boundaries based on the updated watercourse and LiDAR topographic data.

Once the smaller hydraulic catchments had been refined, they were grouped into the six major subwatersheds represented in Figure 1. The catchments were grouped mainly around significant tributaries.

An exception to this approach is found in the divide between the South Bear Brook and Main Bear Brook subwatersheds. Separating the unique conditions of the upper headwater reaches from the rest of the Bear Brook Watershed allows for more consistent evaluation and analysis.

1.1 Watercourses

Key Findings:

- Surface water features are extensive across the Bear Brook Watershed, with over 1,700 km of watercourses recently validated, mapped and corrected for flow direction through a desktop exercise.

There is a total of 1,700 km of watercourses within the six subwatersheds delineated in the Bear Brook Watershed (Figure 1). Table 1 presents watercourses by Strahler Order for each subwatershed. Stream Strahler Order is a hierarchical system used to classify streams based on the structure of a watershed's drainage network. The smallest headwater features are first-order streams. When two streams of the same order join, they form a stream of the next higher order. This classification method groups streams of similar size, depth, and flow characteristics, and it can also indicate the level of sensitivity a watercourse may have to disturbance or development. Lower-order streams, being smaller and often less stable, are typically more susceptible to environmental impacts than higher-order streams (Allan et al., 2007).

There are over 900 km of first order streams in the Bear Brook Watershed, accounting for over 50% of all watercourse length within the watershed (Table 2). By comparison, there's only 47 km of watercourse with a Strahler order of six along the main Bear Brook channel, representing less than 3% of watercourse length in the Watershed.

The watercourse update methodology also included categorizing by type. The percentage of each watercourse type by subwatershed is presented in Table 3.

Table 1. Stream Strahler Orders by subwatershed within the Bear Brook Watershed.

Strahler Order	South Bear Brook		Shaws Creek		Mer Bleue	
	# km	% Total	# km	% Total	# km	% Total
1	122.07	7.18	63.23	3.72	78.95	4.65
2	42.77	2.52	23.19	1.37	32.61	1.92
3	22.50	1.32	11.01	0.65	18.33	1.08
4	19.02	1.12	5.26	0.31	16.88	0.99
5	11.16	0.66	10.46	0.62	0.22	0.01
6	0	0	0	0	0	0
Strahler Order	**South Indian Creek**		**North Indian Creek**		**Main Bear Brook**	
	# km	**% Total**	**# km**	**% Total**	**# km**	**% Total**
1	174.66	10.28	136.69	8.05	328.34	19.32
2	63.42	3.73	54.62	3.21	136.22	8.02
3	36.79	2.17	30.09	1.77	90.48	5.33
4	26.53	1.56	29.86	1.76	32.99	1.94
5	17.54	1.03	9.62	0.57	6.44	0.38
6	0	0	0	0	47.05	2.77
8	0	0	0	0	0.11	0.01

Table 2. A summary of Stream Strahler Orders in the Bear Brook Watershed by length.

Strahler Order	Total Bear Brook Watershed	
	# km	% Total
1	903.94	53.20
2	352.84	20.77
3	209.20	12.31
4	130.54	7.68
5	55.43	3.26
6	47.05	2.77
8	0.11	0.01

Table 3. All watercourses found in the Bear Brook Watershed by type and associated percentage of total watercourses.

Watercourse Type	Percent (%) Watercourse Type by Subwatershed						Bear Brook Watershed Total
	South Bear Brook	Mer Bleue	Shaw's Creek	South Indian Creek	North Indian Creek	Main Bear Brook	
Constructed Drain Closed	0	0.06	0	0.10	0.03	0.26	0.46
Constructed Drain Open	1.39	1.91	1.44	2.94	1.91	4.38	13.97
Culvert/Structure	0.46	0.31	0.16	0.41	0.24	0.70	2.28
Ditch	0.53	0.60	0.29	0.19	0.20	0.77	2.58
Stream	9.29	5.40	3.97	14.29	12.54	29.57	75.05
Swale	0.43	0.14	0.11	0.22	0.06	1.01	1.98
Virtual Connector	0.53	0.11	0.63	0.49	0.20	0.85	2.82
Virtual Flow	0.16	0.13	0.06	0.12	0.18	0.21	0.86

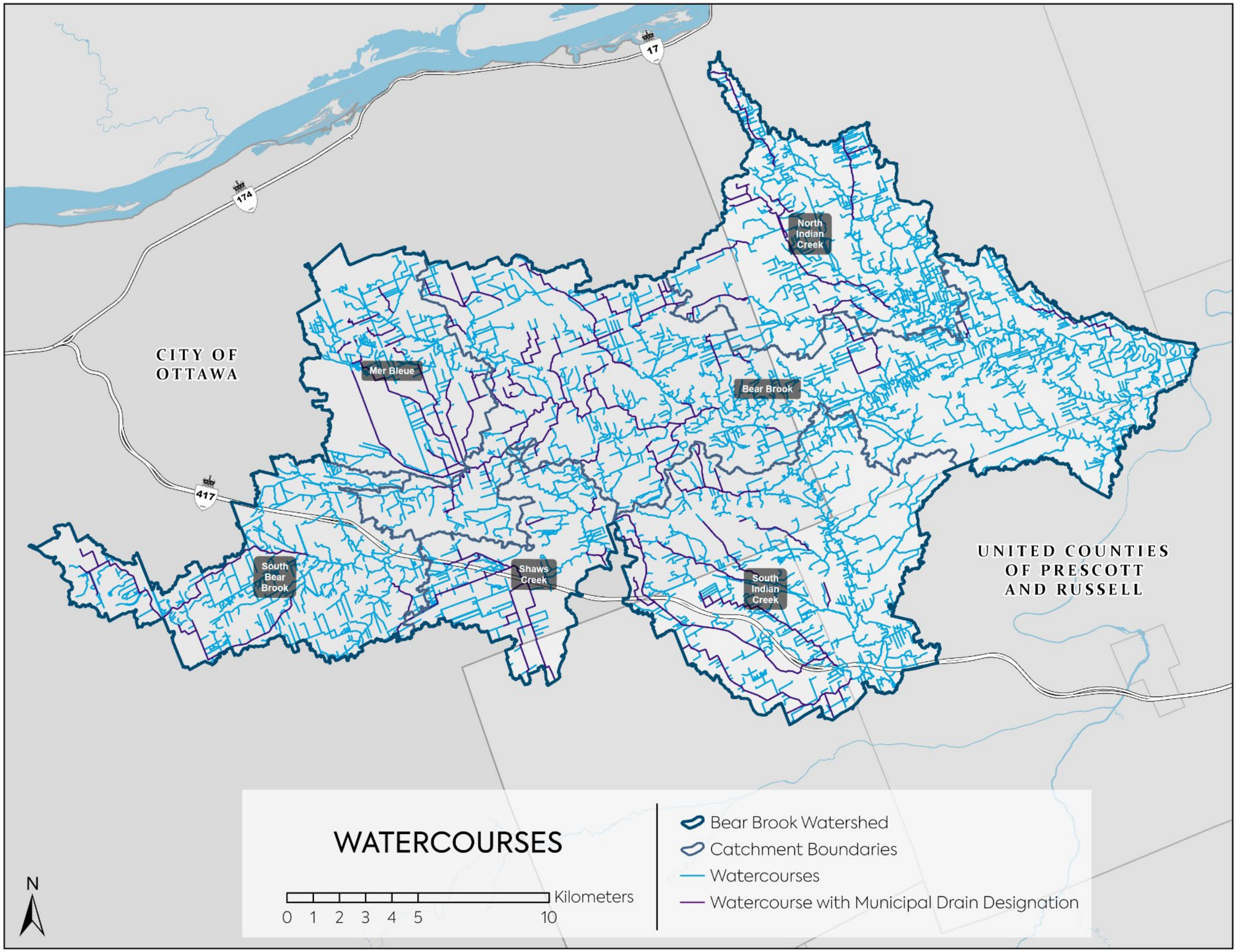

Figure 1. A map of all watercourses identified in the Bear Brook Watershed, 2024.

1.2 Watercourses with Municipal Drain Designations

Key Findings:

- Approximately 14% of watercourses in the Bear Brook Watershed have been designated as municipal drains under the *Drainage Act.*
- The greatest proportion of municipal drains are located in watercourses with high agricultural land cover, including Shaw's Creek Subwatershed and the Main Bear Brook Subwatershed.
- Within the City of Ottawa, the *Drainage Act* is being used to provide legal outlets for stormwater infrastructure from urban developments.

Many watercourses in the Bear Brook Watershed have been designated as municipal drains under the *Drainage Act* to facilitate improved drainage and routine maintenance of drains. A municipal drain is a system to move water. It is created pursuant to a bylaw passed by the local municipality. Municipalities have the legislative responsibility to maintain and repair municipal drains adopted under the *Drainage Act*. Municipal drains are identified by municipal bylaw that adopts an engineer's report. These reports contain plans, profiles and specifications defining the location, size and depth of the drain, and how costs are shared among property owners.

Most municipal drains across Ontario are either ditches or closed systems, such as pipes or tiles buried in the ground. They can also include structures such as dykes or berms, pumping stations, buffer strips, grassed waterways, storm water detention ponds, culverts and bridges. Some creeks and small rivers receive municipal drain status, mainly in agricultural areas to facilitate water conveyance.

Table 4 identifies the proportion of watercourses designated as municipal drains by Subwatershed in the Bear Brook Watershed, while Table 5 provides details on the municipal drains present in different municipalities in the watershed.

The extensive network of tile drainage and municipal drains function to improve the conveyance of runoff from the flat, poorly drained landscape, altering the hydrology of the Bear Brook Watershed. While these drainage systems are crucial for agricultural productivity and local flood prevention, they present challenges to land use decision making that require careful consideration. This is especially true when municipal drains are used to address stormwater conveyance in urban expansion areas.

All new developments are required to manage stormwater on their site. Typically, this consists of a stormwater management pond with an outlet to a receiving watercourse. Depending on the size of the development, managing any impacts to the receiving watercourses can be challenging.

The City of Ottawa has been using the *Drainage Act* in urban expansion areas within the Bear Brook Watershed to deal with this challenge. The receiving watercourses are petitioned to be designated as municipal drains and go through an engineering design process to ensure legal and sufficient outlet for the drainage area.

The challenge with this process is that design standards for municipal drains under the *Drainage Act* do not necessarily address natural hazard concerns under the *Conservation Authorities Act*. This can lead to competing priorities and requires increased collaboration on development proposals.

Table 4. The percentage of surface water features in the Bear Brook Watershed with municipal drain designation and the percentage of agricultural land cover by subwatershed.

Subwatershed	Percentage (%) of Surface Water Features with Municipal Drain Subclass	Percent (%) Agricultural Land Cover by Subwatershed
South Bear Brook	10.88	22.82
Mer Bleue	22.71	32.47
Shaw’s Creek	21.58	49.05
South Indian Creek	16.22	24.52
North Indian Creek	12.65	33.03
Main Bear Brook	12.30	43.30
Bear Brook Watershed (Total)	14.42	34.91

Table 5. All municipal drains found within the Bear Brook Watershed and their classification characteristics.

Municipal Drain Name	Fisheries and Oceans Canada Class	Drain Type	DFO Classification Year	Permanency	Municipality
A. Vinette	C	N/A	2017	Permanent	City of Clarence-Rockland
A. Vinette	F	N/A	2022	Intermittent	City of Clarence-Rockland
Aldema Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Antoine Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Aristide Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Ashton Griffith	NR	N/A	2019	Permanent	City of Ottawa
Bear Brook	E	N/A	2017	Permanent	City of Ottawa
Bear River Drain	E	N/A	2021	Permanent	City of Ottawa
Beauchamp	F	N/A	2017	Permanent	City of Ottawa
Bickerton	E	N/A	2022	Permanent	City of Ottawa
Bourdeau	F	N/A	2017	Intermittent	Nation
Brady	F	N/A	2017	Permanent	City of Ottawa
Charlebois-Vinette	C	N/A	2017	Intermittent	City of Clarence-Rockland
Charlebois-Vinette Branch "B"	C	Open	2017	Intermittent	City of Clarence-Rockland
Chartrand Shaw	F	N/A	2017	Permanent	City of Ottawa
Childs Lacroix	F	N/A	2017	Permanent	City of Ottawa
Christie Dashney	F	N/A	2017	Permanent	City of Ottawa
Clark Rothwell	F	N/A	2017	Intermittent	City of Ottawa
Daoust	F	N/A	2017	Intermittent	City of Ottawa
David Cleroux	E	N/A	2019	Permanent	City of Ottawa
Denis Perrault	F	N/A	2017	Intermittent	City of Ottawa
Desjardins-Morris	NR	N/A	2019	Intermittent	City of Ottawa
Devine	C	N/A	2017	Permanent	City of Ottawa
Dubois	F	N/A	2017	Permanent	City of Ottawa
Dutrisac	C	N/A	2017	Permanent	City of Ottawa
East Branch of Savage	F	N/A	2017	Permanent	City of Ottawa
Edna Griffith	F	N/A	2017	Intermittent	City of Ottawa
Edouard Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Elian Reginbald Drain	NR			Permanent	City of Ottawa
Emmet Garland	F	N/A	2017	Intermittent	City of Ottawa

Municipal Drain Name	Fisheries and Oceans Canada Class	Drain Type	DFO Classification Year	Permanency	Municipality
Ewart Watson	C	N/A	2017	Intermittent	City of Ottawa
Frank Johnston	NR	N/A	2017	Permanent	City of Ottawa
Frank McNeely	F	N/A	2017	Intermittent	City of Ottawa
Gascon	F	N/A	2017	Permanent	City of Ottawa
George Birch	F	N/A	2017	Permanent	City of Ottawa
Griffith Lacroix	F	N/A	2017	Intermittent	City of Ottawa
H. Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Hammond	E	Open	2017	Permanent	City of Clarence-Rockland
Harold Shaw	F	N/A	2017	Intermittent	City of Ottawa
Henry Hill	F	N/A	2017	Permanent	City of Ottawa
Hupe	F	Open	2017	Intermittent	City of Clarence-Rockland
John MacDonald	F	N/A	2017	Intermittent	City of Ottawa
Johnston	NR	N/A	2022	Permanent	City of Ottawa
Labelle	C	N/A	2017	Permanent	Russell
Labreche	F	N/A	2017	Permanent	City of Ottawa
Lalonde Cleroux	F	N/A	2017	Intermittent	City of Ottawa
Leduc	C	N/A	2017	Permanent	Russell
Leo Robinson	F	N/A	2017	Intermittent	City of Ottawa
Lepage Charbonneau	F	N/A	2017	Intermittent	City of Ottawa
Lortie	N/A	Closed /Tiled		Intermittent	City of Clarence-Rockland
Louis Lafleur	C	Open	2017	Permanent	City of Clarence-Rockland
Lowe Armstrong	F	N/A	2017	Permanent	City of Ottawa
M. Phillip	F	N/A	2017	Intermittent	City of Ottawa
Marcel Racine	F	N/A	2017	Permanent	City of Ottawa
McFadden	F	N/A	2017	Permanent	City of Ottawa
McWilliams Branch # 1	F	N/A	2017	Intermittent	City of Ottawa
McWilliams Branch # 2	F	N/A	2017	Permanent	City of Ottawa
McWilliams	E	N/A	2017	Permanent	City of Ottawa
Nelson Charlebois	N/A	Closed /Tiled		Intermittent	City of Ottawa
North Indian Creek Extension	C	Open	2021	Permanent	City of Clarence-Rockland
Patenaude	F	N/A	2017	Permanent	Russell

Municipal Drain Name	Fisheries and Oceans Canada Class	Drain Type	DFO Classification Year	Permanency	Municipality
Raymond Bouvier	F	N/A	2017	Permanent	City of Ottawa
Régimbald	F	Open	2017	Permanent	City of Ottawa
Richard Clark	E	N/A	2017	Permanent	City of Ottawa
Richard Clark	NR	N/A	2018	Permanent	City of Ottawa
Robert Walsh	F	N/A	2017	Intermittent	City of Ottawa
Rochon	F	N/A	2017	Intermittent	City of Ottawa
Royal Goudreau	F	Open	2017	Intermittent	City of Clarence-Rockland
Rudolph Brisson	E	N/A	2017	Permanent	Russell
Salomon Award Drain	E	Open		Permanent	City of Clarence-Rockland
Sarsfield	F	N/A	2017	N/A	City of Ottawa
Savage	F	N/A	2017	Permanent	City of Ottawa
Schnupp	E	N/A	2021	Permanent	City of Clarence-Rockland
Scott Extension	E	N/A	2022	Permanent	City of Ottawa
Simpson	F	N/A	2017	Permanent	City of Ottawa
Smith-Gooding	C	N/A	2019	Permanent	City of Ottawa
Smith-Staal	E	N/A	2017	Permanent	City of Ottawa
Stanley Edwards	N/A	Closed /Tiled	0	Permanent	City of Ottawa
Stanley Edwards	F	N/A	2017	Permanent	City of Ottawa
Sylvio Pilon	N/A	Closed /Tiled	0	Intermittent	Russell
Tasse Regimbald	F	N/A	2017	Intermittent	City of Ottawa
Tessier	F	N/A	2017	N/A	City of Ottawa
Thibodeau Toonders	N/A	Closed /Tiled	0	Intermittent	City of Ottawa
Van Vliet	F	N/A	2017	Intermittent	City of Ottawa
Vas Trudeau	F	N/A	2017	Intermittent	City of Ottawa
Walsh Hayes	F	N/A	2017	Permanent	City of Ottawa
Walter Henn	F	N/A	2017	Intermittent	City of Ottawa
Wilson Johnston	F	N/A	2017	Intermittent	Russell

2. Tile Drainage

<u>Key Findings</u>

- Tile drainage covers approximately 17% of the Bear Brook Watersheds total land area, largely in marine clay surficial soils on agricultural lands.
- The subwatersheds with the greatest proportion of tile drainage includes Shaw's Creek at 31% and the Main Bear Brook at 22%.

Headwater drainage features and first-order streams were once more numerous in the Bear Brook Watershed, especially across the large expanses of clay plain where tile drainage has been installed to facilitate agricultural land use. Tile drainage is a common practice that involves installing a network of perforated pipes (tiles) beneath the soil surface to remove unwanted water from the rooting zone in the spring months and after heavy rains.

Tile drains create networks that collect and convey water, effectively functioning as human-made first-order streams that replace natural depressions, wetlands, or small streams. Unlike natural first-order streams, tile drainage systems often discharge directly and rapidly into natural watercourses or municipal drains and influence the flow regimes of receiving streams. This changes the natural hydrologic flow paths and reduces the residence time of water in the soil (Kladivko et al., 2004).

By diverting water that would otherwise percolate downward, tile drainage decreases groundwater recharge. This lowers groundwater levels over time, affecting water availability for baseflow to streams during dry periods (Schilling & Helmers, 2008). The modification of water flow patterns can also influence flood peaks and durations, potentially exacerbating flooding downstream under certain conditions (Robinson, 1990). Tile drainage systems can also facilitate the leaching of nutrients from fertilizers and pesticides into waterways contributing to pollution and eutrophication in downstream aquatic ecosystems.

To study the potential impact of tile drains on hydrologic functions in the Bear Brook Watershed, SNC undertook a project to delineate tile drains across the watershed for inclusion in future water budget analysis. This was completed by consulting the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) tile drainage database. To ensure geospatial information was up-to-date and accurate, several aerial imagery products were consulted including LiDAR (2021), SkyWatch satellite imagery (April 2024), Google Earth imagery (2023), and DRAPE imagery (2014, 2019). A geospatial exercise was performed following a methodology developed by Northcott et al. (2000). Tile drained lands were delineated and provided to Aquanty Inc. for use in the Bear Brook Watershed Water Budget.

Table 6 summarizes tile drained land by subwatershed. The extent of tile drained lands is shown in Figure 2. As expected, subwatersheds with increased incidence of clay soils and agricultural land cover have higher tile drainage (i.e., Shaw's Creek; 31% and the Main Bear Brook; 22%).

Table 6. The percentage of land area drained by tile drains by subwatershed and the percentage of agricultural land by subwatershed in the Bear Brook Watershed.

Subwatershed	Percent (%) Tile Drained Lands by Subwatershed	Percent (%) Agricultural Land Cover by Subwatershed
South Bear Brook	6.55	22.82
Mer Bleue	13.16	32.47
Shaw’s Creek	31.06	49.05
South Indian Creek	11.12	24.52
North Indian Creek	13.03	33.03
Main Bear Brook	22.18	43.30
Bear Brook Watershed (Total)	16.52	34.91

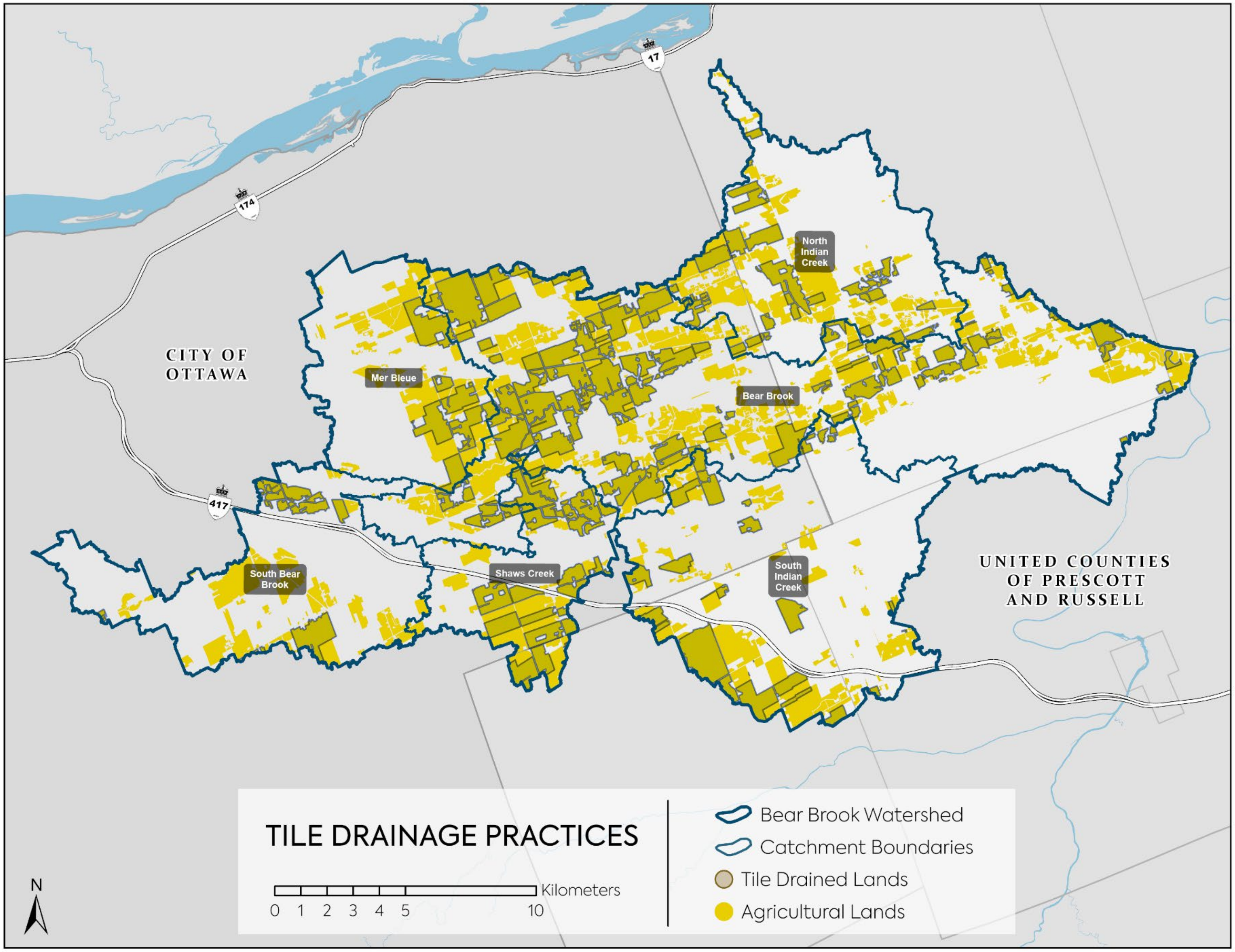

Figure 2. Lands identified as exhibiting tile drainage from SNC's tile drainage mapping exercise. Work was completed using SkyWatch imagery in April 2024.

3. Headwater Drainage Features

Headwater drainage features (HDFs) are important features that provide seasonal habitat for aquatic flora and fauna, as well as water storage and conveyance during the spring and heavy rain events. HDFs have the potential to be large sources, sinks, and conveyors of sediments, detritus, and water flow downstream (Stanfield, 2013).

HDF Policy in the City of Ottawa

The City of Ottawa recognizes the importance and potential impacts of the loss of HDFs through application of standard HDF policies. Specifically, the Official Plan's section on City-Wide Policies (Section 4.9.3(5)) outlines the specific evaluation and assessment requirements for development or site alteration proposed within or adjacent to HDFs, with requests for exceptions to minimum setbacks. The United Counties of Prescott and Russell does not acknowledge HDFs within their Official Plan and it is not common practice for HDF assessments to be completed in UCPR in support of development or site alteration.

South Bear Brook River HDF Assessment

SNC identified and collected HDF data in the South Bear Brook Subwatershed in 2022 under the South Bear Brook Catchment Study project. A full methodology and assessment of results is provided in the South Bear Brook Catchment Study (2022).

SNC surveyed 55 individual HDF sites in 2021 through the Ontario Stream Assessment Protocol (OSAP) HDF Constrained Module (Stanfield, 2013). A unique identifier was assigned at each site and all individual features were mapped, resulting in 110 total features. Management recommendations for each site were determined based upon Credit Valley Conservation's and Toronto and Region Conservation Authority's Evaluation, Classification, and Management of Headwater Drainage Features Guidelines (Toronto Region Conservation Authority and Credit Valley Conservation, 2014).

Table 7 summarizes the number of features identified for each management recommendation. Exact locations of HDFs are available from SNC. Overall, 29 HDFs were assigned a management recommendation of protection due to significant late summer flows, wetlands, and/or fish observations during field assessments. Several sites with protection status included wetland areas with observed wetland vegetation and organic substrate upstream of the culvert and areas where fish were directly observed. These sites require special management and consideration to ensure their form and function are maintained though future development scenarios.

Table 7. 2021 Management recommendations for headwater drainage features in the South Bear Brook River Subwatershed.

Management Recommendation	Number of Features
Protection – Important Function	29
Conservation – Valued Functions	30
Mitigation – Contributing Functions	38
Recharge Protection – Recharge Functions	3
Maintain or Replicate Terrestrial Linkage – Terrestrial Functions	1
No Management Required – Limited Functions	9
Unable to Provide Recommendation – Data Deficient	0

4. Surface Water Flow

Key Findings:

- The Bear Brook River is a dynamic and responsive water system that reacts quickly to weather events. Flows are typically higher through the spring when infiltration is limited due to frozen conditions and there is a combination of melting snow and rainfall creating increased run-off into nearby water features.
- Baseflow from groundwater exfiltration is an important component of surface water flow and makes up approximately 57% of flows in the Bear Brook River at the Bourget Hydrometric Station.

There are many factors that influence the amount of water a river carries including climate, watershed area drainage pattern, slope, land use, and soil type. Hydrographs (a graph that shows flow over time) are effective tools for characterizing trends in flows.

Understanding flows in watercourses requires data collection over long periods of time at regular frequencies using standardized methodologies and specialized equipment. In an assessment of hydrometric data for the Bear Brook River in 2021, it was determined that only one stream gauge with an acceptable period of record existed in the Bear Brook Watershed and was located upstream of the confluence with the South Nation River near the Village of Bourget.

SNC staff identified the need for additional flow data in the upper reaches of the Bear Brook Watershed. Working with staff from the City of Ottawa, the City of Clarence-Rockland, and the National Capital Commission (NCC), SNC staff installed two hydrometric stations at the following locations, depicted in Figure 3:

- South Bear Brook at Hall Road on NCC Property; and
- The Bear Brook River on South Indian Creek Road in the City of Clarence-Rockland.

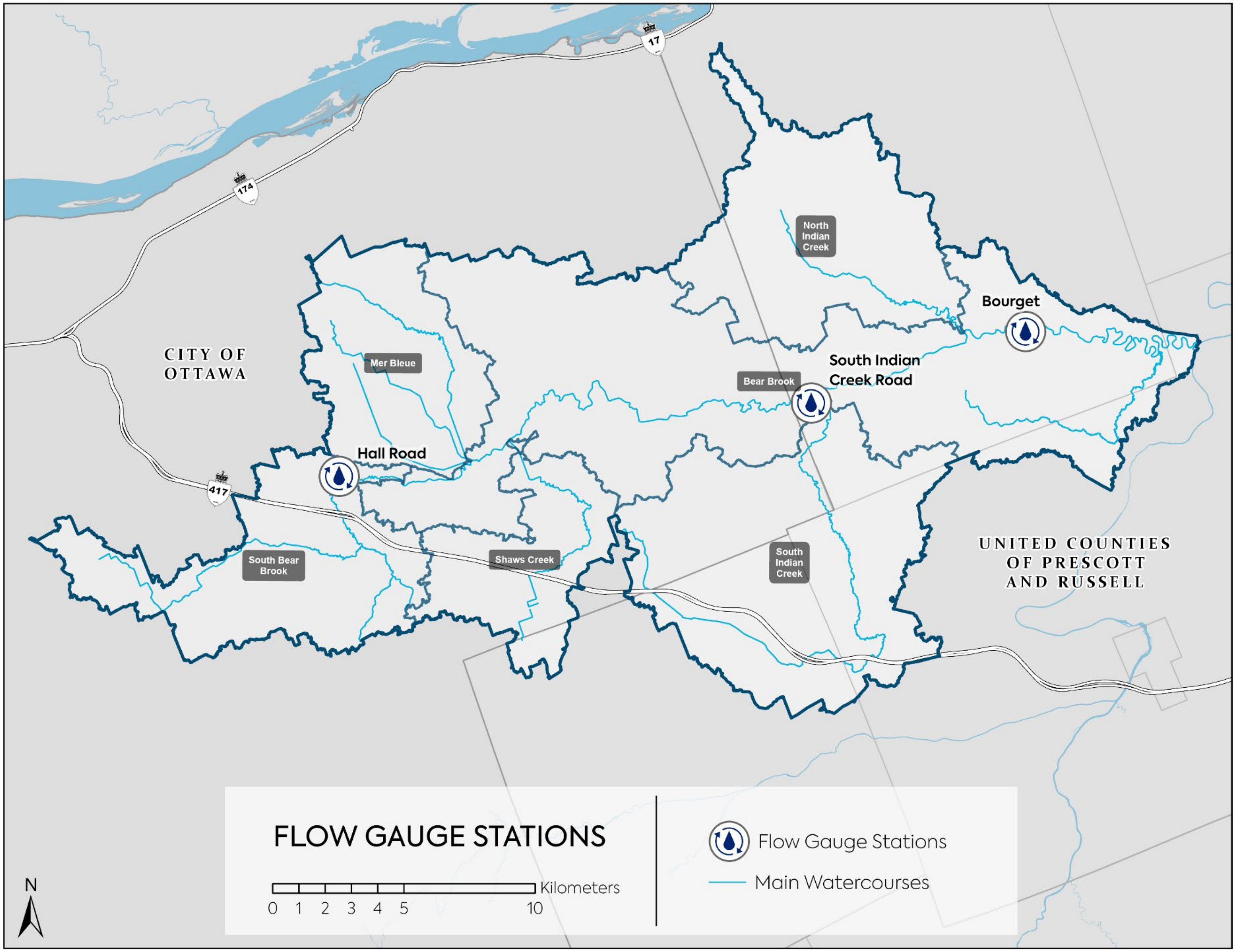

Figure 3. The location of flow gauges in the Bear Brook Watershed.

At flow gauges, water levels are captured in 15-minute intervals using radar technology and transmitted in near real-time over the GOES Satellite Network. To develop stage-discharge relationships, SNC staff captured flow measurements over a range of flow conditions in 2023 and 2024 following a standardized United States Geological Survey (USGS) methodology, in which “stage” refers to the water level (m) above a reference point in the watercourse and “discharge” is the volume of water carried by the watercourse per second (m^3/s). This enabled the development of rating curves for the two locations in the Bear Brook River. Raw flow measurement data is available in Appendix B.

Once the data was collected, a statistical analysis was performed. The relationship between stage and discharge is typically non-linear, necessitating the use of polynomial regression or logarithmic transformations. The following two steps were taken to develop the rating curves:

- A scatter plot of discharge versus stage was created to visualize the relationship between the two variables; and,
- A regression analysis method was used to fit a curve to the data. The choice of polynomial degree was based on the goodness of fit, determined by the R^2 value.

Figures 4 and 5 show the scatter plot and best-fitted curve for the two selected stations.

As a flood wave travels through a river, higher discharges are observed during the rising stage compared to the falling stage at the same water level, leading to looped rating curves. This phenomenon is commonly referred to as hysteresis in the stage-discharge relationship.

The hysteresis pattern of the rating curves was achieved using field verified data and by consulting the dates flow measurements were sampled. Precipitation data and gauge data collected from the Bear Brook River at the Bourget Hydrometric Station was used. The result is presented in Figures 6 and 7.

To conduct calibration and validation analysis, it is recommended to increase the number of stage-discharge measurements (Guan & Wilson, 2012). Specifically, these measurements should be taken at various times throughout the year during a range of flow conditions. SNC will continue to collect flow measurements at the gauge stations in 2025 to further validate existing models.

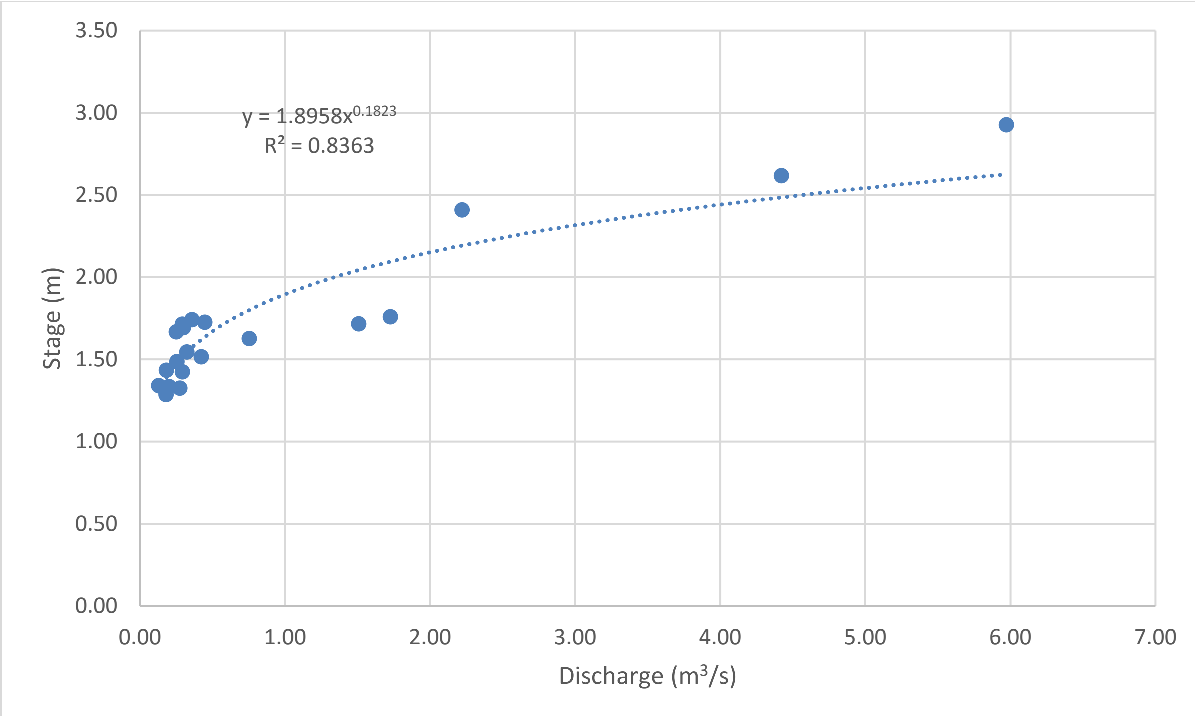

Figure 4. A rating curve for the Bear Brook River at Hall Road resulting from field work done by South Nation Conservation and data collected from a flow gauge in 2024.

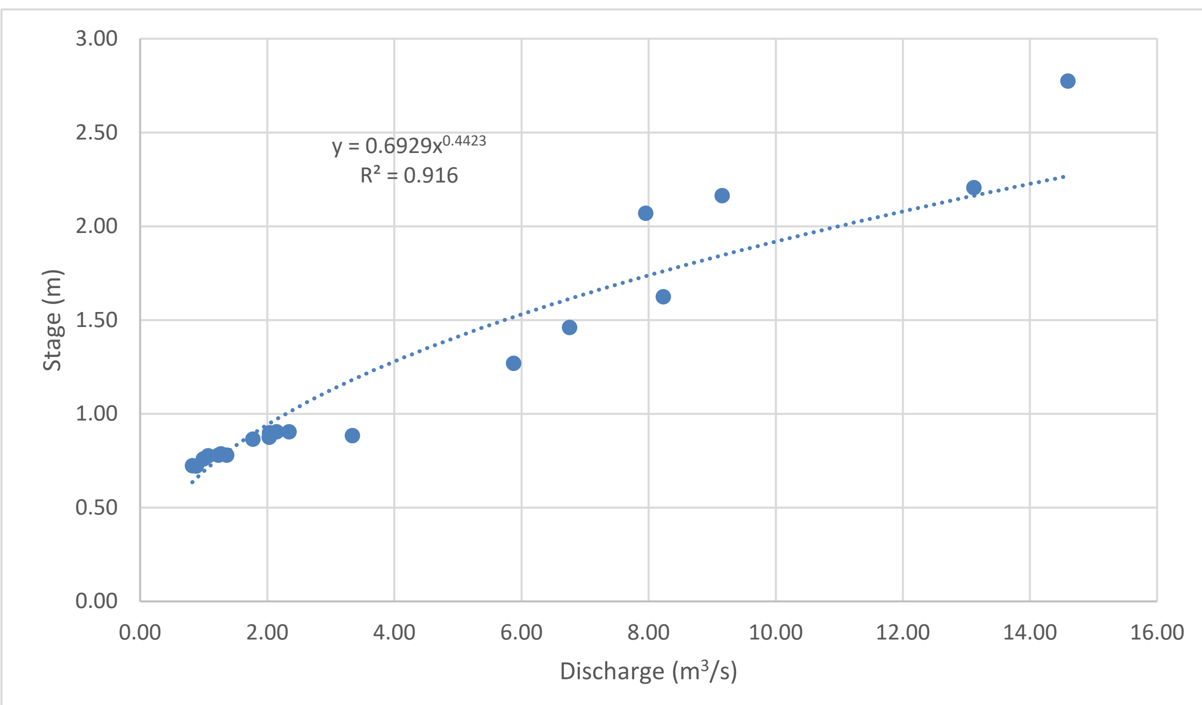

Figure 5. A rating curve for the Bear Brook River at Indian Creek Road resulting from field work done by South Nation Conservation and data collected from a flow gauge in 2024.

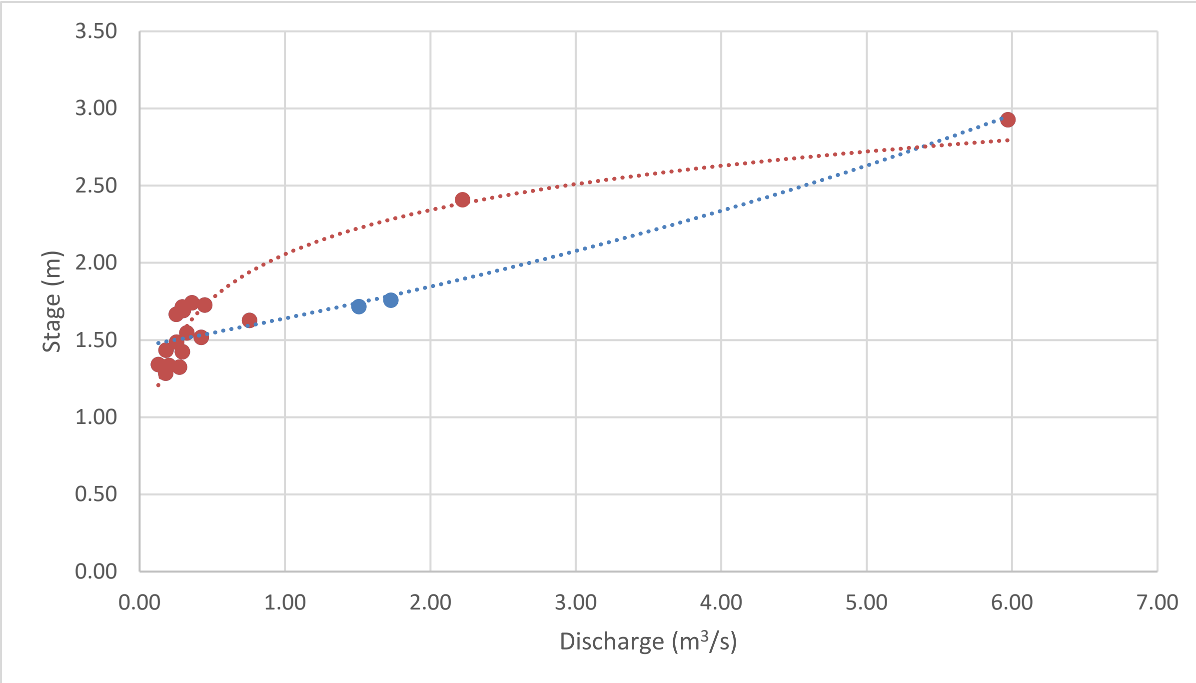

Figure 6. A hysteresis pattern rating curve for the Bear Brook River at Hall Road resulting from field work done by South Nation Conservation and data collected from a flow gauge in 2024.

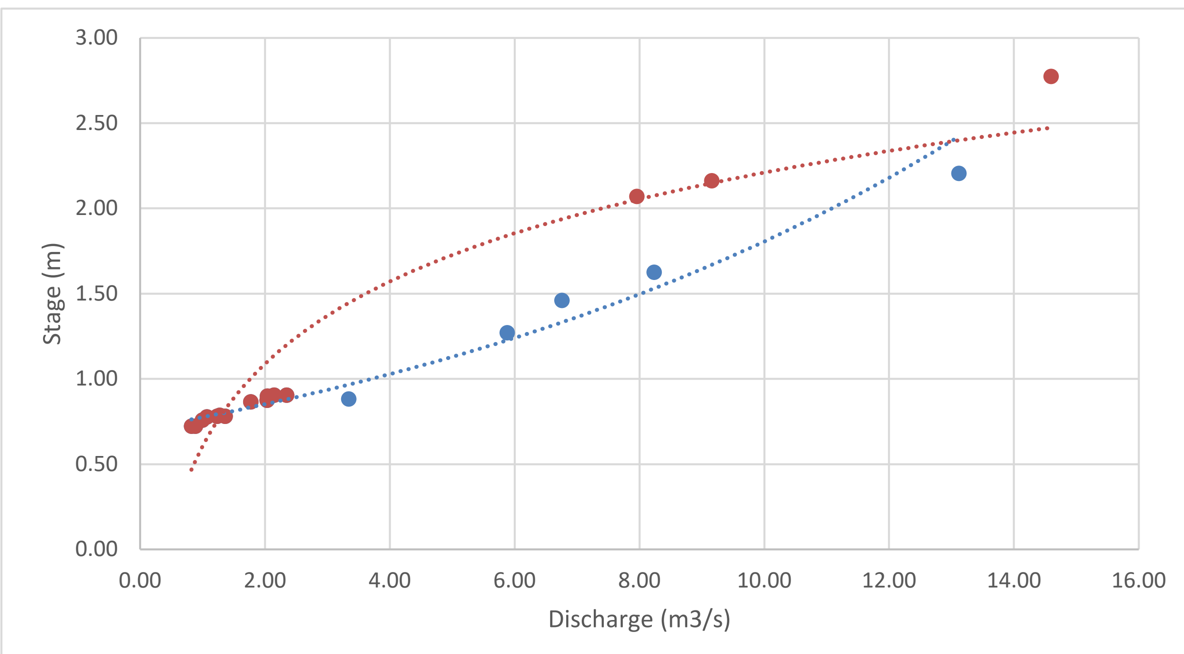

Figure 7. A hysteresis pattern rating curve for the Bear Brook River at Indian Creek Road resulting from field work done by South Nation Conservation and data collected from a flow gauge in 2024.

Bear Brook at Bourget Hydrometric Station

A stream gauge located along the Main Bear Brook River near the Village of Bourget has been operated and maintained by Water Survey Canada since 1949. The 30-year normal range of flows over the 1991 to 2020 period of record are presented in Figure 8. Average monthly precipitation collected over a 30-year period from the Ottawa International Airport is presented in Figure 9.

It is evident from Figure 8 that that the Bear Brook River is a dynamic and responsive system, quickly reacting to storm events. Flows (and therefore water levels) are also highly dependent on weather and season. Although average monthly precipitation is somewhat consistent through the year, maximum flow occurs during the spring months of March to May. This reflects the watershed's response to a combination of rainfall and melting snowpack. Additionally, there is a typical high-flow period in the fall which is likely a combination of rainfall and reduced evapotranspiration after vegetation die-back once temperatures drop in fall.

Flows (and resulting water levels) are normally low during typical growing seasons, as evidenced by the normal range in Figure 8 from late May through to October. This is partially the result of increased evapotranspiration from a productive agricultural and natural landscape. It should be noted that flows are still largely driven by weather events and flooding is possible within these periods. Maximum flows from June to October, depicted by black line in Figure 8, observe several peaks, which would be the result of extreme events, further demonstrating the flashy, dynamic response of the Bear Brook system.

Data collected in 2024 has also been added to Figure 8 in green to demonstrate the abnormal meteorological conditions experienced due to an active hurricane season from June through August. The active 2024 hurricane season led to above normal rainfall accumulation in June, July and August of 2024, leading to several occurrences of above normal flows for the 2024 summer season. Above normal rainfall through the summer led to saturated soils, reducing the ground's ability to absorb additional water leading to higher runoff and several flood events.

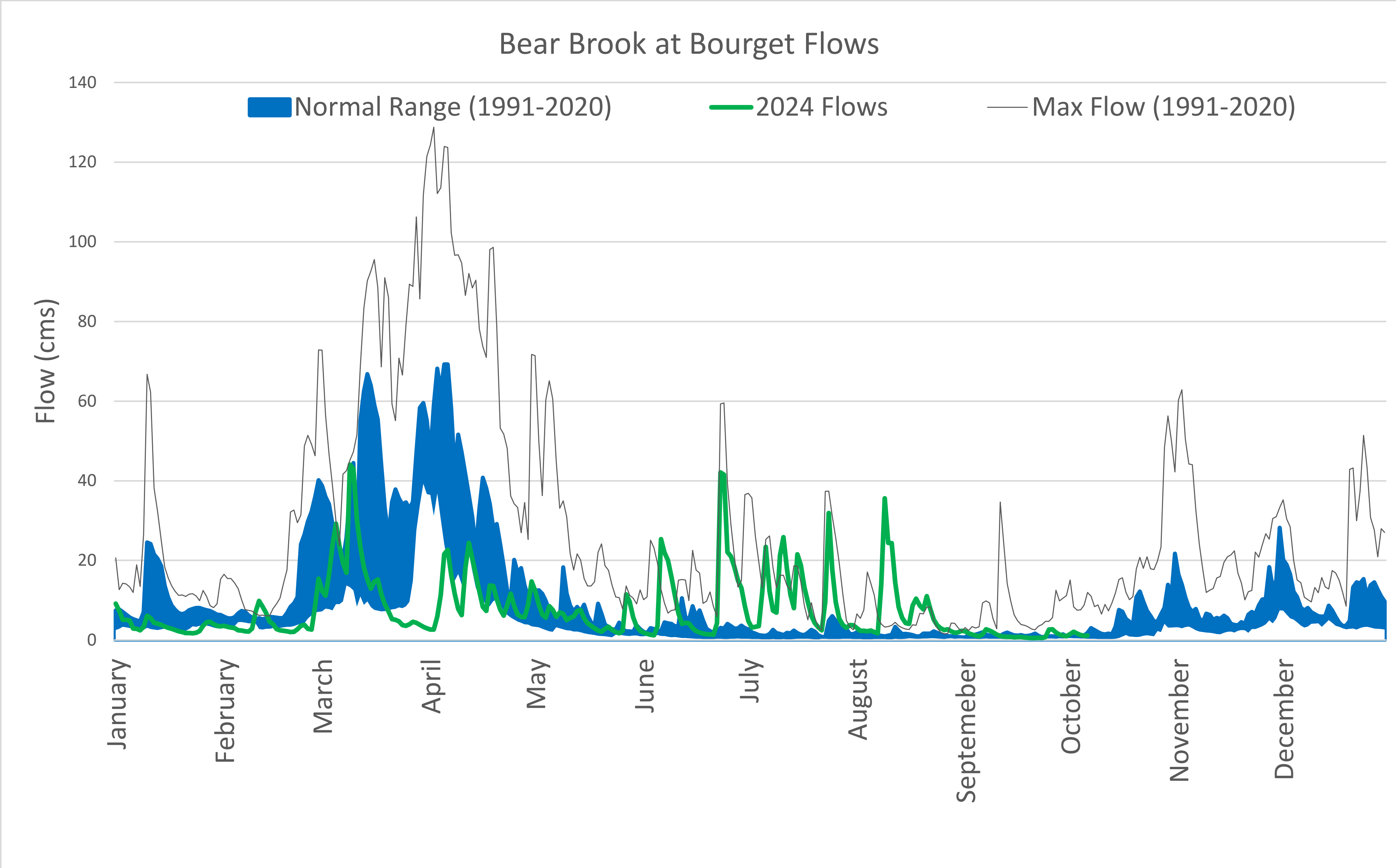

Figure 8. Historic (1991-2020) flows over one year (January-December) captured at the Bear Brook River Bourget Hydrometric Station. The normal range of flows are presented in blue and represent flows that occur 50% of the time within the 25th to 75th percentile. Maximum flows are identified in black.

5. Storm Flows

Hydrographs and hysteresis graphs of the Bear Brook River reveal how flows and water levels are highly dependent on weather. Flows vary month to month, with spring typically bringing the highest flows when large quantities of water are released due to snowmelt and rainfall as a result of warmer spring temperatures. This phenomenon is referred to as the spring freshet.

High flow conditions can result in increased erosion and flooding. SNC has developed a comprehensive hydrology model for the Bear Brook Watershed to assess flood potential under varying seasonal conditions.

This model simulates different scenarios, including summer storms and spring freshet events, across return periods ranging from 2 to 100 years, thereby covering a wide spectrum of potential flood probabilities. Key hydrometric stations, such as those referred to above at Hall Road, Indian Creek Road and the Bourget Hydrometric Station, were selected as primary locations for recording and modeling flood flows, as they are crucial in understanding how seasonal and storm-driven events impact flood behavior across the watershed. Table 8 shows simulated peak flows under different storm conditions and return periods, highlighting the variability between summer storms and spring freshet scenarios at each location.

Table 8 indicates that peak flows during the spring freshet are higher than those during summer storms. This is primarily because soil moisture content in summer is typically lower due to seasonal drying, which allows for greater infiltration rates. As a result, more water is absorbed into the ground, leading to reduced surface runoff. In contrast, spring rain-on-snow events can rapidly increase flows. This occurs due to limited infiltration, as the melting snow adds additional water. Consequently, this creates a high-flow period which can exceed summer flow rates and pose greater flood risks.

The data in this table demonstrates that the 10-day snowmelt + rain scenario produces the highest peak flows across all return periods. For example, the peak flow for a 100-year summer storm and 1-day snowmelt + rain at the Bourget Hydrometric Station are 66.1 Cubic Meters per Second (CMS) and 191.5 CMS respectively, while the same frequency under a 10-day snowmelt + rain scenario results in a significantly higher peak flow of 316.5 CMS. This comparison underscores the importance of considering extended snowmelt periods in flood modeling to estimate potential peak flows better.

Table 8. Modelled peak flows at hydrometric stations in the Bear Brook Watershed.

Condition	Return Period	Annual Exceedance Probability	Hydrometric Station		
			Bourget	Indian Creek Road	Hall Road
Summer storm Peak flow CMS (24hr SCS II)	2	50%	17.4	14.3	1
	5	20%	27.7	22.2	1.6
	10	10%	33.5	26.6	2.2
	25	4%	46.8	37	2.7
	50	2%	56.3	43.9	3.3
	100	1%	66.1	51.1	4.1
Spring Freshet Peak flow CMS (1 Day Snowmelt + Rain)	2	50%	29.1	20.8	3.0
	5	20%	54	37.3	5.4
	10	10%	77.9	53.1	7.6
	25	4%	112.3	77.3	10.9
	50	2%	142.7	99.2	13.9
	100	1%	191.5	135	18.6
Spring Freshet Peak flow CMS (10 Day Snowmelt + Rain)	2	50%	81.5	52.5	9.2
	5	20%	121.1	78.2	13.4
	10	10%	155.1	100.7	17.1
	25	4%	204.4	135.5	22.4
	50	2%	248.3	162.5	27.1
	100	1%	316.5	207.3	34.6

After completing a thorough comparison of different scenarios, regional models, and statistical analyses, SNC selected the 10-day snowmelt plus rain scenario as the dominant design flow for delineating floodplain hazards and regulations. Table 9 shows the peak flow at the Bourget Hydrometric Station across various scenarios.

The 10-day snowmelt plus rain scenario is dominant for several reasons. First, it yields the highest peak flows of any modeled condition, providing a critical reference for maximum flood potential. Second, the peak flow from the statistical analysis is closely aligned with the 10-day snowmelt plus rain scenario. Additionally, this scenario is conservative, offering a robust basis for flood hazard mapping and ensuring comprehensive planning against potential extreme events.

Table 9. Peak flow comparison of the Bear Brook Watershed at the Bourget Hydrometric Station.

	Storms	Estimated Flow at Bourget Hydrometric Station (CMS)
100-year Return Period	100-Year 24-hr SCS II (Wet Condition)	181.4
	100-Year 24-hr SCS II (Dry Condition)	66.1
	1 D Snowmelt + Rain	191.5
	3 D Snowmelt + Rain	274.2
	5 D Snowmelt + Rain	303.1
	10 D Snowmelt + Rain	316.5
	Statistical Analysis	308
	OFAT – Index Flood Method	294.6
	OFAT – Primary Multiple Regression	299.2

2024 Summer Flow Events

Recent flood records from the Bourget Hydrometric Station help align the model's predictions with observed data, particularly during the summer of 2024 when significant flood events occurred. These records provide valuable information for evaluating the actual return periods of summer floods and contribute to understanding flood probabilities and real-world flood frequencies, as shown in Table 10.

Table 10. Observed extreme flows during the Summer of 2024 at the Bourget Hydrometric Station flow gauge.

Date	Flow (CMS)
24-Jun-24	60.5
25-Jul-24	40.7
10-Aug-24	44.0

The observed peak flow values on June 24, 2024, at 60.5 CMS aligns with return periods between 50 and 100 years, indicating an annual occurrence probability of 1% to 2%. Other flood events, such as those recorded in July and August, have shorter return periods and higher recurrence probabilities (between 4% and 10%), highlighting the influence of weather and seasonal variability on flood risk.

Additionally, by comparing peak flows for spring freshest and summer conditions across different return periods, it becomes evident that the 100-year summer flow is approximately close to the 2-year 10-day snowmelt + rain scenario. This suggests a 50% probability of experiencing a flood of this magnitude during the spring freshet. This aligns with natural patterns, as this area experiences flooding regularly in the spring.

Conducting hydrologic modeling for various scenarios and return periods is essential for understanding and managing flood risk in the Bear Brook Watershed. Analyzing hydrological data makes it possible to estimate the probability of extreme flood events, offering insight into the risk associated with severe rainfall and snowmelt conditions. Mapping flood events at different frequencies provides a visual understanding of flood-prone areas, helping to identify regions vulnerable to flooding. This comprehensive approach to flood analysis assesses the watershed’s response to extreme conditions, supporting informed flood management and mitigation strategies to protect the area and guide future planning efforts.

Flood extents have been delineated throughout the Bear Brook Watershed through various flood mapping projects. These projects are discussed in the characterization report under Section 4: Natural Hazards.

6. Baseflow

Over much of the year, flow sustained in rivers and streams is supplied from groundwater or discharged from wetlands. This portion of the flow regime is referred to as baseflow. The ability of a river system to withstand drought depends largely on the baseflow volume the system can generate. Baseflow is the portion of stream flow that is derived from groundwater inflow through springs and seepages that release the cool groundwater into surface water. The baseflow component within streams is vital for maintaining surface water flow in rivers throughout periods lacking precipitation, as well as providing essential habitat to aquatic communities, sometimes referred to as ecological flows.

Measuring the natural baseflow level can reveal the normal amount of water that is expected to flow through a stream each year. This level and amount of flow can then be used as a benchmark when considering water use changes that may cause additions or removals of flow from the stream and subsequent impacts to the aquatic environment.

To perform a baseflow estimation analysis, the SepHydro web tool was utilized on data collected from the Bourget Hydrometric Station over a three-year period of record from October 2021 to October 2024.

SepHydro is a hydrograph separation web tool developed through a collaborative research effort involving the Canadian Rivers Institute (CRI), the University of New Brunswick (UNB), Agriculture and Agri-Food Canada (AAFC), and Environment and Climate Change Canada (ECCC). This tool emerged from research aimed at evaluating the impacts of agricultural production systems on both groundwater and surface water quality, as well as on the health of downgradient aquatic ecosystems.

SepHydro is part of the Hydrology Tool Set (HTS), which encompasses various tools designed to advance the understanding of local and watershed-scale hydrological processes.

The SepHydro tool offers several customizable filtering algorithms for hydrograph separation, allowing users to assess contributions from surface runoff and groundwater to overall streamflow. It features a user-friendly interface and provides flexibility in input and output file formats, streamlining the data processing experience.

SepHydro software was executed using several available models (i.e., Lyne and Hollick, Eckhardt, Pettyjohn and Henning – Fixed Interval, Boughton (AWBM 1993) Method) to estimate the baseflow for the Bear Brook River at the Bourget Hydrometric Station. A Comprehensive approach was followed to ensure robust results by averaging multiple methods for hydrograph separation.

The results of the analysis are presented in Table 11. Pertinent statistics for the estimated baseflow alongside the variation of the baseflow in comparison to the total streamflow are provided. The average baseflow across the selected models ranges from 4.06 to 5.26 CMS, resulting in an overall average of 4.7 CMS, which constitutes approximately 57% of the total streamflow. Figure 9 depicts streamflow and baseflow hydrographs for the four selected baseflow separation methods.

Table 11. Statistical results for the selected baseflow separation methods at the Bourget Hydrometric Station. Q represents streamflow (CMS), q denotes surface or quick runoff (CMS), and b indicates baseflow (CMS).

Statistic	Lyne & Hollick	Eckhardt	Pettyjohn & Henning – Fixed Interval	Boughton (AWBM 1993)
Q_{min}	0.130	0.130	0.130	0.130
Q_{avg}	8.193	8.193	8.193	8.193
Q_{max}	88.962	88.962	88.962	88.962
Q_{stdev}	11.740	11.740	11.740	11.740
q_{min}	0.000	0.000	0.000	0.000
q_{avg}	3.772	4.137	2.928	3.145
q_{max}	73.482	63.136	53.115	53.492
q_{stdev}	8.467	7.518	6.507	6.170
b_{min}	0.130	0.101	0.130	0.116
b_{avg}	4.421	4.056	5.265	5.048
b_{max}	35.353	36.624	55.797	48.743
b_{stdev}	4.859	5.001	7.148	6.451
b > Q	396 / 1095	35 / 1095	0 / 1095	90 / 1095
b > Q (%)	36.16 %	3.20 %	0.00 %	8.22 %
Avg. of b/Q	53.96 %	49.51 %	64.26 %	61.61 %

Notes:

*Lyne & Hollick utilized a catchment constant value of 0.95, which is standard practice in this region.

*Eckhardt method had a groundwater recession constant of 0.85, and a long-term ratio of baseflow to total streamflow of 0.5.

*Boughton method had a groundwater recession constant of 0.85, and a shape constant was 0.25.

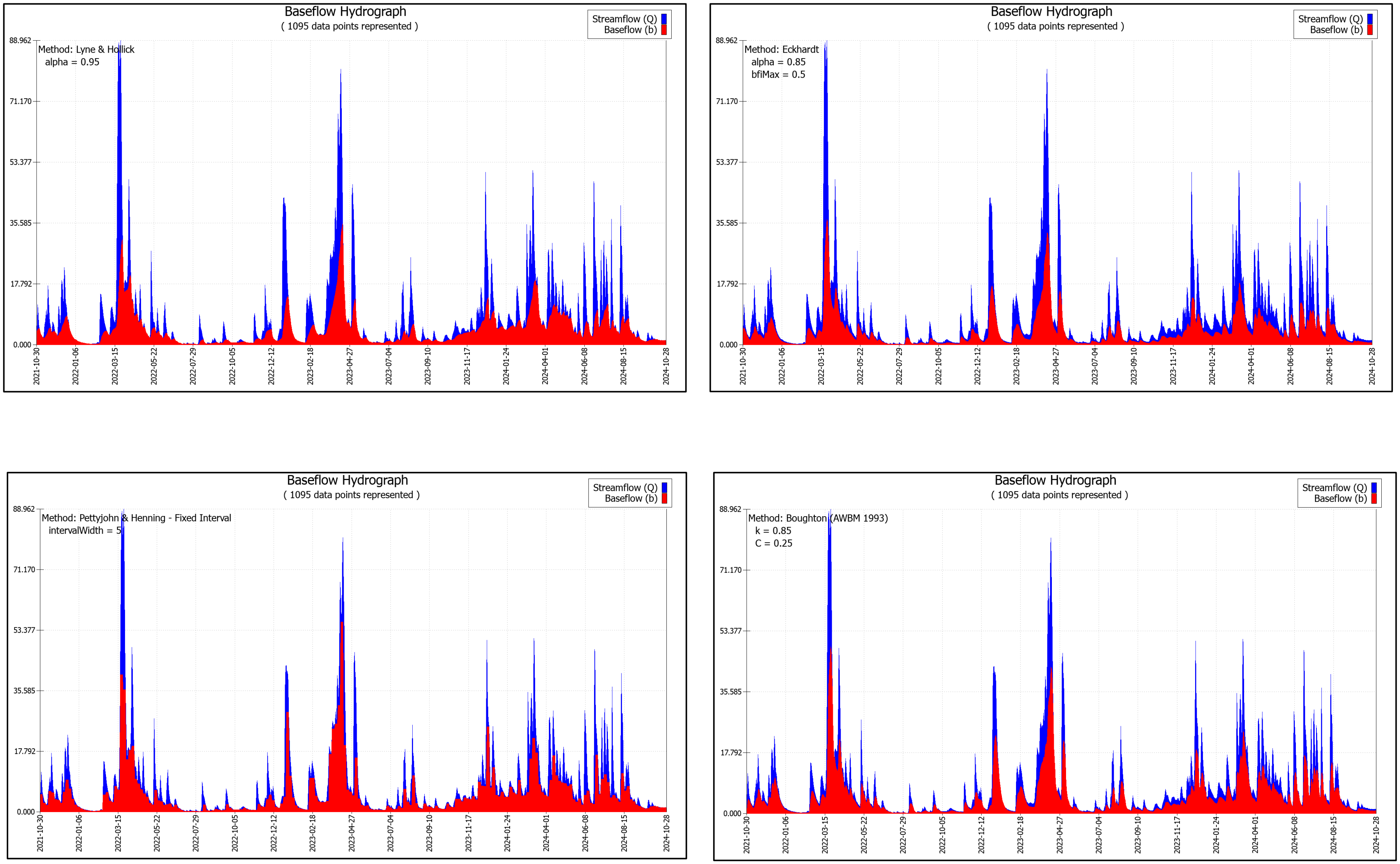

Figure 9. Baseflow hydrographs obtained from different baseflow separation techniques. Data is a result of flow data captured at the Bourget Hydrometric flow gauge in 2024.

7. Water Budget

Key Findings:

- The average surface water outflow composes 45 % of total precipitation in the Bear Brook Watershed.
- Groundwater recharge accounts for 6 % of precipitation in the Bear Brook Watershed.
- Modelling results highlight how water balance partitioning is affected by individual dry and wet years across subwatersheds in the Bear Brook Watershed.
    - Quartile ranges for precipitation are consistent across subcatchments;
    - There is slightly more variability in evapotranspiration due to differences in land cover, topography, and lithology that drive water demand and availability; and,
    - There is considerably more variability in the magnitude and range of stream outflow and groundwater recharge across different subcatchments.

Effective water budget analysis and groundwater recharge management are crucial for enhancing the sustainability of water resources and reducing the risks associated with water scarcity and excess (Dillon, 2005; Panday et al., 2009 in Aquanty Inc., 2024). Understanding and quantifying the components of the water budget, such as precipitation, evapotranspiration, surface water outflow and groundwater recharge, are essential for assessing the risks of both flood and drought, and for evaluating the impact of land use change and climate change on hydrologic behavior. Infiltration is a crucial process driving groundwater recharge, while groundwater discharge into surface water and uptake by vegetation are equally important components of the overall water budget (Griebler & Avramov, 2015 in Aquanty Inc., 2024).

These hydrologic processes influence the availability of water within a system, playing a significant role in balancing water inputs, outputs, and overall availability. Groundwater discharge, for instance, contributes to maintaining base flow in streams and rivers, which is essential during periods of low precipitation. Similarly, vegetation uptake regulates the distribution of water between the surface and subsurface, impacting evapotranspiration rates and influencing groundwater recharge (Booth et al., 2016; Li et al., 2014 in Aquanty Inc., 2024). When groundwater levels drop, ecological and vegetation water demands are often unmet. Fully understanding these fluxes within a water balance assessment is essential for accurately assessing water availability under different climatological and land use scenarios.

The City of Ottawa has identified that understanding and maintaining watershed hydrologic functions during all stages of development planning is necessary for environmental, social, and economic sustainability. As such, the City has developed a Water Budget Assessment – Terms of Reference, which outlines requirements for all watershed and subwatershed plans, environmental management plans (EMPs), master servicing studies (MSSs), and updates to existing Master Drainage Plans (MDPs).

The Terms of Reference identifies the need to complete a thorough analysis of existing water budget conditions and assess potential impacts due to proposed land use changes. This analysis can be used to define appropriate water budget targets, which will be achieved through the design of the proposed development to mitigate any identified impacts.

A fully-integrated HydroGeoSphere groundwater-surface water model has been constructed for the Bear Brook Watershed. The simulation interval upon which the results of this work are based extends from 1997–2017 and consists of both flood and drought conditions. The model is shown to successfully reproduce the continuous surface water flow rates in the Bear Brook River at the Bourget Water Survey of Canada (WSC) 02LB008 hydrometric station. The results from the modelling are used to quantify the surface water outflow, groundwater recharge, precipitation, and evapotranspiration components of the overall water balance in the Bear Brook River subwatershed as well as in nine subcatchment areas within the Bear Brook River subwatershed.

The Bear Brook Water Budget detailed methodologies and results are presented in Appendix C.

8. Groundwater Quality

Key Findings:

- *Key findings will be populated with results from Aquanty's report.*

The Bear Brook Watershed is underlain by extensive groundwater features that provide drinking water for residents, sustain natural ecosystems and processes, and support agricultural, industrial, commercial, and recreational uses.

An assessment of groundwater quality by Aquanty Inc. included data from a series of aquifer capability screening tools for eastern Ontario municipalities (Morton et al., 2013; Di Iorio, et al., 2015; Di Iorio et al., 2017; Di Iorio et al., 2019). The Ontario Geological Survey (OGS) acquired comprehensive datasets, including data from the studies listed above, as well as others across southern Ontario to characterize the ambient groundwater geochemistry for both bedrock and overburden wells across southern Ontario (Hamilton, 2021). The main purpose of the study was to:

- Characterize baseline groundwater geochemistry of the major rock and overburden units in southern Ontario (subject to accessibility);
- Relate the groundwater chemistry to aquifer chemistry; and,
- Support the determination of groundwater flow and aquifer conditions.

Aquanty Inc. has accessed this data to summarize conditions across the Bear Brook Watershed.

The Bear Brook Watershed groundwater quality methodologies and results are available in Appendix D.

9. Drinking Water and Source Water Protection

<u>Key Findings</u>

- The Vars/Limoges Municipal wells currently services approximately 2,103 units (i.e., single dwellings are 1 unit) in The Nation Municipality and approximately 1,240 people in the community of Vars in the City of Ottawa.
- There are no water quantity threats identified for the Vars/Limoges Municipal wells.

Ontario's *Clean Water Act*, 2006, protects existing and future Municipal drinking water sources. This Act was created in response to the Walkerton, Ontario tragedy in May of 2000, where a Municipal drinking water source was badly contaminated. The protection of drinking water sources is the first step of a multi-barrier approach to prevent Municipal drinking water contamination.

Under the *Clean Water Act*, source protection plans were developed by source protection committees representing municipal, First Nation, and public interests. The Raisin-South Nation Source Protection Plan (SPP) applies in the Bear Brook Watershed.

The Bear Brook Watershed contains the Vars/Limoges Municipal wells, which service the communities of Limoges in the Nation Municipality and Vars in the City of Ottawa. Both systems draw their drinking water supplies from the Vars-Winchester esker aquifer.

A Wellhead Protection Area (WHPA) was delineated around the Vars/Limoges Municipal wells in the direction the water travels towards the well (Figure 10).

Four WHPAs have been delineated representing different times of travel to the well:

- WHPA-A, immediate
- WHPA-B, 2 years
- WHPA-C, 5 years
- WHPA-D, 25 years

The WHPAs have been scored based on their vulnerability from 2 to 10. The vulnerability score is a measure of the drinking water source's susceptibility to contamination. Higher numbers indicate higher vulnerability.

Figure 10. Wellhead Protection Areas for the Vars and Limoges municipal wells.

The Raisin-South Nation SPP contains policies to protect Municipal drinking water systems. The following activities listed in Table 12, if occurring in the Vars/Limoges WHPA, could be a significant drinking water threat (Clean Water Act, 2021). To date, there have been no water quantity threats identified for the Vars/Limoges Municipal wells.

Table 12. Significant Drinking Water Threats identified under the *Clean Water Act* (2021) for the Vars/Limoges Well Head Protection Area.

Significant Drinking Water Threat Categories
Waste Disposal Sites
Disposal of Hauled Sewage to Land
Application of Processed Organic Waste to Land
Landfarming of Petroleum Refining Waste
Landfilling (Hazardous Waste or Liquid Industrial Waste)
Landfilling (Municipal Waste)
Liquid Industrial Waste Injection into a well
PCB Waste Storage
Storage of Hauled Sewage
Storage of Processed Organic Waste or Waste Biomass
Transfer/Processing Sites approved to receive Hazardous Waste or Liquid Industrial Waste
Transfer/Processing Site approved to receive only Municipal Waste under Part V of the Environmental Protection Act
Storage of Subject Waste at a Waste Generation Facility
Storage, Treatment and Discharge of Tailings from Mines
Sewage Works
Industrial effluent discharge
On-site sewage works
Stormwater management facilities and drainage systems
Wastewater collection facilities and associated parts
Wastewater treatment facilities and associated parts
Agricultural Activities
Application and storage of agricultural source material (ASM)
Application and storage of non-agricultural source material (NASM)
Application and storage of commercial fertilizer
Livestock grazing or pasturing and outdoor confinement area or farm animal yard
Application and Storage of Pesticides
Application and storage of road salt
Storage of snow
Fuel Handling and Storage
Chemicals
Handling and storage of dense non-aqueous phase liquids
Handling and storage of organic solvents
Aircraft de-icing
Conveyance of a liquid hydrocarbon by a pipeline

The Municipal well for the Village of Limoges is owned by the Nation Municipality and currently services 2,103 equivalent units. A single-family home counts as 1 unit, while a house with an apartment is considered 1.6 units. Business units are adjusted based on their water consumption. The Village of Limoge's water system is supplemented by water from the City of Clarence-Rockland, which is taken from the Ottawa River. The maximum allowable consumption for the well is 2,080 m^3/day.

The Municipal well for the community of Vars is owned by the City of Ottawa and has 363 billed service connections. The population serviced by the Vars Municipal well system was 1,240 in 2023.

Existing drinking water threats have been identified and managed by the Source Protection Office. Drinking water threats are managed through Section 57 and 58 of the *Clean Water Act*. Section 58 requires a person to agree to a risk management plan before they may engage in an activity regulated by the *Clean Water Act*. Section 57 prohibits a person from engaging in an activity that is considered a significant drinking water threat.

Future drinking water threats are managed through Section 59 of the *Clean Water Act*. A person shall not make an application under the *Planning Act*, construct or change the use of a building unless the Risk Management office issues a notice for the application to proceed.

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Appendix A Watercourse Update for the Bear Brook Watershed

A watercourse update was completed as part of the March 2024 Land Cover update, which included the Bear Brook Watershed. The purpose of this update was to increase spatial accuracy of the existing watercourse network and identify any missing features that were now visible through the evaluation of LiDAR derived hillshades.

For this project, watercourses were defined as surface features with visible beds and banks that carry water for at least part of the year. The watercourses are represented as center lines, based on elevation data from LiDAR and aerial imagery. Several technical specifications were considered in the development of the product and are detailed below. This report details Percent (%) Watercourse Class for each Subwatershed, as well as at the Watershed level.

Watercourse features were digitized at a scale between 1:2000 and 1:5000.

Data Classification Schema

The data schema for this update is largely based on the MNRF Data Capture Specifications For Hydrographic Features (Large Scale) (2011).

The main classification attribute is WATERCOURSE. This attribute will be used to define the type of watercourse within the dataset. Table 1 breaks down each watercourse type.

Table A1. Classification schema for watercourses in the Bear Brook Watershed.

Main Class	Sub Class	Description
WATERCOURSE	1. Stream	Default watercourse feature. Represents a visually identifiable, often natural, watercourse feature within the landscape that does not meet criteria of other features.
	2. Ditch	Roadside watercourse feature that conveys water. Are digitized when they form a part of the overall drainage network and connect natural watercourses within that network.
	3. Culvert	Any man-made structure that conveys water. Includes other structures such as bridges.
	4. Virtual Flow	Watercourse features that flow through waterbodies to ensure continuity to the flow network.
	5. Virtual Connector	A surface or subsurface feature that cannot be viewed from imagery or LiDAR (e.g., a stream within a dense forest, or flow through a wetland to a definable outlet). Used to maintain continuity of flow network.

Main Class	Sub Class	Description
	6. Constructed Drain Open	An open, and visually identifiable watercourse that has been verified by comparing it to the Provincial Constructed Drain layer. In the absence of a feature in the base layer, features will be copied from the Provincial dataset. Any constructed drains, (whether already present or copied in) that require spatial editing based on the reference data, will be attributed as having been altered.
	7. Constructed Drain Closed	Closed or tiled drainage features. Will not be digitized but will be copied into the main dataset based on the latest version of the Provincial Constructed Drain Layer if missing.
	8. Swale	Visibly discernable depression intended to convey runoff water on agricultural lands. Where swales exist in the base layer data they will be retained. However, new swale features ***will not*** be digitized.

Additional data has been captured in the attribute table from the existing watercourse data set but was not corrected and expanded upon.

Reference Data

The DRAPE 2019 aerial photography product and LiDAR derived elevation products were used to visually identify watercourses. Elevation products like DTMs and hillshade aided in watercourse identification by showing detailed topography and overall drainage patterns across the watershed. Staff utilized the most recent LiDAR data available, including data from 2019 to 2022 across the project extent.

Network and Topological Considerations

Analysis for connectivity and flow were completed to produce a connected network, with continuous flow in a downstream direction from headwaters to outlet. Flow direction was interpreted from LiDAR elevation products, and any inconsistencies, disconnections, and circular flow loops breaking the continuous flow of the network were identified and corrected.

Special Considerations

Land cover across the project extent is highly variable and includes agricultural lands, developed urban areas, forest, wetland and others. As such, certain considerations need to be made based on the type of landscape that watercourse features are found.

Ditches within approved subdivisions

In general, approved subdivisions have detailed grading and drainage plans. For the purposes of this project, only watercourses that formed part of the overall network within approved subdivisions were digitized to ensure network connectivity. These included any inflows into the subdivision as well as outflows that contribute to the network (Figure 1)

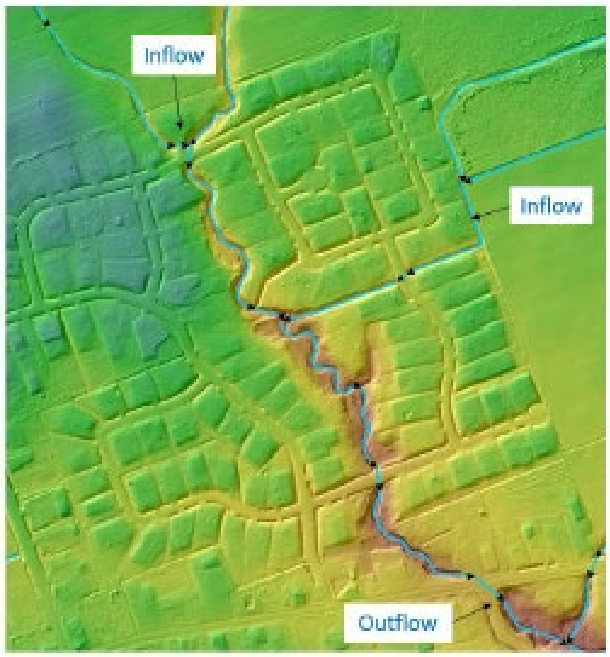

Figure A1. A drainage network with an inflow and outflow within a subdivision.

Roadside ditches

Outside subdivisions, ditches located along roads in rural areas are very common. Roadside ditches were captured when they formed part of the overall watercourse network, acting as a conduit to ensure flow through the network.

Sub-Watersheds

The six major sub-watersheds were developed from existing watercourse and catchment data. As described above, watercourses were evaluated against LiDAR derived topography to increase spatial correctness and confirm or correct flow direction. These watercourses were compared against existing sub-catchments derived from previous hydraulic modeling of the Bear Brook watershed, which had been developed to identify the extents of the floodplain for the Bear Brook.

Where a discrepancy between the watercourse data and the hydraulic catchments existed, catchments were reevaluated using the ArcHydro suite of tools for ArcGIS to redefine the catchment boundaries based on the updated watercourse and LiDAR topographic data.

Once the smaller hydraulic catchments had been refined, they were grouped into the six major sub-watersheds comprising the Bear Brook (Figure 2). The catchments were grouped mainly around significant tributaries. An exception to this approach can be found in the divide between the Upper and Main Bear Brook sub-watersheds. This allowed separation between the unique conditions found in the upper headwater reaches and the rest of the Bear Brook as it makes its way east to the South Nation River.

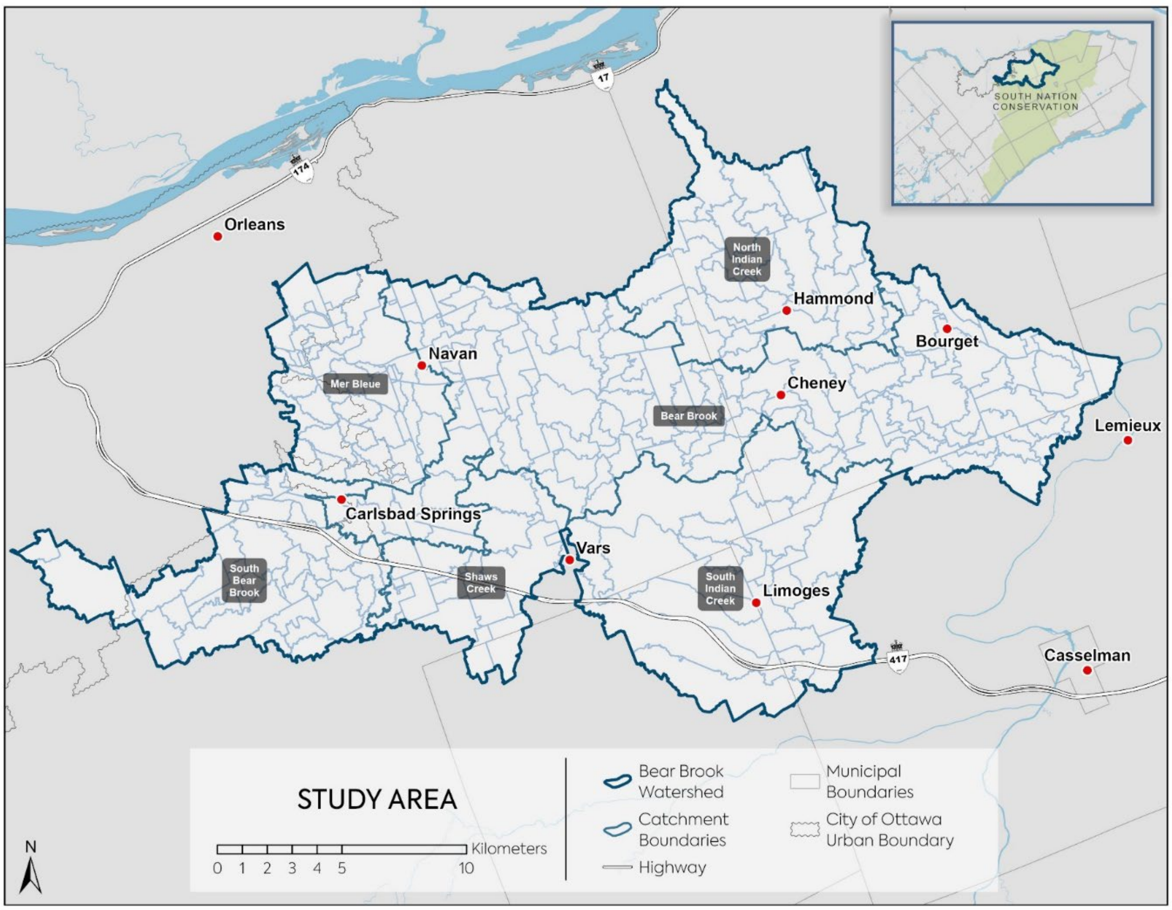

Figure A2. Subwatersheds of the Bear Brook Watershed

Appendix B Flow Data at Hydrometric Stations

Table B1. Flow data, measured as stage-discharge, at the Bourget Hydrometric Station.

Date	Time	Stage (m)	Discharge (CMS)
02-May-24	12:30:00	1.72	1.51
07-May-24	09:00:00	1.63	0.75
17-May-24	09:30:00	1.55	0.32
23-May-24	11:30:00	1.74	0.36
31-May-24	12:50:00	1.67	0.25
07-Jun-24	10:00:00	2.93	5.97
13-Jun-24	11:30:00	1.69	0.30
13-Jun-24	14:30:00	1.72	0.29
14-Jun-24	09:30:00	1.73	0.45
18-Jun-24	09:30:00	1.49	0.25
19-Jun-24	10:00:00	1.43	0.18
21-Jun-24	15:00:00	1.34	0.13
25-Jun-24	09:00:00	2.41	2.22
03-Jul-24	09:00:00	1.42	0.29
09-Jul-24	11:30:00	1.52	0.42
11-Jul-24	11:50:00	1.76	1.73
16-Jul-24	09:00:00	2.62	4.42
23-Jul-24	09:30:00	1.33	0.27
30-Jul-24	09:30:00	1.34	0.20
06-Aug-24	12:30:00	1.29	0.18

Table B2. Flow data, measured as stage-discharge, at Indian Creek Road station

Date	Time	Stage (m)	Discharge (CMS)
08-Nov-23	09:45:00	0.78	1.36
17-May-24	14:00:00	0.90	2.04
23-May-24	14:00:00	0.88	2.03
29-May-24	14:00:00	1.27	5.88
31-May-24	13:30:00	0.88	3.34
07-Jun-24	10:30:00	2.21	13.11
11-Jun-24	13:30:00	1.46	6.76
13-Jun-24	13:20:00	0.91	2.15
14-Jun-24	12:50:00	0.91	2.34
18-Jun-24	12:30:00	0.78	1.07
19-Jun-24	12:30:00	0.76	0.99
21-Jun-24	12:30:00	0.72	0.88
25-Jun-24	13:00:00	2.77	14.59
03-Jul-24	11:30:00	0.87	1.77
11-Jul-24	13:00:00	2.07	7.96
12-Jul-24	11:00:00	2.16	9.16
16-Jul-24	13:20:00	1.63	8.23
23-Jul-24	11:30:00	0.78	1.23
30-Jul-24	12:00:00	0.79	1.27
06-Aug-24	11:30:00	0.72	0.82

Appendix C Development of a Fully-Integrated GW-SW Model for the Bear Brook Watershed: Preliminary Water Balance Analysis

Development of a Fully-Integrated GW-SW Model for the Bear Brook Sub-Watershed:

Preliminary Water Balance Analysis

Report Submitted to:

Katherine Watson
South Nation Conservation

Draft: November 05, 2024

aquanty
HYDROSPHERE ANALYTICS

519 279 1080
info@aquanty.com
www.aquanty.com

aquanty inc.
564 Weber St.N., Unit 12
Waterloo, ON, N2L 5C6

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Summary

A fully-integrated HydroGeoSphere groundwater – surface water model has been constructed for the Bear Brook Creek sub-watershed within the South Nation River watershed. The model has undergone preliminary calibration for surface water simulation performance, and was subsequently used for a 1997 to 2017 water balance analysis for nine sub-catchment areas within the Bear Brook Creek. Preliminary results show that on average across all sub-catchments, evapotranspiration accounts for 58 % of precipitation, stream and surface water outflow accounts for 38 % of precipitation, and groundwater recharge accounts for 4.3 % of precipitation. Work is ongoing to further develop the model prior to its use with land use change scenario analysis. Model development also continues with implementation of groundwater monitoring points, updating landcover to incorporate new wetland mapping data, and to test the impact of tile drainage on watershed hydrologic behavior.

1.0 INTRODUCTION

Effective water budget analysis and groundwater recharge management are crucial for enhancing the sustainability of water resources and reducing the risks associated with water scarcity and excess (Dillon, 2005; Panday et al., 2009). Understanding and quantifying the components of the water budget, such as precipitation, evapotranspiration, surface water outflow and groundwater recharge, are essential for assessing the risks of both flood and drought, and for evaluating the impact of land use change and climate change on hydrologic behavior. Infiltration is a crucial process driving groundwater water recharge, while groundwater water discharge into surface water and uptake by vegetation are equally important components of the overall water budget (Griebler & Avramov, 2015). These hydrologic processes influence the availability of water within a system, playing a significant role in balancing water inputs and outputs, and availability. Groundwater discharge, for instance, contributes to maintaining base flow in streams and rivers, which is essential during periods of low precipitation. Similarly, vegetation uptake regulates the distribution of water between the surface and subsurface, impacting evapotranspiration rates and influencing groundwater recharge (Booth et al., 2016; Li et al., 2014), and when groundwater levels drop, vegetation water demands and ecological demands can often not be met. Fully understanding these fluxes within a water balance assessment is essential for accurately assessing water availability under different climatological and land use scenarios.

In this project a large scale (482 km^2), structurally complex, fully integrated groundwater-surface water model was developed using HydroGeoSphere (HGS) for the Bear Brook Creek sub-watershed. The sub-watershed is in the northwest corner of the 3830 km^2 South Nation River watershed (Figure 1). The simulation interval upon which the results of this work are based extends from 1997 – 2017 and consists of both flood and drought conditions. The model is shown to successfully reproduce the continuous surface water flow rates in Bear Brook Creek at the Bourget Water Survey of Canada (WSC) 02LB008 hydrometric station. The results from the modelling are used to quantify the surface water outflow, groundwater recharge, precipitation, and evapotranspiration components of the overall water balance in the Bear Brook Creek sub-watershed as well as in nine sub-catchments areas within the Bear Brook Creek sub-watershed.

2.0 METHODOLOGY

2.1 Study Area:

The Bear Brook Creek watershed has an area of 482 km^2, across which the elevation descends from approximately 120 meters above sea level (mASL) closer to the city of Ottawa in the west to 42 mASL at the outlet (Figure 2). Of particular importance in this study, the eastern flank of the city of Ottawa encroaches on the western corner of the watershed and is expected to continue expanding east.

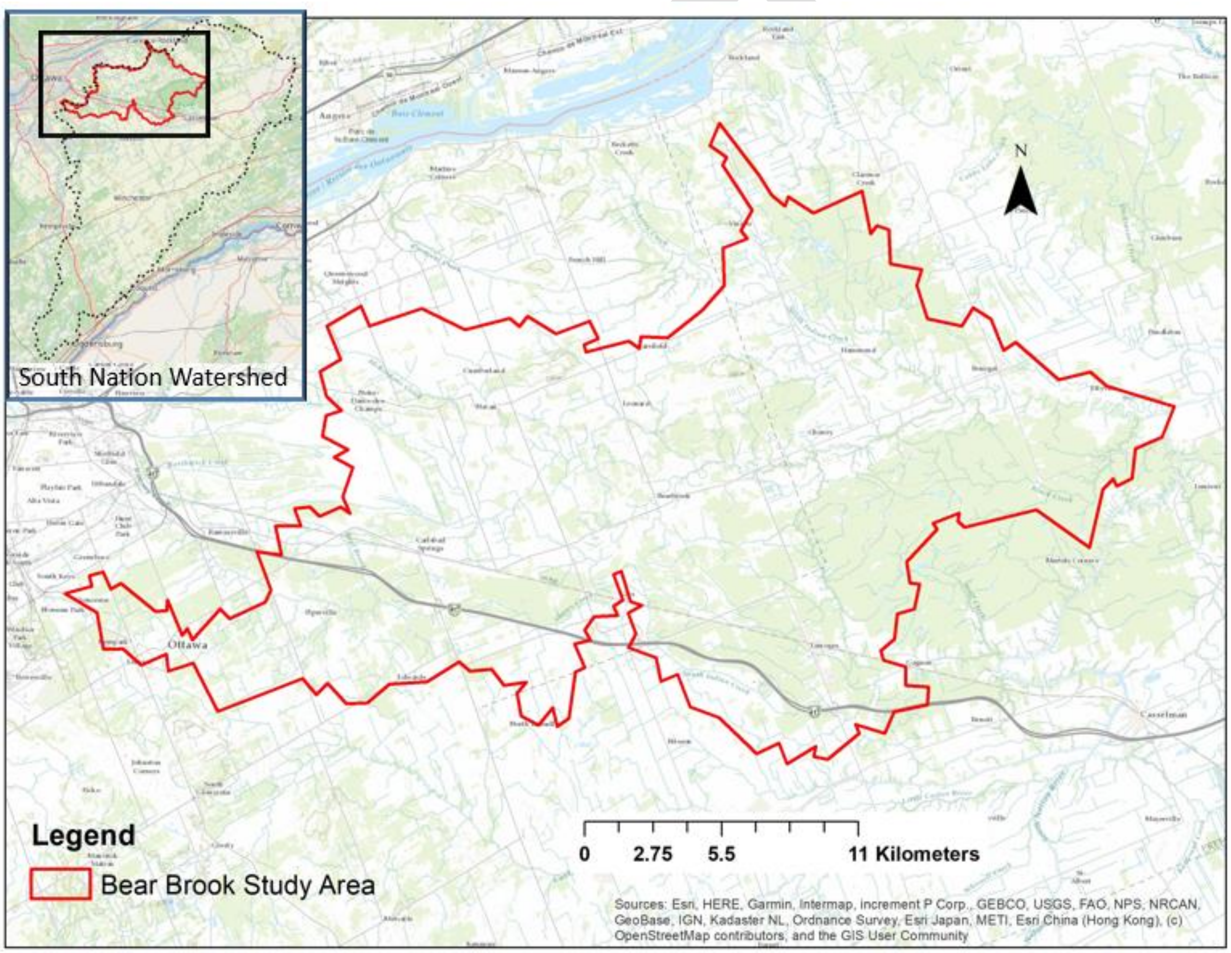


Figure 1: The inset figure shows the location of the Bear Brook Creek sub-watershed within the South Nation watershed, while the main figure shows the extent of the Bear Brook sub-watershed in detail. The red study area delineation conforms with the HydroGeoSphere (HGS) model domain.

2.2 Model Description:

The HydroGeoSphere (HGS) fully integrated surface water-groundwater model was employed for the study herein. For a detailed technical description of HGS, interested readers are referred to Aquanty (2023), while only a brief overview of the HGS features relevant to this study is provided here. For water flow, HGS utilizes a globally implicit control volume finite difference approach with adaptive time stepping and OpenMP parallelization (Hwang et al., 2015) to solve a coupled set of equations based on the three-dimensional Richards' equation for variably saturated subsurface flow, the two-dimensional diffusion wave equation for surface flow, and the Manning's one-dimensional open channel flow equation for channel flow. The exchange of water between the surface and subsurface domains occurs seamlessly in response to pressure gradients that vary in response to climate and hydrologic conditions. Evapotranspiration processes in HGS consider climate conditions, time-varying plant root growth and leaf area index, spatially varying land cover, and surface and subsurface moisture availability (Kristensen & Jensen, 1975). For the representation of sub-mesh scale topographic detail such as small wetlands and other depressional features, HGS utilizes an element-based spatially varying rill storage formulation to equate depressional topographic storage into an equivalent element-based surface water depth, which in turn acts as an exceedance threshold required for the initiation of overland flow. Readers are referred to Frey et al. (2021) for a detailed description of the HGS formulation used in this study.

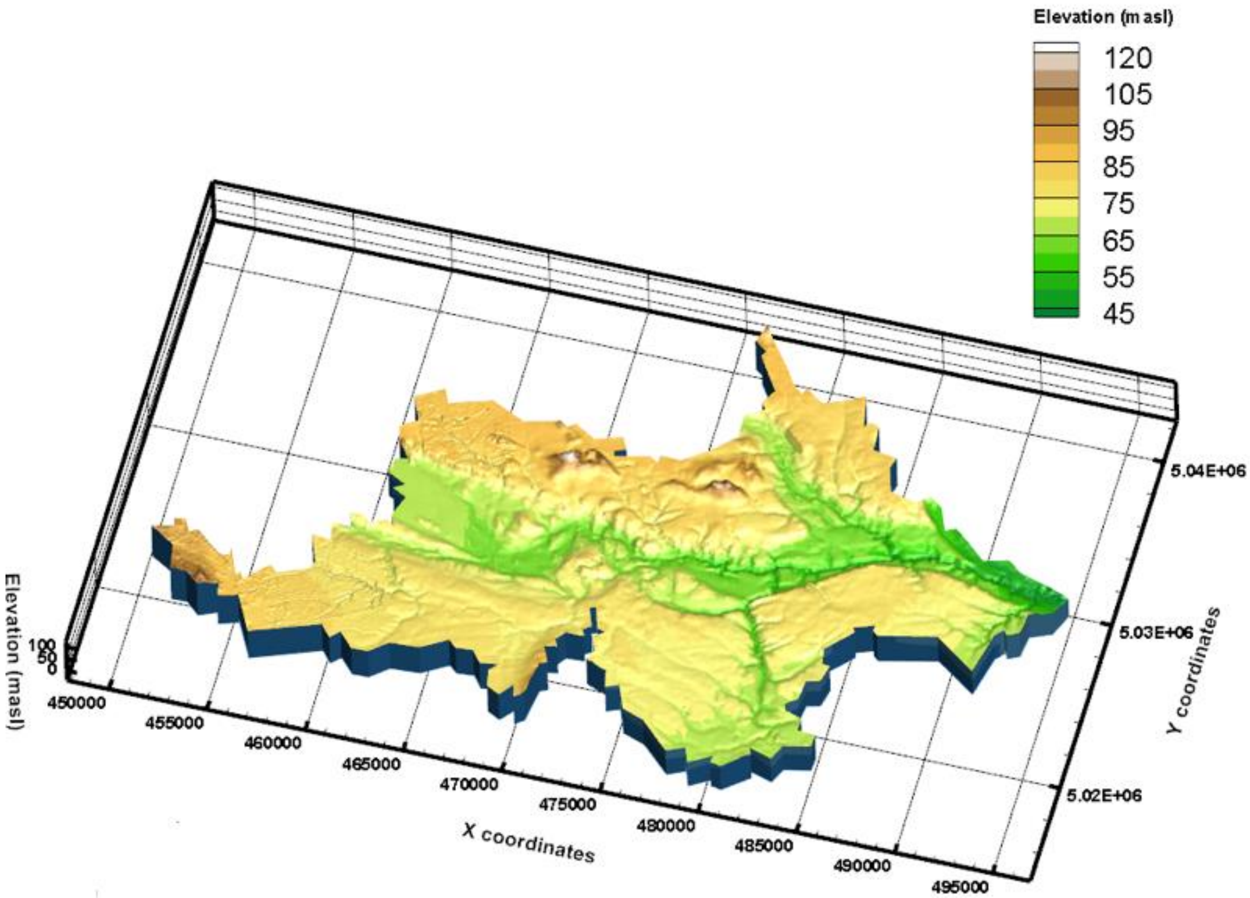


Figure 2: Three-dimensional representation of the Bear Brook sub-watershed HydroGeoSphere (HGS) model.

2.2.1 Finite Element Mesh:

AlgoMesh (HydroAlgorithmics, 2016) was used to generate the unstructured finite element mesh (FEM) employed in the HGS model. The use of unstructured meshes allows scaling of spatial resolution, and potentially accuracy, on local areas of importance while still capturing larger scale hydrologic behaviors. The FEM was designed with up to 250 m spatial resolution along the surface water channels and roadways and in areas distal to channels (Figure 3); however, it should be noted that in areas with complex stream vector geometry the mesh resolution is much finer. There are 55,290 total nodes (triangular element vertices) per mesh sheet, equating to a total of 663,480 nodes across all 12 sheets in the full three-dimensional FEM with its 11 subsurface layers. In terms of triangular prism finite elements, there are 108,838 triangular elements per layer for a total of 1,197,218 triangular elements across the 11-layer subsurface model domain. In the two geographic areas of specific interest in this study, a very high mesh refinement of 60 m was applied, namely McKinnon's Creek (northwest corner) and the City of Ottawa (west corner) (Figures 3a and 3b).

(a)

(b)

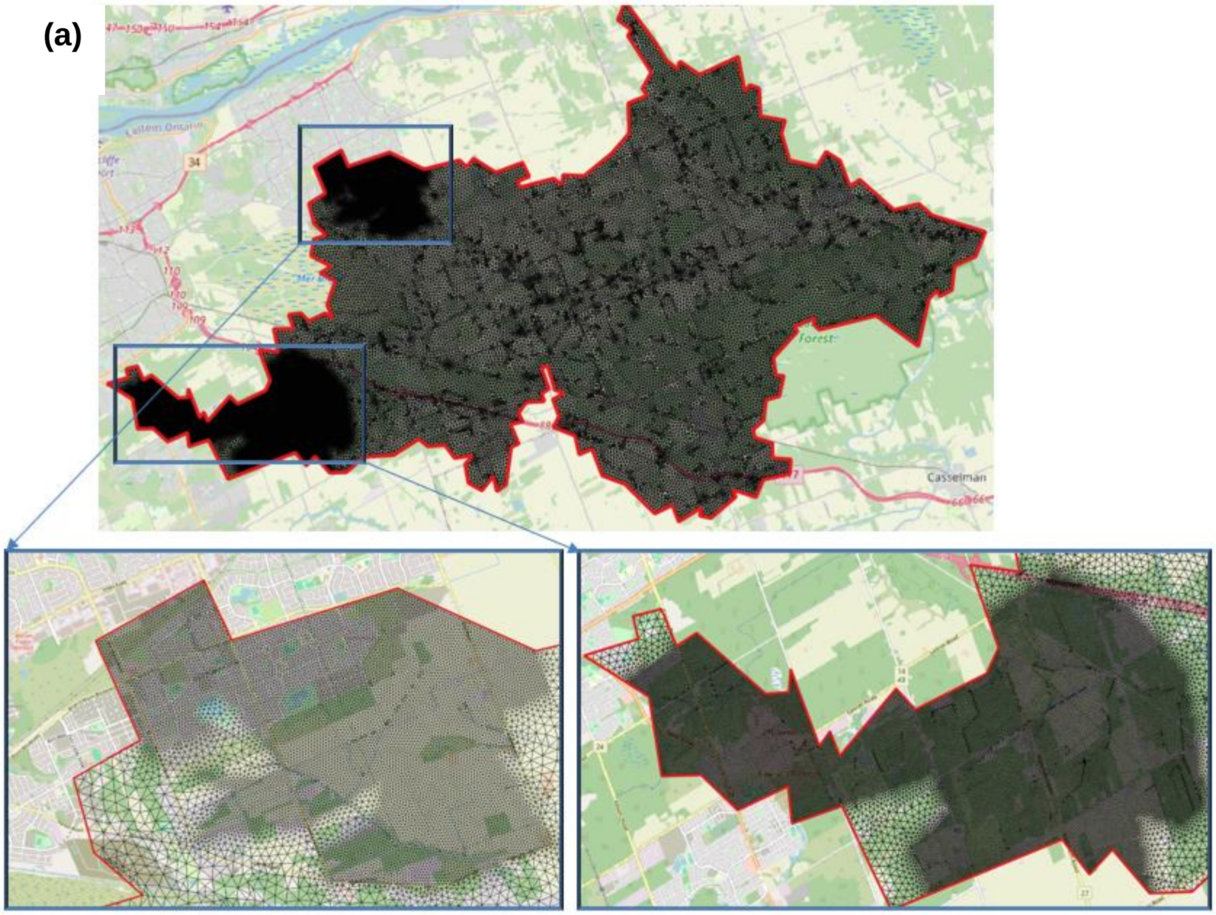


Figure 3: (a) The Bear Brook sub-watershed with complete Finite Element Mesh, (b) a magnified portion of the Finite Element Mesh showing the high spatial refinement in the McKinnon's Creek and City of Ottawa areas.

2.3 Digital Terrain Model:

The Digital Terrain Model (DTM) utilized in the HGS model is derived from the Ontario Digital Terrain Model (Lidar-Derived) raster dataset which represents the bare-earth terrain derived from a classified lidar point cloud. It has a spatial resolution of 0.5 m and was used to define the surface topography of the HGS model (Figure 4). The DTM was not subjected to a stream burning procedure, as all elevation adjustments were made directly to the finite element mesh (FEM).

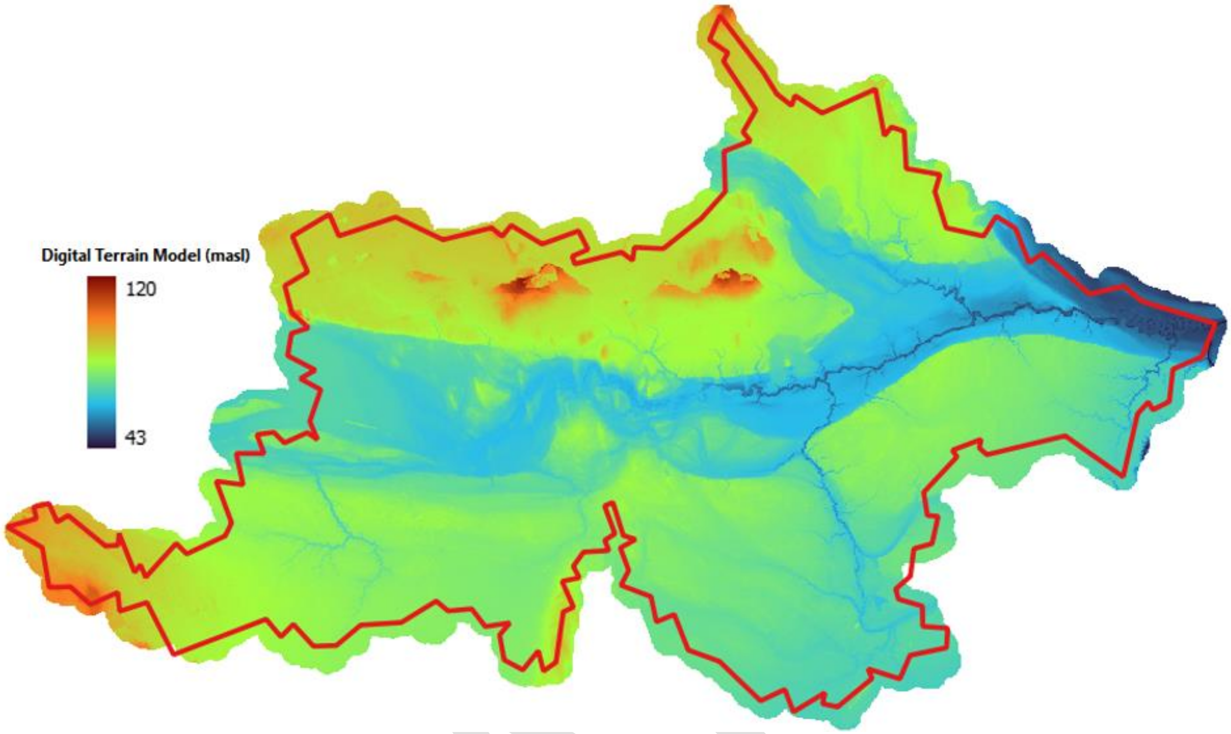


Figure 4. Digital Terrain Model (DTM) based surface elevation across the Bear Brook sub-watershed.

2.4 Surface Water Network and Road Network:

There are approximately 815 km of one-dimensional surface water channels (Figure 5) in the surface water feature dataset, provided by South Nation Conservation (SNC), that are resolved in the HGS model. All features extending from extremely small drains (Strahler Order 1) to the South Nation River (Strahler Order 7) are represented in the model. For each river/stream vector segment, the Manning's *n* surface friction coefficient was initially set to 0.04 and then manually adjusted during model calibration in order to optimize the match between simulated and observed daily flow rates at the WSC 02LB008 hydrometric station on the Bear Brook Creek near the outlet. Down-gradient flow was enforced along the channels using elevation controls on FEM nodes coincident with channel locations. In addition to the rivers and streams, there are approximately 315 km of one-dimensional road features resolved in the model topography that were derived from the Ontario Road Network (ORN). In areas where rivers and streams flow under roads, the roads were overwritten by channel elevation to facilitate continuous stream flow.

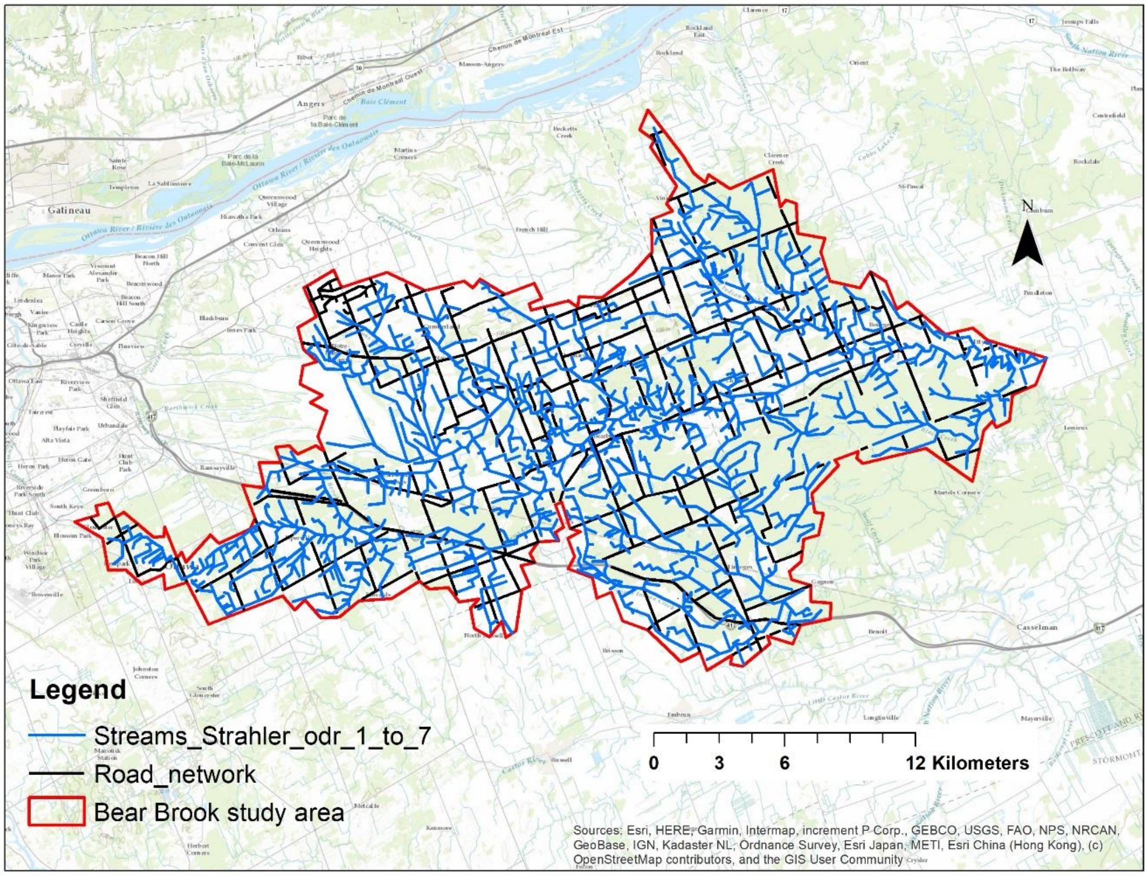


Figure 5: The stream and road network resolved in the Bear Brook Sub-watershed HGS model.

2.5 Landcover:

The spatially distributed land cover used in the HGS model was also provided by SNC (Figure 6). The land use categories and percentage of the model area attributed to the different land uses are presented in Table 1. When using the landcover data, HGS reads the value of pixels from the landcover raster file and assigns evapotranspiration (ET) parameters based on vegetation and/or landcover type, and overland flow hydraulic properties. The ET parameters include transpiration limiting pressure (wilting point, field capacity, oxic limit, and anoxic limit), Leaf Area Index (LAI), a time-varying root density function (RDF) and evaporation limiting factors (evaporation depth, canopy evaporation). In the Bear Brook Creek model, root depth was derived from (Canadell et al., 1996), while LAI was derived from MODIS imagery (Myneni et al., 2015). For all landcover classes, evaporation depth was set to 0.2 m, meaning that water in the top 0.2 m of the soil profile would be able to evaporate.

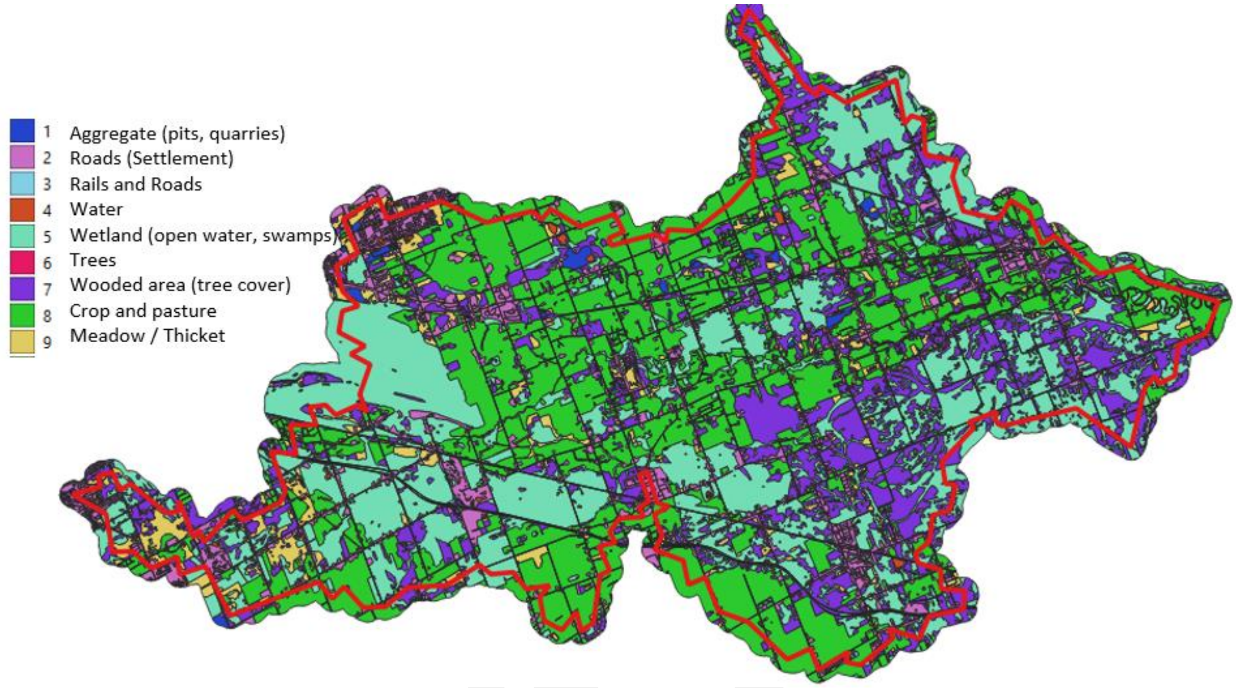


Figure 6: Spatially distributed land cover map for the Bear Brook sub-watershed.

Table 1: Percentage of each component of land cover in Bear Brook sub-watershed

Land Cover Component	Percentage by Area
Aggregate (pits, quarries)	0.62 %
Settlements	8.71 %
Rail and Roads	2.16 %
Water	0.44 %
Wetland and Swamp	28.9 %
Wooded Area (Tree cover)	19.1 %
Cropland and Pasture	34.5 %
Meadow/Thicket	5.6 %

2.6 HGS Model Boundary Conditions:

The specified flux (Neumann) boundary conditions were used on the top surface of the model to represent daily transient liquid water flux (rainfall and snowmelt), and potential evapotranspiration (PET). Groundwater recharge is computed internally by HGS. A critical depth boundary condition was applied to the surface domain perimeter nodes to facilitate water outflow from the model. The perimeter of the subsurface porous media domain and the base of the model were considered no-flow boundary conditions. It is recognized that regional (from outside the Bear Brook sub-watershed) groundwater flow influences will be omitted in this boundary condition configuration, and in ongoing work the effect of this will be quantified. However, because the objective of this study primarily focuses on local scale (sub-catchment) water balances, regional groundwater inflow to these smaller areas is anticipated to be a small overall component of the water balance. More importantly, the model does capture the shallow local groundwater flow in and out of the sub-catchments.

2.7 Soil

Spatially distributed soil property information was derived from the Agriculture and Agri-Food Canada (AAFC) Detailed Soil Survey (DSS), which defines 50 different soil types across the watershed. In the model, soil layers were defined at 0.25, 0.5 and 1 m depths. Hydraulic properties for each DSS polygon were unique for each of the three soil layers. These properties were estimated based on using the reported sand, silt, and clay percentages, bulk density, and moisture retention information for KP33 and KP1500 tensions within the Rosetta pedotransfer function model (Schaap et al., 2001). Rosetta in turn generated the parameter values for residual and saturated water content (θ_r, θ_s), the van Genuchten α and n parameters, and saturated hydraulic conductivity (K_s) required by the HGS model. For areas where the DSS were missing data (Figure 7a), soil information from the Soil Landscape of Canada (SLC) was used (Figure 7b).

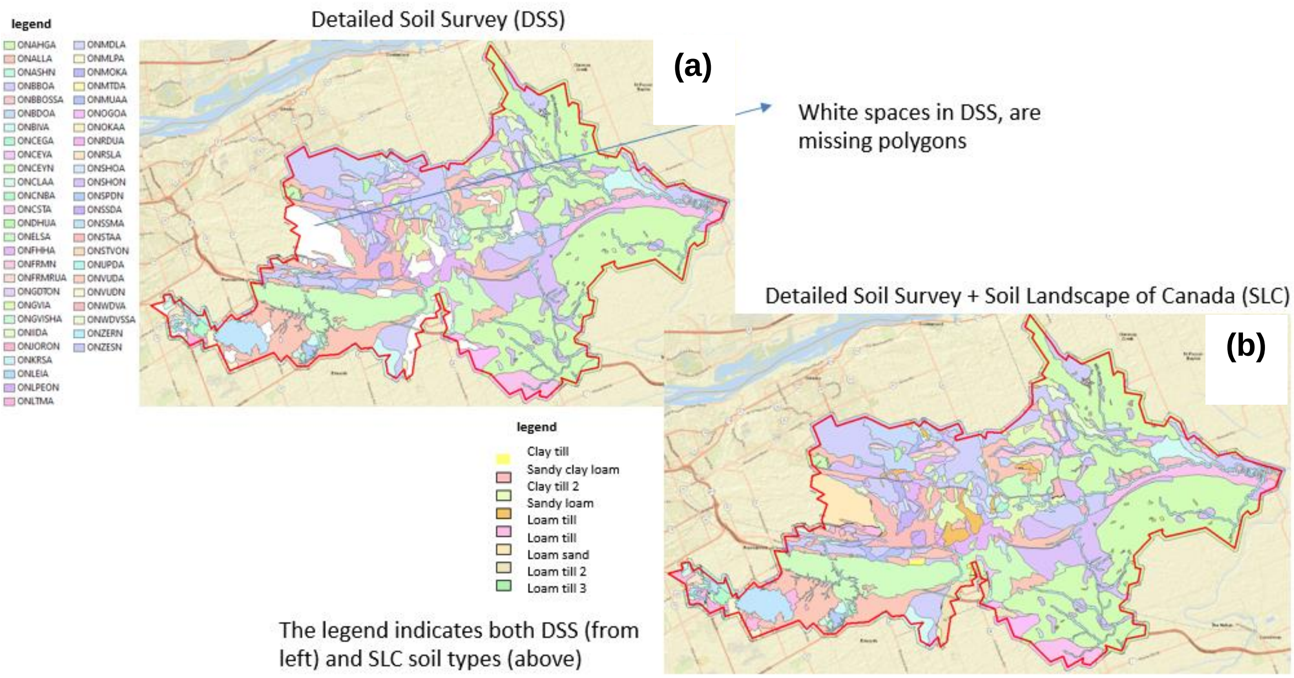


Figure 7: (a) Detailed Soil Survey (DSS) soil map for the Bear Brook sub-watershed (with missing soil polygons), and (b) the soil map used in the HydroGeoSphere model where missing DSS data was infilled with soil information from Soil Landscapes of Canada (SLC).

2.8 Hydrostratigraphy

The hydrostratigraphic model for the Bear Brook sub-watershed, which forms the subsurface component of the HGS model, was derived from the Vars-Winchester Esker Model provided by SNC in combination with additional borehole logs that were provided by SNC from the City of Ottawa's borehole database, and bedrock control points generated from the Canada1Water (C1W) drift thickness map (publication pending). The hydrostratigraphic model contains 6 Quaternary and 2 bedrock layers with spatially varying hydraulic properties within each layer, and complex 3D geometry that reflects the spatial variation in geologic contact depths across the different hydrostratigraphic layers (Figure 8). The geometry of the layer surfaces coincides with the interface between contrasting lithologies (i.e. the top of a modelled unit).

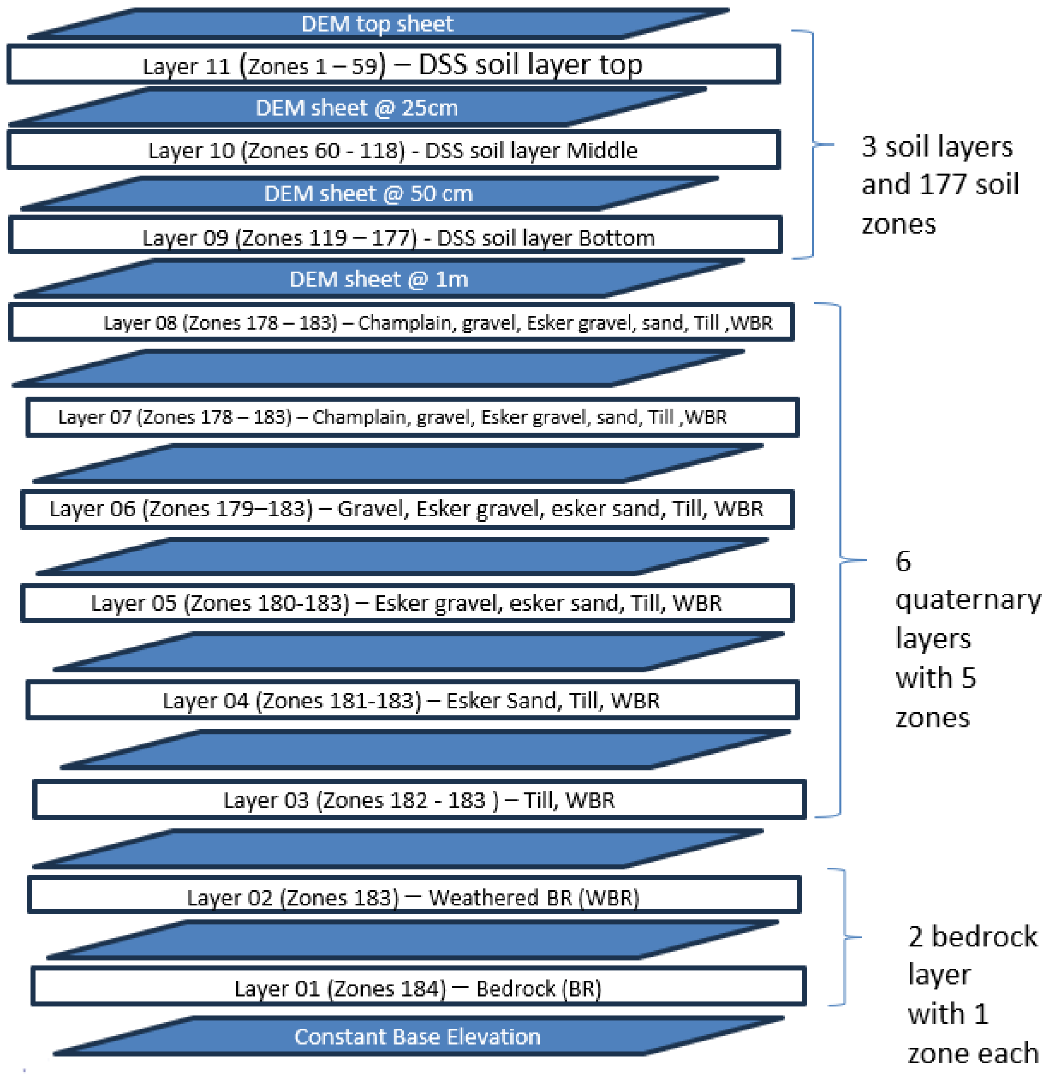


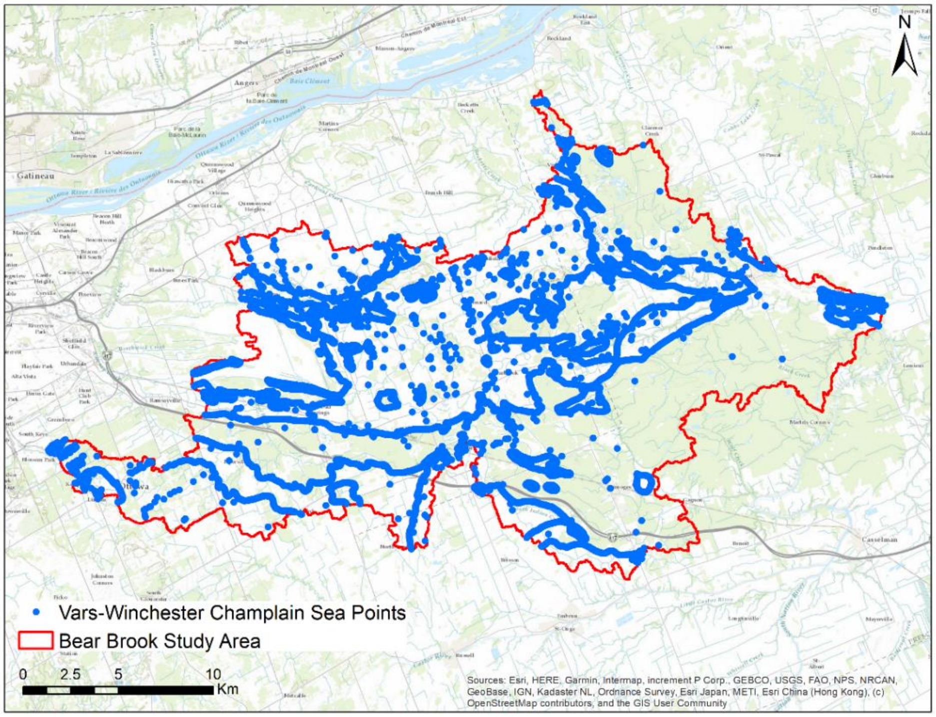
Figure 8. Layer-based representation of the lithology zones in the soil, Quaternary, and bedrock layers within the Bear Brook sub-watershed HGS model. Note that in the model, the layer surfaces are not flat but instead follow complex geometry that conforms with the geologic contacts defined in the Vars-Winchester Esker Model and in the subsurface borehole records.

All input geological models, data, and maps were converted to point datasets for use in interpolating the 3D volumes associated with each hydrostratigraphic unit. The majority of the subsurface lithology control points were derived from the Vars-Winchester Esker model (47,231 control points across 5 material types). The Esker model included both well picks and points along the edges of outcrops corresponding to the OGS seamless surficial geology map (Ontario Geological Survey, 2010) and was supplemented with 525 additional borehole logs from City of Ottawa's borehole database. These two datasets were used to define the geometry and material distribution across the six Quaternary layers within the model. Additional control points for the top of bedrock surface were derived from the C1W drift thickness map, where the MNR DEM (Ministry of Natural Resources, 2006) for the watershed is used as the reference surface. The C1W drift thickness map provided 2324 control points on the top of bedrock surface, and in the Bear Brook Watershed area it is largely derived from Parent et al, (2021). Figures 9a to 9d show the extent of the control points derived from input maps, models, and boreholes.

Initial processing of all input datasets was conducted using ArcGIS© software. These datasets were then imported into LeapFrog© for 3D interpolation, with the resulting Leapfrog outputs presented in Figures 10 and 11. After several iterations of 3D volume generation in LeapFrog©, the hydrostratigraphic unit top elevations from the 3D volume model were then exported in ascii raster format for use in the HGS model. The general processing steps used were as follows:

1. Convert all input datasets to points in ArcGIS©
2. Import to LeapFrog©
3. Set up stratigraphic rules and create model framework
4. Assign points to appropriate hydrostratigraphic unit
5. Add manual control points where needed close to unit boundaries to insure proper outcrop extent
6. Interpolate surfaces and volumes
7. Adjust manual points as needed and repeat step 5 and 6 until volumes are clipped as expected to match map extents
8. Run model interpolation at highest resolution possible within reasonable computing constraints (15m in this case)
9. Export surfaces from LeapFrog© to ascii format
10. Perform quality control inspection on ascii surfaces and run post-processing in ArcGIS to prepare layers for use in HGS

Hydrostratigraphic cross sections, extracted from the LeapFrog© model in the North-West and West regions of the Bear Brook watershed, and approximately perpendicular to the Vars-Winchester esker, are presented in Figures 12, 13, and 14, respectively.



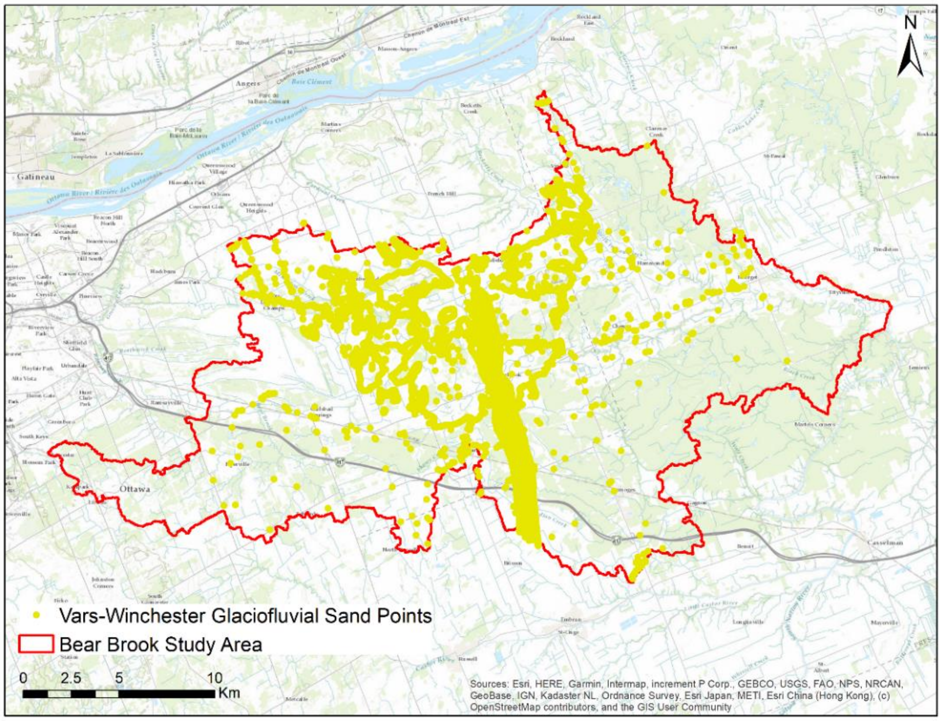
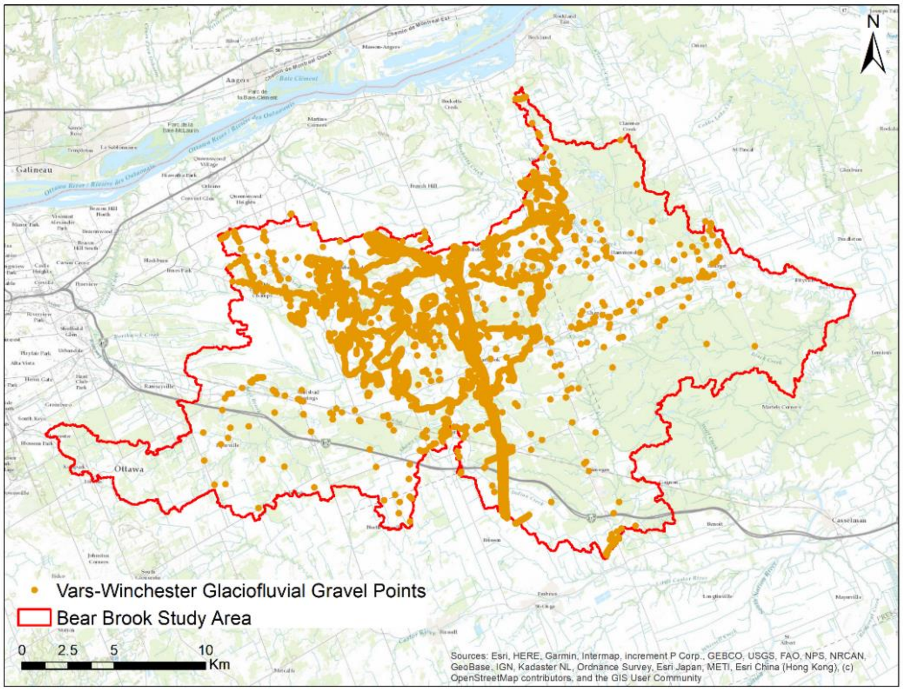


Figure 9a. Extents of input control points for the (top) Champlain Sea and (bottom) glaciofluvial sand sediments used in the 3D model generation.



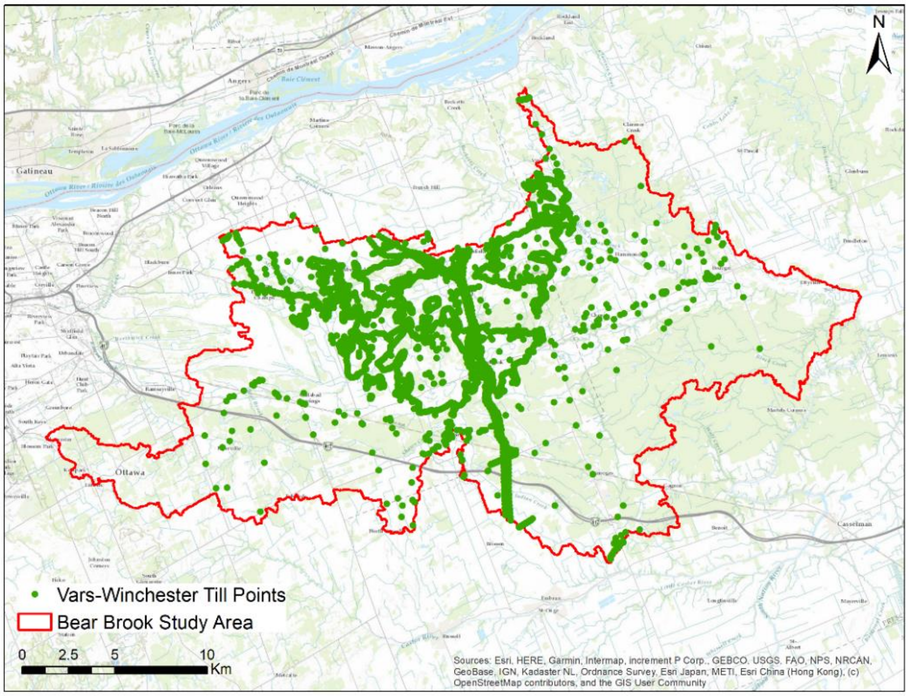


Figure 9b. Extents of input control points for the (top) glaciofluvial gravel and (bottom) Winchester Till sediments used in the 3D model generation.

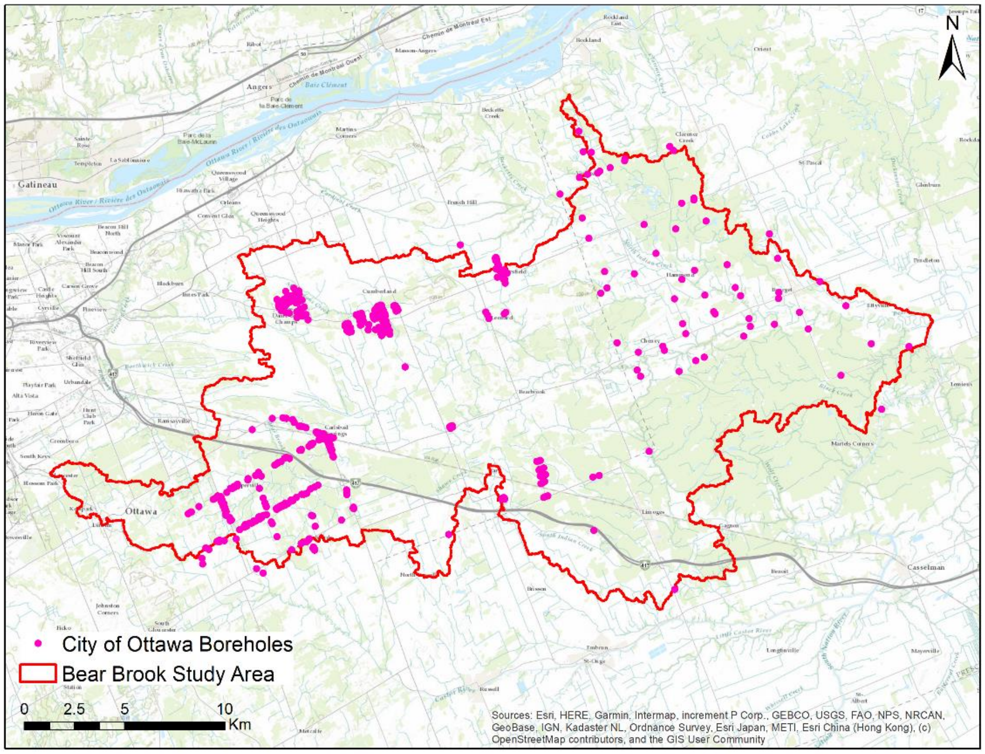


Figure 9c. Location of the City of Ottawa boreholes that were used to augment the Vars-Winchester Esker Model data in the development of the hydrostratigraphic model.

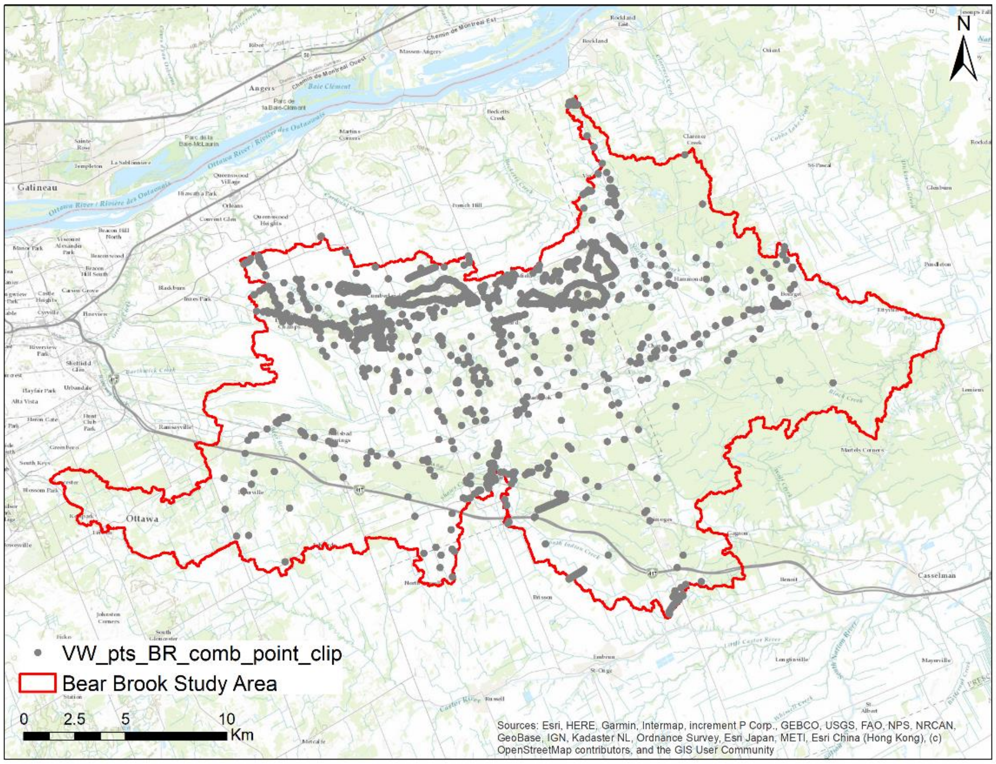


Figure 9d. Top of bedrock elevation control points extracted from the Canada1Water top of bedrock surface for developing the hydrostratigraphic model.

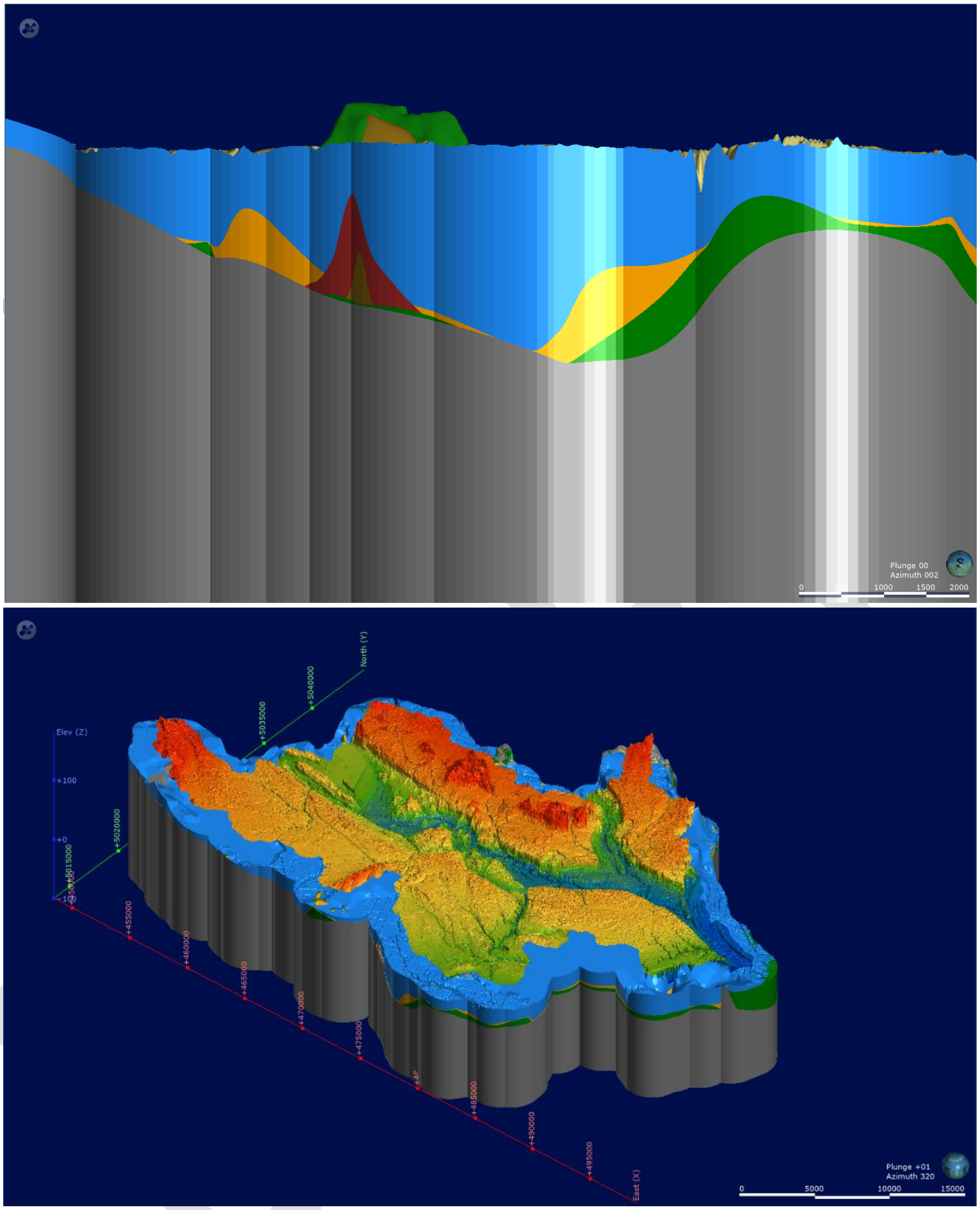
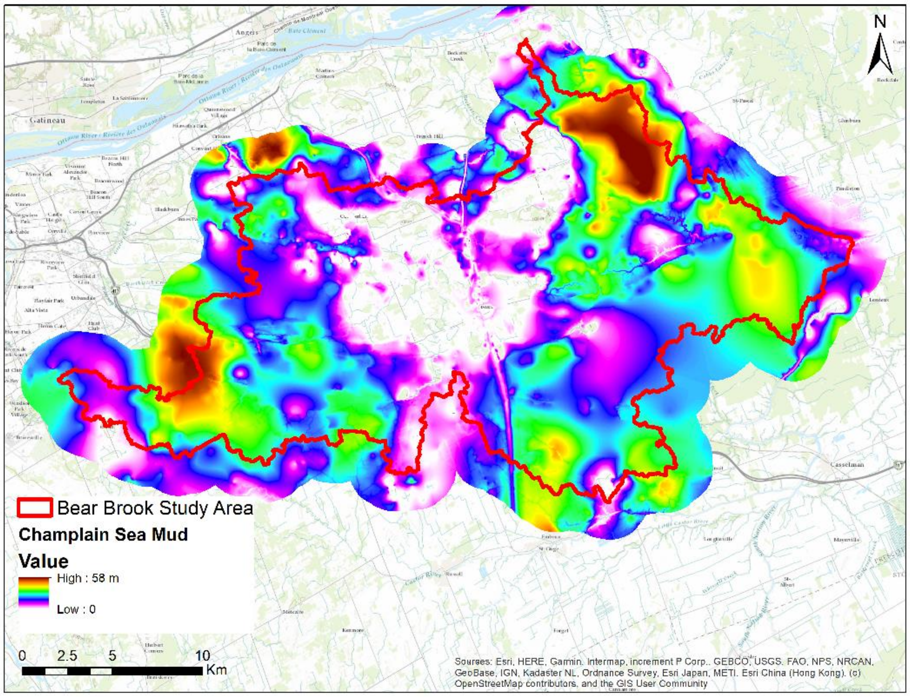


Figure 10. Side view (top) and isometric (bottom) perspectives of the 3D volumes generated in LeapFrog© to support development of the hydrostratigraphic model.



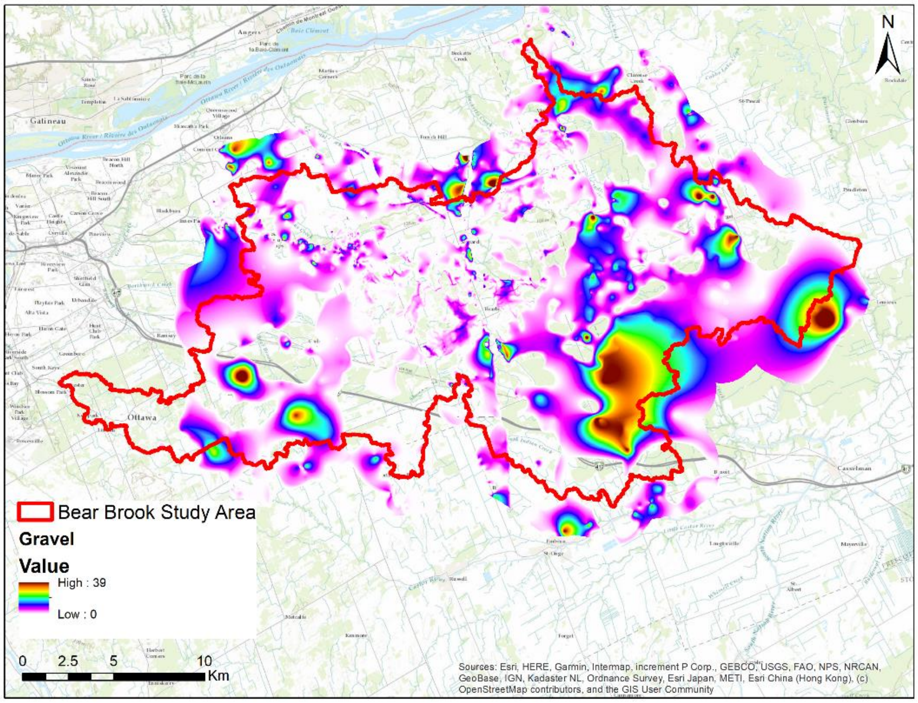
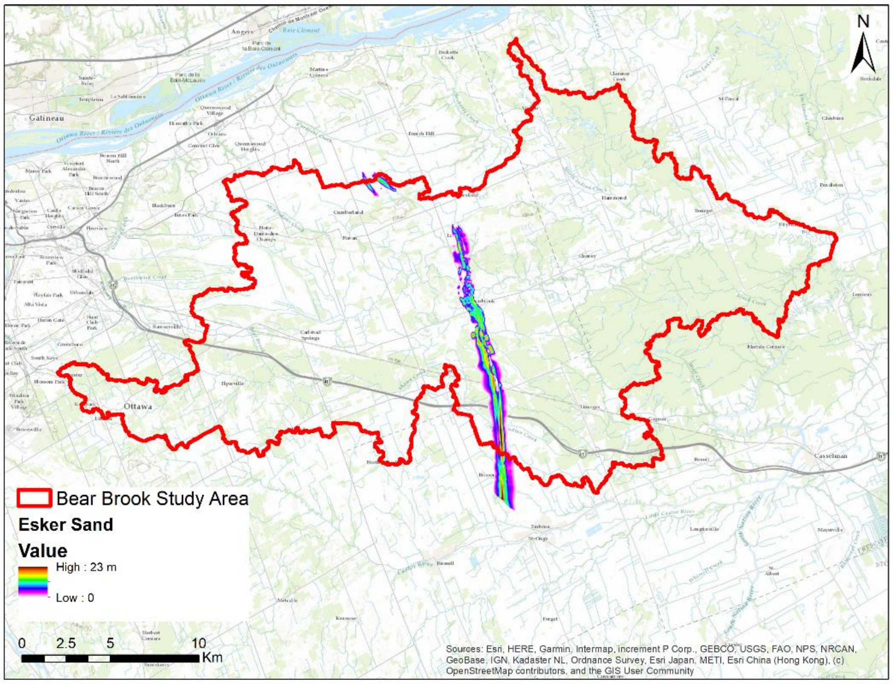


Figure 11a. Isopach maps for the Champlain Sea (top) and gravel (bottom) sediments, as exported from Leapfrog 3D model.



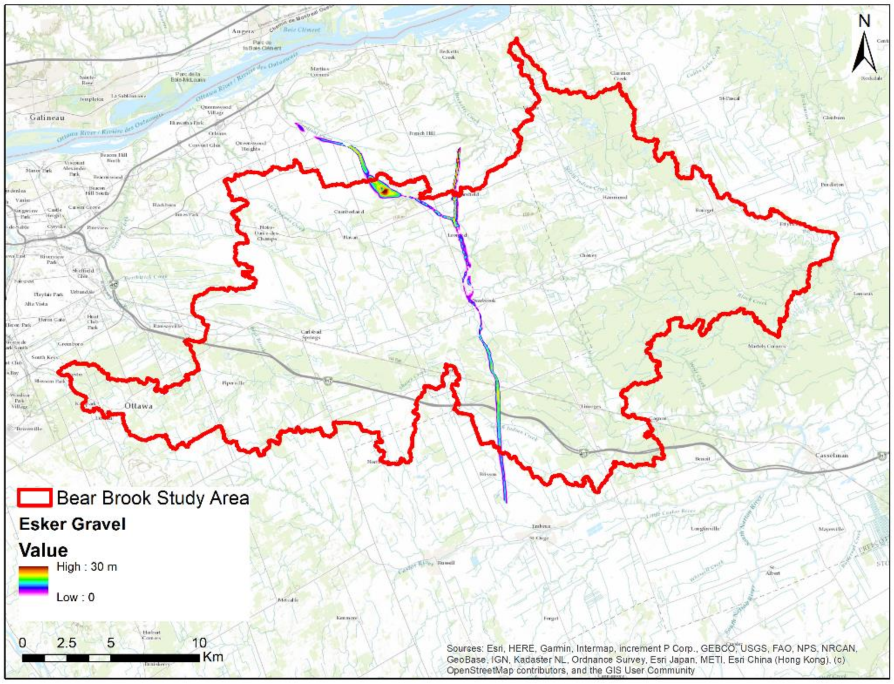


Figure 11b. Isopach maps for the Esker sand (top) and Esker gravel (bottom) sediments, as exported from Leapfrog 3D model.

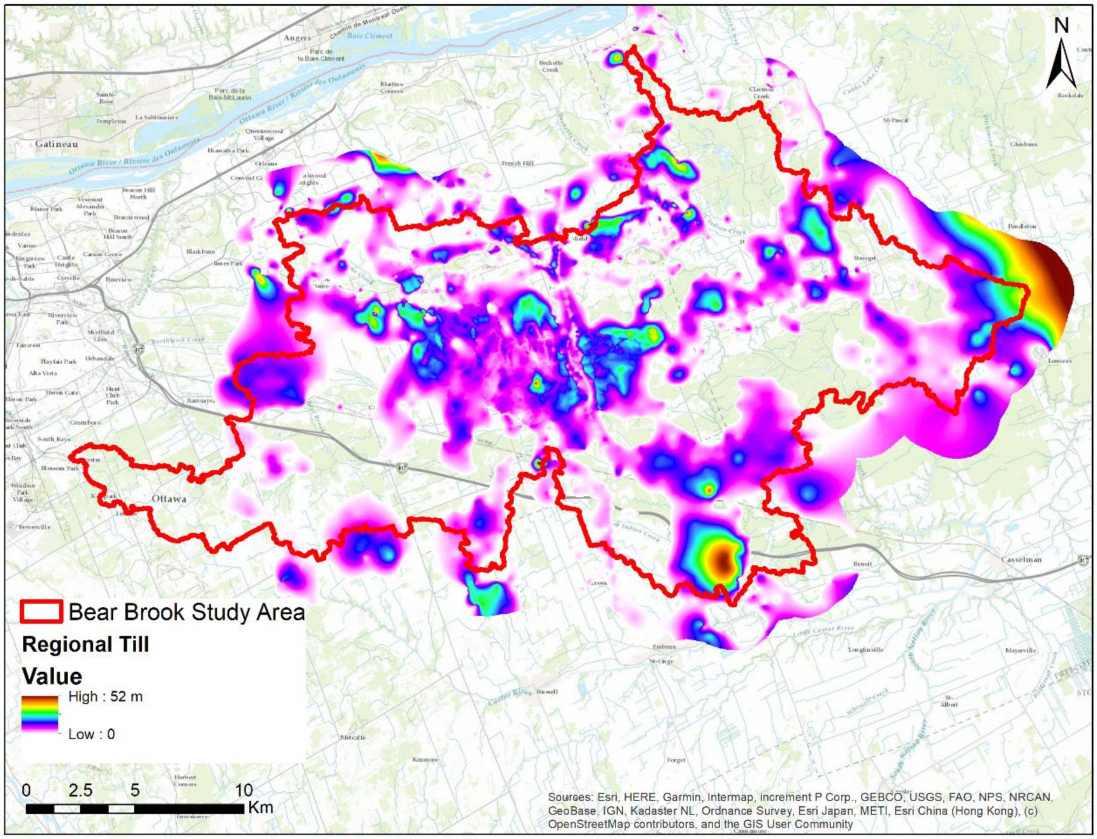


Figure 11c. Isopach map for the Winchester till sediments, as exported from Leapfrog 3D model.

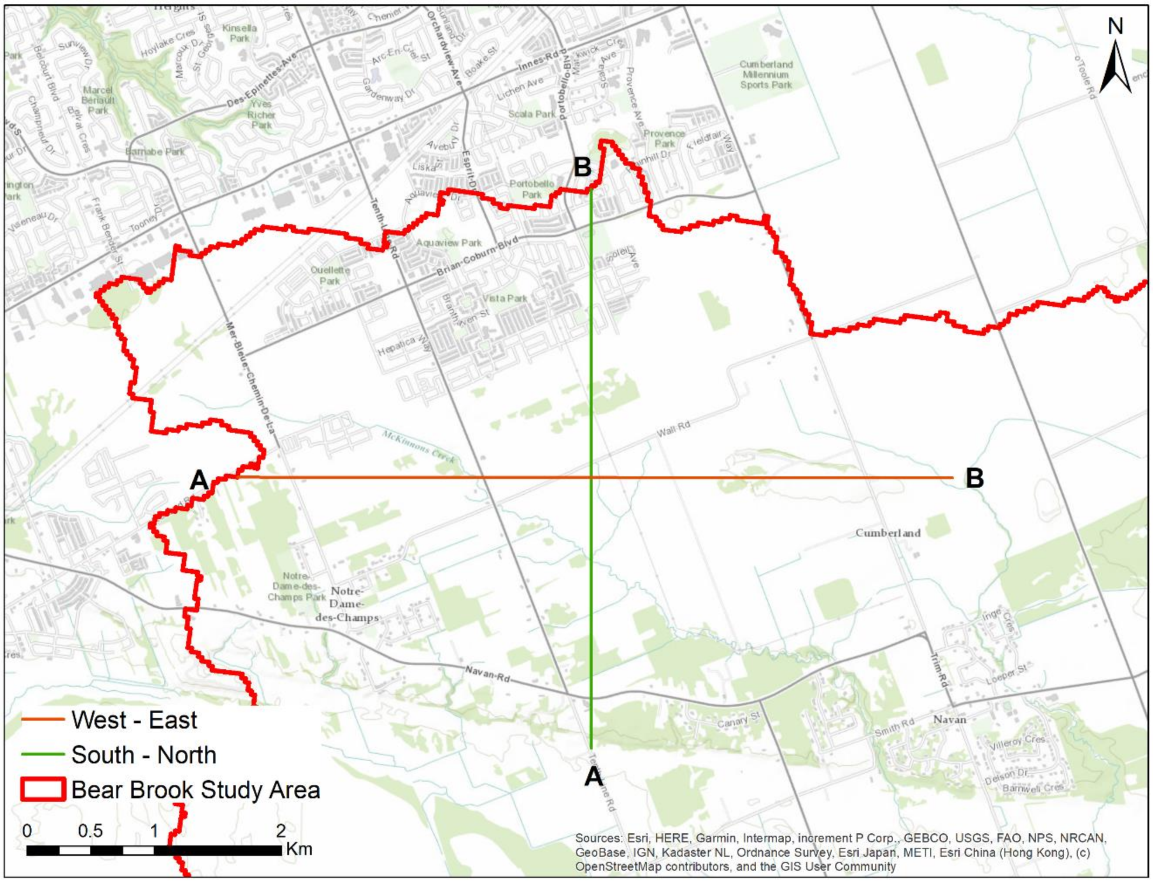
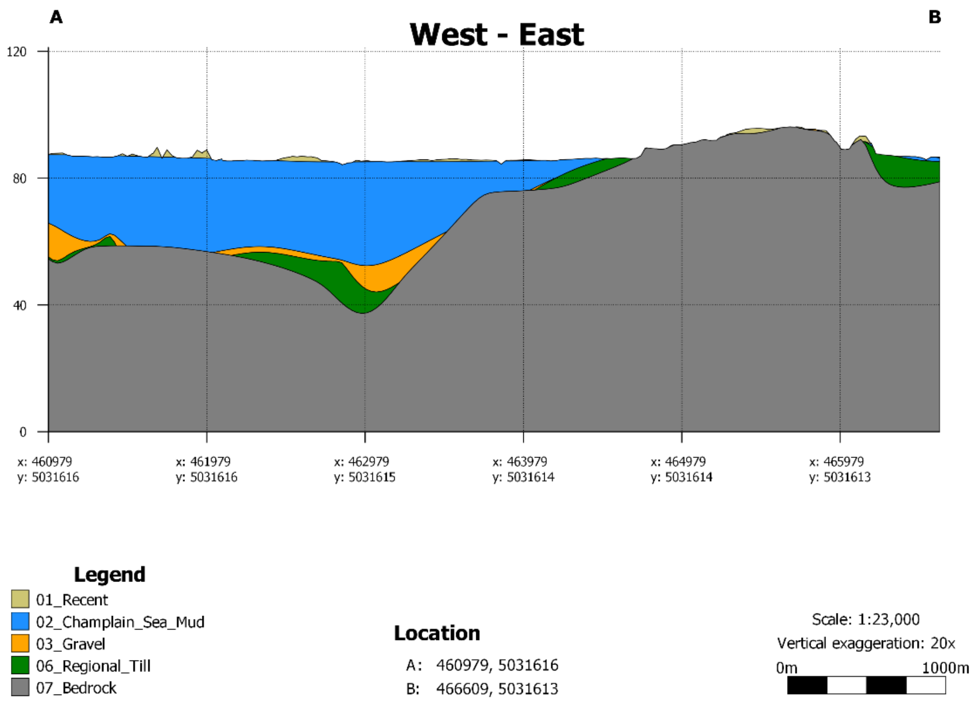


Figure 12a. Location of the hydrostratigraphic cross sections extracted from the North-West area of the Bear Brook Model.



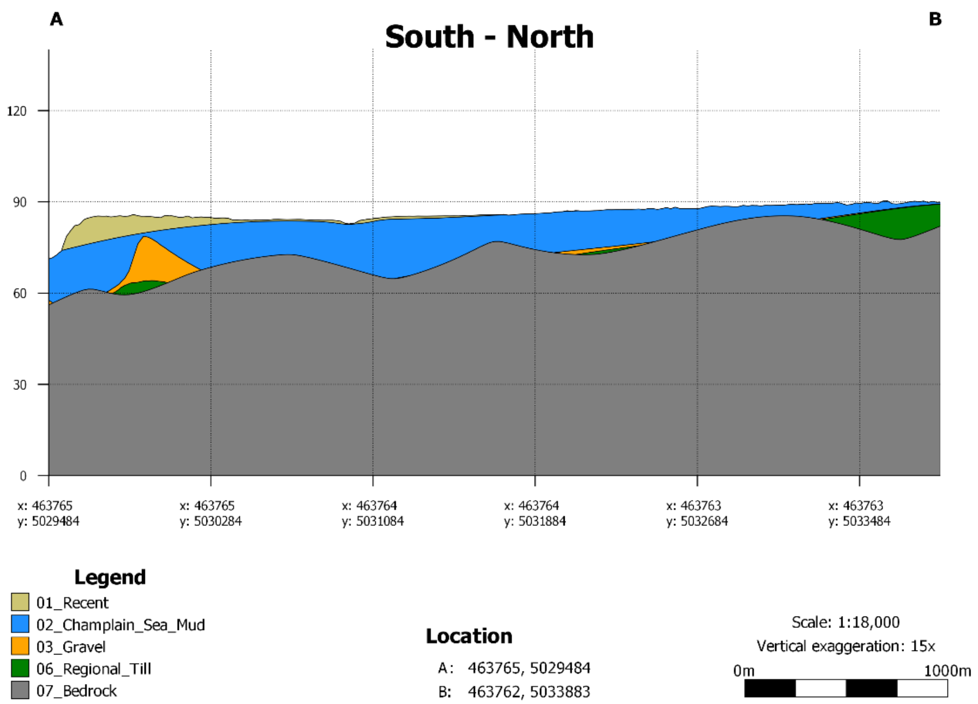


Figure 12b. Hydrostratigraphic cross-sections along West-East and South-North transects within the North-West area of the Bear Brook model.

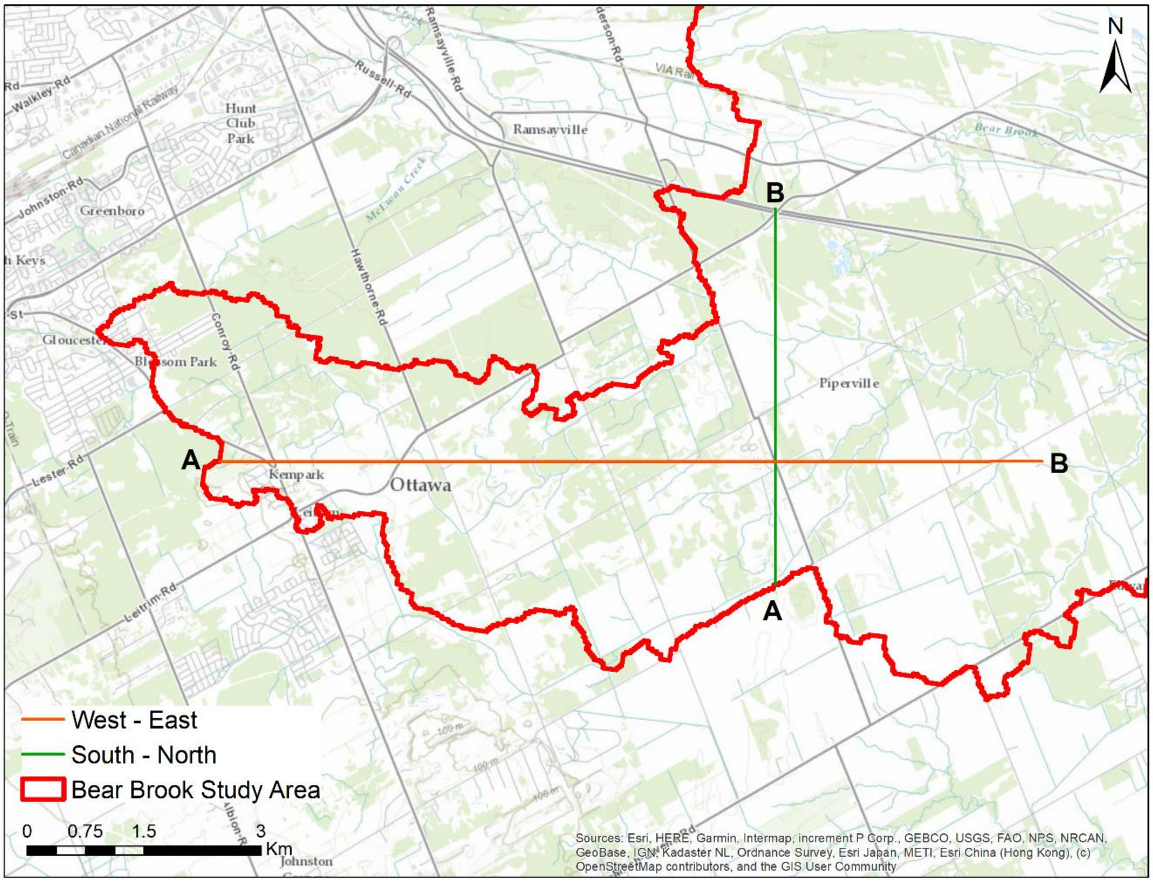
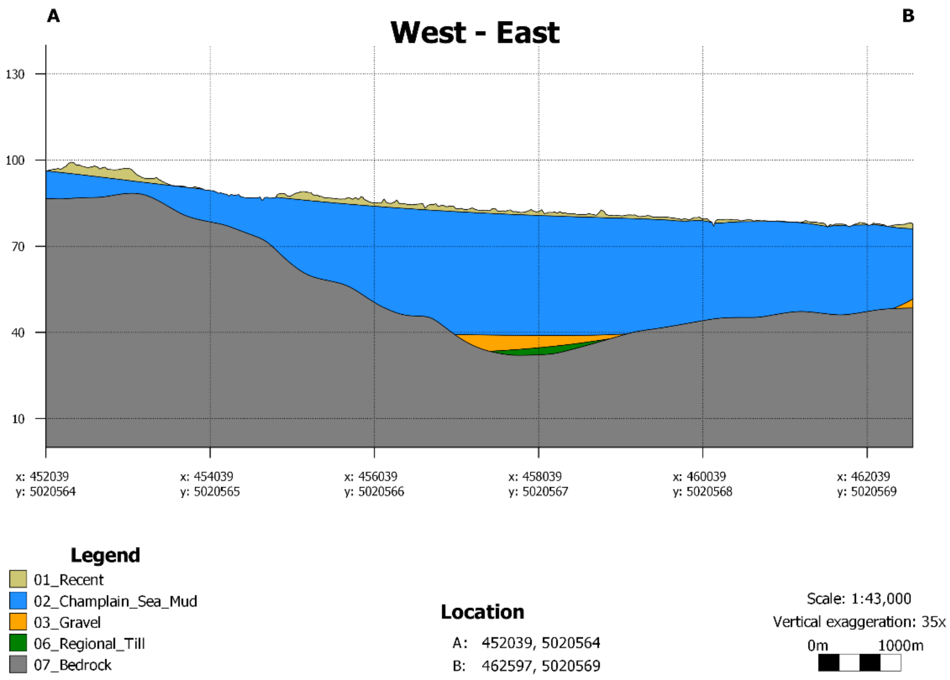


Figure 13a. Location of the hydrostratigraphic cross sections extracted from the Western area of the Bear Brook Model.



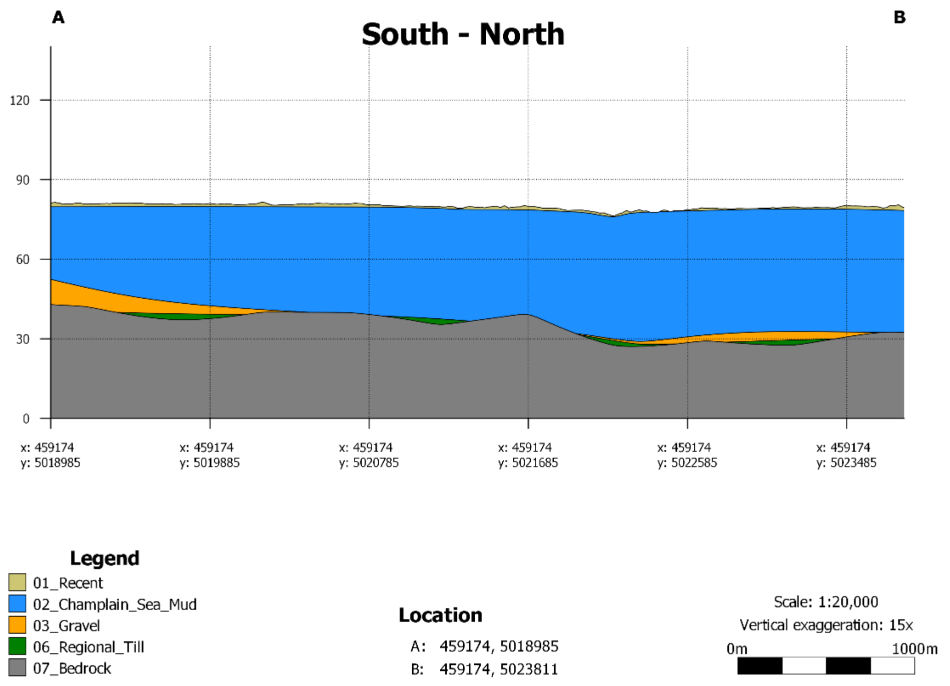


Figure 13b. Hydrostratigraphic cross-sections along West-East and South-North transects within the Western area of the Bear Brook model.

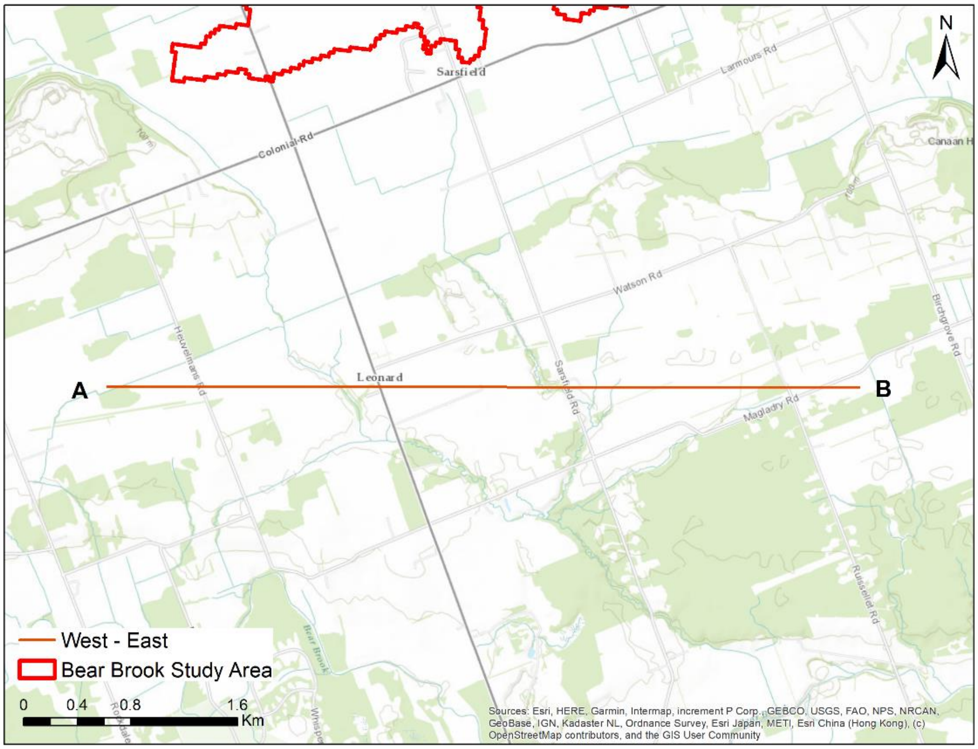


Figure 14a. Location of the hydrostratigraphic cross sections extracted across the Vars-Winchester esker within the Bear Brook Model.

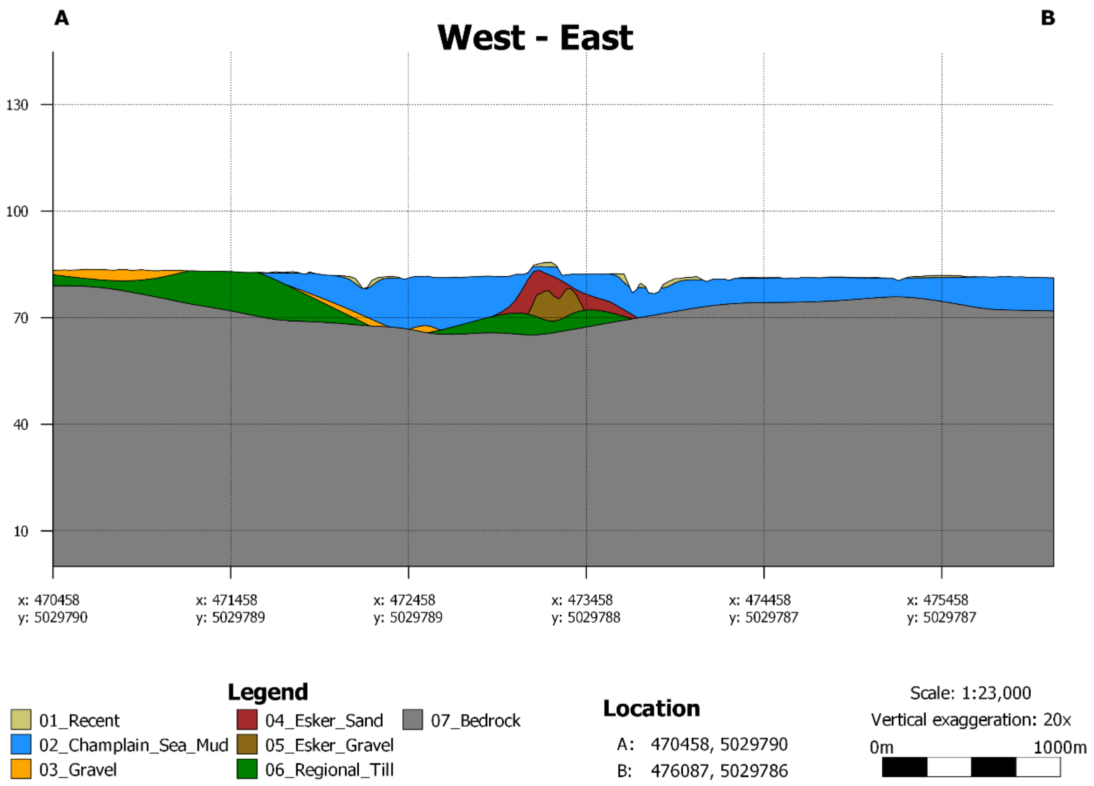


Figure 14b. Hydrostratigraphic cross-sections along a West-East transect across the Vars-Winchester esker within the Bear Brook model.

2.9 Climate Forcing Data

The daily transient Liquid Water flux (LWF) and Potential Evapotranspiration (PET) boundary conditions used in this study to force HGS were derived from precipitation and temperature data obtained from Natural Resources Canada (NRCan; McKenney et al. 2011), while snowpack snow-water-equivalent (SWE) estimates were obtained from the ERA5-Land land-surface reanalysis. Importantly, the NRCan gridded data is derived from station-based meteorological observations that have been interpolated using a thin plate spline method (ANUSPLIN) to provide continuous spatial variability. Data from 1997 to 2017 were used to force the HGS model over the continuous 21-year simulation and analysis interval. The NRCan dataset includes daily minimum and maximum temperatures, and daily precipitation totals, and was resolved at 2 km resolution over the Bear Brook sub-watershed. ERA5-Land is a recent land-surface reanalysis released by the European Centre for Medium Range Weather Forecasts (ECMWF, Muñoz-Sabater et al., 2021) that was used to calculate changes in SWE that ultimately represent snow melt. The Hogg method was used to compute PET using daily maximum and minimum temperature from the NRCan dataset (Hogg, 1997).

2.10 Model Spinup

Model spinup can be equated to initializing the model by filling it with water prior to launching an analysis simulation. For initializing the Bear Brook Creek model prior to launching the daily transient simulations, a monthly normal (long term monthly average) liquid water input and PET, derived from the MERRA-2 climate reanalysis dataset, were used to establish model conditions that reflect average seasonal variability. During spinup, the same average annual average climate cycle was simulated in 10-year repeating cycles until year-over-year stability was achieved (i.e. a quasi-equilibrium state). Using the quasi-equilibrium as an initial condition in the HGS model, the continuous 1997 – 2017 daily transient time interval was then simulated using the daily transient forcing data.

2.11 Model Calibration

The calibration effort of the Bear Brook sub-watershed has thus far been kept to a minimum, however calibration is still ongoing. During the initial simulations it was observed that the model was too dry when initiated from the quasi-equilibrium state. Hence, initial conditions from successive 21 year daily transient simulations were used as initial conditions for subsequent simulations, which caused the model to wet up to the point where simulated and observed conditions were better matched. Model performance was evaluated using the Nash-Sutcliffe model efficiency coefficient

(NSE), percent bias, and visual comparison between simulated and observed daily flows over the 1997 – 2017 time interval. The streamflow observation data from the WSC hydrometric station near Bourget (02LB008) (Government of Canada., 2021) was the primary calibration target and prior to use this data was subject to quality control. Streamflow data were not incorporated into the calibration assessment if ice buildup was reported in the data record. In addition to 02LB008, outflow locations for nine sub-catchments within the Bear Brook sub-watershed were provided by SNC for inclusion in the model in order to derive more localized water budget information for specific areas. The sub-catchment list includes: South Indian Creek, North Indian Creek, Shaw's Creek, Piperville Drain, South Bear Brook, East Savage Drain, McKinnon's Creek, Nelson Charlebois Drain, and Labreche Drain (Figure 15).

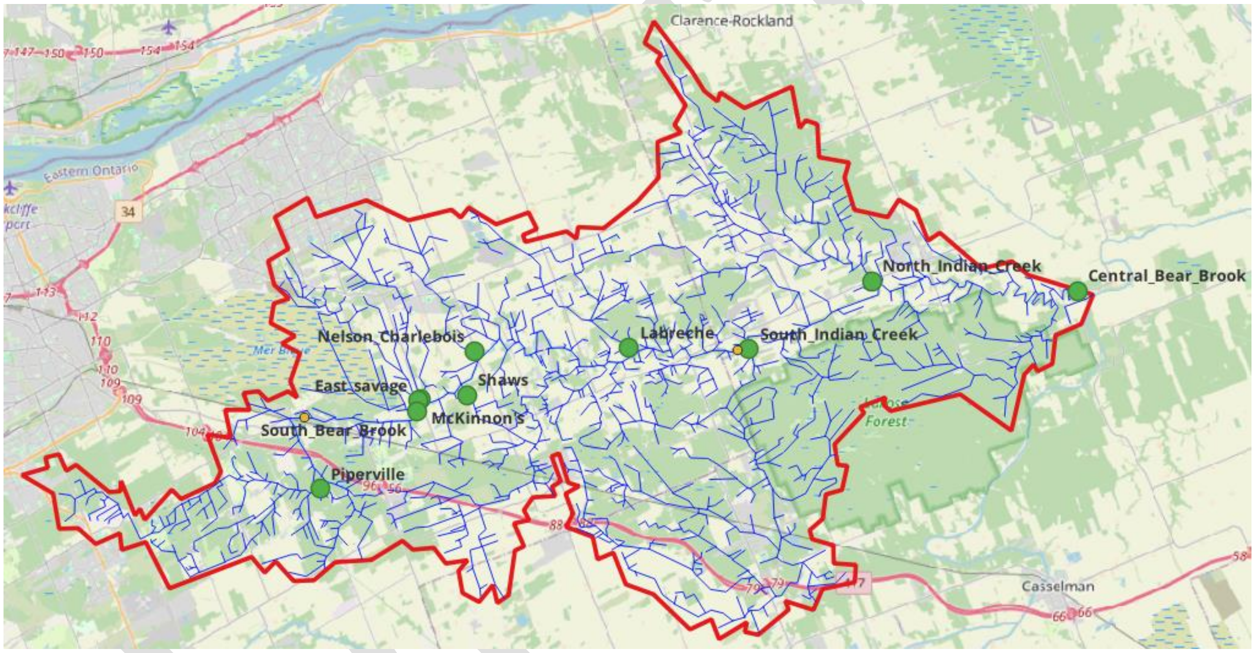


Figure 15: Location of the nine additional streamflow gauge points that were added to the HGS model as synthetic hydrographs to quantify localized water balances.

Groundwater level monitoring points have also been built into the model. In total, groundwater levels are reported at 1859 locations, representing 1431 bedrock, 403 lower Quaternary, and 23 upper Quaternary static groundwater level data points; and 2 real-time in-stream water level gauges that are being used as a proxy for shallow groundwater levels (Figure 16). In ongoing work, these points are being used to evaluate groundwater simulation performance.

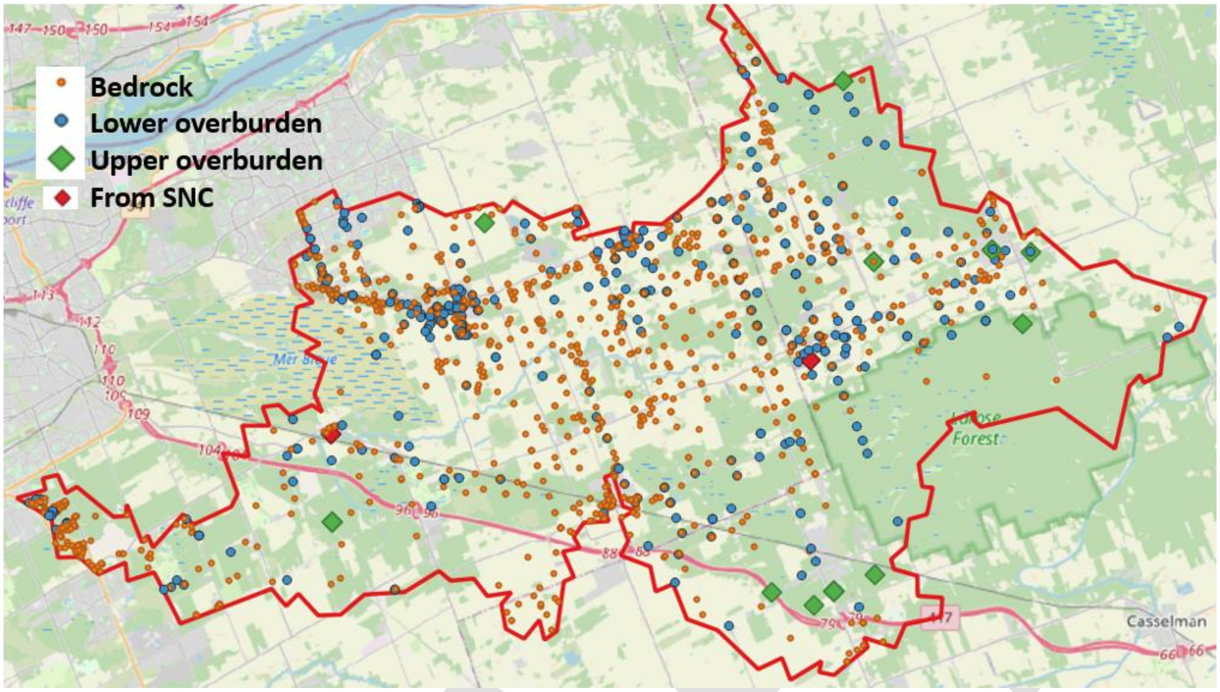


Figure 16. Groundwater monitoring points built into the Bear Brook HydroGeoSphere model. 1859 locations in total, representing 1431 bedrock, 403 lower Quaternary, and 23 upper Quaternary static groundwater level data points; and 2 real-time in-stream water level gauges (From SNC).

2.12 Simulation Run Times

It should be noted that for structurally complex, fully-integrated groundwater – surface water models such as the Bear Brook HGS model, a major advantage over simpler empirically-based models is that they incorporate a physics-based evaluation of the natural system, and hence many of the model parameters are constrained by physically measurable characteristics, including those relating to groundwater – surface water interactions. This makes the model ideal for robust scenario analysis, where different aspects of the model domain are changed to reflect things like land cover/land use change, because the parameterization changes induced in the model are tied to physics-based governing equations. However, for such complex models, the simulation run times can be long relative to simpler models. For example, the HGS model herein requires approximately 13 days for the completion of a 21-year continuous daily simulation when using four cores on an Intel i7-10800 processor.

3.0 RESULTS

3.1 Model Performance

The simulated vs. observed stream flow rates for the WSC hydrometric station close to the Bear Brook sub-watershed outlet (02LB008) are presented in Figure 17. The model performance for the surface water flow was assessed using the Nash-Sutcliffe Efficiency coefficient (NSE) and percent bias (Pbias). The NSE value is 0.55, where a value of 1 means a perfect match between the model and observations, values at or above 0.50 indicates satisfactory performance, a value of zero indicates the model is no better than the mean of the observed data, and a value less than zero indicates the mean of the observed data has better predictive skill than the model. The Pbias is -19 %, where a negative value indicates a tendency to underestimate flows, and with values from +25 % to -25 % generally considered satisfactory. Visually, it is apparent that the model captures the major trends in surface water flow rates across seasons, and during floods and droughts. Because the gauge station is located closer to the outlet, there is also confidence that the model is capturing the overall water balance for the Bear Brook sub-watershed well.

At the time of writing, model calibration is still ongoing, with the addition of groundwater levels as a calibration target not yet completed.

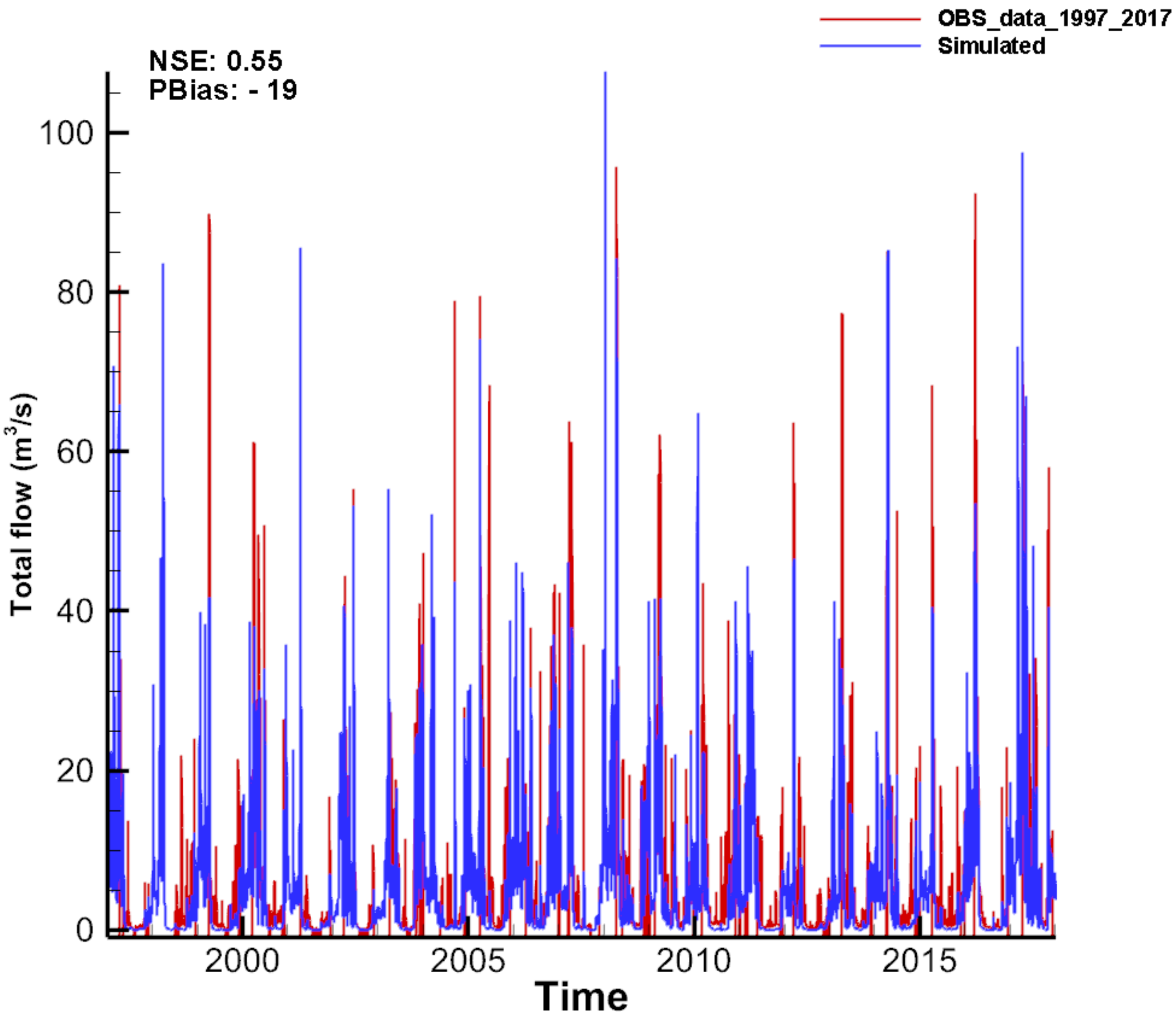


Figure 17: Simulated vs observed surface water flow rates at the WSC 02LB008 station for the 1997 – 2017 simulation interval along with NSE and PBias model performance metrics.

3.2 Synthetic Hydrograph Simulated Flows

The simulated flow rates at the nine synthetic hydrographs (Figure 15), representing simulated outflow from the nine sub-catchments for the 1997 – 2017 time interval, are presented in Figures 18a – i. No statistical model performance evaluation was made for these locations due to the unavailability of measured flow data. Of the sub-catchments, McKinnon's Drain has relatively low average flow at 1.5 m^3/s (Figure 18a), an area of 14 km^2, and has the largest proportion of urbanized land. The South Indian and North Indian Creeks are the largest of the sub-catchments, with 92 km^2 and 59 km^2 respectively (Figures 18b and c). Hence, they are relatively high flowing locations with approximate average flow rates of 15 m^3/s and 11 m^3/s, with peak flows reaching up to 30 m^3/s for South Indian Creek and 28.5 m^3/s for North Indian Creek. East Savage Drain (Figure 18f) located on the northwest of the model domain and Shaw's Creek (Figure 18d) in the south have similar flow rates, with averages of approximately 4 m^3/s. The South Bear Brook Creek (Figure 18g) and Piperville Drain (Figure 18i) are adjacent to each other, with Piperville Drain capturing flow from the westernmost parts of the city of Ottawa and then draining into the South Bear Brook sub-catchment. The Nelson Charlebois Drain (Figure 18h) is the smallest of the nine sub-catchments (8 km^2) and is a low-flow station with an approximate average flow rate of 1.5 m^3/s.

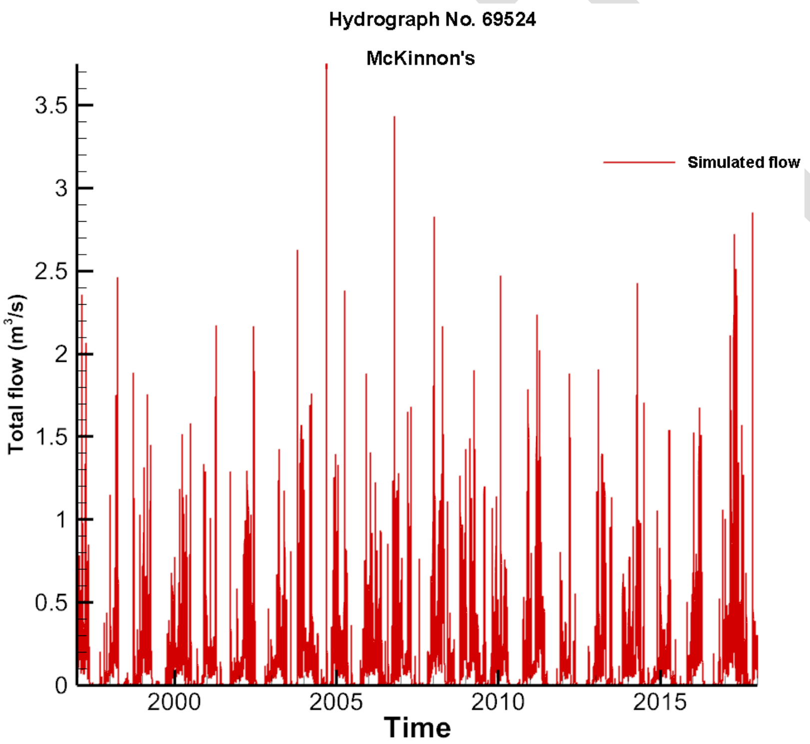


Figure 18a, Simulated surface water flow rates in McKinnon's Drain for the 1997 – 2017 interval.

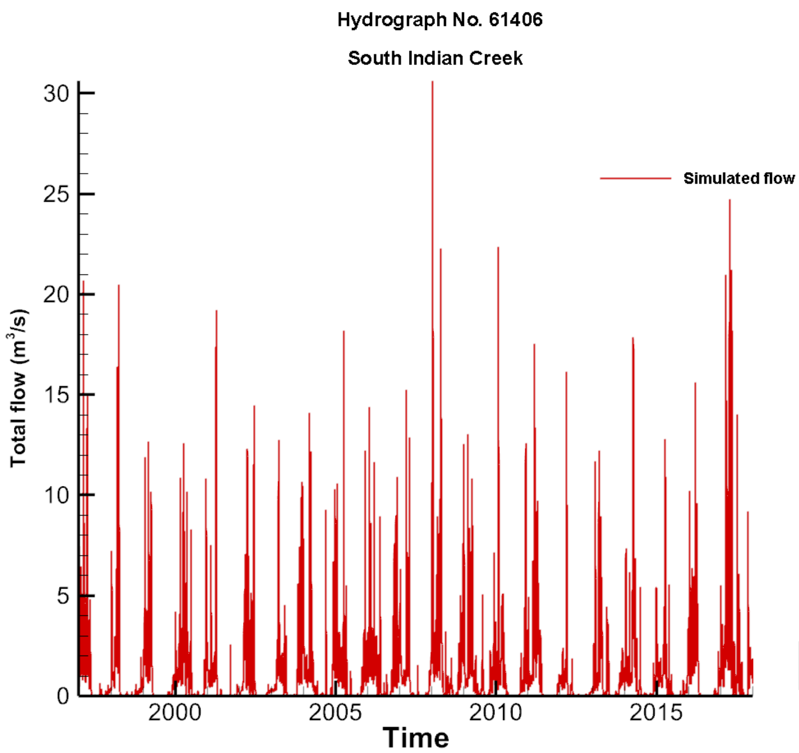


Figure 18b: Simulated surface water flow rates in South Indian Creek for the 1997 – 2017 interval.

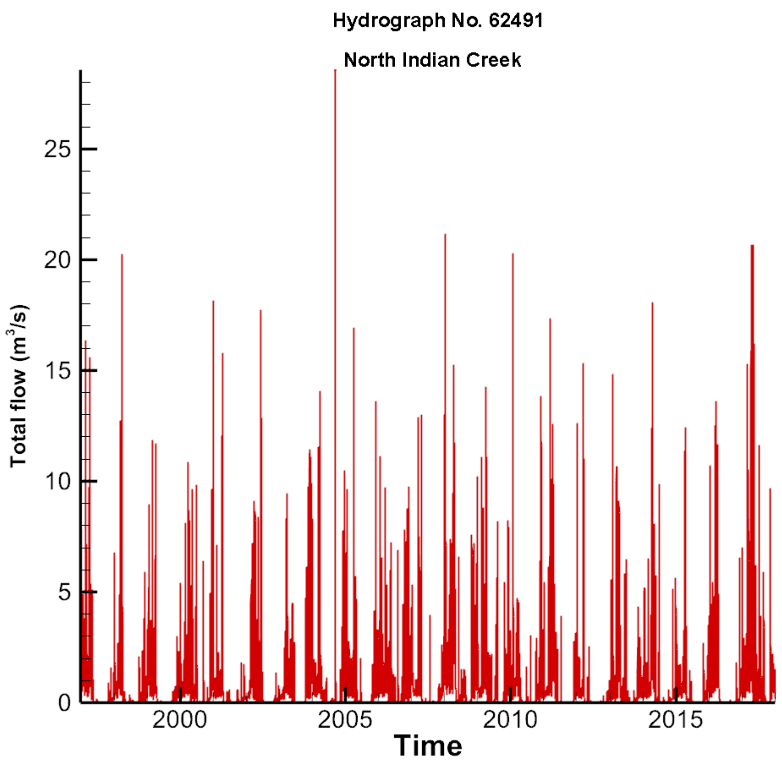


Figure 18c: Simulated surface water flow rates in North Indian Creek for the 1997 – 2017 interval.

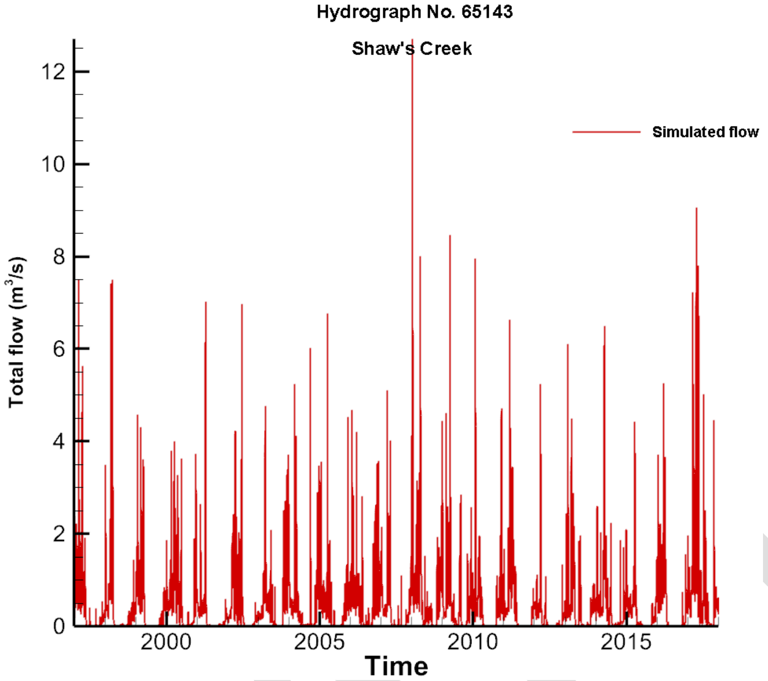


Figure 18d: Simulated surface water flow rates in Shaw's Creek for the 1997 – 2017 interval.

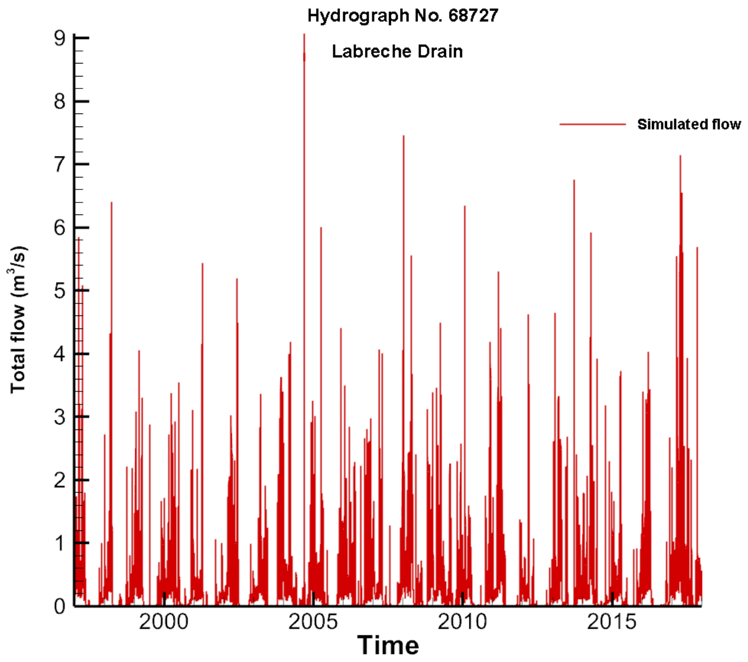


Figure 18e: Simulated surface water flow rates in Labreche Drain for the 1997 – 2017 interval.

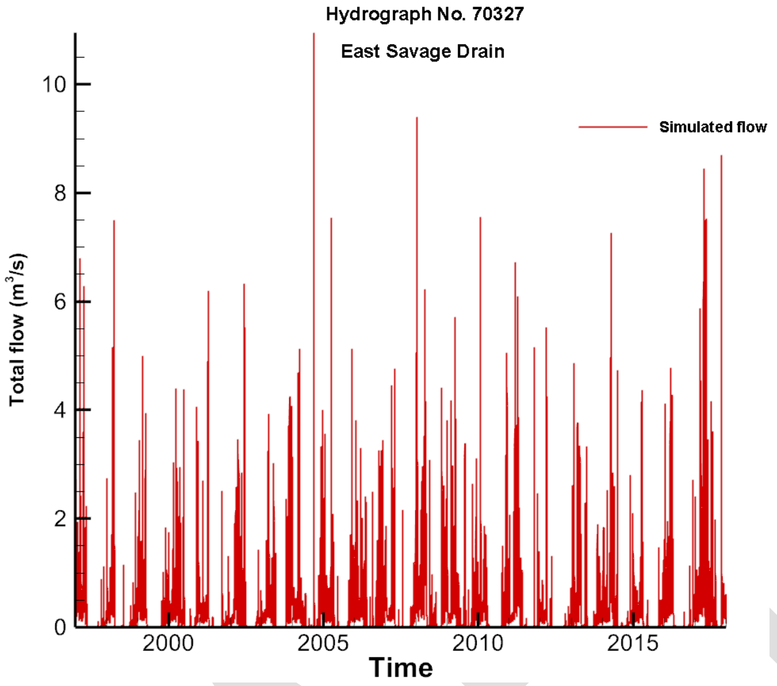


Figure 18f: Simulated surface water flow rates in East Savage Drain for the 1997 – 2017 interval.

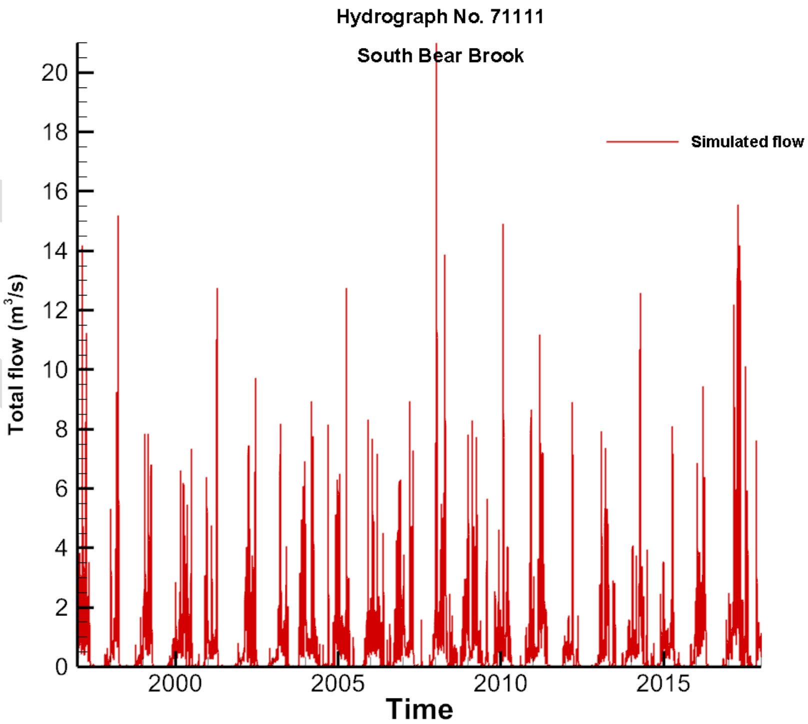


Figure 18g: Simulated surface water flow rates in South Bear Brook Creek for the 1997 – 2017 interval.

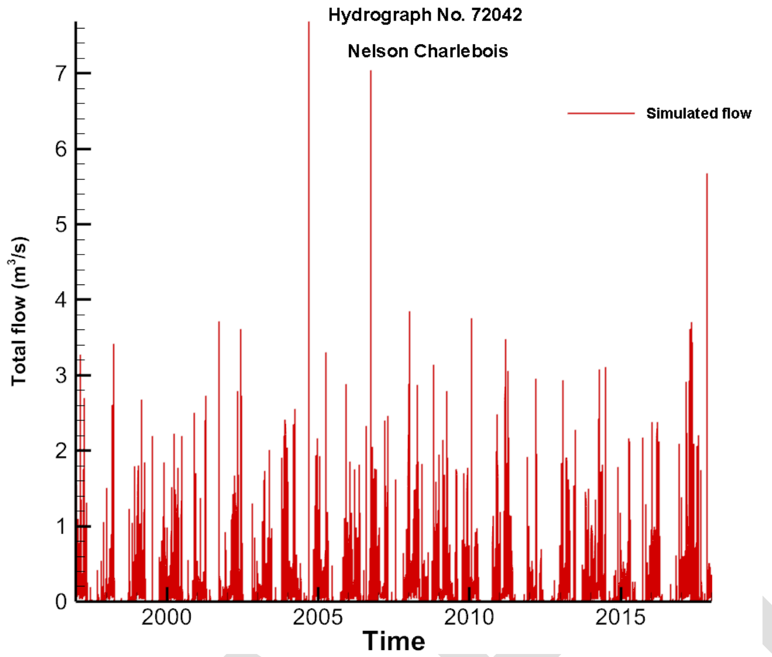


Figure 18h: Simulated surface water flow rates in Nelson Charlebois Drain for the 1997 – 2017 interval.

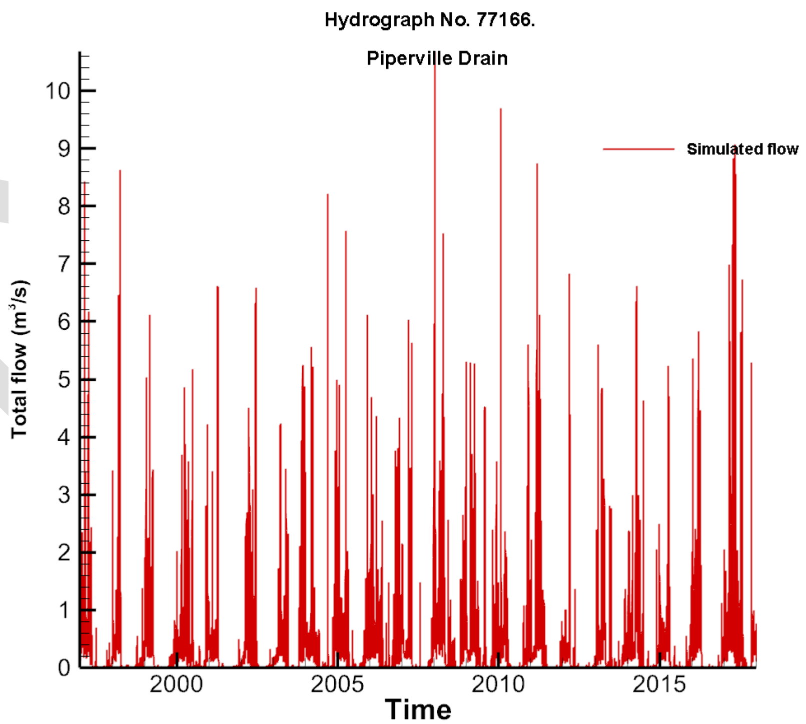


Figure 18i: Simulated surface water flow rates in Piperville Drain for the 1997 – 2017 interval.

3.3 Water Budget Calculation

There are nine sub-catchments delineated within the Bear Brook sub-watershed that correspond with the synthetic hydrograph catchment areas (Figure 19). Within the HGS simulation, precipitation, evaporation and transpiration (evapotranspiration, ET), and water flow over the land surface, river channels, and each of the subsurface layers within these nine catchment areas was continuously monitored and water balance estimates were made. Stream network connections across multiple sub-catchments and upstream contributions to downstream sub-catchments were fully accounted for in the catchment delineation process. (Figure 20). The stream networks within each sub-catchment were merged into a single feature for water balance analysis and for quantifying the groundwater – surface water exchange along the channels. An example stream network for Piperville Drain is presented in Figure 20, showing where multiple network sections are merged to form a common catchment area. Each of the eight other sub-catchments were delineated with the same methodology. The delineated sub-catchments are referred to as tracking polygons in the HGS model.

The water balance calculation for each sub-catchment consists of the key hydrologic cycle components, including precipitation, evapotranspiration, surface water flow entering and leaving the model domain, infiltration and exfiltration, and storage change in both surface and subsurface domains. These values are reported by the HGS model for each of the tracking polygons. Net channel/stream flow out of each tracking polygon is calculated as the sum of overland flow and groundwater discharge into stream channels within that polygon. Net groundwater recharge is calculated as the volume of water that moves across the 1 m depth threshold, which coresponds to the interface surface between the base of the soil profile and the top of the Quaternary deposits in the model. In the water balance reporting, the volume of groundwater discharging into stream channels is also reported, and it is important to note that this represents water movement across the channel – subsurface interface surface. In effect, groundwater discharge into streams includes subsurface water from both the soil (0 – 1 m) and Quaternary deposits and is therefore, in some cases, different in magnitude from groundwater recharge.

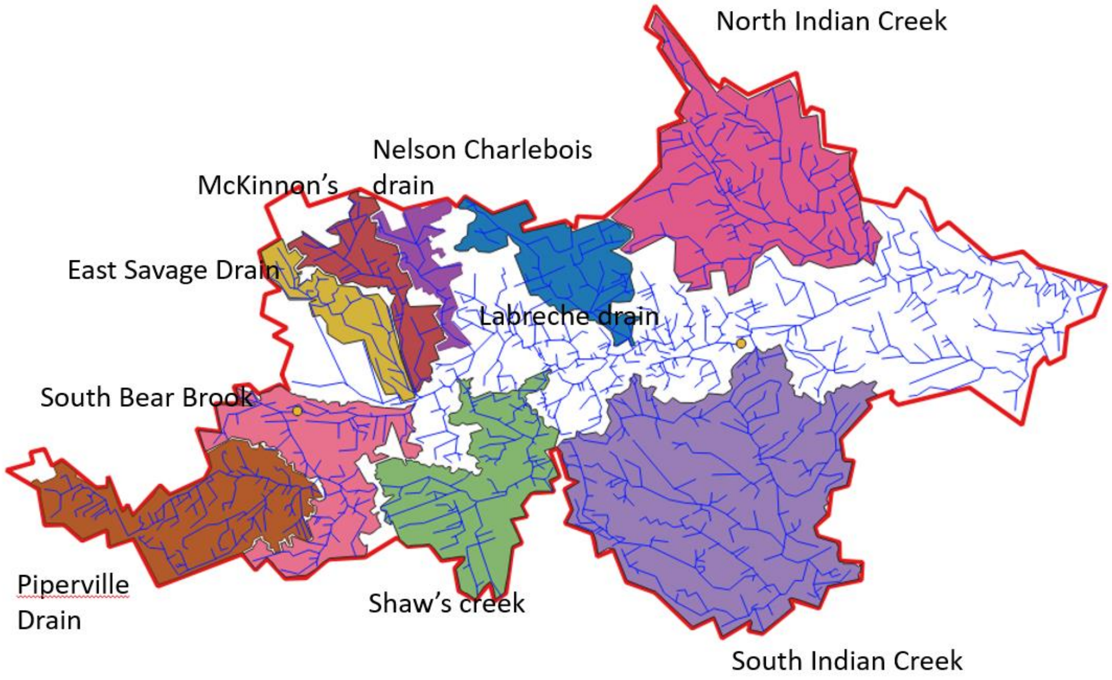


Figure 19. Delineated tracking polygons in the HGS model to facilitate water balance analysis in each of the nine sub-catchment areas.

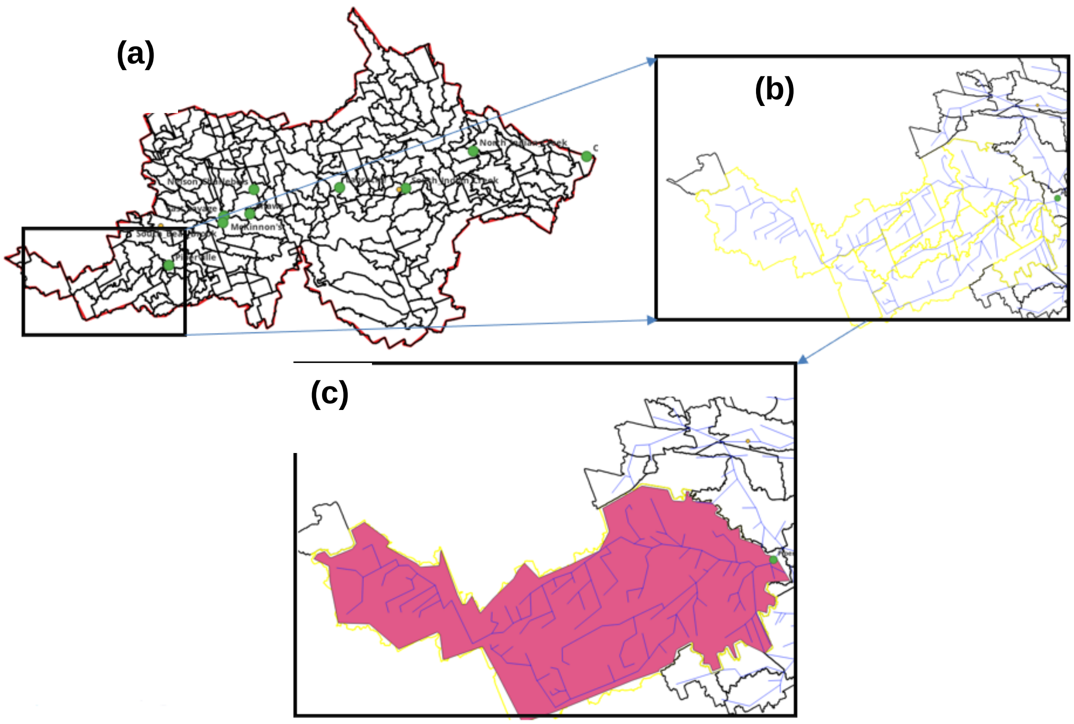


Figure 20. (a) Subbasins for the whole of the Bear Brook sub-watershed, b) an example subbasin for the stream network covering the Piperville Drain sub-catchment is selected, c) merged polygon to form a common sub-catchment for water budget calculation.

An important part of a numerical model-based water balance analysis is a mass balance error analysis, which in effect aims to quantify the potential impact of numerical error or unanticipated flow paths on model results. For each of the nine sub-catchments, their associated tracking polygons in the HGS model were subject to a mass balance test. The mass balance error is reported as a percentage of under and/or over accounted inflows, outflows, and changes in storages relative to rainfall and snowmelt. Negative error indicates that simulated outflow plus change in storage is greater than the cumulative rainfall plus snow melt and vice versa for the positive error case. A more detailed explanation is as follows:

Error (%) = (Water entering polygon – Water leaving the polygon + Change in overland storage + Change in porous media storage)/ (Total water entering the polygon) X 100

Water balance components and mass balance error for each sub-catchment are presented in Table 3.

Table 3: The total aggregate summation of the individual water balance components for each of the sub-catchments over the 1997 – 2017 period, along with the cummulative mass balance error. Note that groundwater exfiltration into streams in parts consists of groundwater recharge so the values do not sum to zero.

Sub-Catchment	Precipitation (mm)	Net Runoff (mm)	Evapotranspiration (mm)	Groundwater Recharge (mm)	Groundwater + Soil Water Contribution to Streams (mm)	Error (%)
South Indian Creek	21248	7390	12607	842	1305	0.30
North Indian Creek	21570	7671	12448	1387	1483	0.38
Shaw's Creek	21083	7997	12371	592	1099	1.51
Piperville Drain	20885	7559	12574	1205	934	0.25
South Bear Brook	20985	5644	12442	702	3035	0.25
East Savage Drain	21103	8713	12329	694	637	1.37
McKinnon's Creek	21180	8731	12084	1121	722	0.24
Nelson Charlebois Drain	21268	9013	11981	1074	203	0.60
Labreche Drain	21358	8549	12074	968	491	0.37

From the data presented in Table 3, groundwater recharge (downward water movement across the 1 m depth surface) rates are calculated as a percentage of total precipitation, as follows: Recharge (%) = (Recharge /Precipitation) * 100, with results presented in Figure 21.

Also important to note, groundwater recharge is net downward vertical flux across the 1 m depth horizon, while it is groundwater + water draining out of the soil profile that provide subsurface water contribution to streams (baseflow).

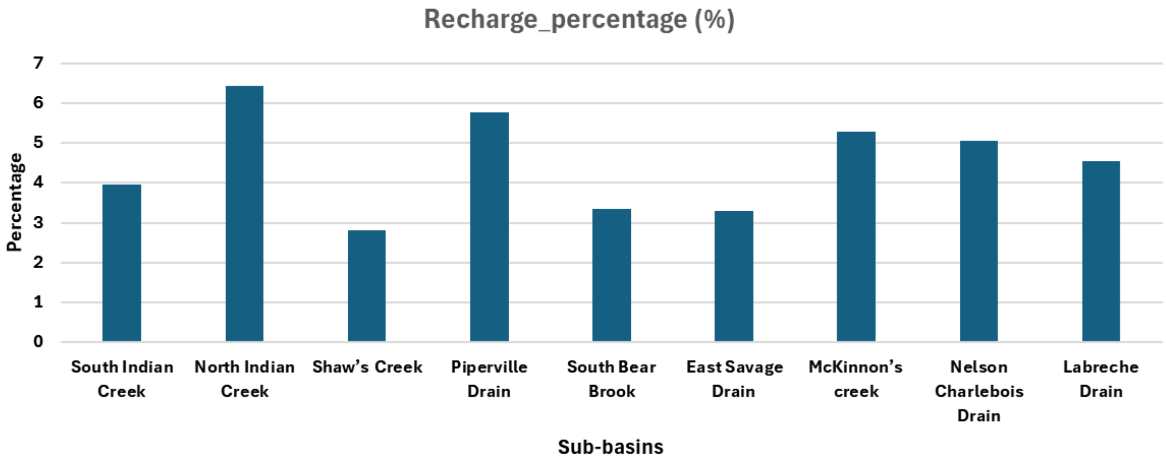


Figure 21. Average groundwater recharge as a percentage of total precipitation, over the 1997 – 2017 simulation interval, for each of the nine sub-catchments.

3.4 Sub-catchment Water Balance Summary

Averaged across all nine sub-catchments and over the full 1997 – 2017 simulation interval, evapotranspiration consumes 58 % of total precipitation, groundwater recharge accounts for 4.3 % of total precipitation, and maximum polygon mass balance error is 1.51 % (Table 3). Net surface water outflow composes 38 % of total precipitation. A detailed water balance summary for each sub-catchment is provided below.

3.4.1 South Indian Creek

The South Indian Creek sub-catchment covers 92 km^2. The area received 21248 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12607 mm (59 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 7390 mm (35 %), while groundwater recharge amounted to 842 mm or 4 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.3 %.

3.4.2 North Indian Creek

The North Indian Creek sub-catchment covers an area of 59 km^2. The area received 21,570 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12448 mm (58 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 7671 mm (36 %), while groundwater recharge amounted to 1387 mm or 6 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.38 %.

3.4.3 Shaw's Creek

The Shaw's Creek sub-catchment covers approximately 33 km^2. The area received 21,083 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12371 mm (59 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 7997 mm (38 %), while groundwater recharge amounted to 592 mm or 3 % of total precipitation. Mass balance error across all components of the simulated water balance is 1.51 %.

3.4.4 Piperville Drain

The Piperville Drain sub-catchment covers approximately 32.23 km^2. The area received 20885 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12574 mm (60 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 7559 mm (36 %), while groundwater recharge amounted to 934 mm or 6 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.25 %.

3.4.5 South Bear Brook

The South Bear Brook Creek sub-catchment covers approximately 28.82 km^2. The area received 20985 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12442 mm (59 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 5644 mm (27 %). Groundwater recharge amounted to 702 mm or 3 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.25 %.

3.4.6 East Savage Drain

The East Savage Drain sub-catchment covers approximately 12 km^2. The area received 21103 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12329 mm (58 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 8713 mm (41 %). Groundwater recharge amounted to 694 mm or 3 % of total precipitation. Mass balance error across all components of the simulated water balance is 1.37 %.

3.4.7 McKinnon's Creek

The McKinnon's Creek sub-catchment covers approximately 14 km^2. The area received 21180 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12084 mm (57 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 8731 mm (41 %). Groundwater recharge amounted to 1121 mm or 5 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.24 %.

3.4.8 Nelson Charlebois Drain

The Nelson Charlebois Drain sub-catchment covers approximately 8 km^2. The area received 21268 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 11981 mm (56 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 9013 mm (42 %). Groundwater recharge amounted to 1074 mm or 5 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.60 %.

3.4.9 Labreche Drain

The Labreche Drain sub-catchment covers approximately 19.5 km^2. The area received 21358 mm of precipitation over the 1997 – 2017 time period (Table 3) of which 12074 mm (57 %) was consumed by ET. Total net surface water outflow from the sub-catchment was 8549 mm (40 %), while groundwater recharge amounted to 968 mm or 6 % of total precipitation. Mass balance error across all components of the simulated water balance is 0.37 %.

3.5 Temporal Variation in Water Balance Partitioning

The previous discussion focused on the long-term average water balance behavior for each of the nine sub-catchments, however, the HGS modelling is completely transient and can therefore also inform on interannual variability. For example, modelling results can highlight how water balance partitioning is affected by individual dry, as well as wet, climatological years. The following set of figures present the annual variability in water balance partitioning (Figures 22 – 30).

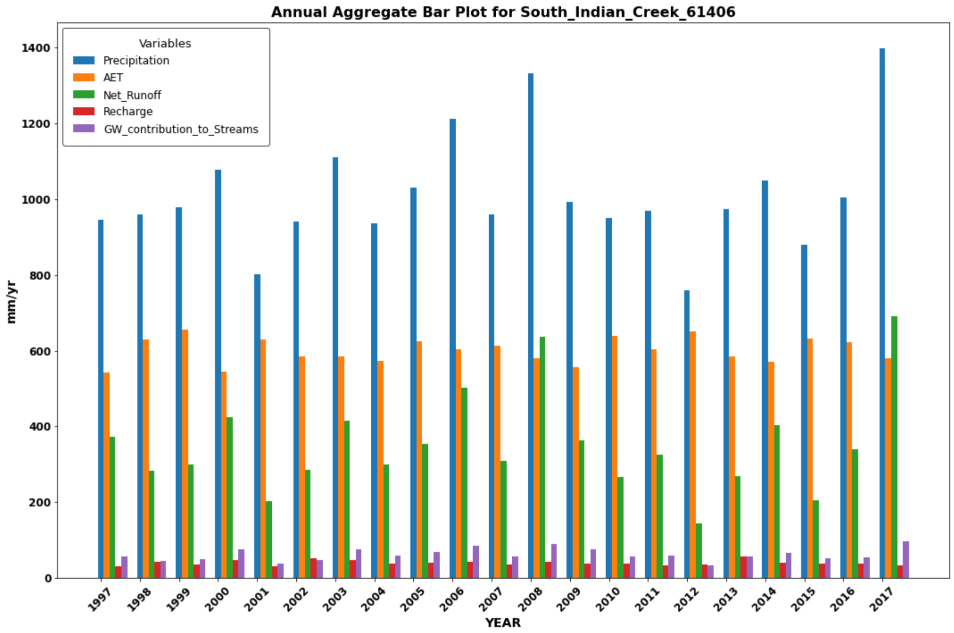


Figure 22. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the South Indian Creek subbasin for the 1997-2017 time frame.

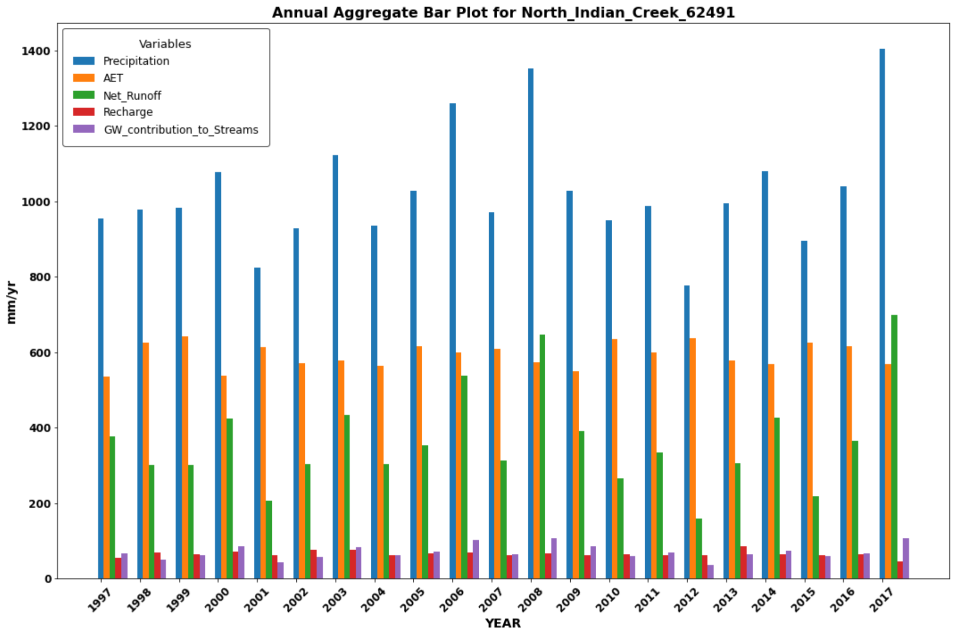


Figure 23. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the North Indian Creek subbasin for the 1997-2017 time frame.

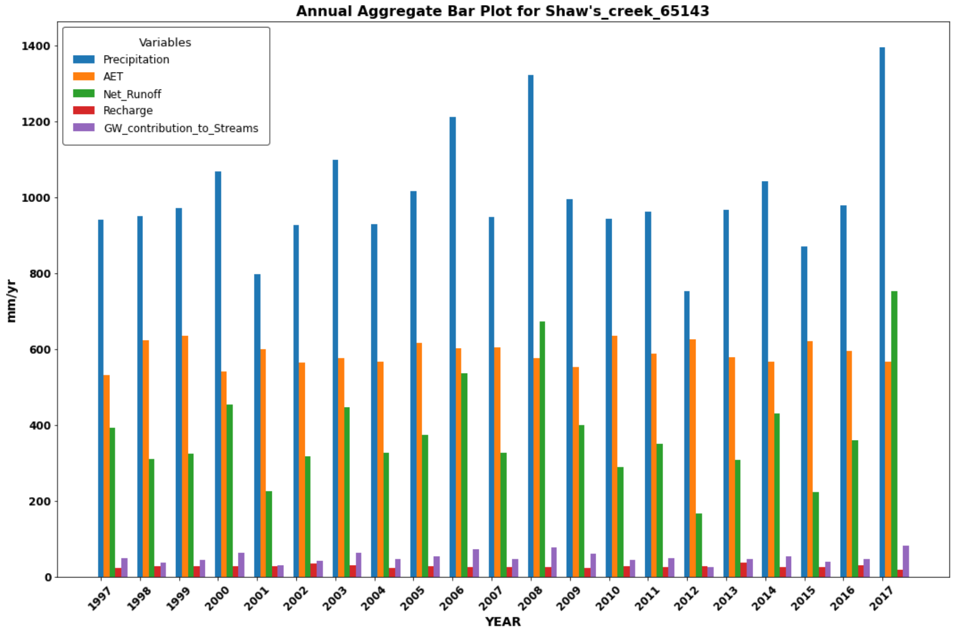


Figure 24. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the Shaw's Creek subbasin for the 1997-2017 time frame.

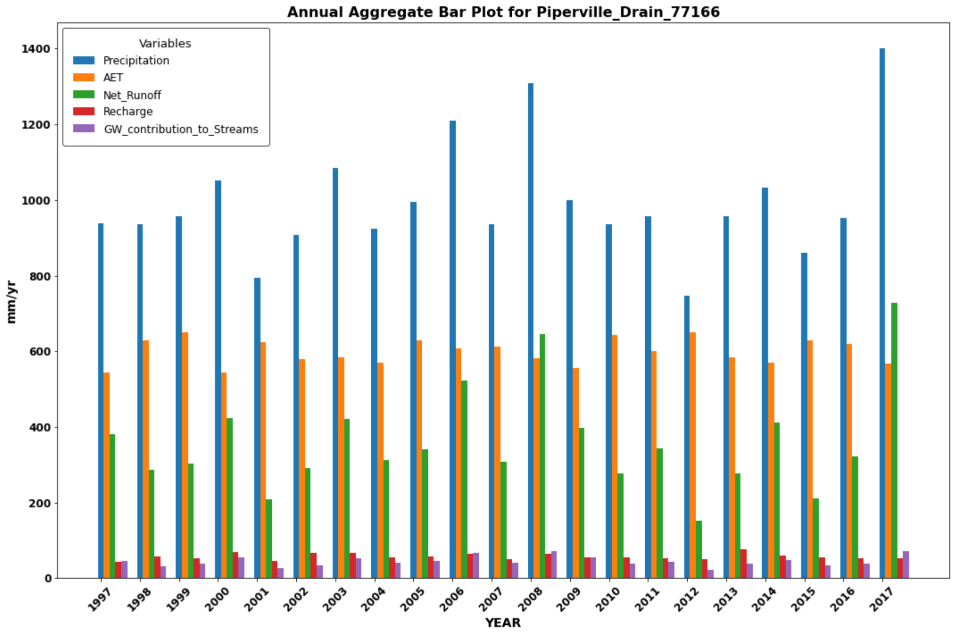


Figure 25. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the Piperville Drain subbasin for the 1997-2017 time frame.

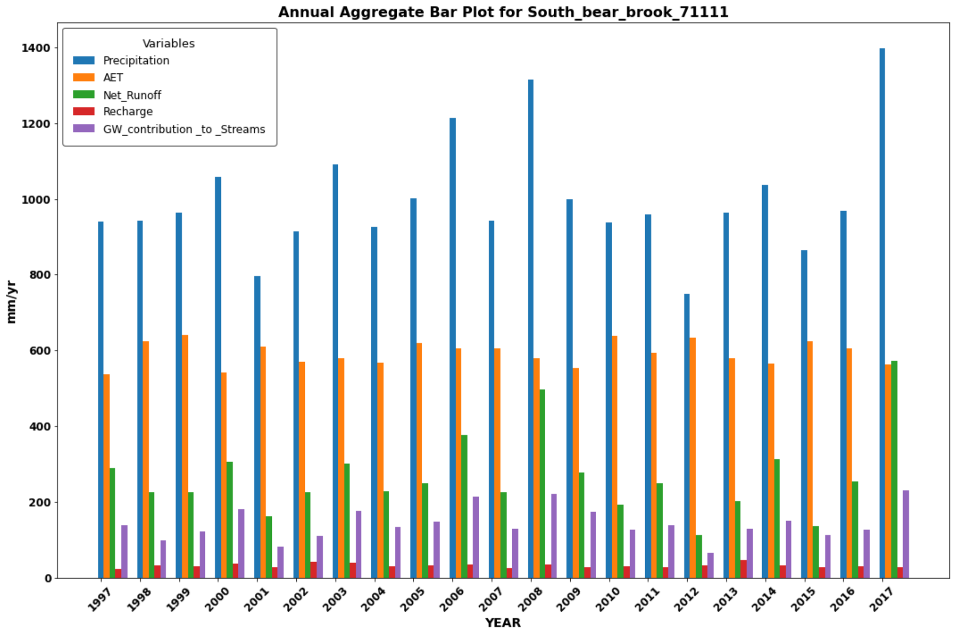


Figure 26. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the South Bear Brook subbasin for the 1997-2017 time frame.

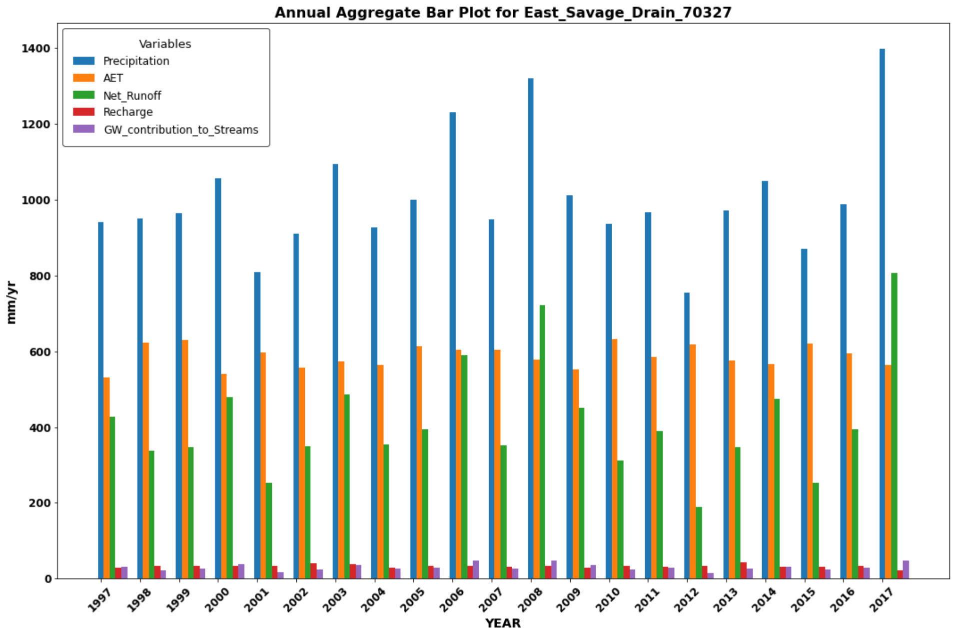


Figure 27. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the East Savage Drain subbasin for the 1997-2017 time frame.

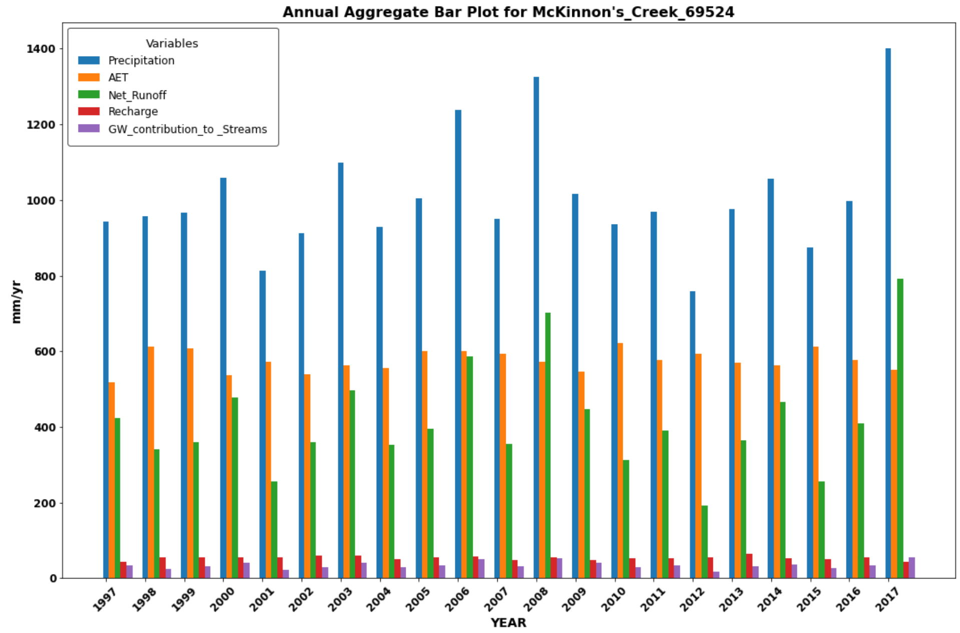


Figure 28. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the McKinnon's Creek subbasin for the 1997-2017 time frame.

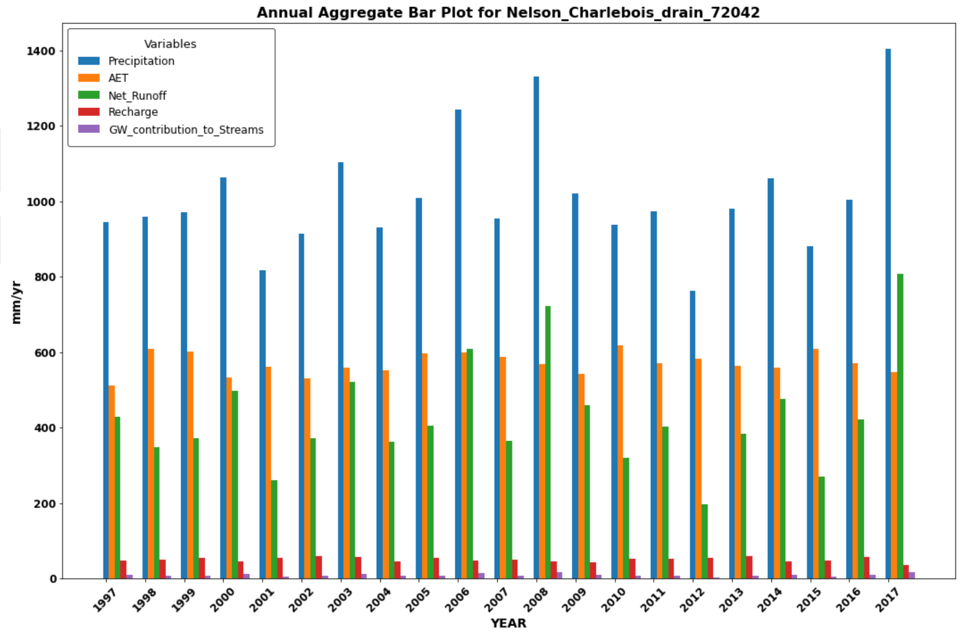


Figure 29. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the Nelson Charlebois Drain subbasin for the 1997-2017 time frame.

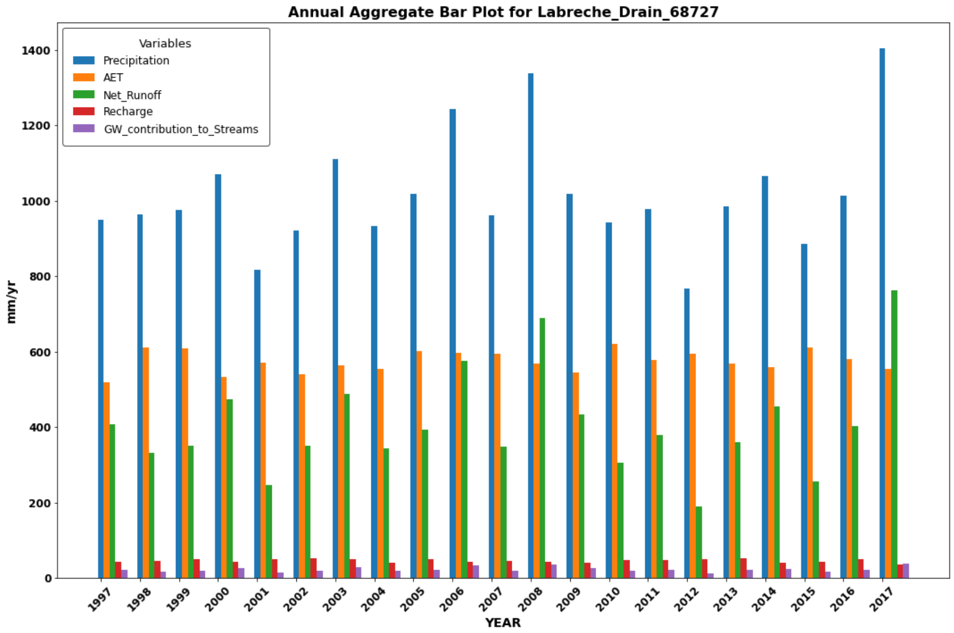


Figure 30. Barplot showing the magnitude of annual precipitation, evapotranspiration, channel (river/stream) outflow, and groundwater recharge in the Labreche Drain sub-catchment for the 1997-2017 time frame.

A box and whisker plot synopsis of the interannual variability is presented for: annual total precipitation in Figure 31, annual total evapotranspiration in Figure 32, annual total stream outflow in Figure 33, and annual total groundwater recharge in Figure 34. As would be expected, the median and lower and upper quartile ranges for precipitation are consistent across the nine sub-catchments; whereas there is slightly more variability in evapotranspiration due to differences in land cover, topography, and lithology that drive both water demand and availability. In contrast to precipitation and evapotranspiration, there is considerably more variability in the magnitude and range of both stream outflow and groundwater recharge across the nine sub-catchments.

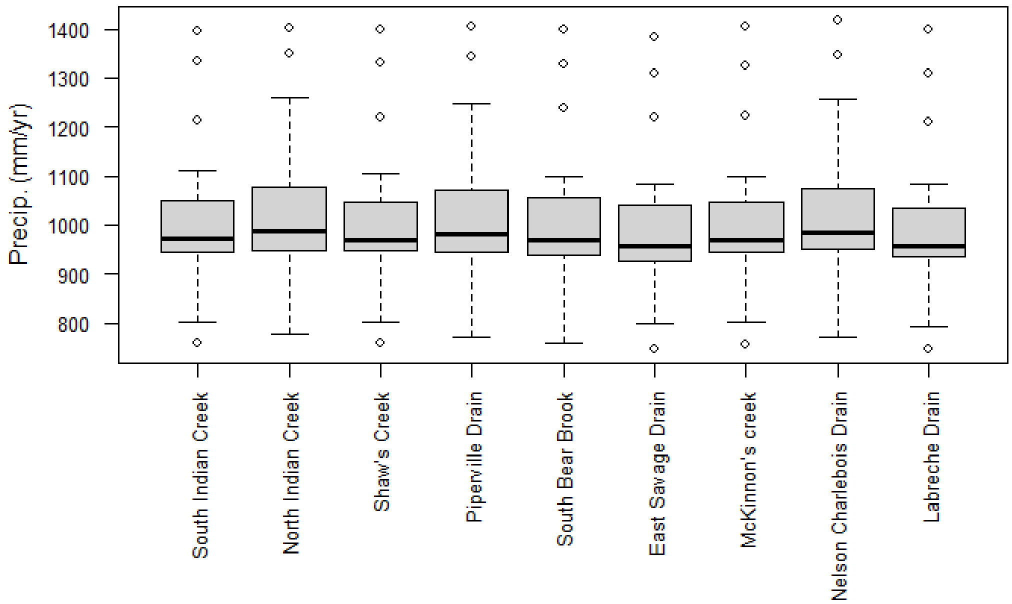


Figure 31. Box and whisker plot showing the median annual precipitation (black line), upper and lower quartile range (box), whisker lines at 1.5 x interquartile range, and possible outliers (dots), for each of the nine sub-catchments within the Bear Brook sub-watershed.

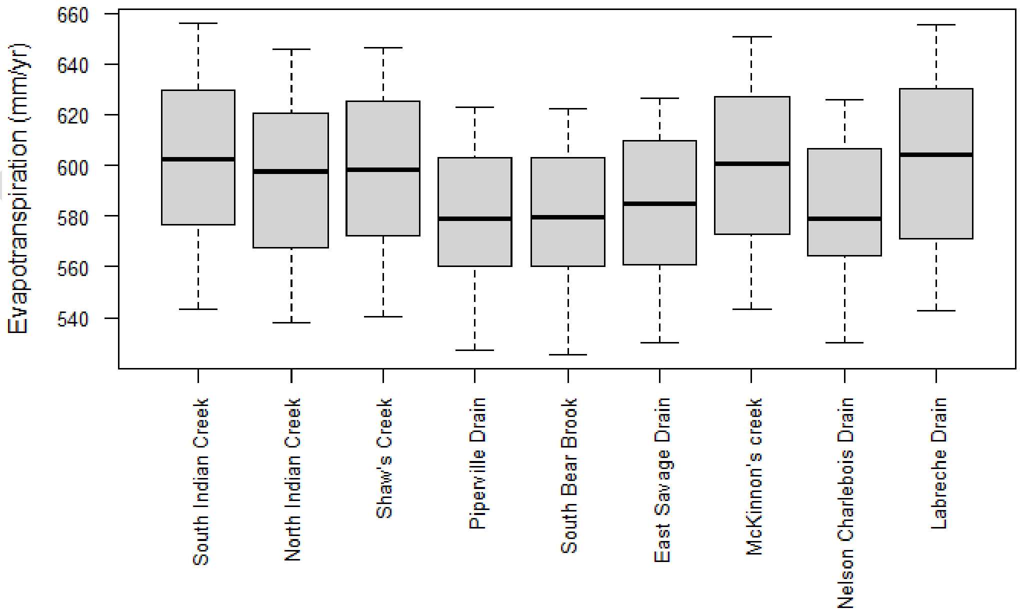


Figure 32. Box and whisker plot showing the median annual evapotranspiration (black line), upper and lower quartile range (box), whisker lines at 1.5 x interquartile range, and possible outliers (dots), for each of the nine sub-catchments within the Bear Brook sub-watershed.

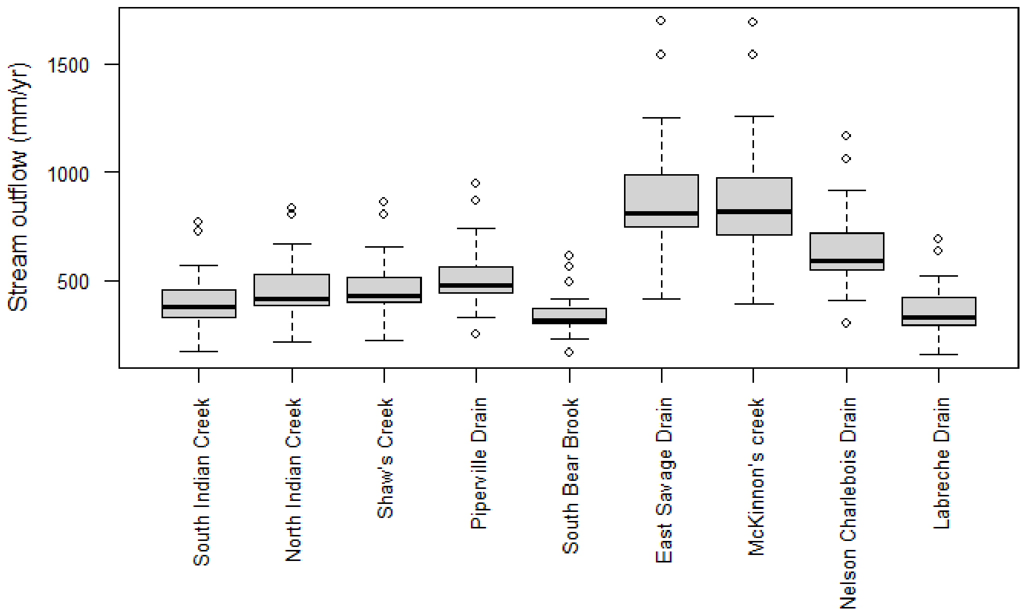


Figure 33. Box and whisker plot showing the median annual stream outflow (black line), upper and lower quartile range (box), whisker lines at 1.5 x interquartile range, and possible outliers (dots), for each of the nine sub-catchments within the Bear Brook sub-watershed.

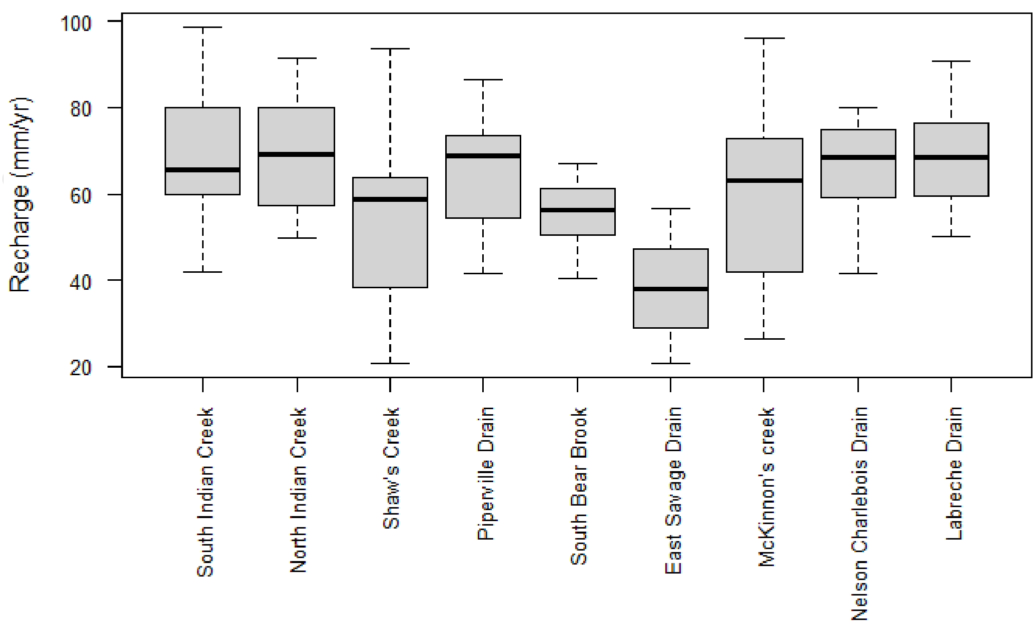


Figure 34. Box and whisker plot showing the median annual groundwater recharge (black line), upper and lower quartile range (box), whisker lines at 1.5 x interquartile range, and possible outliers (dots), for each of the nine sub-catchments within the Bear Brook sub-watershed.

3.6 Baseflow Index

Subsurface water contribution to streamflow can be summarized as a baseflow index (BFI) value, representing the proportion of groundwater + soil water in total surface water flow. Baseflow index values for the nine subcatchments are presented in Figure 35. For all but one subcatchment (namely South Bear Brook), BFI is less than 20 %, which is not unexpected given the low permeability of the Champlain Sea clay deposits that are ubiquitous in the shallow subsurface across much of the Bear Brook subwatershed. The low BFI is also reflective of the extremely flashy hydrologic response to precipitation in the subcatchments, as evidenced by the steep geometry on the rising and falling limbs of the simulated hydrographs.

The South Bear Brook subcatchment has a BFI of approximately 37 %, or roughly double that of the other subcatchments. This is also reflected in the annual groundwater discharge data presented in Figure 26, which is over 2 times higher than groundwater recharge. This difference indicates a disproportionately high ratio of water discharging from the 0 – 1 m subsurface interval (soil) relative to the deeper subsurface deposits. The mostly likely cause is the high proportion of wetlands (relative to the other subcatchments) in the South Bear Brook (Figure 36) which hold water, promote infiltration and enhance shallow horizontal flow/seepage into streams. The extensive Champlain Sea clay deposits in the South Bear Brook also promotes wetland formation and shallow subsurface flow.

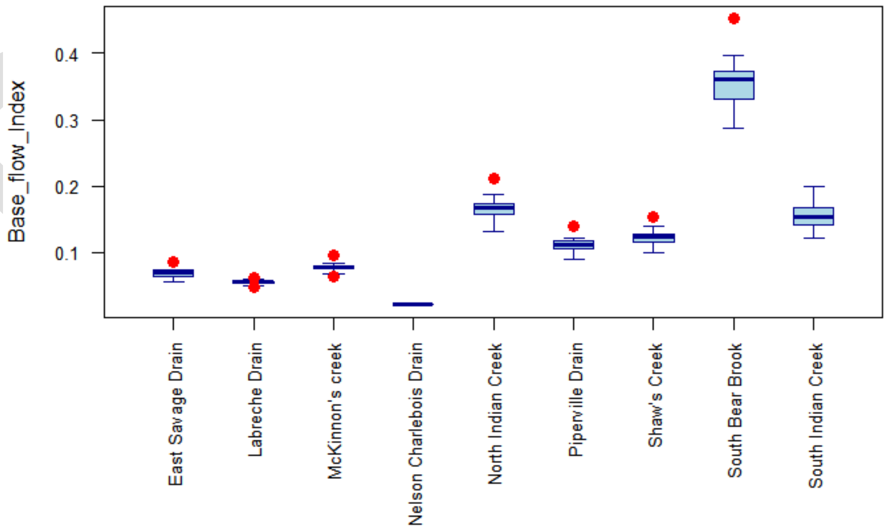


Figure 35. Distribution of baseflow index (BFI) values over the 21 year simulation interval for each of the nine subcatchments. Median annual value (bold line), upper and lower quartile range (box), whisker lines at 1.5 x interquartile range, and possible outliers (dots).

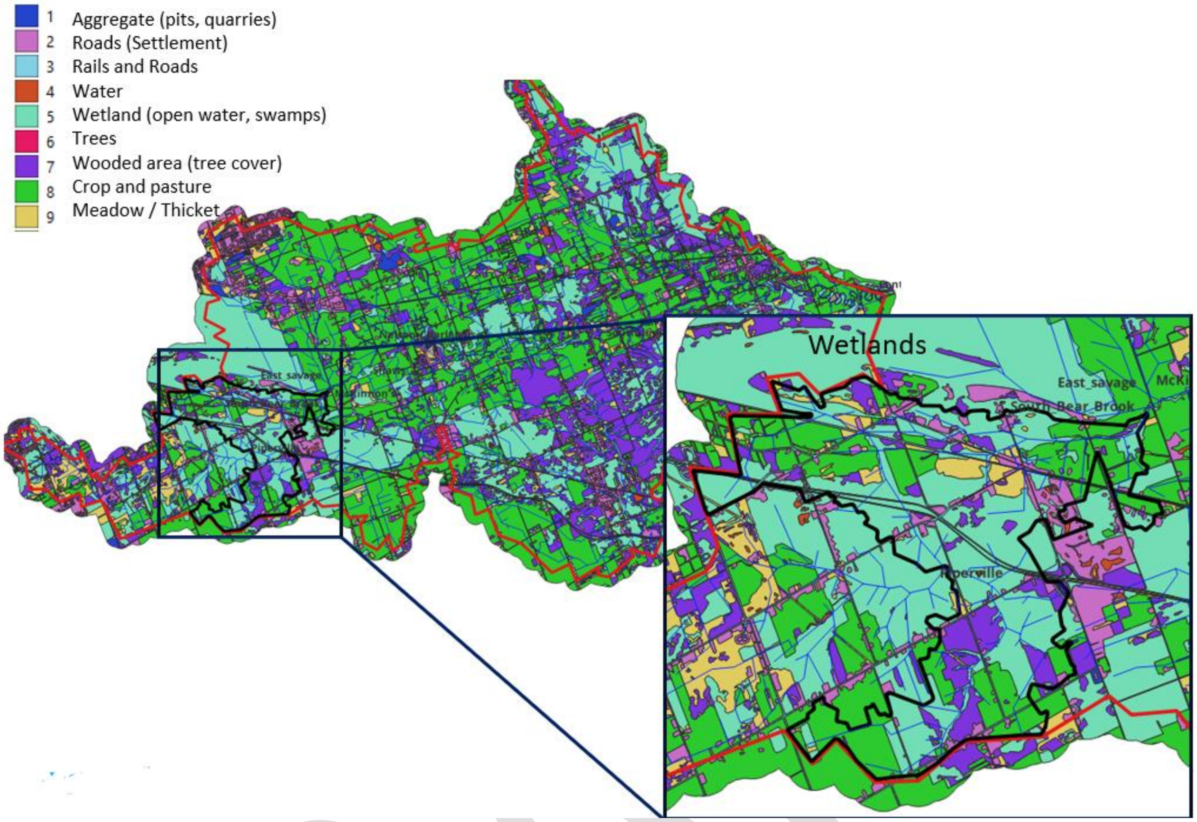


Figure 36. Inset map showing landcover distribution within the South Bear Brook subcatchment.

4.0 ONGOING WORK

Work continues on the Bear Brook Creek Sub-watershed HGS model. The following list outlines the ongoing tasks.

1) Additional calibration of surface water flows and surface water depths using newly provided gauge data and newly implemented monitoring points.
2) Updating the landcover representation to reflect newly mapped wetland coverage. The newly provided landcover map includes 106.83 km^2 of wetlands whereas the original landcover map included 165.38 km^2 of wetlands (Figure 37).

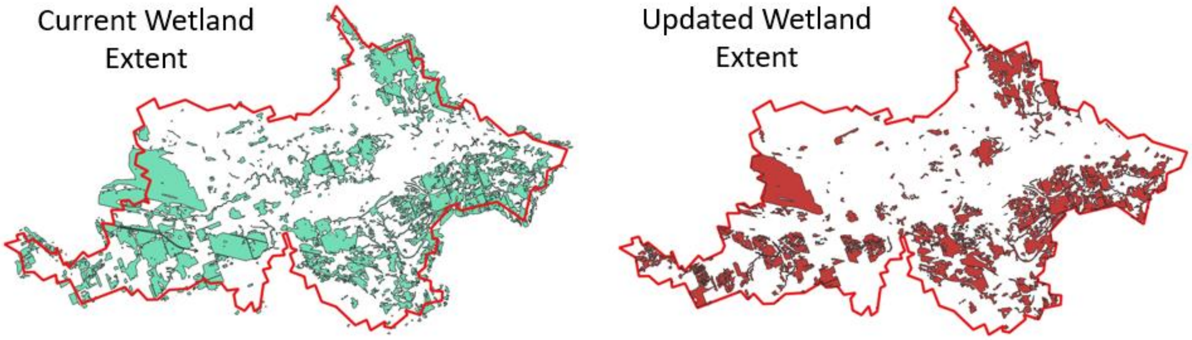


Figure 37. Original (left) and new (right) mapped wetland extent across the Bear Brook watershed.

3) Incorporating the approximately 79 km^2 of mapped tile drained agricultural fields into the HGS model soil layers and running sensitivity tests to evaluate the hydrologic significance (Figure 38).

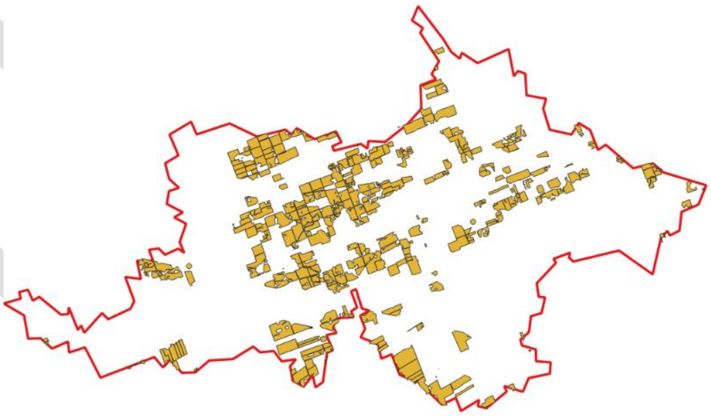


Figure 38. Tile drainage extent across the Bear Brook watershed as depicted in updated SNC mapping.

4) In collaboration with SNC, design and run land use change scenarios and analyse results.

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Appendix D Groundwater Quality in the Bear Brook Watershed

Water Quality Investigation within the Bear Brook Sub-Watershed:

Including:

MRB283_-REV2_data_BB.xlsx

Report Submitted to:

Katherine Watson
South Nation Conservation

Draft: November 08, 2024

aquanty HYDROSPHERE ANALYTICS

519 279 1080
info@aquanty.com
www.aquanty.com

aquanty inc.
564 Weber St.N., Unit 12
Waterloo, ON, N2L 5C6

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Summary

The ambient groundwater geochemical and isotopic database for southern Ontario (Hamilton, 2021) has 144 groundwater wells within the Bear Brook sub-watershed area. Here we looked at the geospatial distribution of common groundwater quality parameters, and separate water quality trends within the two dominant aquifer types, namely near surface overburden and the deeper bedrock. Similar groundwater qualities in each aquifer type indicate a strong hydrological connection across the overburden-bedrock interface. There is evidence for urban and agricultural contamination which decreases the overall water quality in the overburden layer but may in part be explained by sampling and methodological biases between dug (shallow overburden) and drilled (deep bedrock). High nutrient (NO3) and total coliform concentrations present in overburden and bedrock layers also indicate potential contamination from agriculture and septic systems in the Bear Brook area.

1.0 INTRODUCTION

Beyond health and safety (Ontario Drinking Water Quality Standards O.Reg. 169/03), a water quality assessment can be useful in understanding the large hydrogeologic cycle in a watershed. Trends in water quality or groundwater geochemistry can inform hydrological modeling by identifying key aquifer types and their hydrological connections.

The Ambient groundwater geochemical and isotopic data for southern Ontario (MRD283-REV2) database (Hamilton, 2021) was used as the basis of the work herein. It includes 3,944 samples collected between 2007 and 2019, over a ~96,000 km^2 coverage area. Parameters tested include dissolved gases, major ions, trace elements, isotopes of water, and field measurements of alkalinity, temperature, pH, redox potential and electrical conductivity.

Within the Bear Brook sub-watershed in the South Nation River Watershed (SNW) there are 144 water samples in the Hamilton (2021) database that were used in the subsequent analysis. Sixteen water quality parameters were of specific focus: Specific Conductance, Total Dissolved Solids, pH, Alkalinity, Calcium, Magnesium, Sodium, Iron, Chloride, Sulphate, Bicarbonate, Nitrate, Phosphate, Total Coliform, Uranium, and Radon.

While Radon was not detected, and Uranium was detected at levels well below those prescribed in the Ontario Safe Drinking Water Act (2002), levels of the other parameters do exceed regulations or aesthetic guidelines on occasion. However, as the water quality samples do not represent drinking water samples, the exceedance levels are presented herein as reference only.

2.0 METHODOLOGY

2.1 Study Area

The Bear Brook Creek watershed has an area of 482 km^2, across which the elevation descends from approximately 120 meters above sea level (mASL) closer to the city of Ottawa in the west to 42 mASL at the outlet (Figure 1). Of particular importance in this study, the eastern flank of the city of Ottawa encroaches on the western corner of the watershed and is expected to continue expanding east.

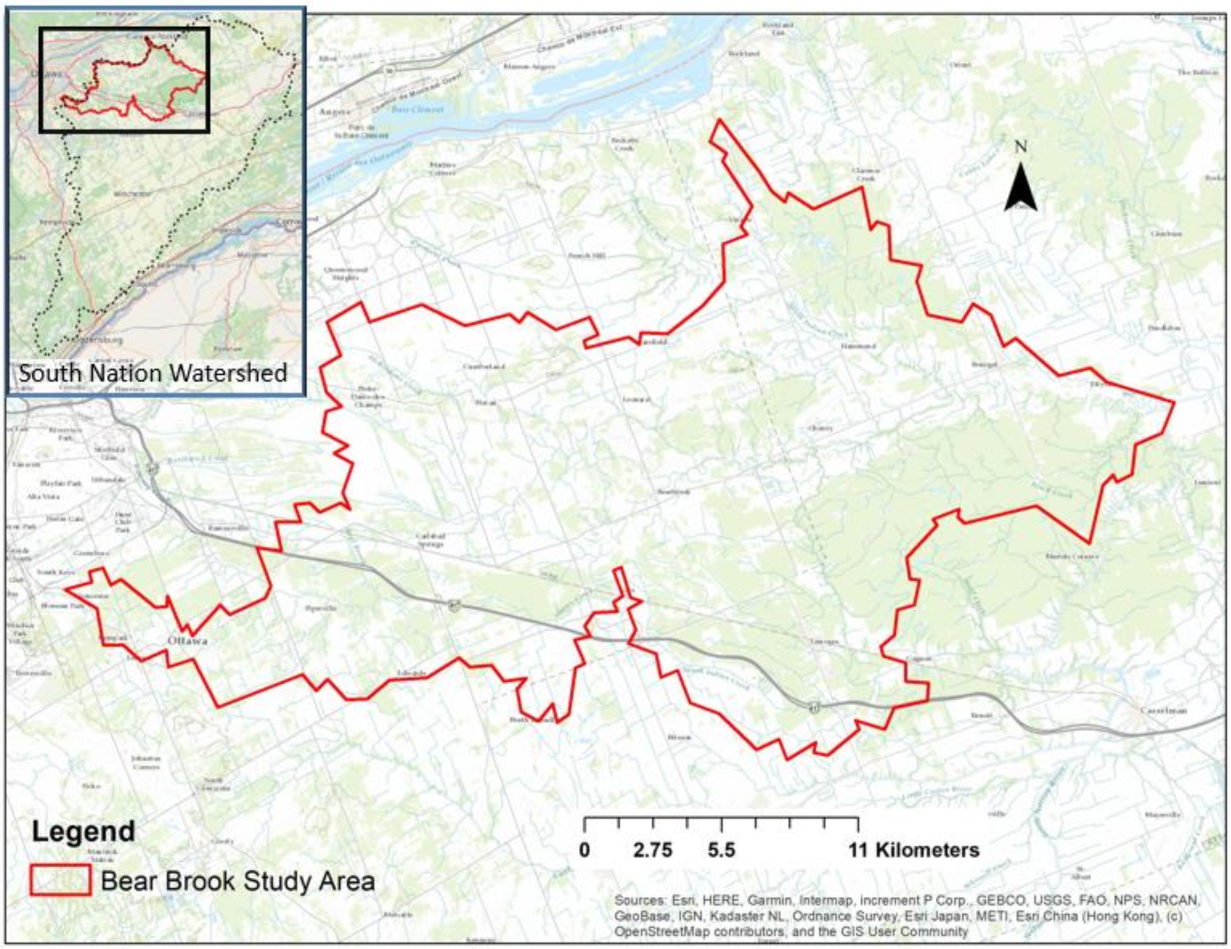

Figure 1. The inset figure shows the location of the Bear Brook Creek sub-watershed within the South Nation watershed, while the main figure shows the extent of the Bear Brook sub-watershed in detail.

2.2 Land Cover

Spatially distributed land cover was provided by South Nation Conservation (SNC) (Figure 2). The land use categories and percentage of area attributed to the different land uses are presented in Table 1.

Figure 2. Spatially distributed land cover map for the Bear Brook sub-watershed.

Table 1. Percentage of each component of land cover in Bear Brook sub-watershed

Land Cover Component	Percentage by Area
Aggregate (pits, quarries)	0.62 %
Settlements	8.71 %
Rail and Roads	2.16 %
Water	0.44 %
Wetland and Swamp	28.9 %
Wooded Area (Tree cover)	19.1 %
Cropland and Pasture	34.5 %
Meadow/Thicket	5.6 %

2.1 Well Types

There are generally two types of wells in MRD283-Rev2 for the Bear Brook Subwatershed, dug (52) and drilled (92) (Figure 3). Dug wells are typically shallower (<10 m) and occur in overburden, whereas drilled wells are deeper and tend to penetrate bedrock (Figure 4).

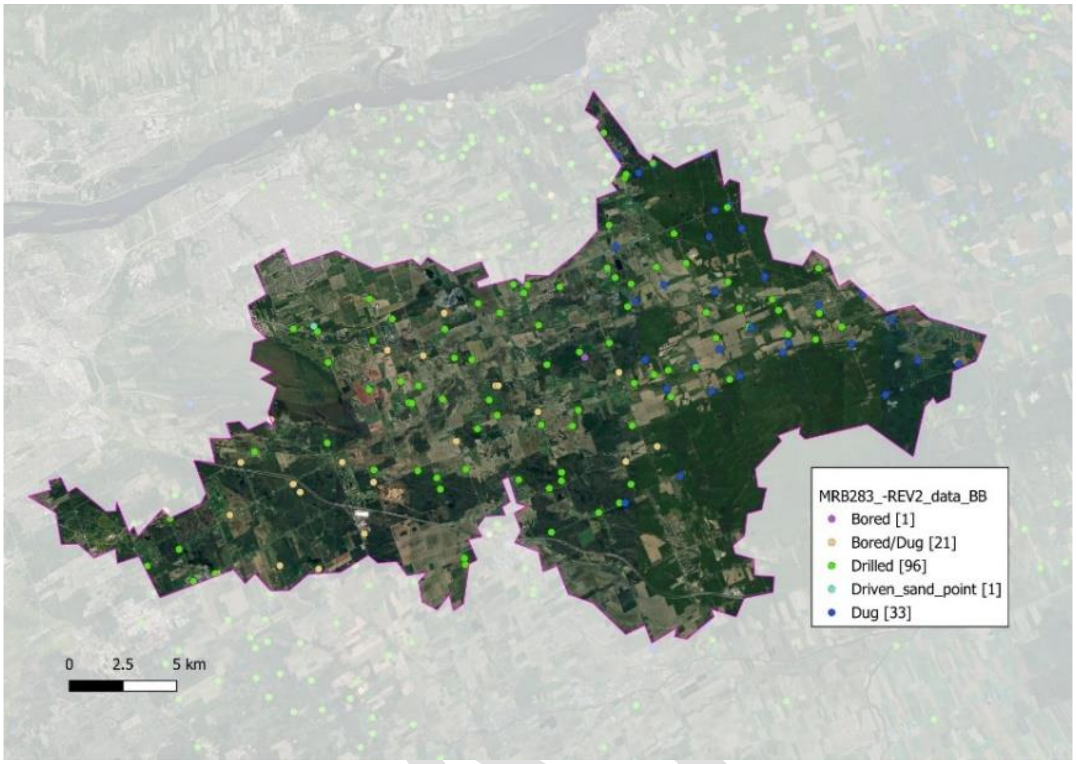

Figure 3. Distribution of well types across the Bear Brook subwatershed.

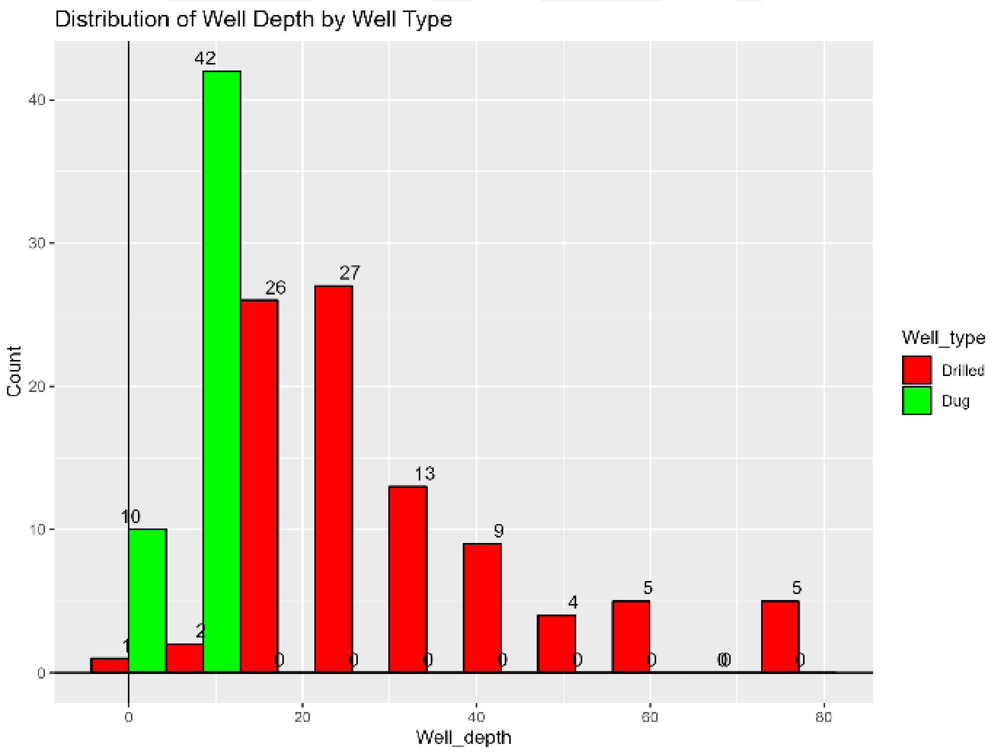

Figure 4. Histogram of well depth (m) by well type.

2.2 Southern Ontario GW Quality database (MRD283-REV2)

MRD283-Rev2 (Hamilton, 2021) is a water quality database of 3944 groundwater well water samples across Southern Ontario, collected between 2007 and 2019, of which 152 are within the Bear Brook sub-watershed. Ignoring duplicate samples, there are 144 unique water samples for Bear Brook. These samples can be separated by aquifer type, with 69 overburden and 75 bedrock samples (Figure 5).

See MRB283_-REV2_data_BB.xlsx

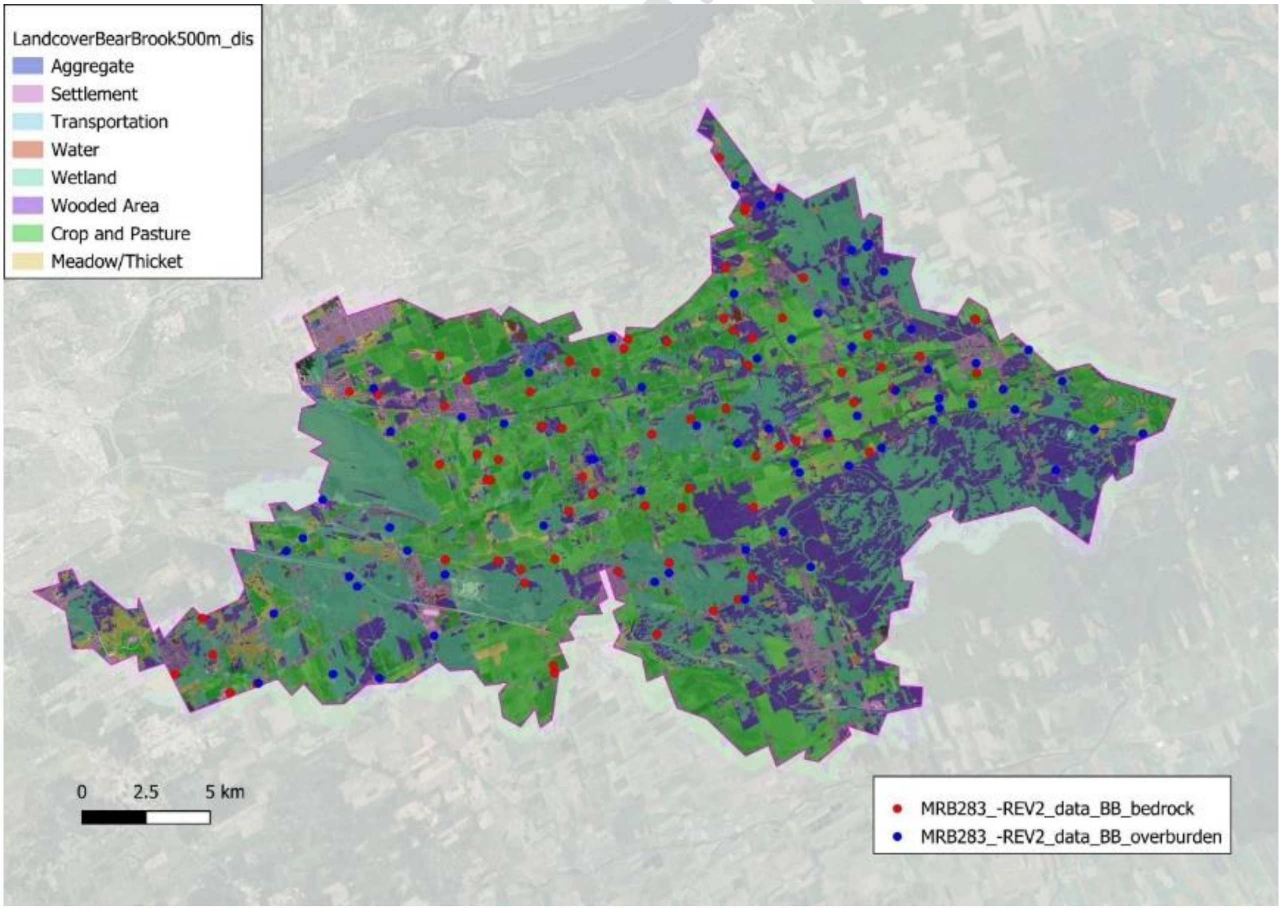

Figure 5. Groundwater sample locations separated by overburden and bedrock well screen locations.

2.3 Well Depths by Aquifer Type

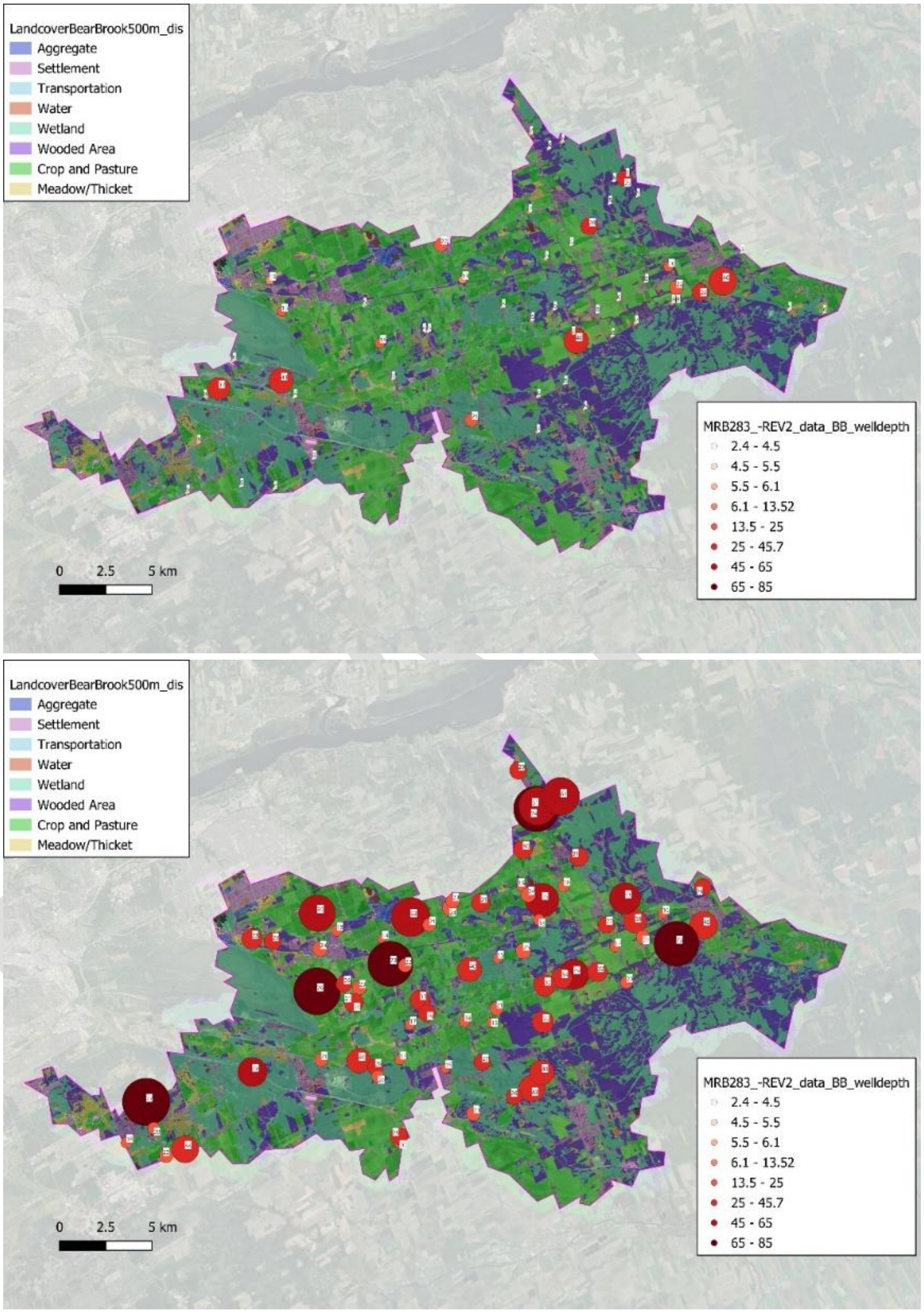

Figure 6. Spatial distribution of overburden (top panel) and bedrock (bottom panel) groundwater quality sampling points, along with associated well depths (m).

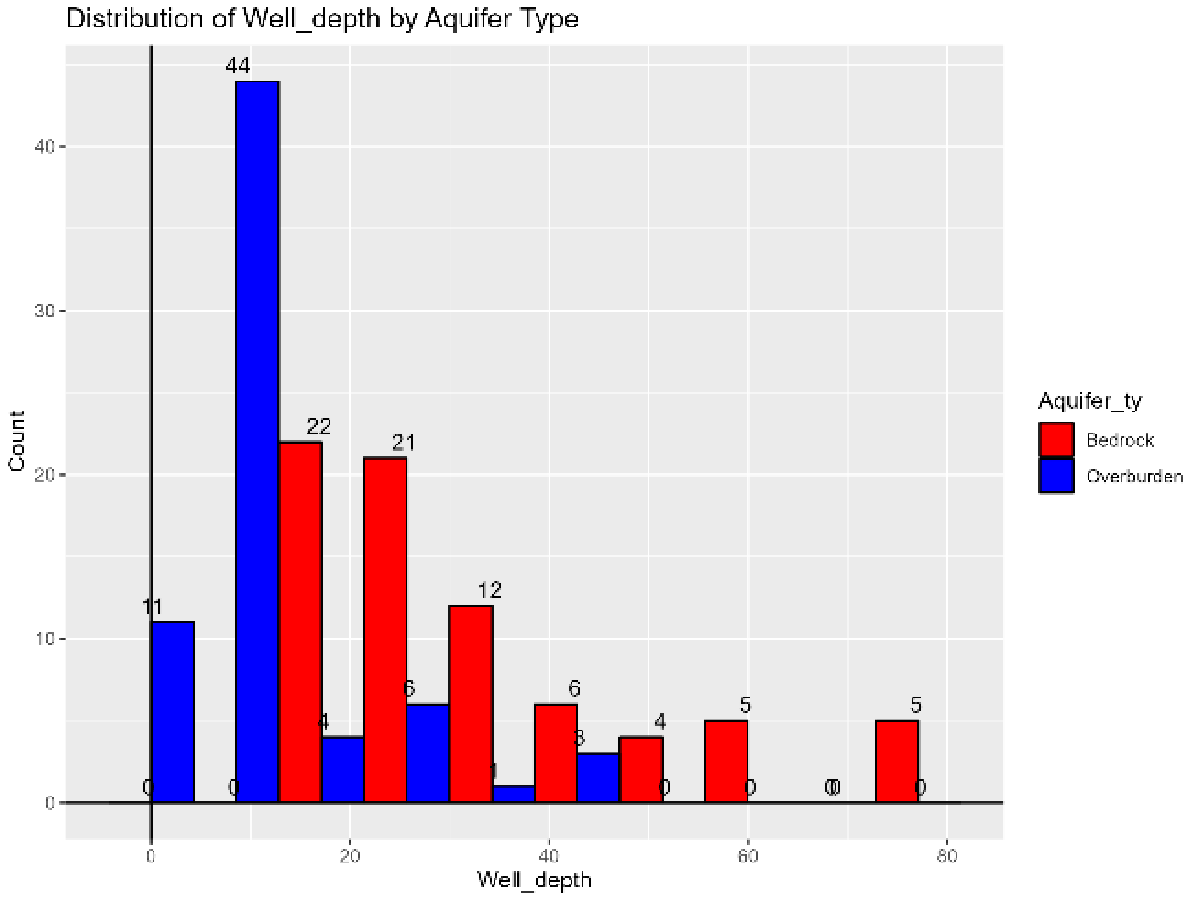

Figure 7. Histogram depiction of well depth distribution (X-axis, m) in the overburden and bedrock.

3.0 WATER QUALITY

The following sixteen water quality parameters were plotted in XY coordinate scatter plots (EPSG26918) where the size and color magnitudes are proportional to the concentration of the given parameter type; Specific Conductance, Total Dissolved Solids, pH, Alkalinity, Calcium, Magnesium, Sodium, Iron, Chloride, Sulphate, Bicarbonate, Nitrate, Phosphate, Total Coliform, Uranium, and Radon. These parameters, while only a small part of the MRD283-REV2 database, provide a good snapshot of agricultural, radiological, and microbiological contamination in the Bear Brook subwatershed, along with the ambient groundwater geochemical characteristics.

Linear scales were used if appropriate, but some parameters required non-linear (quartile) scales to effectively illustrate the spatial patterns. In general, a larger size and dark color illustrates a higher concentration. Groundwater well samples were separated by aquifer type, namely overburden or bedrock.

The following maps and histograms present the results of the water quality analysis.

3.1 Specific Conductance

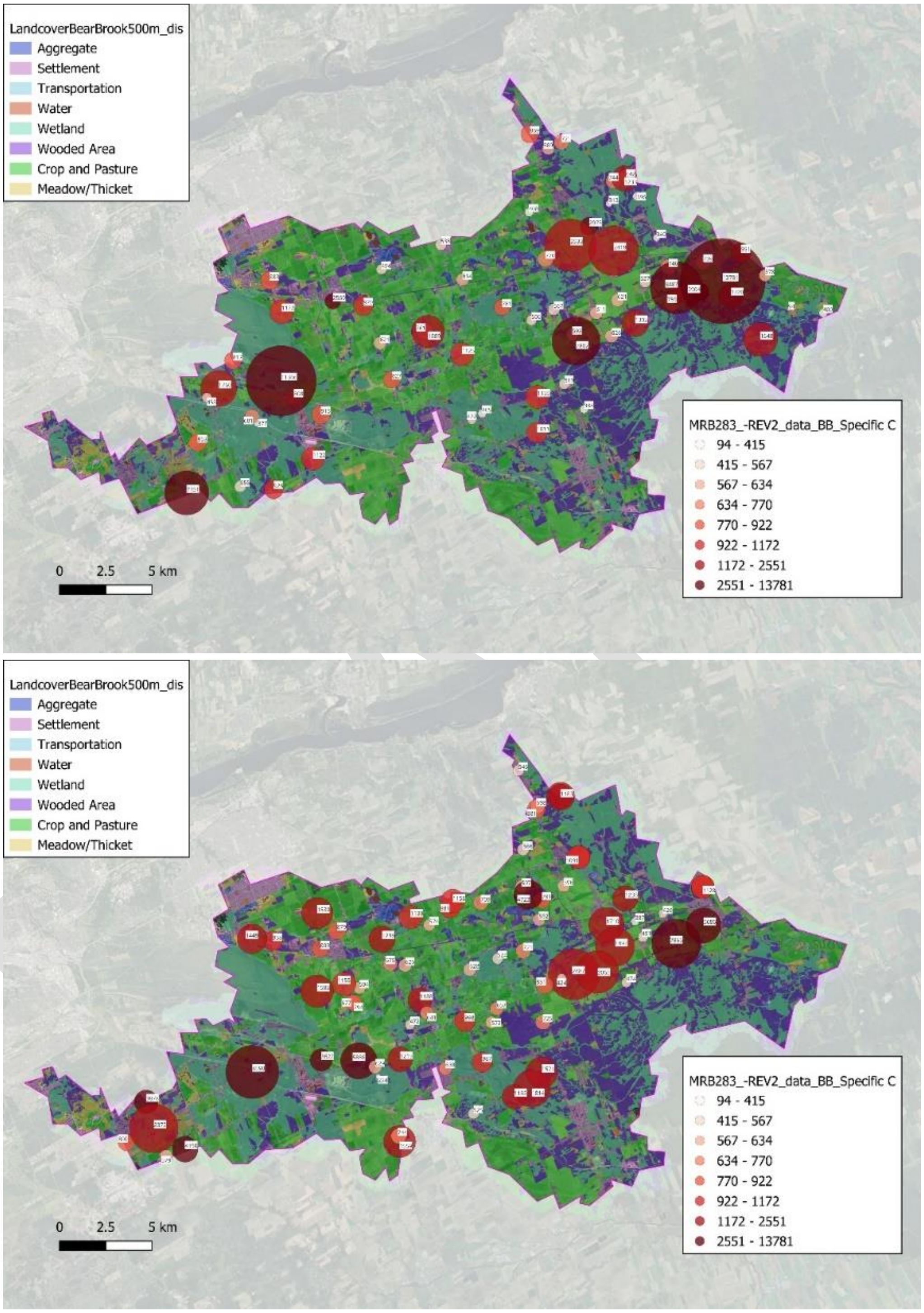

Figure 8. **Specific Conductance** levels (µS/cm) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

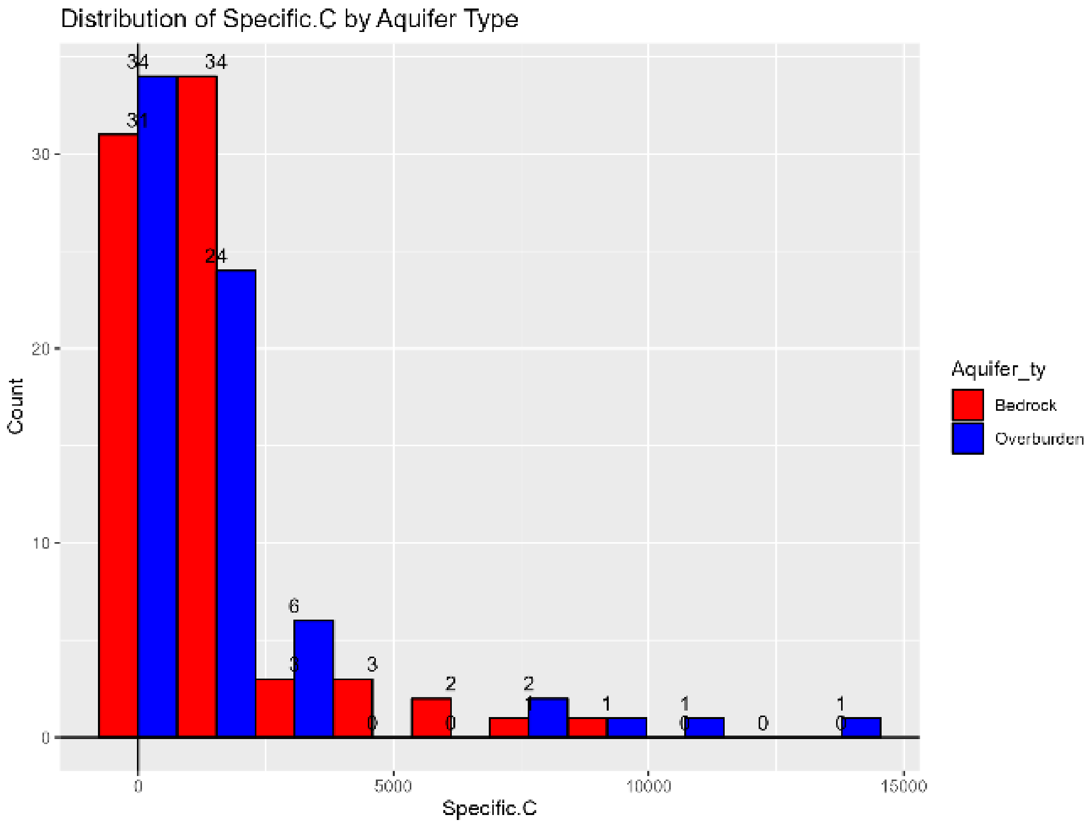

Figure 9. Histogram of **Specific Conductance** level distribution (X-axis, µS/cm) at the overburden and bedrock groundwater quality sampling locations.

3.2 Total Dissolved Solids

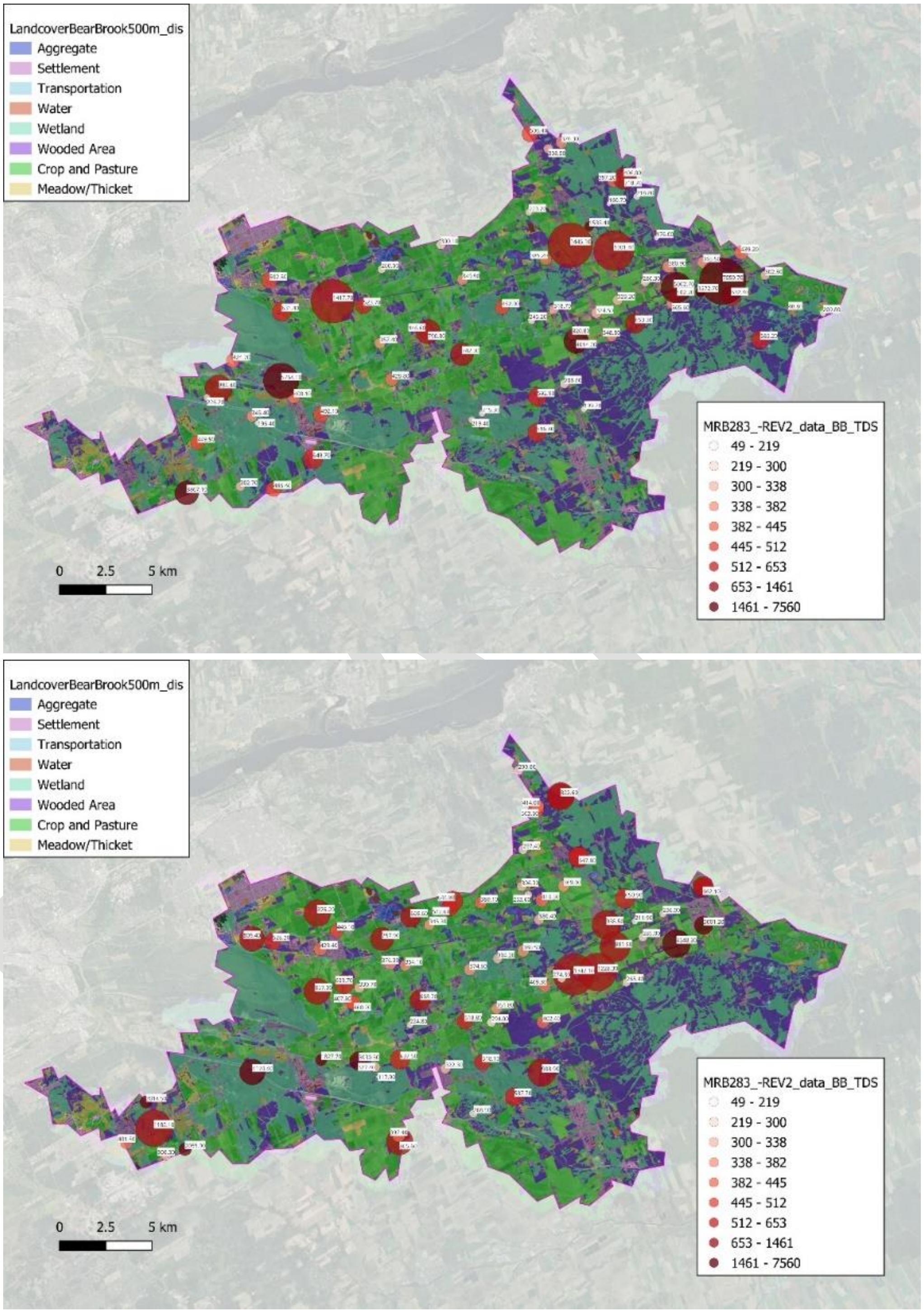

Figure 10. **Total Dissolved Solids** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

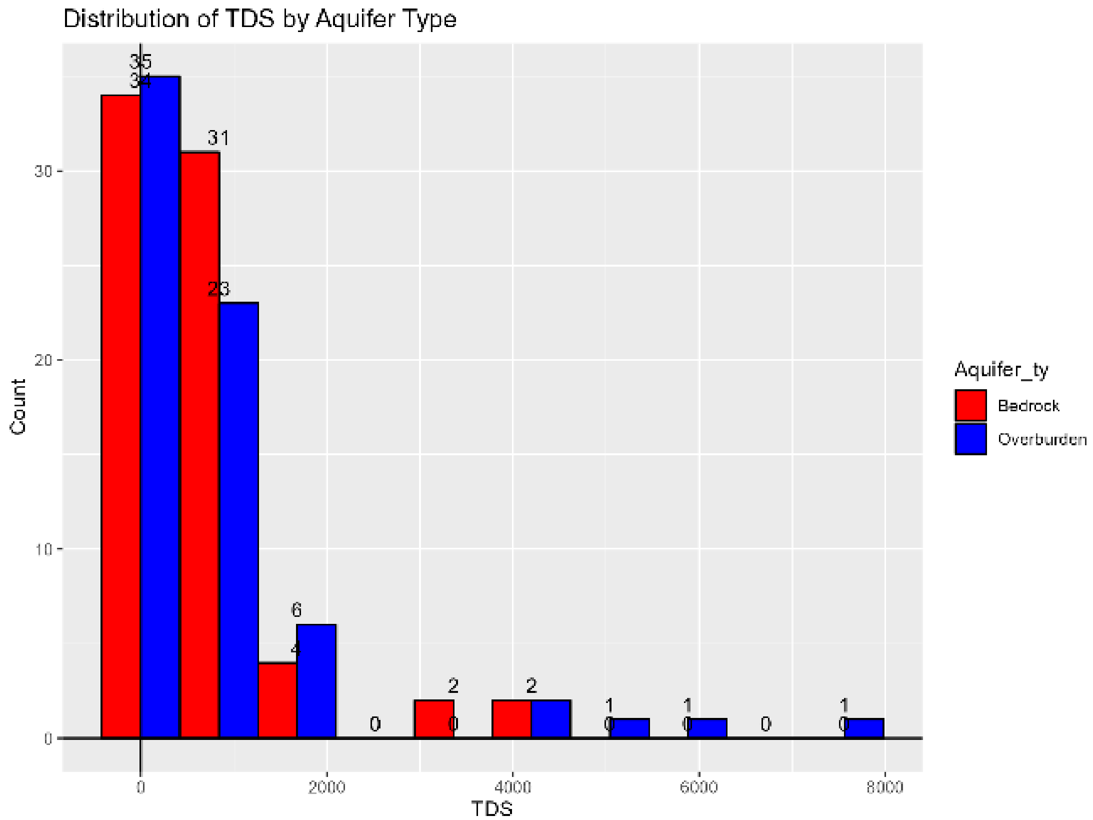

Figure 11. Histogram of **Total Dissolved Solids** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.3 pH

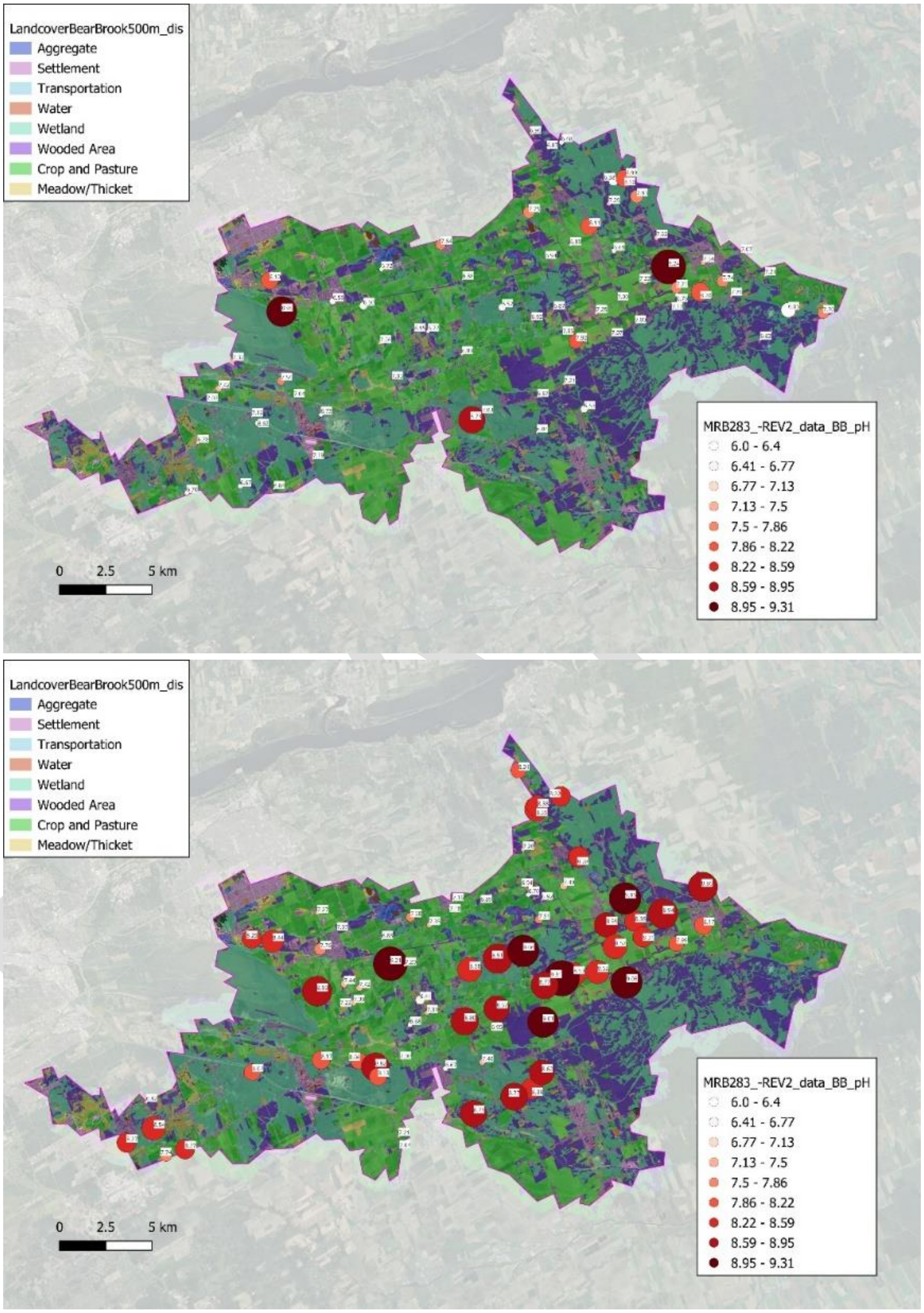

Figure 12. **pH** levels at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

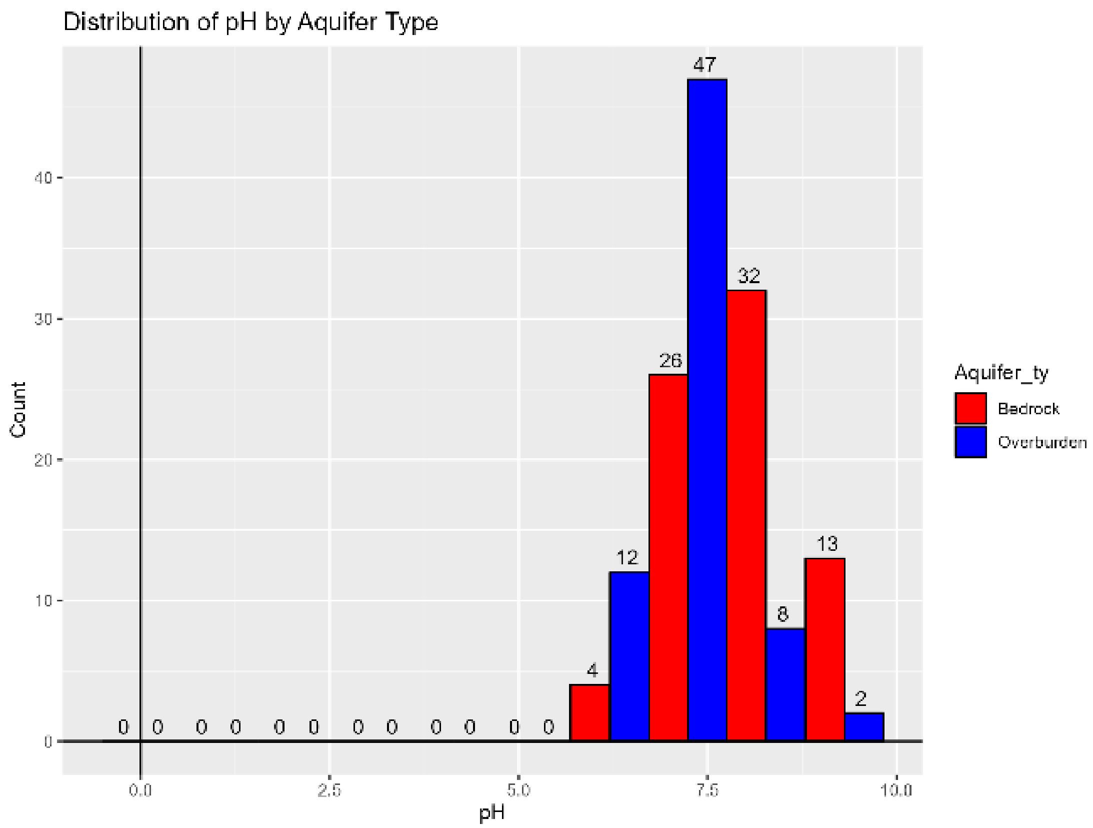

Figure 13. Histogram of **pH** level distributions (X-axis) at the overburden and bedrock groundwater quality sampling locations.

3.4 Alkalinity

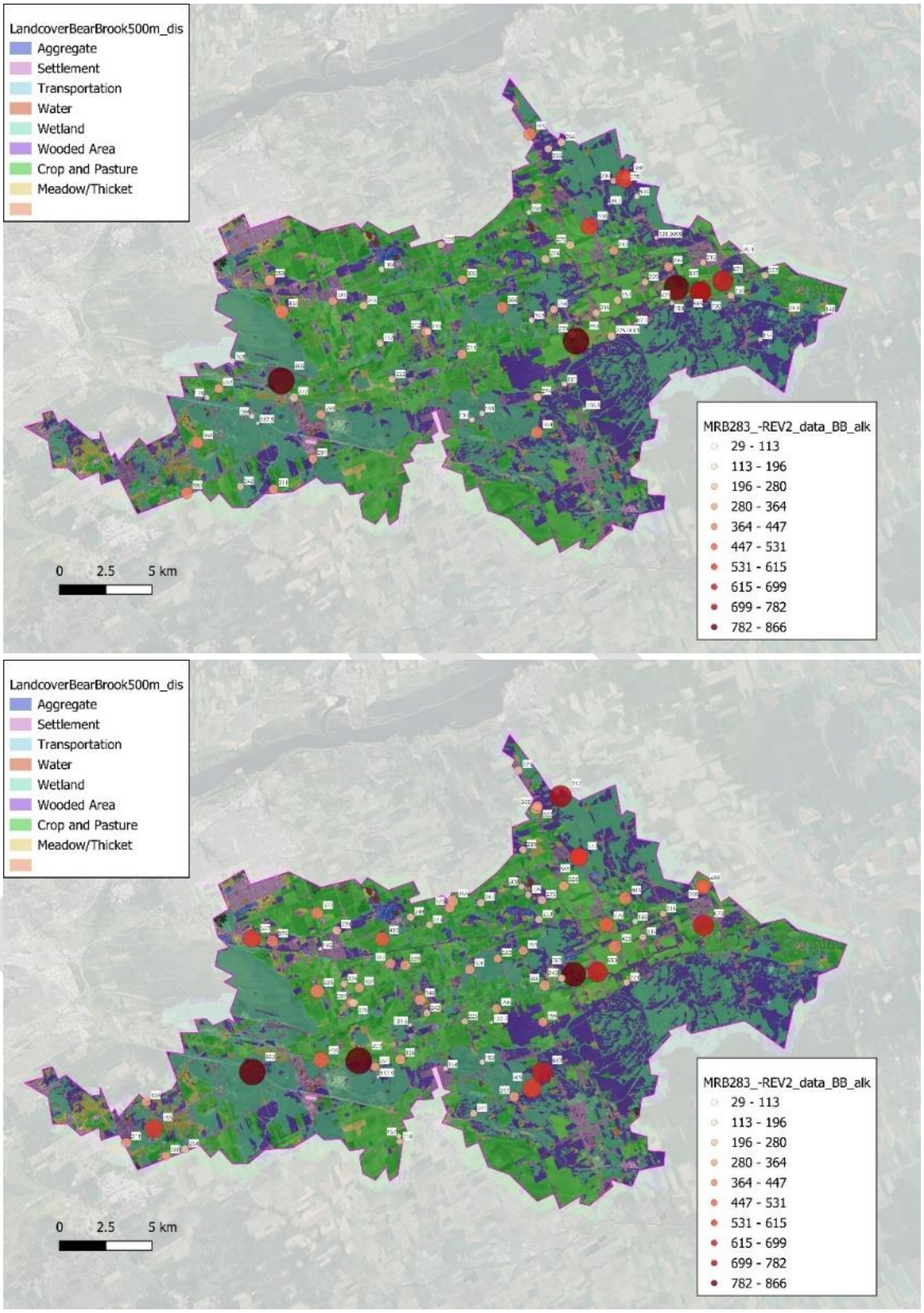

Figure 14. **Alkalinity** levels (mg/l as CaCO3) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

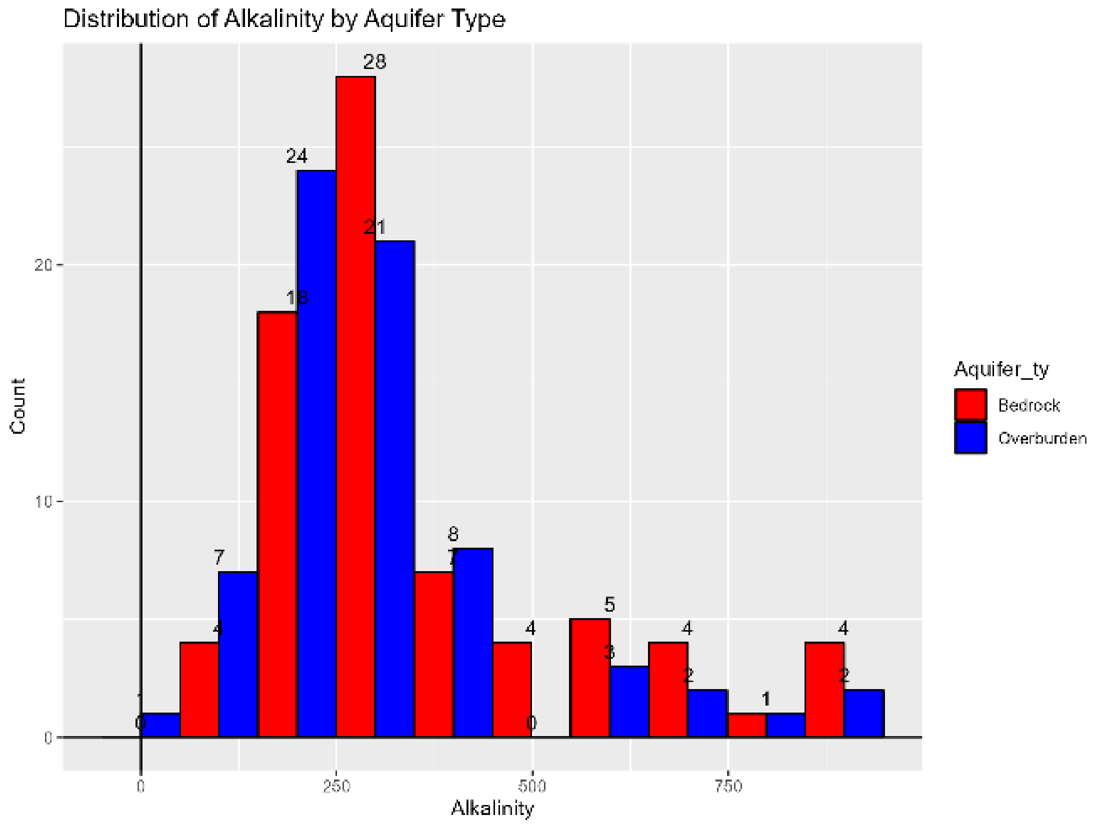

Figure 15. Histogram of **Alkalinity** level distributions (X-axis, mg/l as CaCO3) at the overburden and bedrock groundwater quality sampling locations.

3.5 Calcium

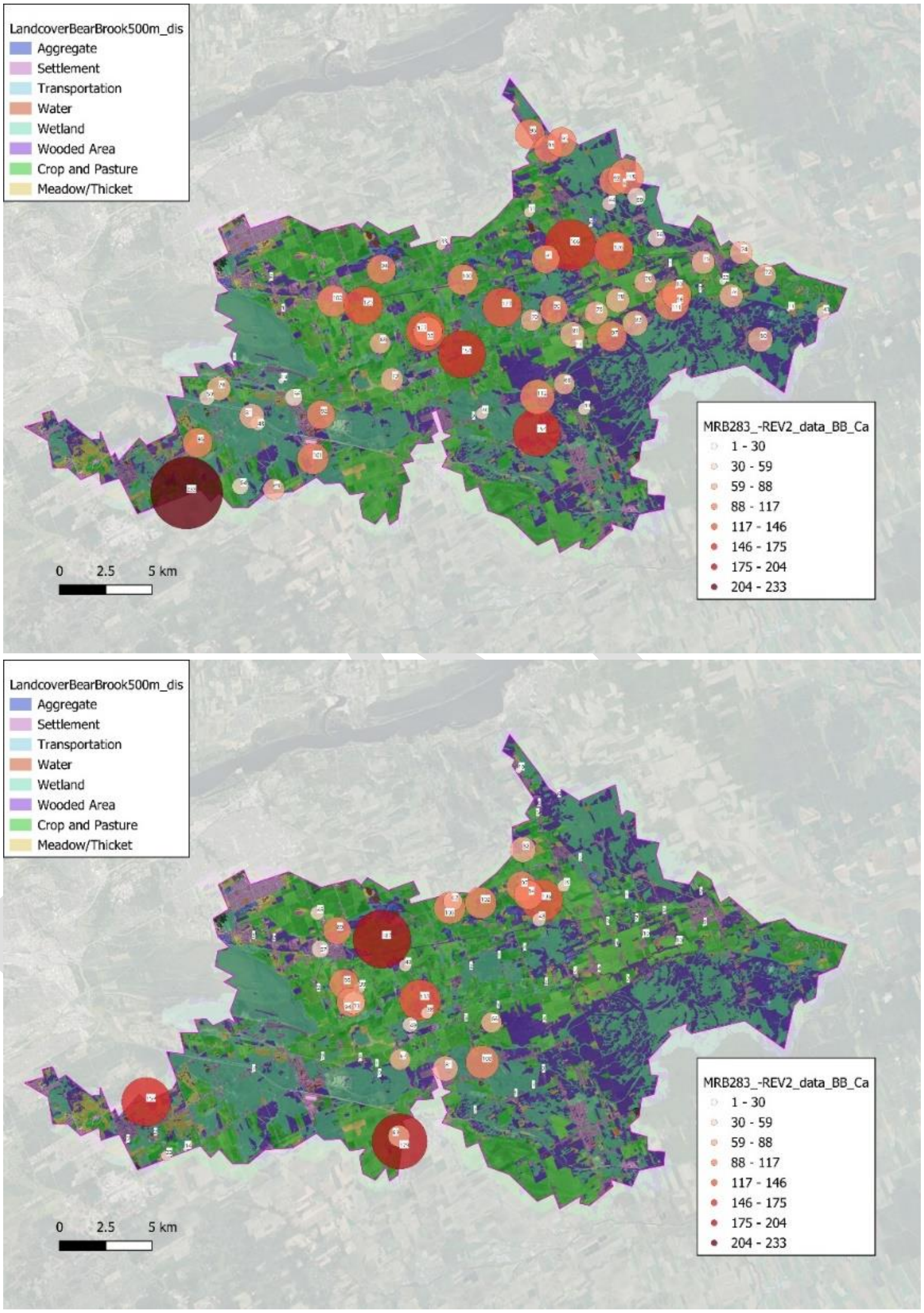

Figure 16. **Calcium (Ca)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

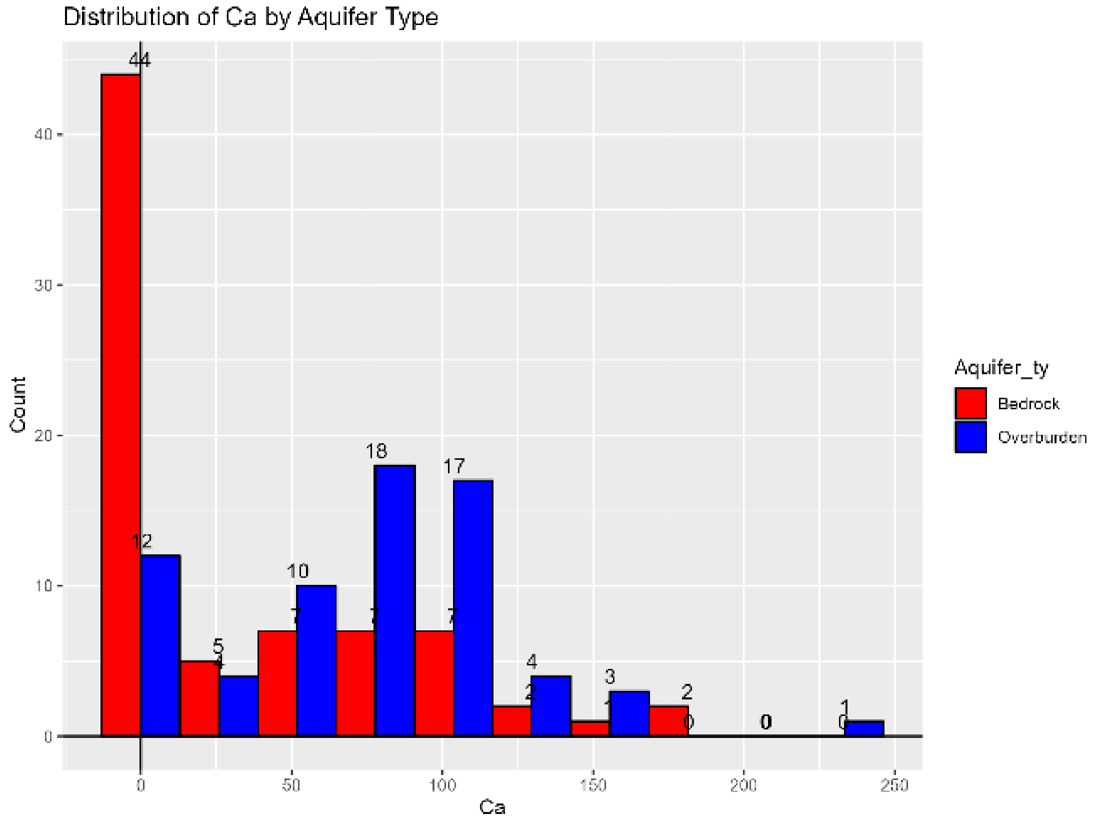

Figure 17. Histogram of **Calcium (Ca)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.6 Magnesium

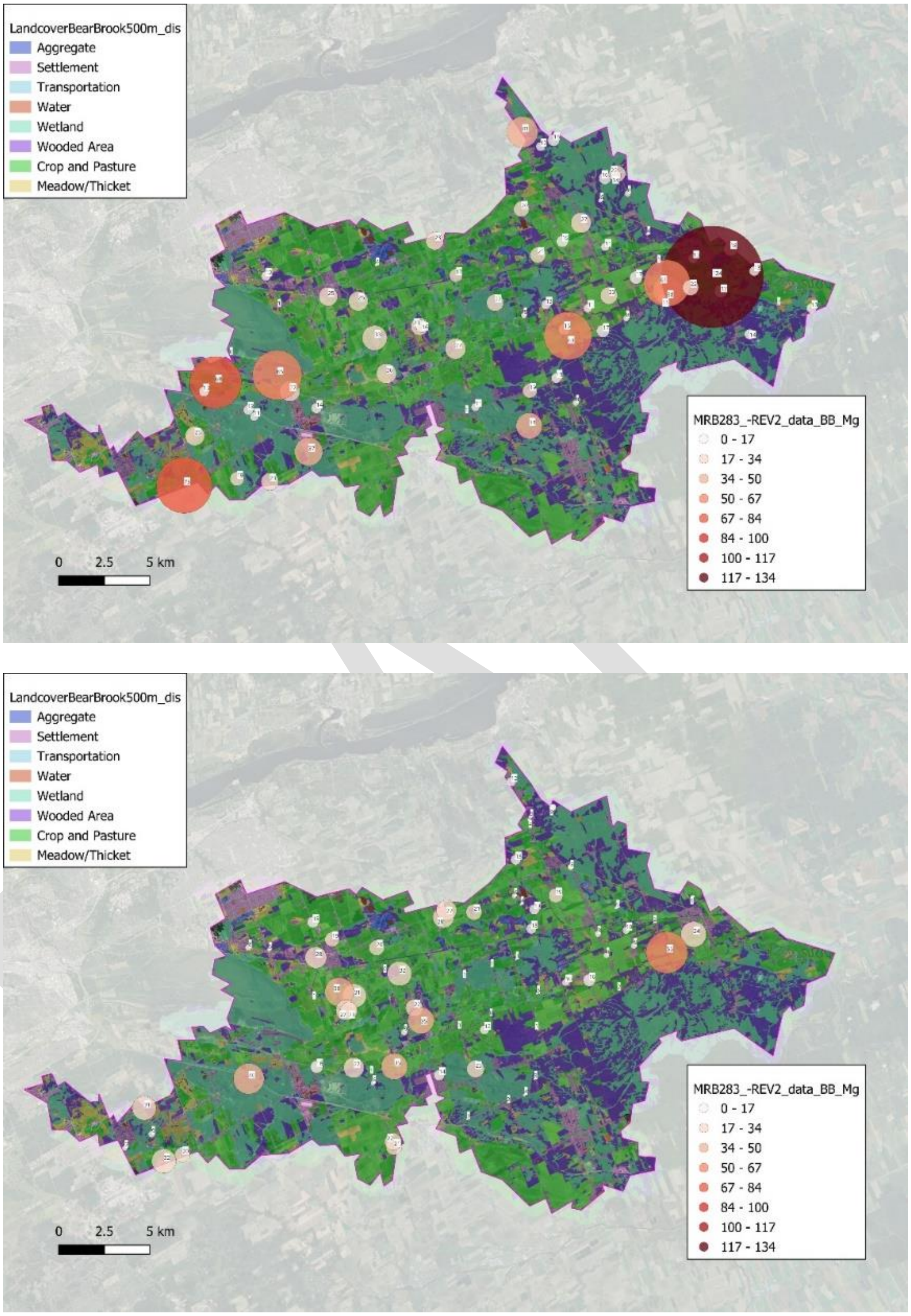

Figure 18. **Magnesium (Mg)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

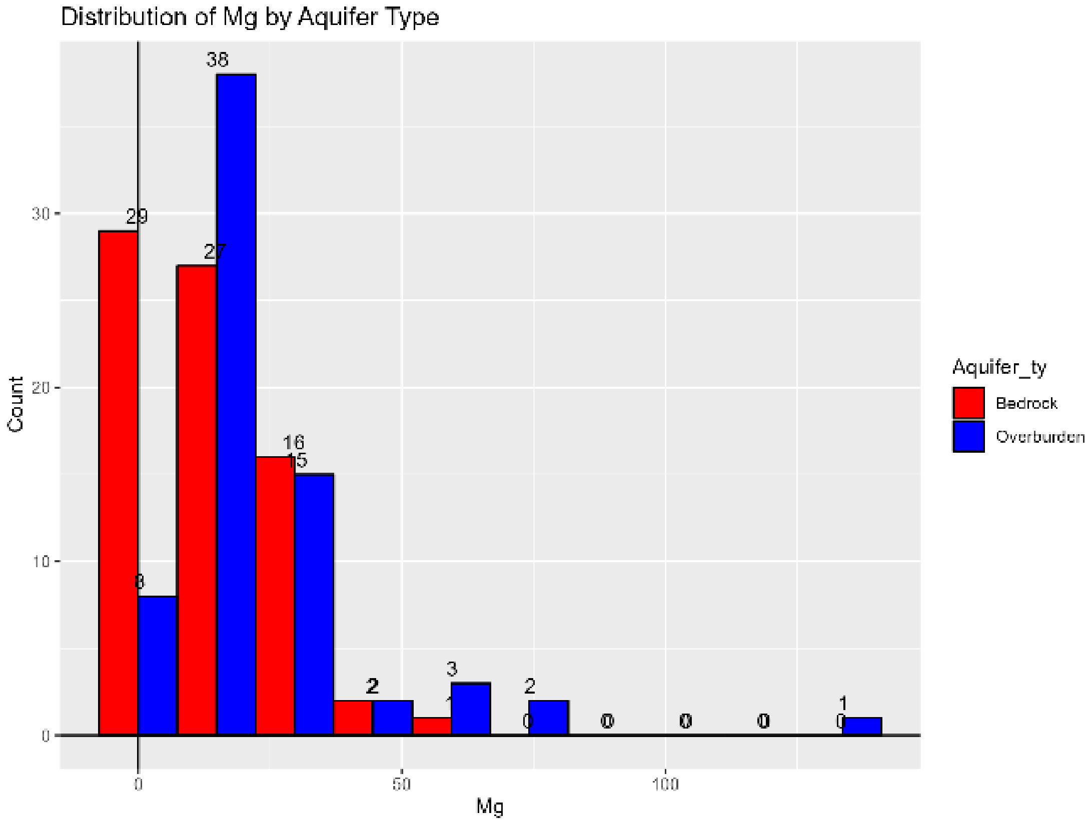

Figure 19. Histogram of **Magnesium (Mg)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.7 Sodium

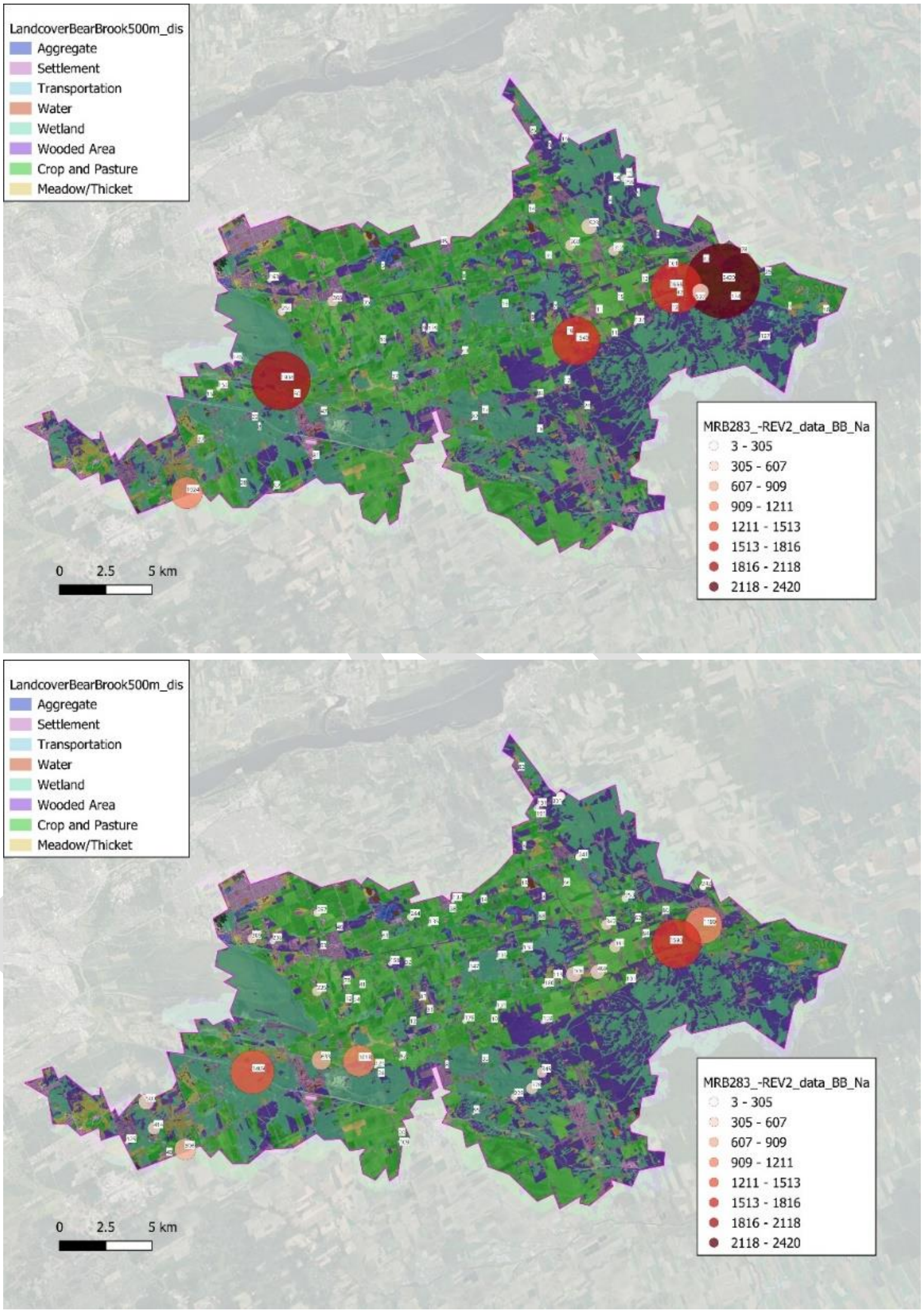

Figure 20. **Sodium (Na)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

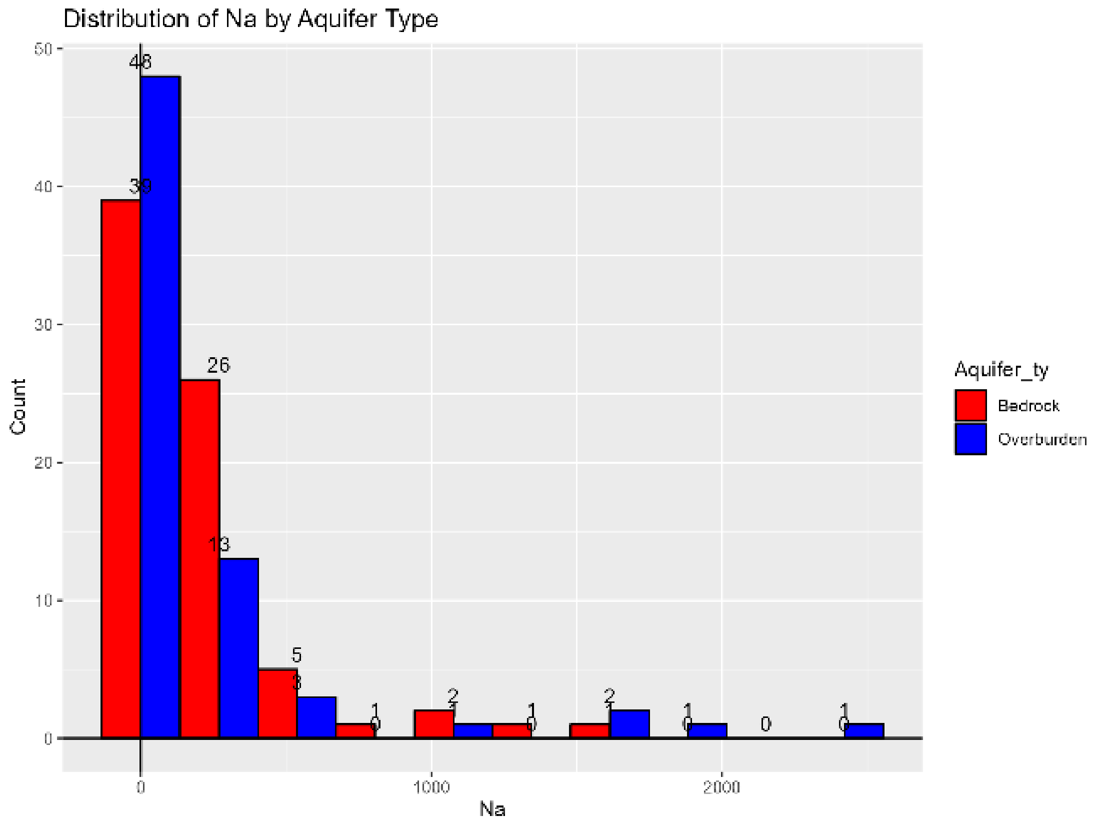

Figure 21. Histogram of **Sodium (Na)** concentration (mg/l) distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.8 Iron

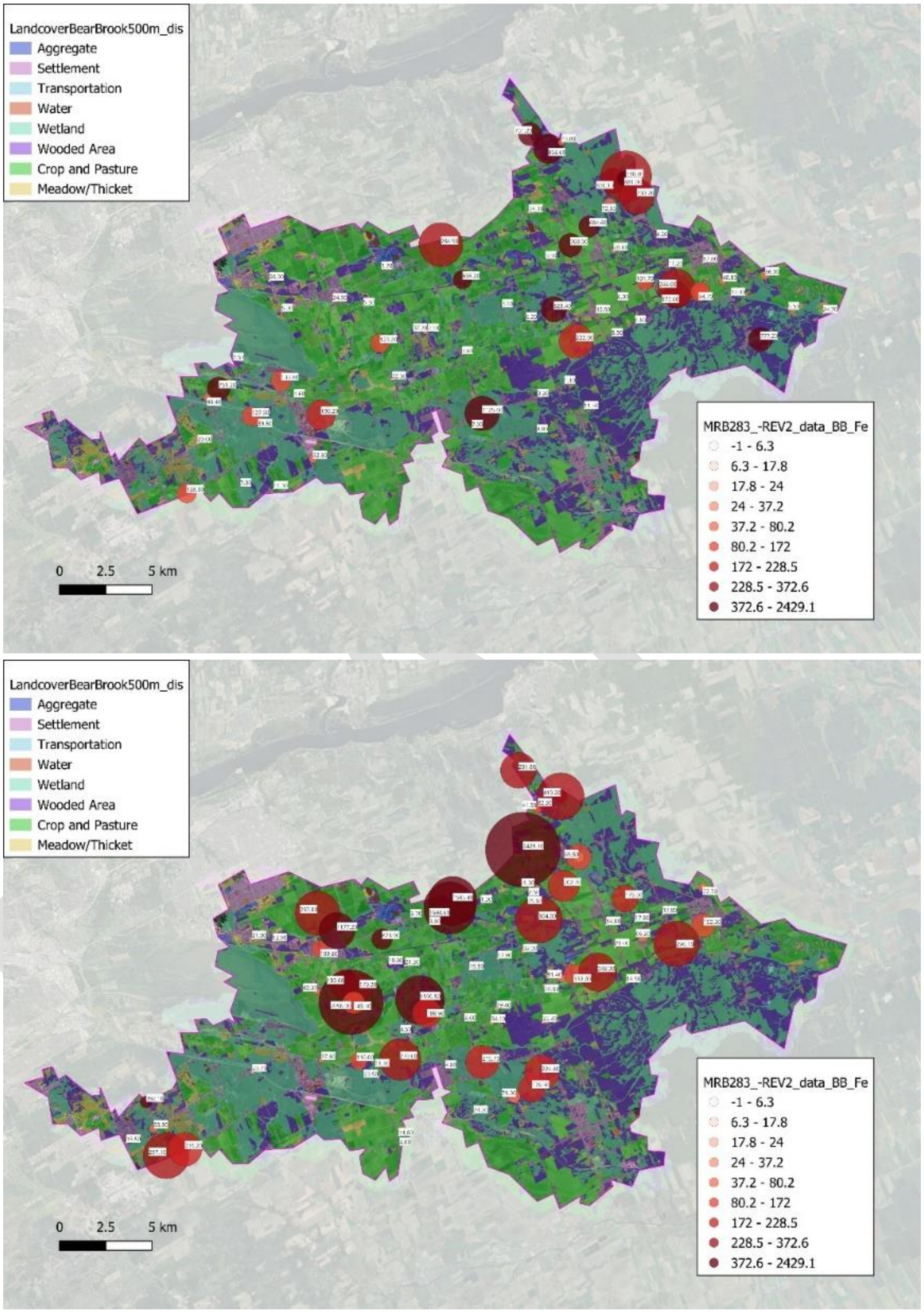

Figure 22. **Iron (Fe)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

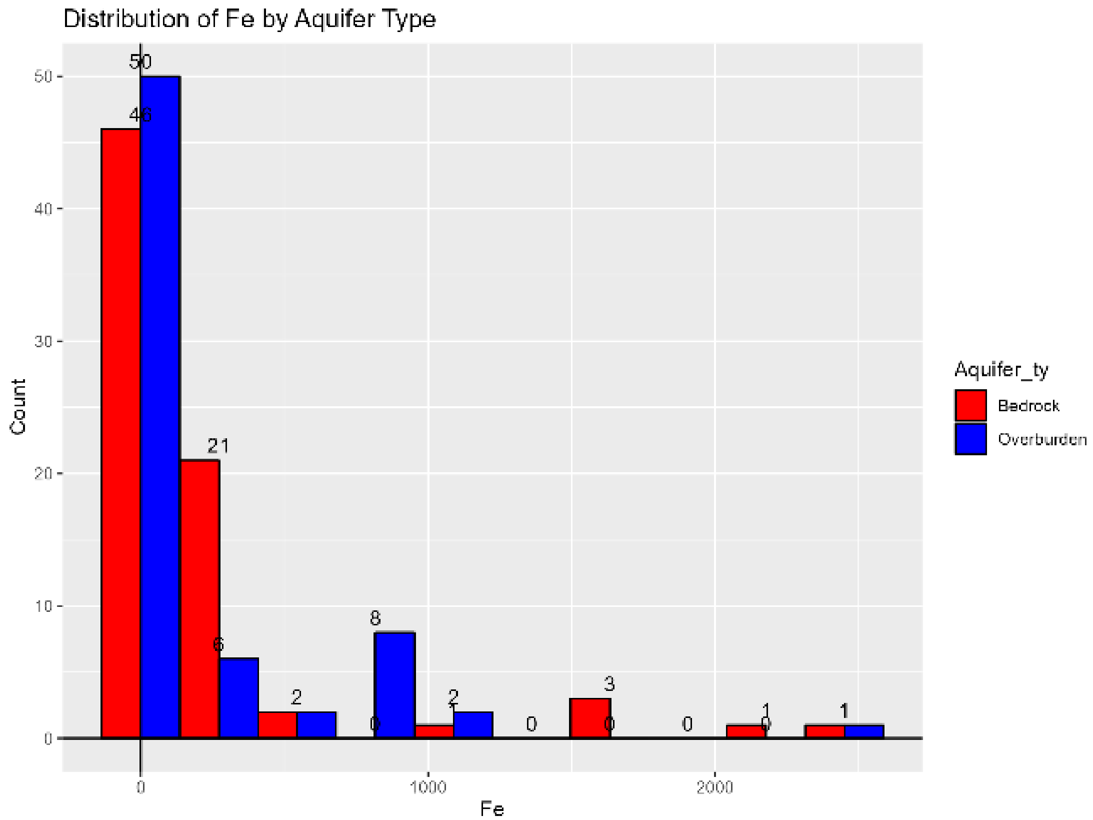

Figure 23. Histogram of **Iron (Fe)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.9 Chloride

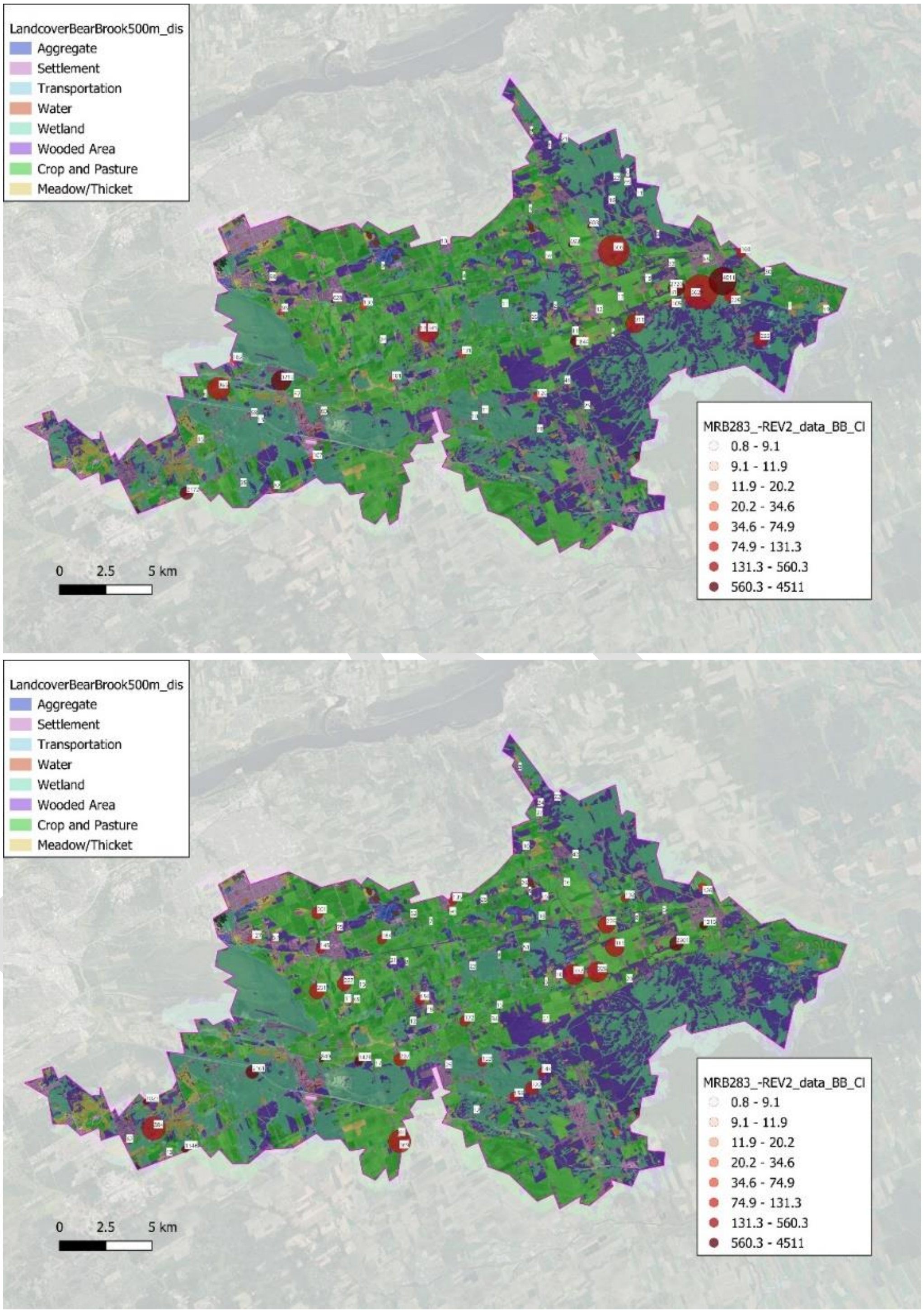

Figure 24. **Chloride (Cl)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

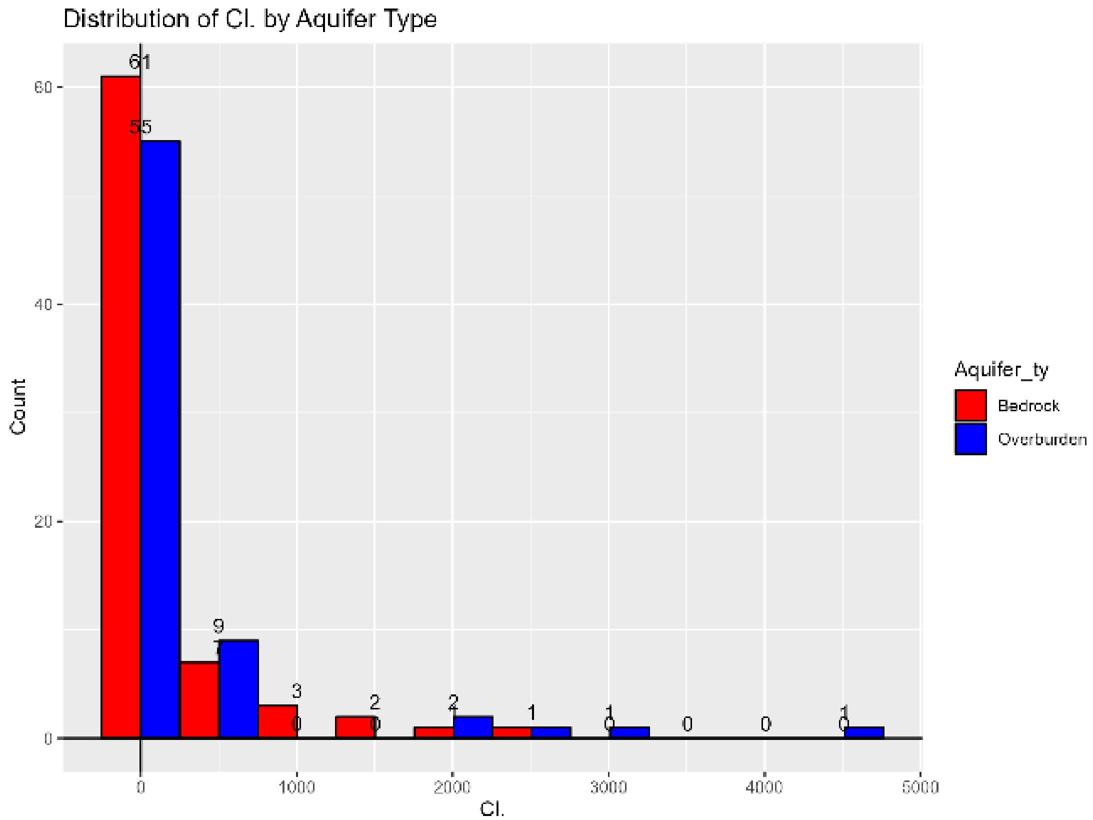

Figure 25. Histogram of **Chloride (Cl)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.10 Sulphate

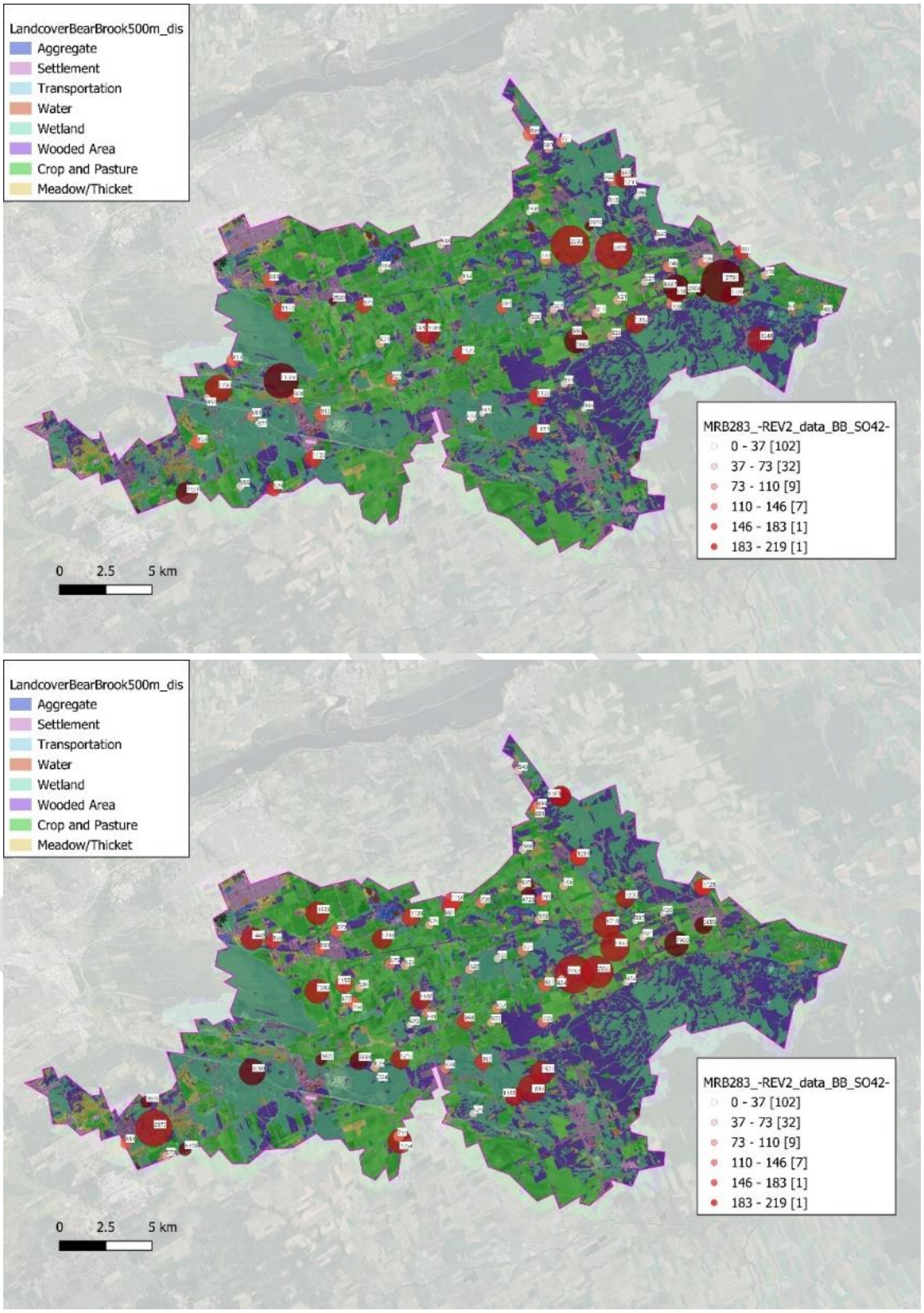

Figure 26. **Sulphate (SO4)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

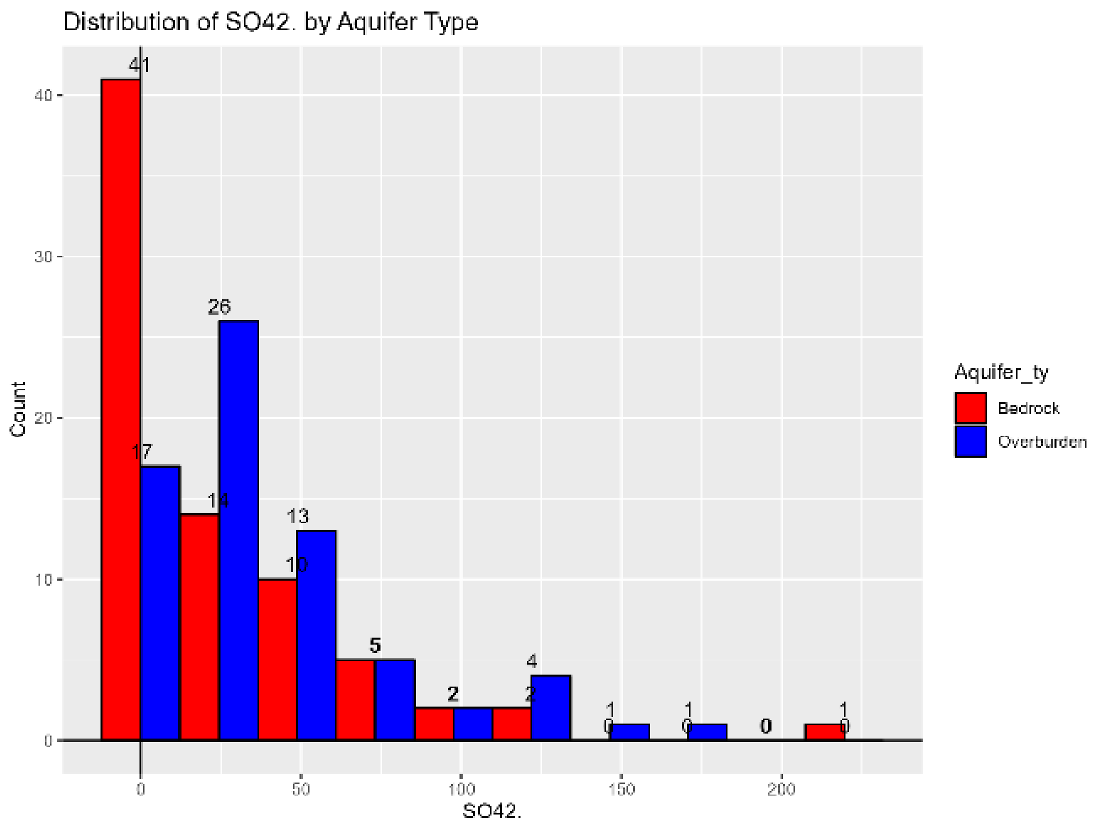

Figure 27. Histogram of **Sulphate (SO4)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.11 Bicarbonate

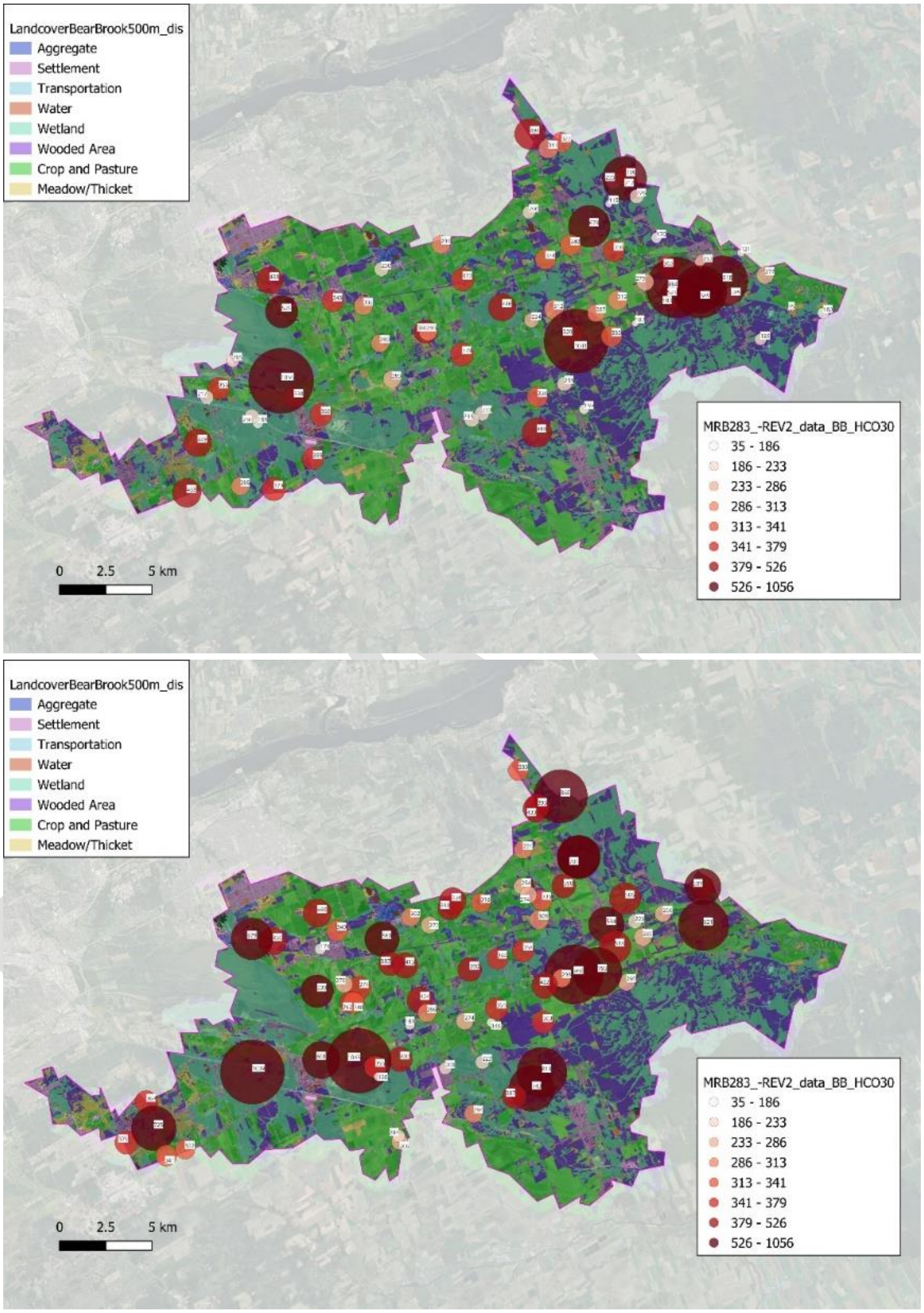

Figure 28. **Bicarbonate (HCO3)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

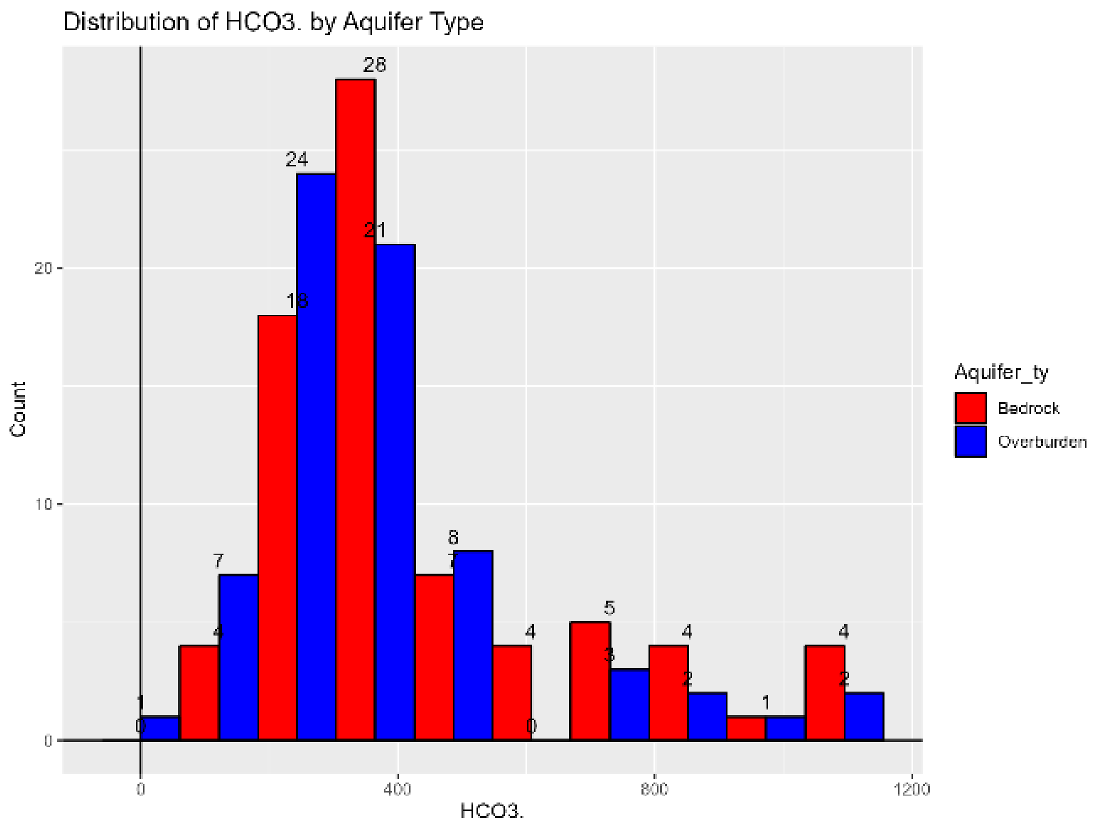

Figure 29. Histogram of **Bicarbonate (HCO3)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.12 Nitrate

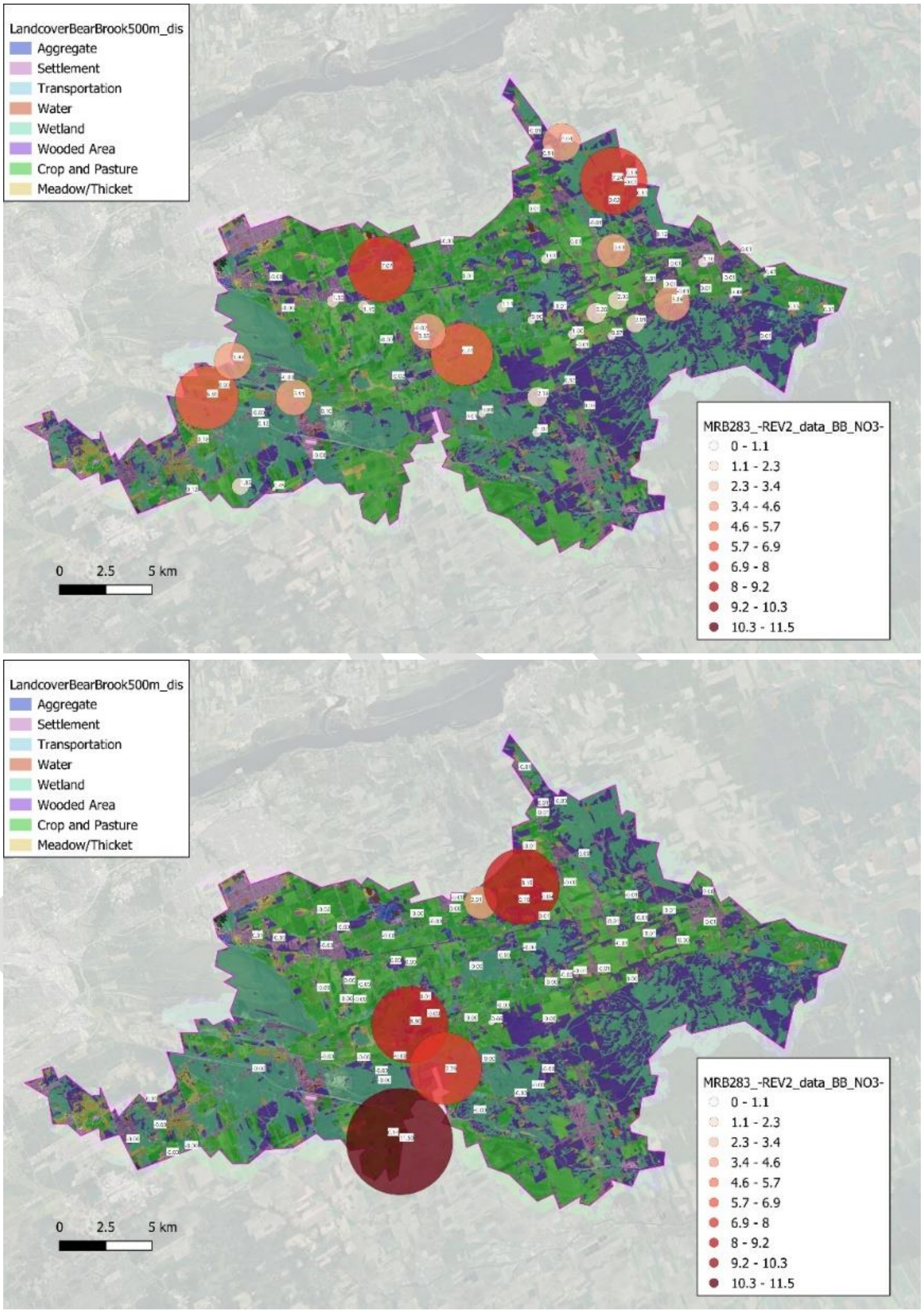

Figure 30. **Nitrate (NO3)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

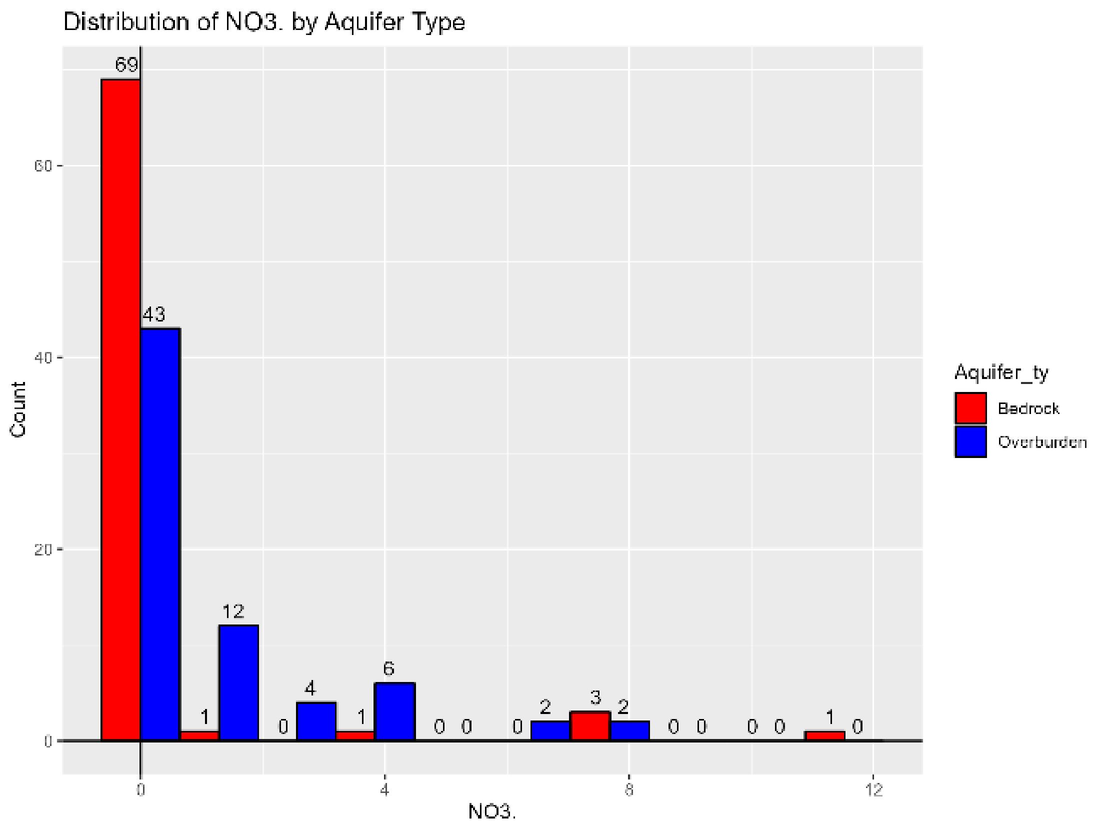

Figure 31. Histogram of **Nitrate (NO3)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.13 Phosphate

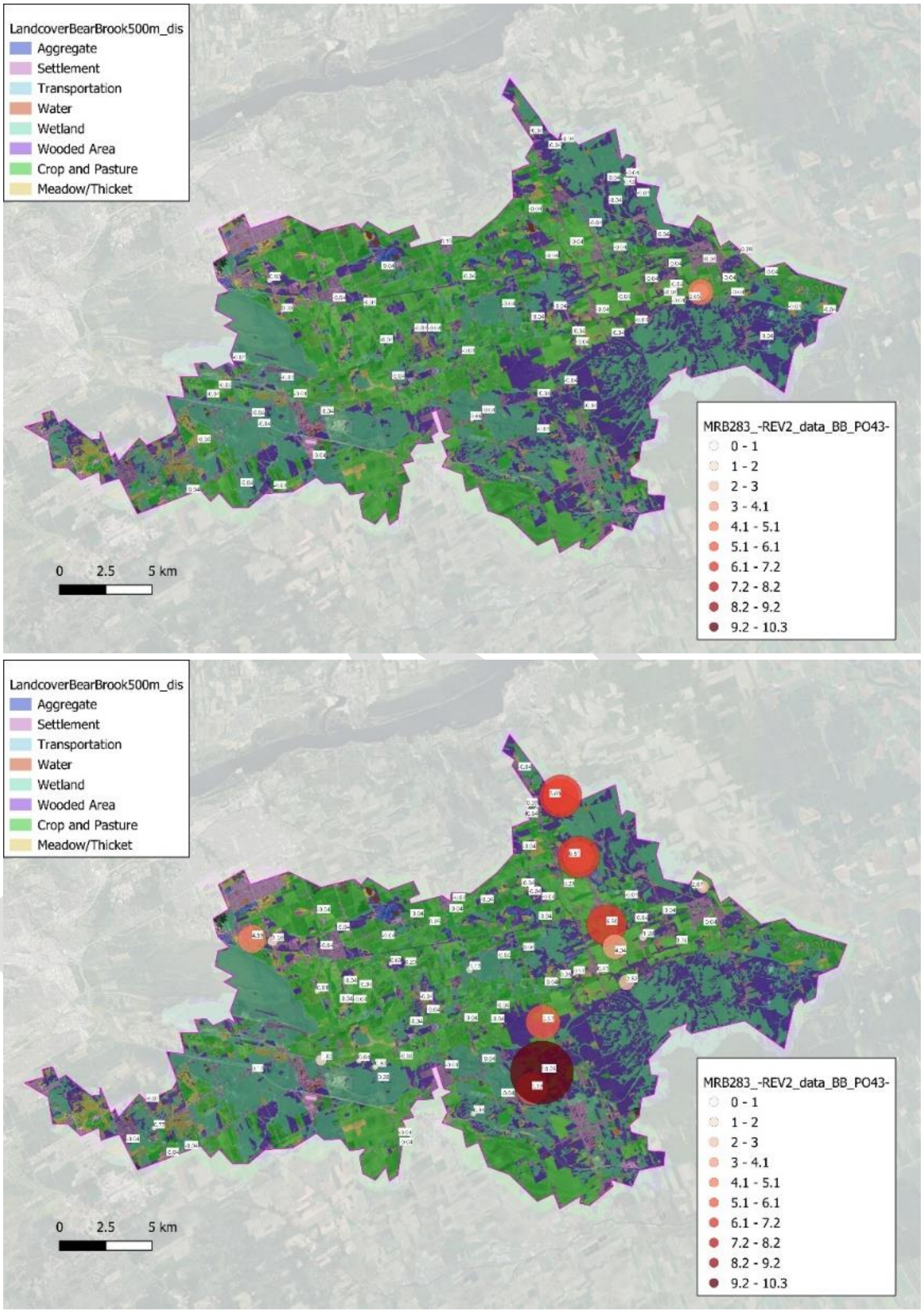

Figure 32. **Phosphate (PO4)** concentrations (mg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

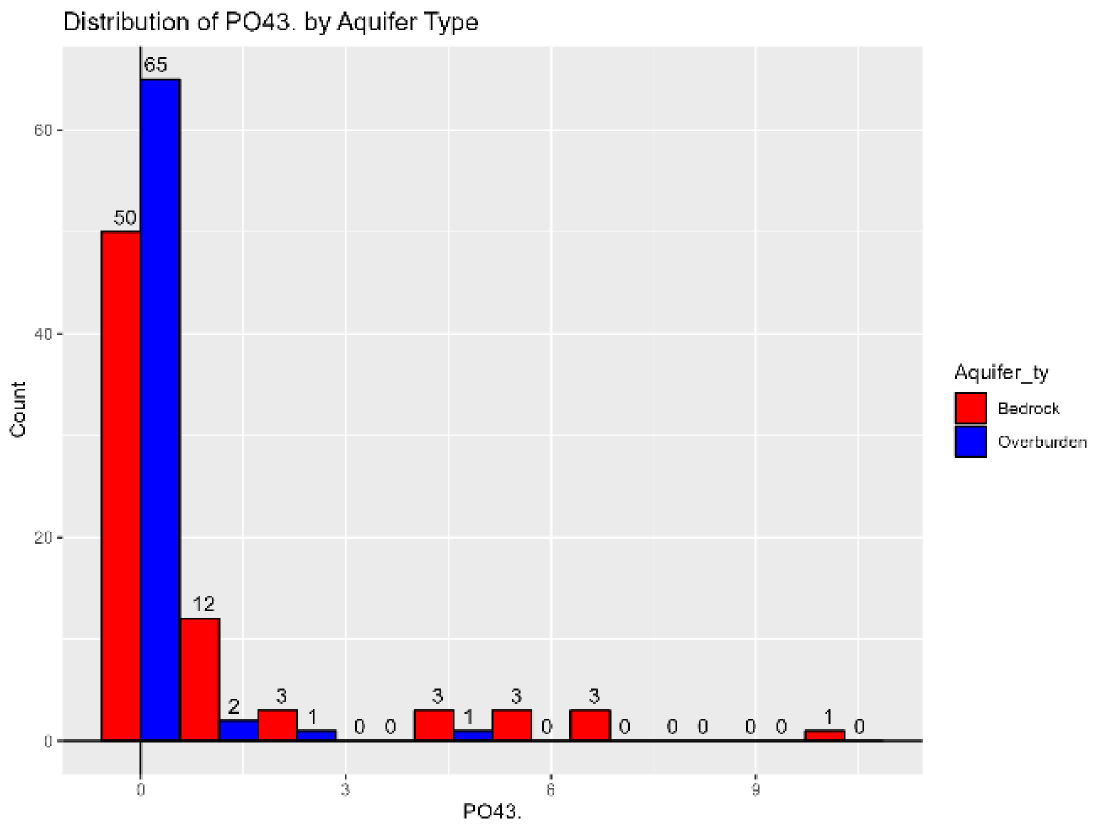

Figure 33. Histogram of **Phosphate (PO4)** concentration distributions (X-axis, mg/l) at the overburden and bedrock groundwater quality sampling locations.

3.14 Total Coliform

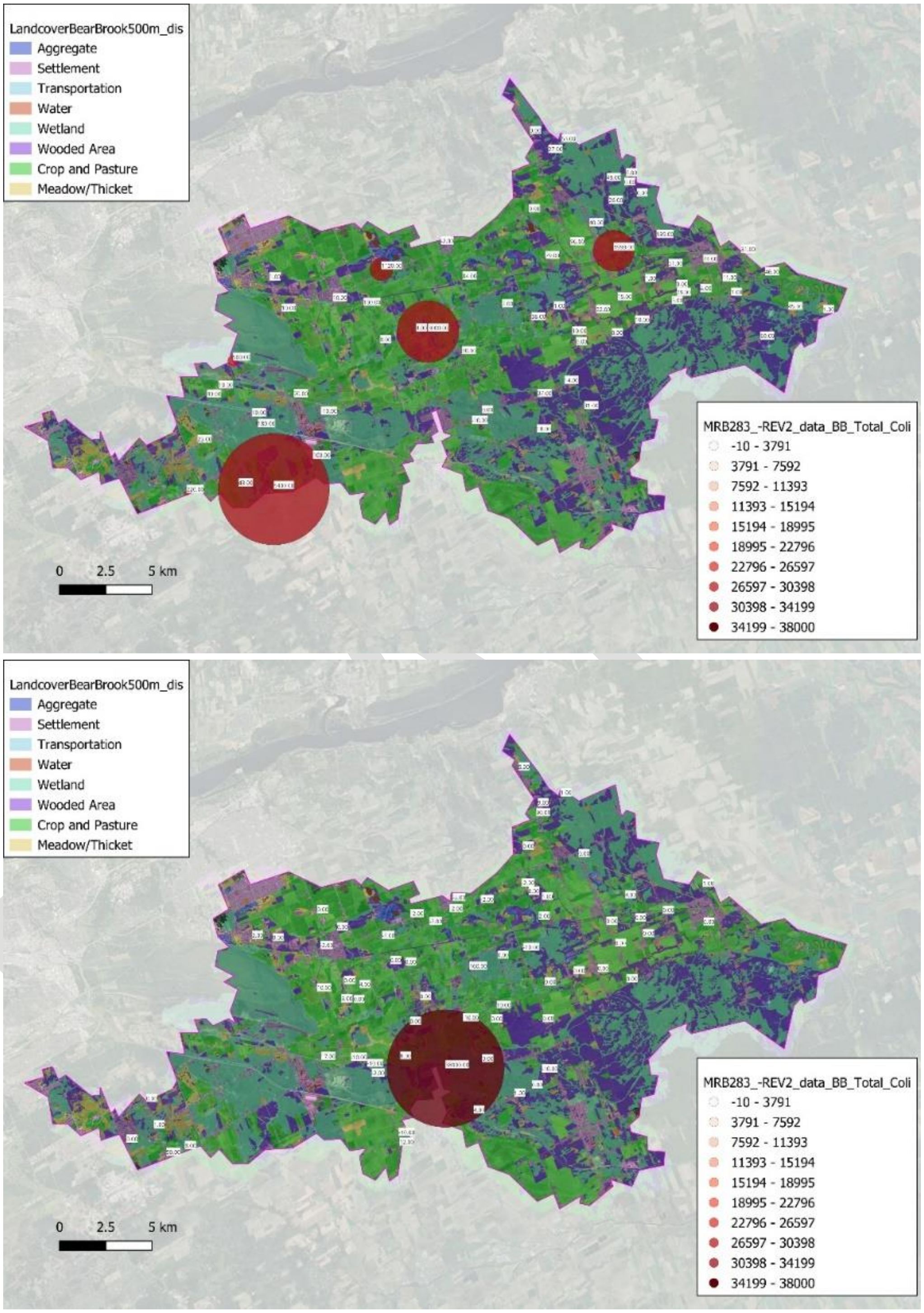

Figure 34. **Total Coliform** levels (counts/100 ml) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

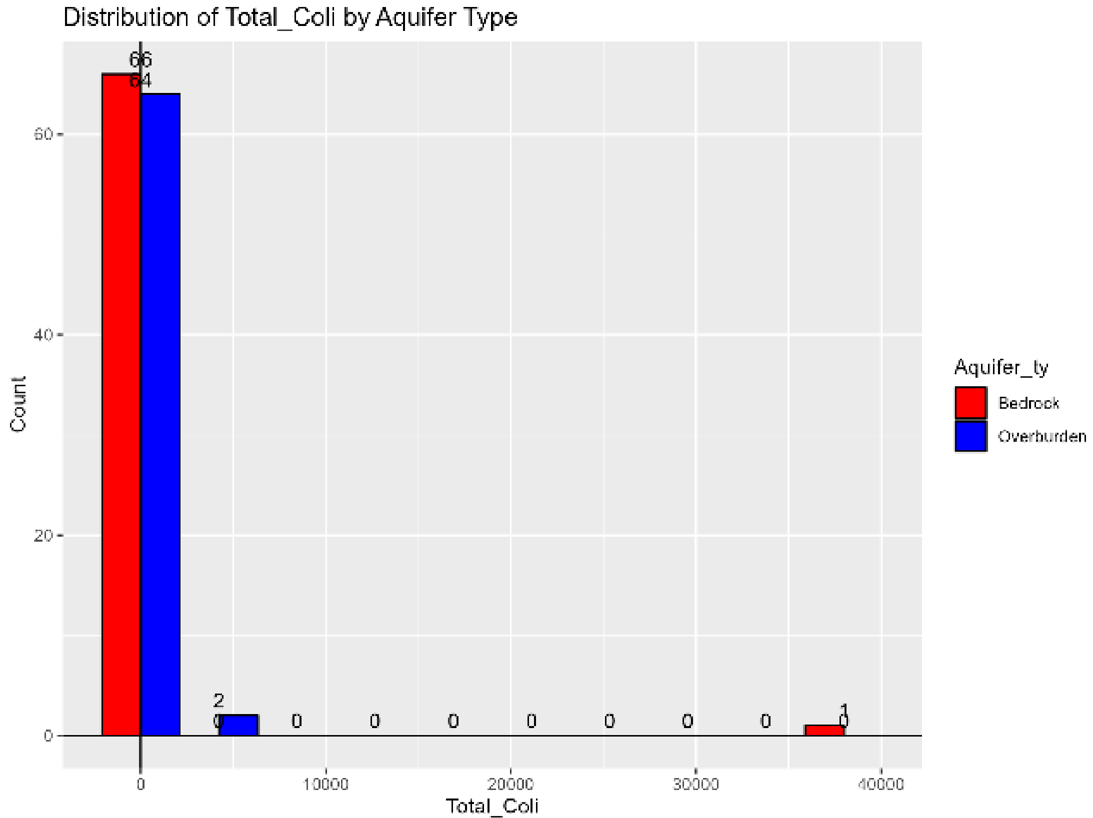

Figure 35. Histogram of **Total Coliform** level distributions (X-axis, counts/100 ml) at the overburden and bedrock groundwater quality sampling locations.

3.15 Uranium

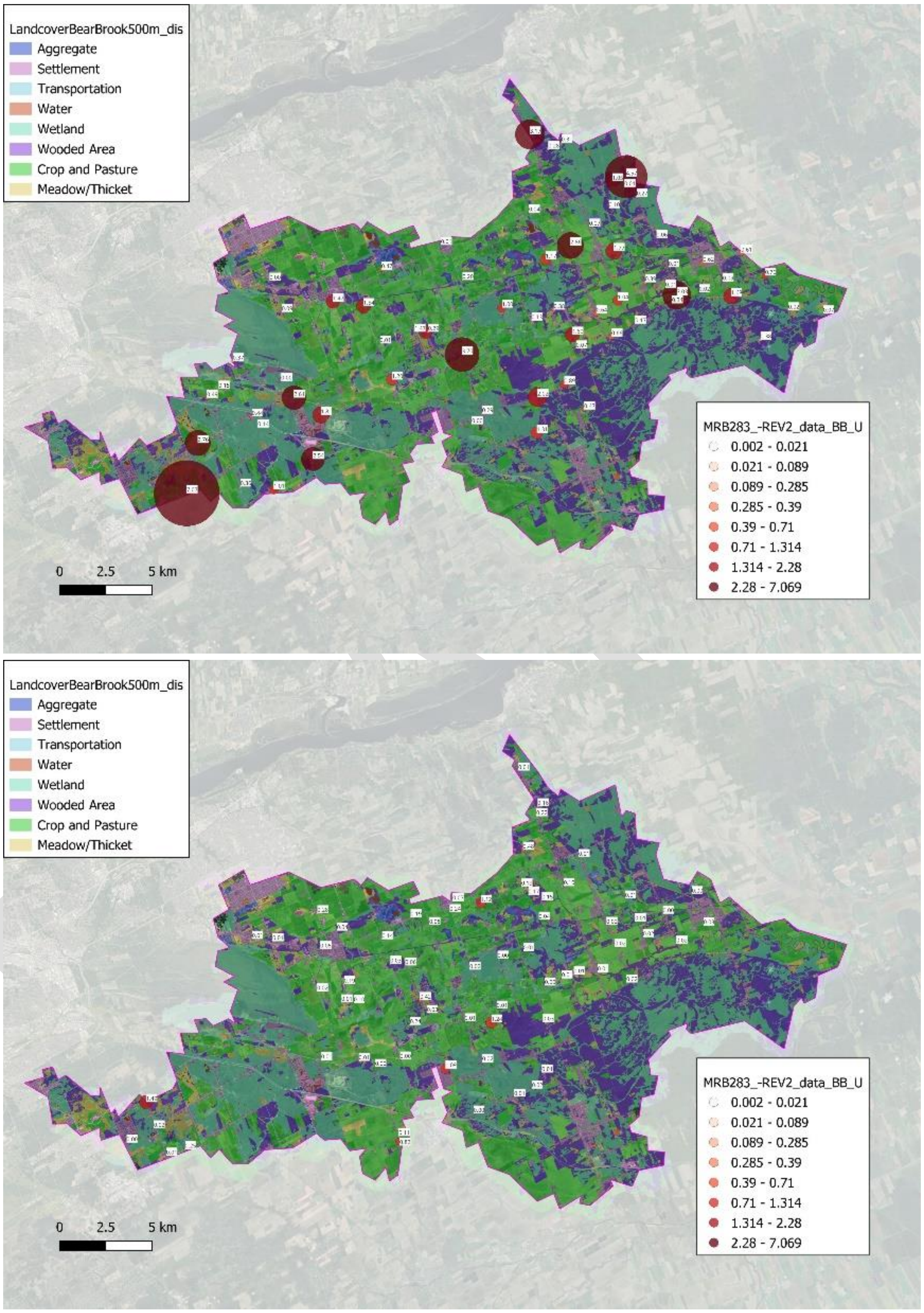

Figure 36. **Uranium (U)** concentrations (µg/l) at the overburden (top panel) and bedrock (bottom panel) groundwater quality sampling locations.

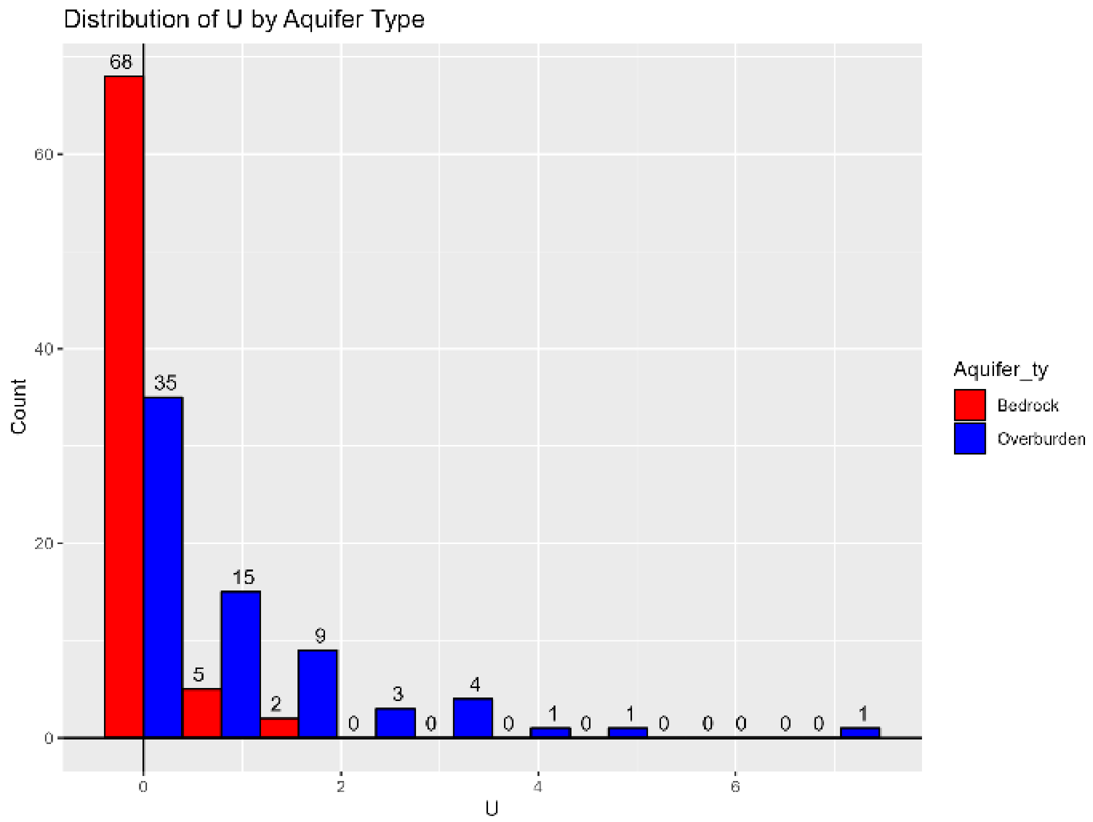

Figure 37. Histogram of **Uranium (U)** concentration distributions (X-axis, µg/l) at the overburden and bedrock groundwater quality sampling locations.

3.16 Radon

Radon was undetected in all 144 groundwater samples in the Bear Brook area.

4.0 LANDUSE INFLUENCE ON WATER QUALITY

To identify any relationships between land use and groundwater quality, nitrate (as an indicator of agricultural contamination) and chloride (as an indicator of urban contamination) concentrations were compared against land use. To reduce the influence of minor land use categories, the land use map was reduced to three classes (wetland, woodland, and cropland), with the minor classes mapped as the closest dominant type (Figure 38).

Upon preliminary evaluation, there are no clear indications that chloride levels (Figure 39) or nitrate levels (Figure 40) are notably different beneath different land uses.

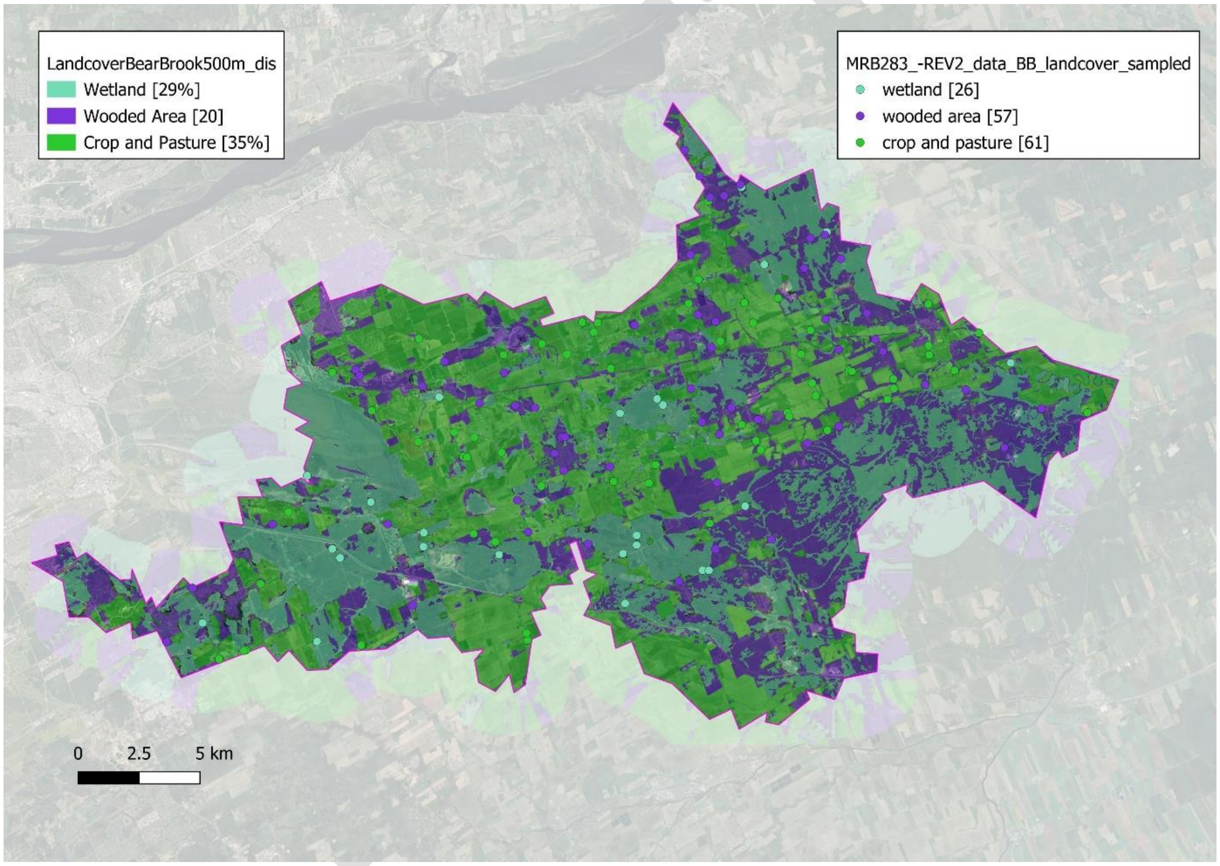

Figure 38. Modified land use map used for water quality vs land use assessment. Minor land use categories were merged with neighbouring major land use categories (i.e. wetland, wooded, and crop and pasture).

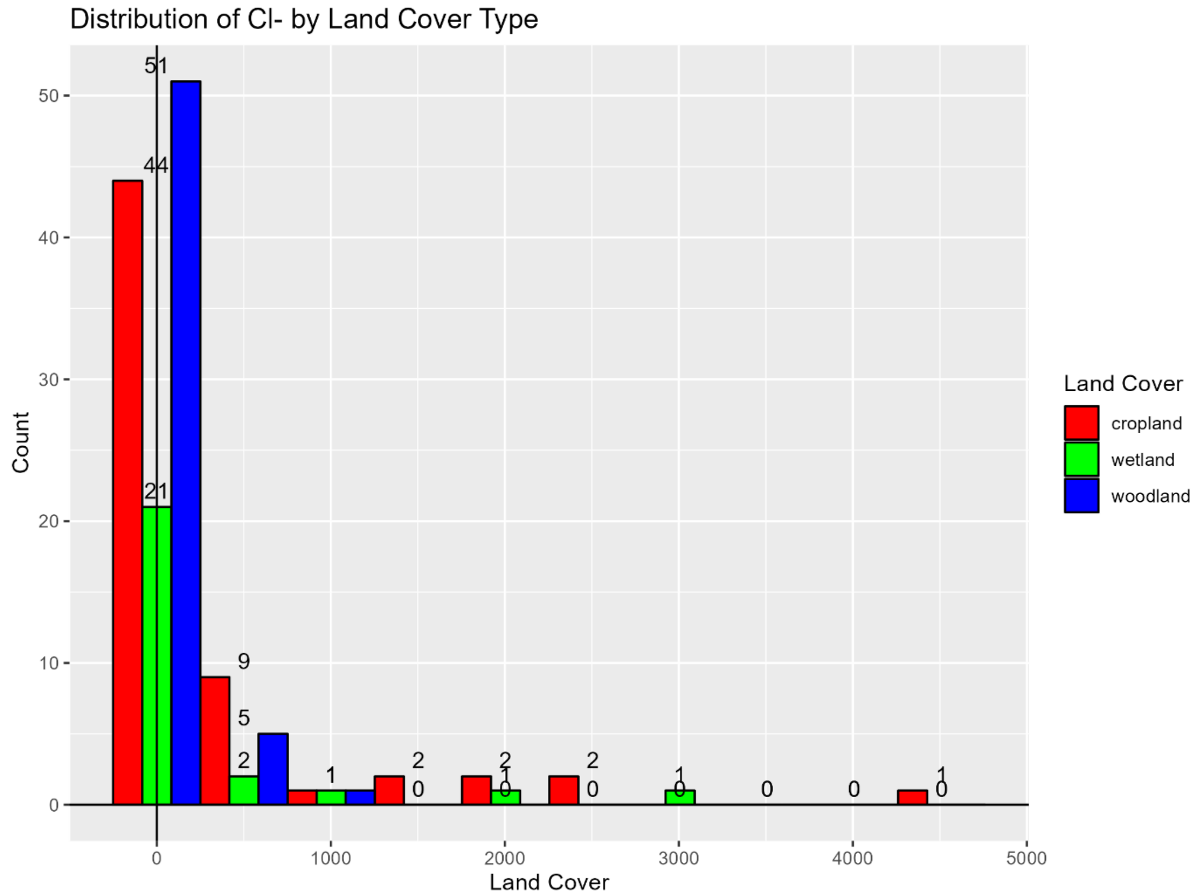

Figure 39. Chloride concentration (X-axis, mg/l) classification vs sample count for each of the three major land uses.

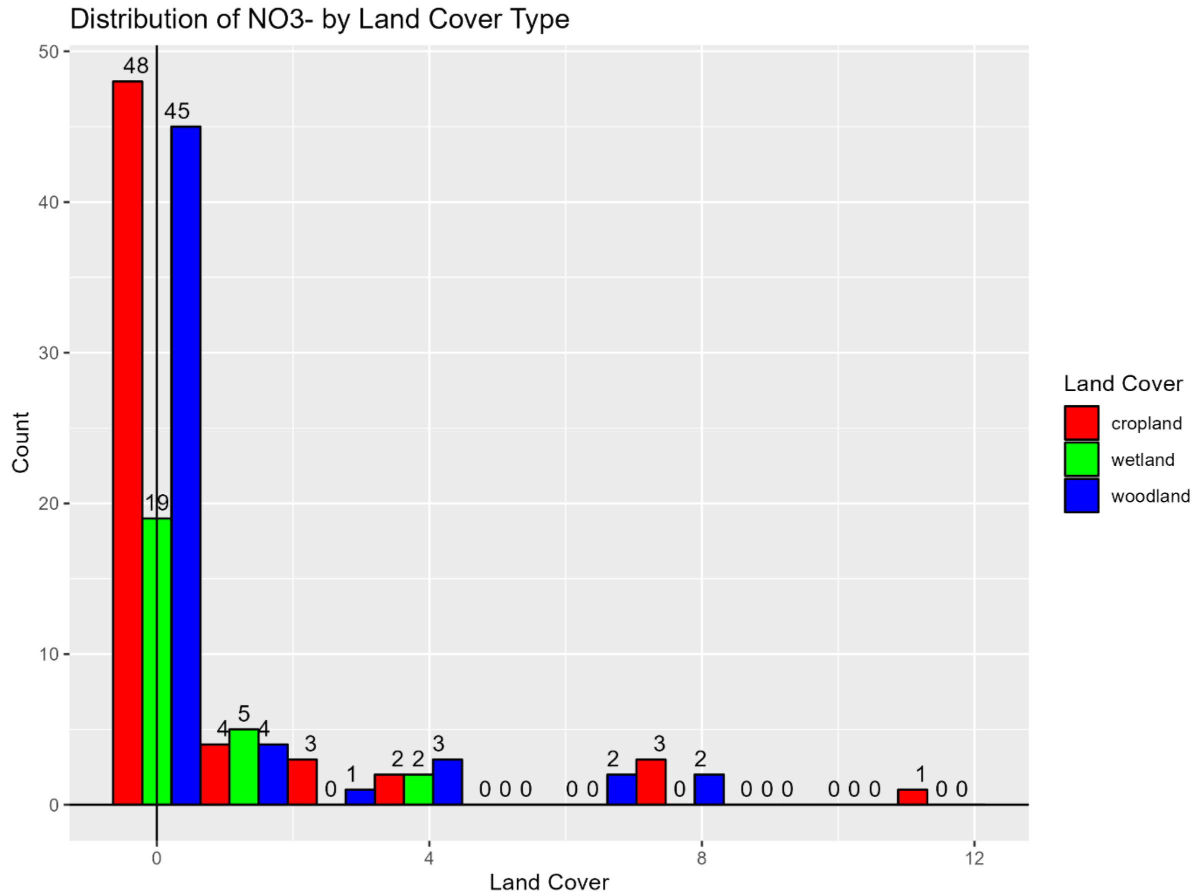

Figure 40. Nitrate concentration (X-axis, mg/l – N) classification vs sample count for each of the three major land uses.

5.0 SUMMARY

Separating the water quality by aquifer type is useful in distinguishing groundwater regions, however, within the Bear Brook sub-watershed there is little separation/difference in the overall water quality metrics, indicating a strong hydrological connection between the overburden and underlying bedrock. There is considerable spatial variability in concentrations in all parameters, which is likely influenced by local soil types and underlying geological formations. More sophisticated spatial analysis (i.e. spatial-auto correlation or co-kriging) may reveal geological controls on the groundwater geochemistry. Upon the very preliminary analysis conducted herein, there does not appear to be any clear relationship between land use and water quality.

Specific Conductance (Figure 9), Total Dissolved Solids (Figure 11), and Bicarbonate (Figure 29) all indicate similar water quality between overburden and the underlying bedrock, whereas higher concentrations in Chloride (Figure 24) and Nitrate (Figure 31) indicate a propensity to surface contamination potential from urban runoff or agriculture. It should be recognized that higher concentrations in the overburden materials may in part be explained by sampling and methodological biases between dug (shallow overburden) and drilled (deep bedrock).

An overall summary of the water quality measurements, in relation to aesthetic objectives or maximum allowable concentrations is presented in Table 2. The data shows that for raw groundwater quality, there are instances for all parameters but Uranium where drinking water guidelines are exceeded. However, as these samples do not necessarily reflect drinking water, this information is provided as reference only and is reflective of the extreme case of each parameter.

Table 2. Water quality parameter summary for the sixteen constituents of interest in this investigation.

Water Quality Parameter		Units	Recommended, Aesthetic Objective, or Maximum Allowed	Max Observed
1	Specific Conductance	(µS/cm)	-	13781.0
2	**Total Dissolved Solids	(mg/l)	500	7559.7
3	pH		7.0 - 10.5	9.3
4	Alkalinity	(mg/l as CaCO3)	-	898.0
5	Calcium	(mg/l)	-	233.3
6	Magnesium	(mg/l)	-	133.6
7	**Sodium	(mg/l)	200	2420.0
8	**Iron	(mg/l)	0.3	2447.1
9	**Chloride	(mg/l)	250	4511.0
10	**Sulphate	(mg/l)	500	219.5
11	Bicarbonate	(mg/l)	-	1094.9
12	*Nitrate	(mg/l)	10	11.5
13	Phosphate	(mg/l)	-	10.3
14	**Total Coliform	(counts/100 ml)	0	38000
15	*Uranium	(mg/l)	0.02	0.007
16	Radon		-	NA
*Safe Drinking Water Act (2002)				
**Guidelines for Canadian Drinking Water Quality (2024)				

6.0REFERENCES

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