4 EXISTING SUBWATERSHED CONDITIONS

4.1 General

The following sections provide an overview of the environmental features and functions of the Mid-Spencer Subwatershed and Rural Settlement Area. The natural ecosystem that existed prior to human settlement has been altered. Activities that have resulted in change include agricultural practices, construction of roads, buildings and quarries, and the construction of the Christie and Crooks Hollow Dams in the Mid-Spencer Creek.

Defining the current state of the environment, as well as the relationship between each feature is necessary in order to characterize key environmental functions, establish alternative strategies to protect the environmental features and to develop an implementation plan to protect, enhance or restore the features over time.

4.2 Environmental Features

For the purposes of this study, the term environmental feature has been used to describe various environmental or water related attributes which presently exist within the Mid-Spencer or Rural Settlement areas. These include:

- Terrestrial features, including landforms, vegetation, wetlands and wildlife;
- Aquatic features, including aquatic habitats, aquatic vegetation, and aquatic communities;
- Water resource features, including the quantity and quality of water in the watercourses, and floodplain features;
- Groundwater resources, including the quantity and quality of water which is recharged and discharged from the groundwater table; and
- Stream morphologic features including erosion.

It is important to recognize that the environmental features are highly inter-related because of their ecological functions and environmental pathways or linkages. For example, a vegetated floodplain feature may provide conveyance for floods and spring melts, provide habitat for plants and animals and provide shade for the watercourse, maintaining cool water temperatures for fish.

4.3 Surface Water Resources – Flooding

4.3.1 Introduction

Hydrology is the science which deals with the interaction of water on the land, and the processes by which precipitation is transformed into runoff to the receiving watercourses, evaporated and transpired to the atmosphere, or infiltrated into the groundwater system. These processes are generally called the hydrologic cycle. One of the most dramatic changes brought about by urbanization is the change in the hydrological cycle and stream hydrology. For example, the replacement of vegetation and undisturbed terrain with impermeable surfaces (i.e. pavement, roof tops, graded surfaces and the provision of an underground storm drainage network) results in greater interception of water that would naturally infiltrate into the ground, and instead provides a direct and rapid transport of surface runoff to streams.

Uncontrolled, the hydrologic changes resulting from urbanization can cause increases in flooding, channel erosion, sediment transport, and pollutant loadings. These changes can also result in deterioration in natural channel morphology, fish and wildlife habitats, recreational opportunity and aesthetics.

Changes in the hydrologic and hydraulic regime are key concern for the study area, specifically the Greensville RSA, where future development covers a considerable area. Therefore, and as part of the Surface Water Resources component of this report, hydrologic and hydraulic baseline conditions are investigated as follows:

- Review and synthesize background information on hydrologic conditions
- Develop a calibrated continuous hydrologic model;
- Develop an event-based hydrologic model;
- Establish a hydraulic model;
- Establish floodline mapping.

Baseline conditions provide essential information that would direct the quest for the protection, maintenance and enhancement of surface water hydrology and hydraulics within the study area, including the Mid Spencer Creek Subwatershed and Greensville RSA.

4.3.2 Background Review

Several background documents have been reviewed, specifically technical reports and appendices related to the hydrology and hydraulics of the study area.

In particular, the Spencer Creek Watershed Hydrology Study (MacLaren Plansearch, 1990) was reviewed, and relevant material was cross-referenced with this study, including:

- Delineated catchments areas;

- Stage-storage discharge curve for the Christie Dam;
- Some of the hydrologic parameters, especially for Upper Spencer Creek.

In addition, the results of this study were compared to those of MacLaren Plansearch (1990). Specifically, extreme events such as the Regional Flow and the 100-year flow.

4.3.3 Hydrology – Continuous Model

4.3.3.1 Continuous Model Development

The main objective of the continuous hydrological model is to evaluate the hydrology of the overall study area (i.e. Spencer Creek Subwatershed and Greensville RSA) under existing conditions with focus on defining larger surface runoff events and developing floodline mapping within RSA. The evaluation includes examining surface runoff rates and runoff volumes resulting from selected storm events.

4.3.3.1.1 Model Coverage

The hydrologic model covers the Mid Spencer Creek Subwatershed and the Upper Spencer Creek Subwatershed.

4.3.3.1.2 Model Selection and Setup

The hydrologic model selected for application in this study was MIKE-11. This model was selected inconsultation with City staff and is part of the MIKE suite of models that the City uses for various hydrology and hydraulic studies. The model can be used in both "event" and "continuous" mode to estimate the precipitation-runoff response.

Since the major landuses in the study area are rural, the Nam approach within MIKE-11 model was selected. The Nam approach uses a deterministic, lumped and conceptual rainfall-runoff model approach which accounts for the water content in up to 4 different storage zones. The Nam approach was set up using 9 parameters representing the Surface zone, Root zone and the Ground water storage. The nine parameters for each subcatchment can be found in the **Appendix A**.

4.3.3.1.3 Meteorological Data

The MIKE-11 model requires three kinds of input data time series: precipitation, temperature and potential evaporation. The following provides details of the meteorological records that were used.

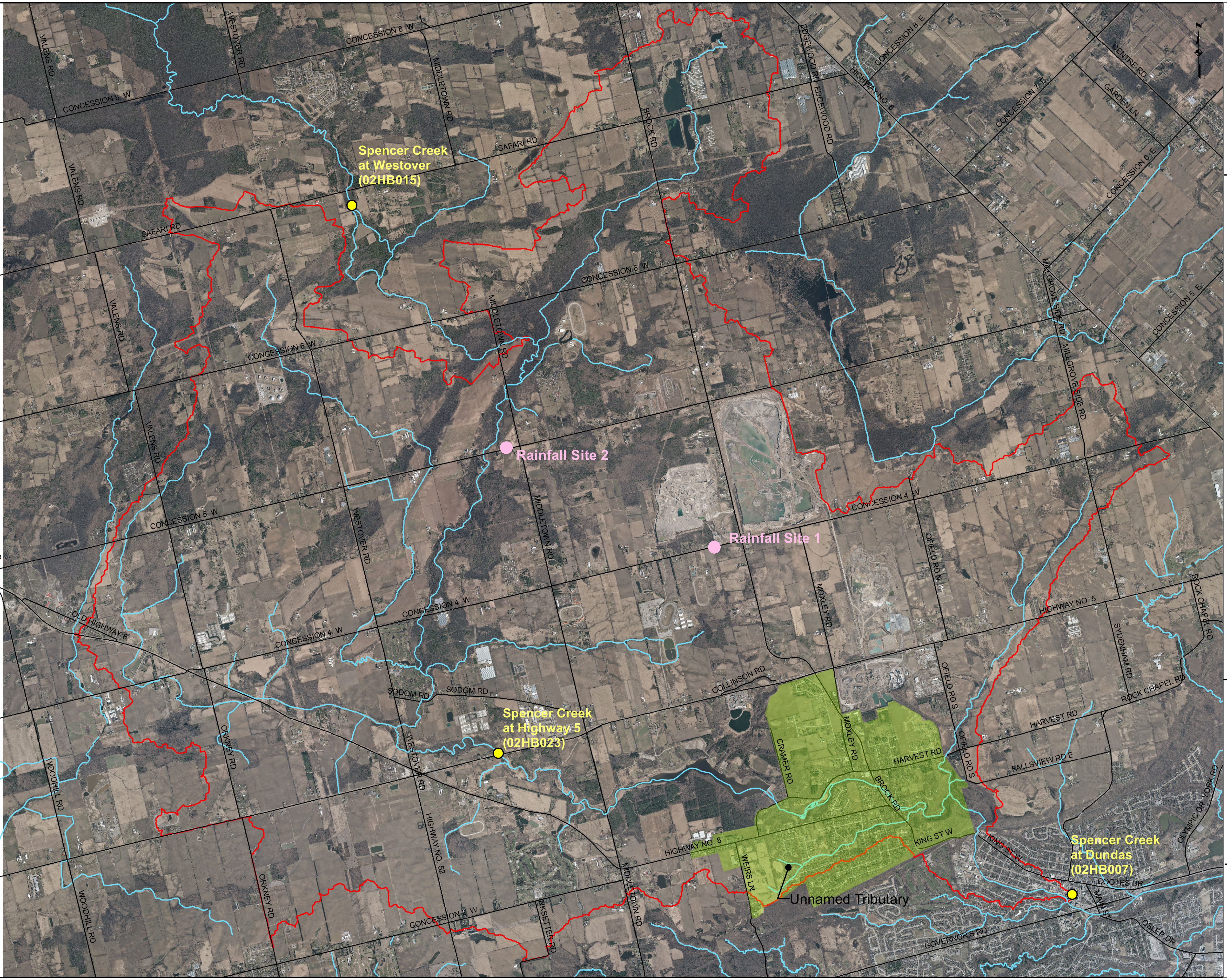
Precipitation records were available for the period between 2010 and 2013 for two precipitation gauges: Rainfall Site 1and Rainfall Site 2 as shown in **Figure 4.3.1**. Data from both stations were provided by the City of Hamilton. The precipitation data from Rainfall Site 2 was used for rainfull input for the Upper Spencer Creek subwatershed because of its proximity to the subwatershed. Rainfall Site 1 was used for rainfall input for the Mid Spenser Creek subwatershed (**Figure 4.3.1**).

An hourly interval air temperature record was extracted from the Royal Botanical Gardens station for the years between 2010 and 2013. In addition, potential evaporation was estimated from pan evaporation data collected at Rainfall Site 1.

4.3.3.1.4 Streamflow Data

The streamflow stations within the Mid-Spencer Creek are shown in **Figure 4.3.1**. They are Spencer Creek near Westover (02HB015), Spencer Creek at Highway 5 (02HB023), and Dundas station(02HB007). For the MIKE 11 model development, hourly discharge data from Spencer Creek near Westover (02HB015) and Spencer Creek at Highway 5 (02HB023) were provided by Hamilton Conservation Authority.

Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study



Legend

- Roads
- Watercourses
- Water Survey Canada Streamflow Station
- Precipitation gaugae (Rainfall site)
- Mid-Spencer Creek Watershed
- Rural Settlement

FIGURE 4.3.1

Meteorological and Streamflow Gauge Locations

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4.3.3.1.5 Catchment Delineation

Catchment delineation was carried out using the ArcGIS tool with the Hamilton Digital Elevation Model (DEM) for Spencer Creek. As illustrated in **Figure 4.3.2**, a total of twenty two (22) subcatchments were defined to simulate the hydrologic characteristics of the Study Area. The catchments areas were compared to the ones delineated in the Spencer Creek Watershed Hydrology Study (MacLaren Plansearch, 1990), and they were similar in their boundaries and drainage areas.

4.3.3.1.6 Hydrologic Soil Classification

Soil information for the study area was obtained from the Soil Survey Mapping for Hamilton (Wentworth County) Regional Municipality of Niagara. Appropriate CN values for each subcatchment were estimated. Hydrologic soil classifications are shown in **Figure 4.3.3a** and **Figure 4.3.3b**. A detailed tabulation of the hydrologic soil classification for each subcatchment can be found in **Appendix A**.

4.3.3.1.7 Landuse

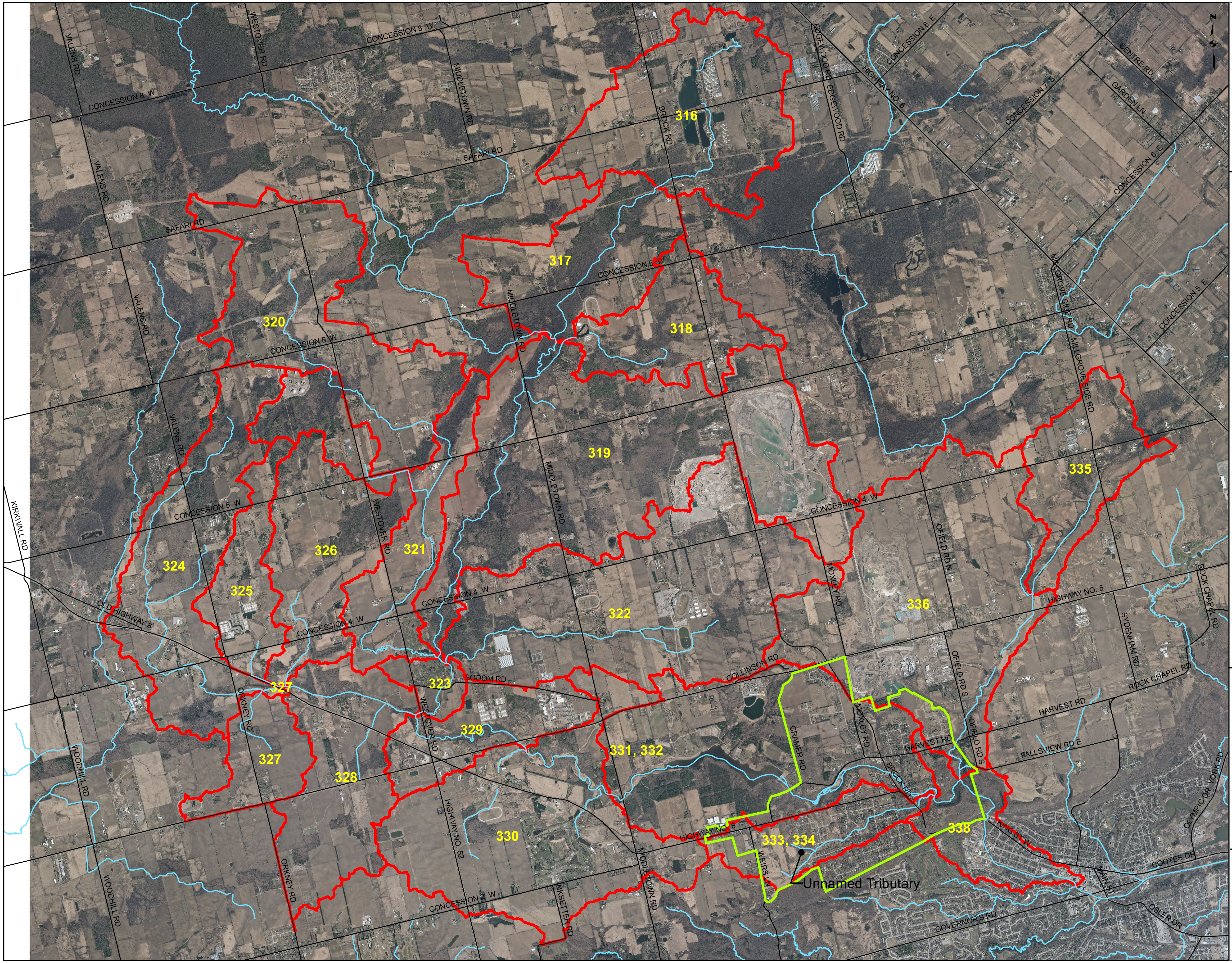
The Mid-Spencer Creek subwatershed and the Upper Spencer Creek subwatershed are predominantly rural with a small amount of developed area located at the downstream limit of the subwatershed (downstream of Christie Dam).

4.3.3.1.8 Dams and Reservoirs

Within Spencer Creek, there are several physical features which tend to attenuate flood peaks, such as Beverly Swamp (natural regulation), Christie Dam and Reservoir and CNR Embankment across Spencer Creek. The Christie Dam and Reservoir is one of these features located within the study area. The dimensions and the operation rules of the gate for Christie Dam were provided by Hamilton Conservation Authority. The flow from Christie Dam is controlled by two 4.9m by 4.9m spillway gates and a concrete overflow spillway with removable stop logs. There are two sets of operation rules for the gate at the Christie Dam. One for the period during snow melt or rain on snow melt. The other one for the period of rain only. Each set of operation rules has a procedure for opening the gate when the event starts and closing the gate after the event. The gate opening would depend on the rising water level and time period. After the flood event, the gate would close slowly depending on the falling water level. The details of the Christie Dam operation can be found in the **Appendix A**.

The stage-storage discharge curve for the Christie Dam from the previous study (MacLaren Plansearch, 1990) was used in the model to simulate the flow from Christie Dam.

Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study



Legend

- Roads
- Watercourses
- Mid-Spencer Creek Watershed
- Rural Settlement

FIGURE 4.3.2

Hydrologic Model Subcatchments

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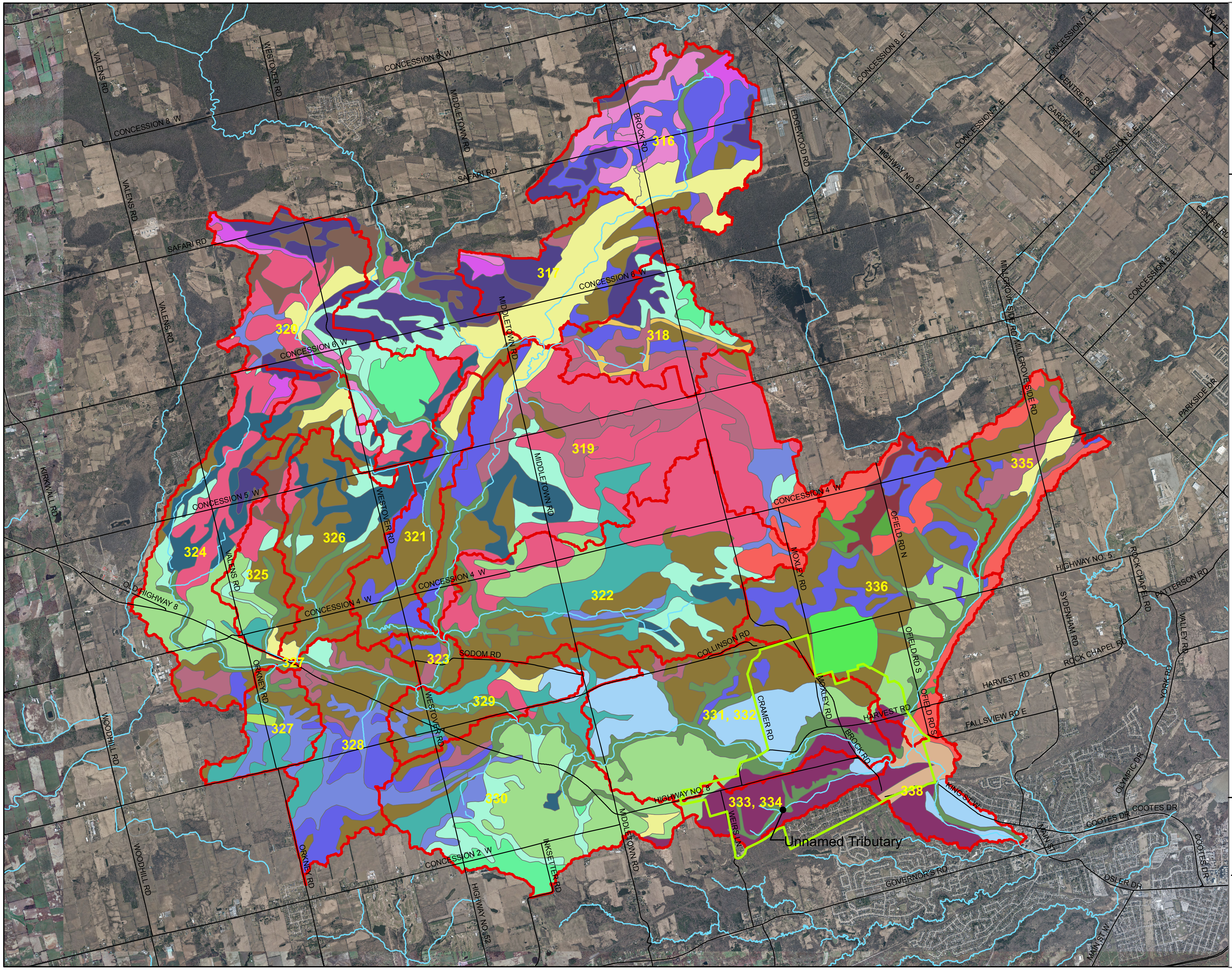
Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study



Legend

- Rural Settlement
- Roads
- Watercourses
- Subcatchment

Soil Type

- ANCASTER silt loam
- BEDLOCK
- BEVERLY silt clay loam
- BRANFORD silt loam - GRIMSBY sandy loam
- BRANT Silt Loam
- BURFORD LOAM
- CHINGUACOUSY loam
- COLWOOD silt loam
- DONNYBROOK gravelly loam
- ESCARPMENT
- FARMINGTON loam
- FLAMBORO sandy loam
- GRIMSBY SANDY LOAM
- GRMSBY sandy loam - BRANT silt loam
- GUELPH Loam
- JEDDO Loam
- LONDON Loam
- MUCK
- ONEIDA loam
- PARKHILL loam
- QUARRIES
- SPRINGUALE SANDY LOAM
- TOLEDO silt loam
- TUSCOLA silt loam
- VINELAND Sandy Loam

FIGURE 4.3.3 a

Soil Types

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Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study

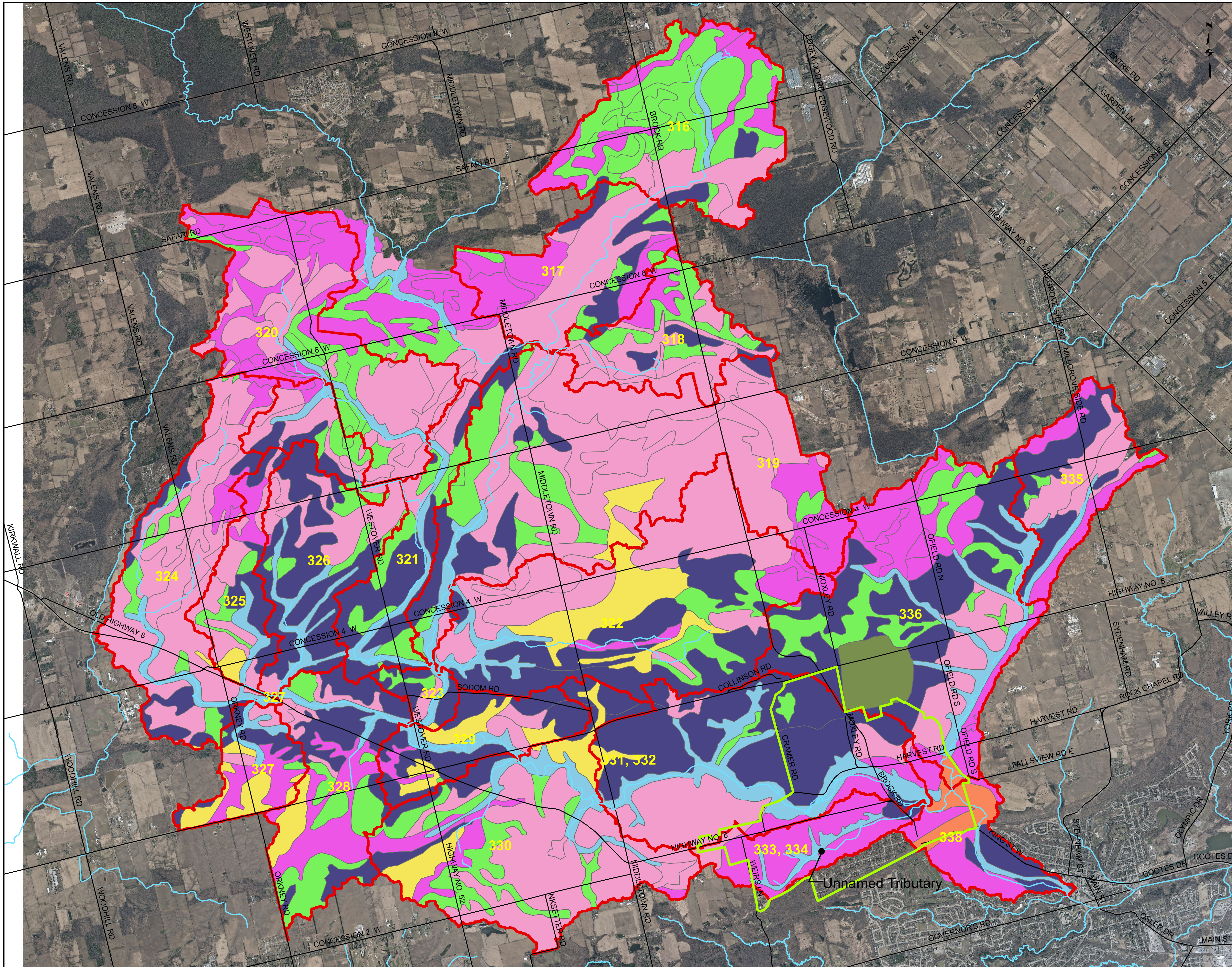

FIGURE 4.3.3 b

Soil Groups

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4.3.3.1.9 Routing Reaches and Reservoirs

One of the key components of the MIKE-11 model was the river cross-section network. The river cross-section network is used to route the river flow along the subcathcment. In order to set up the river cross-section network, the cross-section information for the study area must be obtained.

Information for a total of 48 cross-sections of the Mid-Spencer Creek was obtained by using ArcGIS software and the Hamilton digital elevation model (DEM) (**Figure 4.3.4**). These cross-sections were then supplemented with “bank-full” channel dimensions. For those cross-section located in the main branch of Mid-Spencer Creek, the “bank-full” channel dimensions and channel inverts were measured by a field survey. A Total Station survey was undertaken at 19 culvert crossings. The data which was collected included invert and obvert elevations and culvert dimensions. The results of the crossing surveys are presented in the Culvert Inventory Forms in **Appendix A**. For those cross-sections located in the tributary of Mid-Spencer Creek, the typical “bank-full” channel dimensions were used.

Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study

Legend

- Roads
- Watercourses
- Subcatchment
- Cross-section

FIGURE 4.3.4

Cross-section Location

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4.3.3.2 Continuous Model Application

4.3.3.2.1 Model Configuration and First Run

Preliminary estimates of model parameters described above were input to the MIKE-11 model, and the model was run for four years (2010-2013). This first run was intended to evaluate the following:

- Suitability of the overall model framework for processing;
- Any errors in the model related to the hydrology and/or the hydrodynamics within the study area;
- Any missing data or data gaps; and
- Reasonableness of results, including:
    - Key water budget elements, mainly surface runoff, infiltration, and evapotranspiration volumes; and
    - General hydrograph patterns and peaks, and how they relate to observed hyetographs.

4.3.3.2.2 Model Calibration and Validation

Hydrologic model calibration involves a comparison of model results to streamflow observations at selected locations. The calibration and validation have been carried out using streamflow data extracted from the HWY 5 station (02HB023).

In order to provide sound basis for the calibration process, the percent difference between the modeled and observed streamflows was used as an indicator for the adequacy of calibration and validation. Specifically, ranges of tolerance were specified as shown in **Table 4.3.1**:

Table 4.3.1: HydrologicParmeters Used in Mike 11 and their Tolerance for Calibration

<table>
<tr><th>Hydrologic Parameter</th><th>Tolerance</th><th>Quality of Fit</th></tr>
<tr><td>Peak Flow Rate</td><td>-25 to +25%</td><td rowspan="2">< 10% : Very Good
10 – 15% : Good
15- 25% : Fair
> 25% : Poor</td></tr>
<tr><td>Total Flow Volume</td><td>-25 to +25%</td></tr>
<tr><td>Flow Hydrograph</td><td colspan="2">Match general timing and shape characteristics</td></tr>
</table>

Five storm events provided by the City, ranging from 11.6 to 37.6 mm for Rainfall Site 1, and from 11.8 to 33.6 mm for Rainfall Site 2, were used for model calibration and validation. The calibration of the model, which is the adjustment or fine tuning of rainfall-runoff modelling parameters, was carried out on two storm events (June 28th 2013 and May 25th 2011). The validation of the model, where the calibrated parameters were applied without further adjustment, was carried out on three storm events (November 30th 2010, May 3rd, and May 18th) (**Table 4.3.2**).

Table 4.3.2: Storm Events used to Calibrate and Validate the MIKE 11 Model

Storm Event	Date	Rainfall Depth (mm) / Site 1 (Mid Spencer)	Rainfall Depth (mm) / Site 2 (Upper Spencer)	Calibration/Validation
1	June 28th 2013	25.6	64.4	Calibration event
2	May 25th 2011	37.6	33.6	Calibration event
3	November 30th 2010	20.4	5.6	Validation event
4	May 3rd 2011	11.6	11.8	Validation event
5	May 18th 2011	17.2	16.2	Validation event

The Nam approach used for the hydrologic modelling of the study area has an automatic calibration routine that allows calibration of the 9 parameters based on the observed flow. The automatic calibration first focused on the agreement between the average simulated and observed catchment runoff. It then focused on the overall agreement of the shape of the hydrograph, followed by agreement of the peak flows. Finaly, the calibration focused on the agreement of low flows.

The results of the model calibration and validation are shown in **Figures 4.3.5** to **4.3.9**, where simulated and observed flows were plotted and errors in estimating runoff rates and volumes were estimated. Accordingly, for the Hwy 5 gauge, the calibration resulted in a fair to a very good agreement between the simulated and observed runoff volume at the calibration stage, and a good to a very good agreement at the validation stage (**Table 4.3.3)**. The validated hydrographs also showed good agreement in hydrograph shapes and baseflows.

Table 4.3.3: MIKE 11 Results for the Calibrated and Validated Storm Events

Storm Event	Date	Simulated Flow (m^3/s)	Observed Flow (m^3/s)	Peak Flow Error (%-Fit)	Simulated Volume (x 1000 m^3)	Observed Volume (x 1000 m^3)	Volume Error (%-Fit)
1	June 28th 2013	4.11	4.20	(-2.1 – Very Good)	1127.34	1397.45	(-19.3% - Fair)
2	May 25th 2011	9.97	8.53	(+17.1 – Fair)	4570.39	4153.90	(+10.0% - Good)
3	November 30th 2010	6.05	6.18	(- 2.1% - Very Good)	2100.47	2123.06	(-1.1% - Very Good)
4	May 3rd 2011	4.67	4.89	(-4.5% - Very Good)	1851.27	1804.14	(+2.6% - Very Good)
5	May 18th 2011	8.93	9.69	(-7.9 – Very Good)	4583.303	4057.78	(+12.9% – Good)

The model could not be calibrated to the Dundas gauge as hydraulic jumps and associated instability occurred in the model as a result of the significant elevation difference along the Niagara Escarpment. A smaller time-step was used in order to solve the hydraulic jump problem, however this approach did not resolve the problem. The model calibration was therefore base on WSC gauges 02HB015 and 02HB023 (**Figure 4.3.1**)

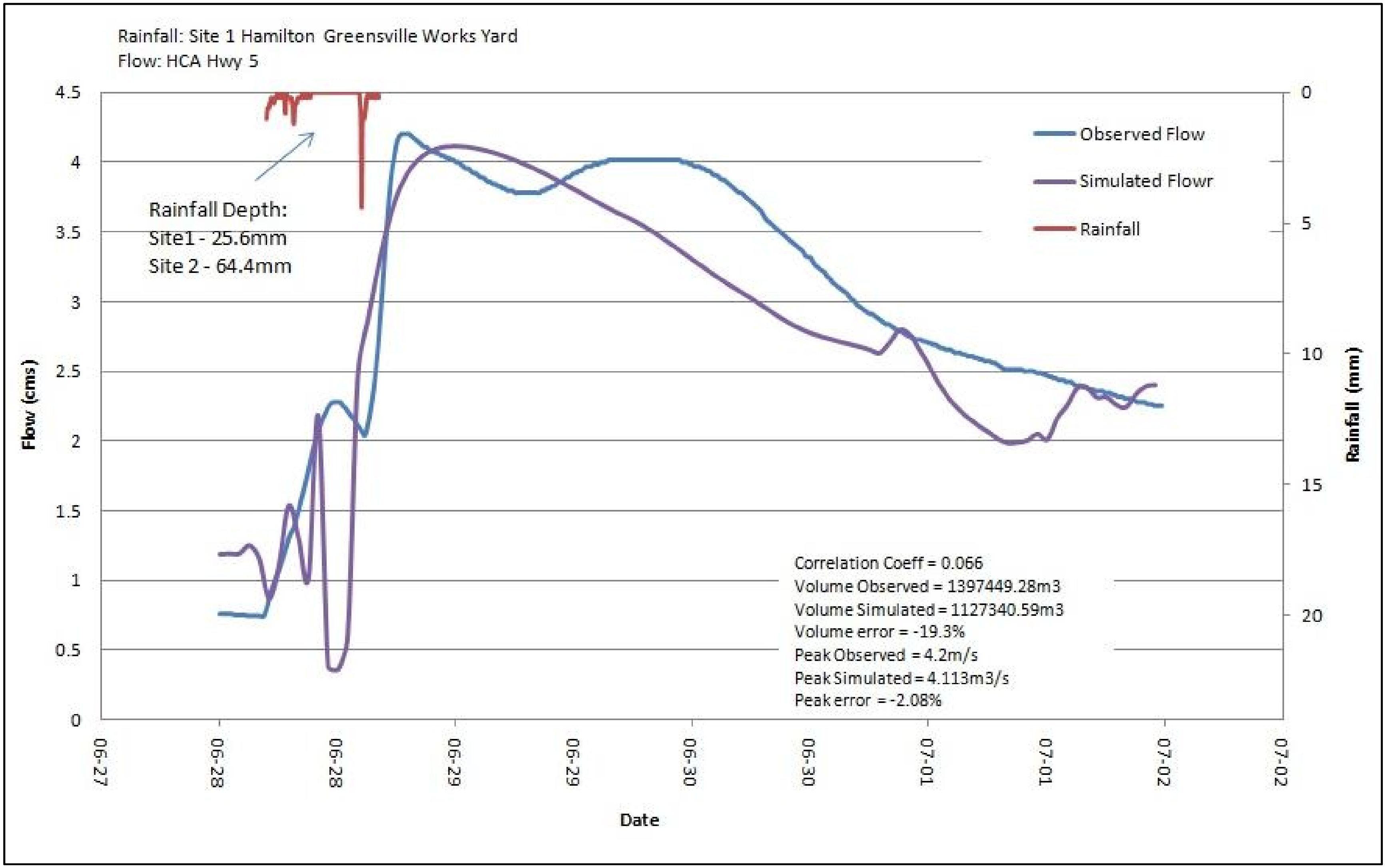


Figure 4.3.5: **Calibration June 28th 2013**

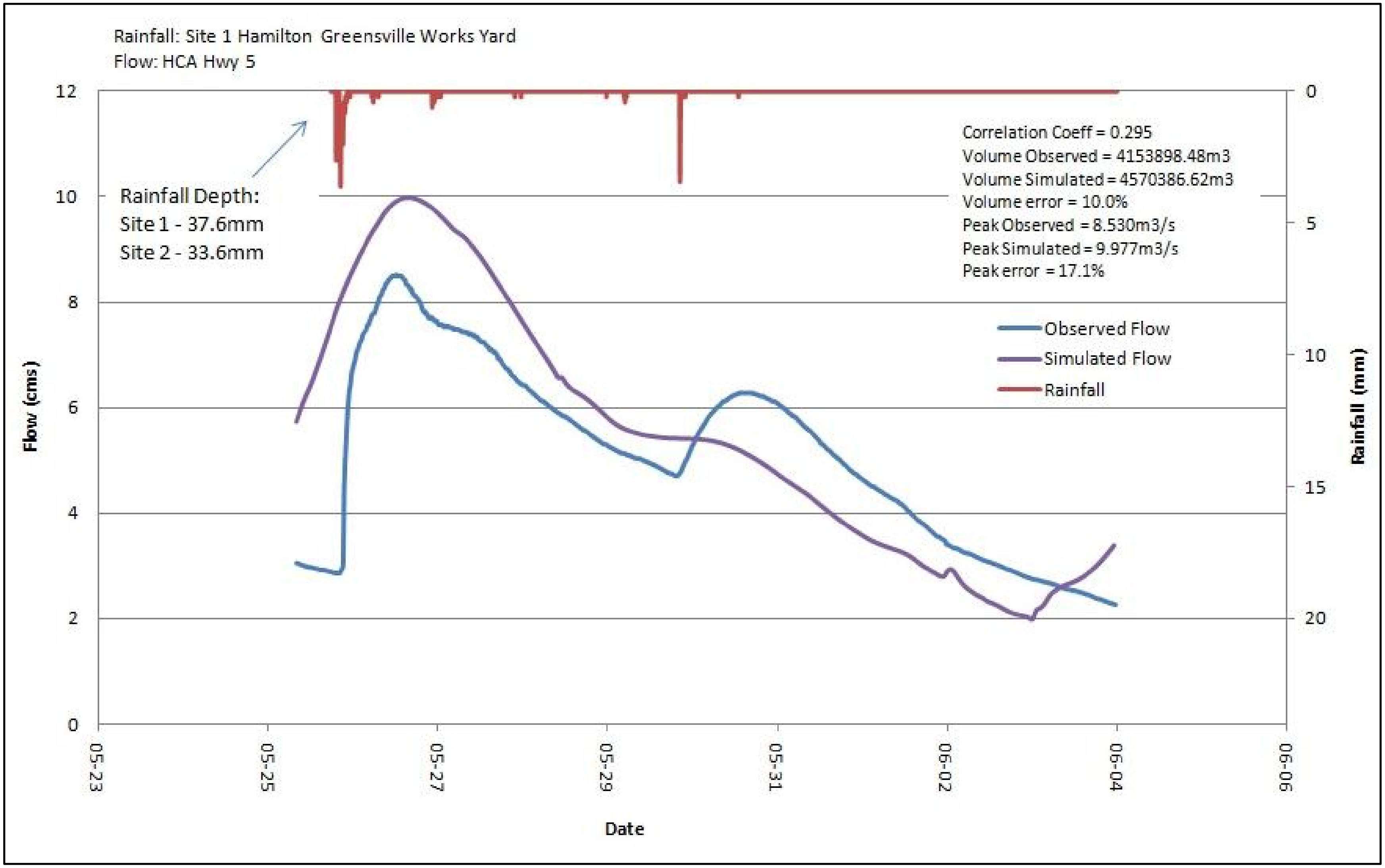


Figure 4.3.6: Calibration May 25th 2011

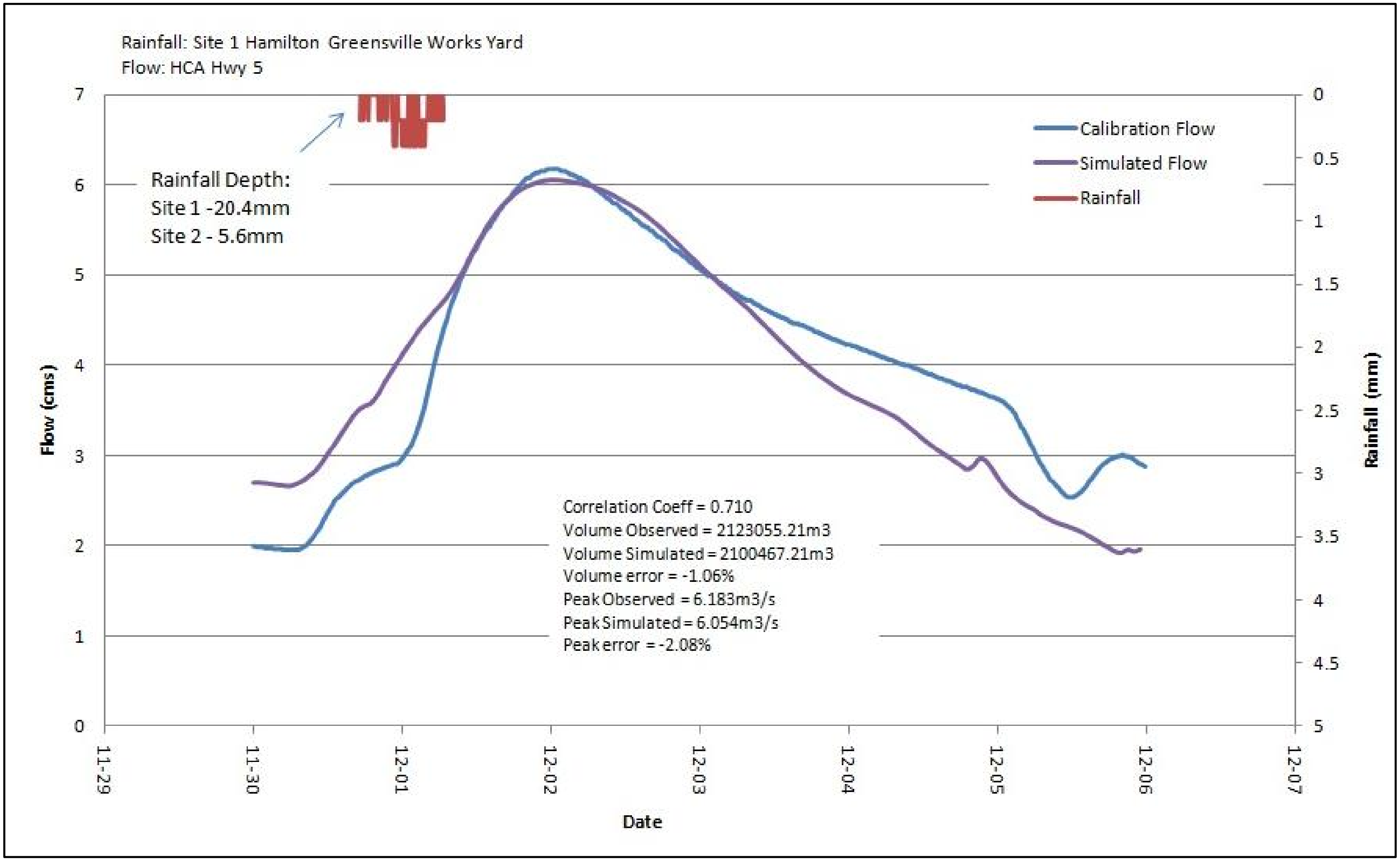


Figure 4.3.7: Calibration November 30th 2010

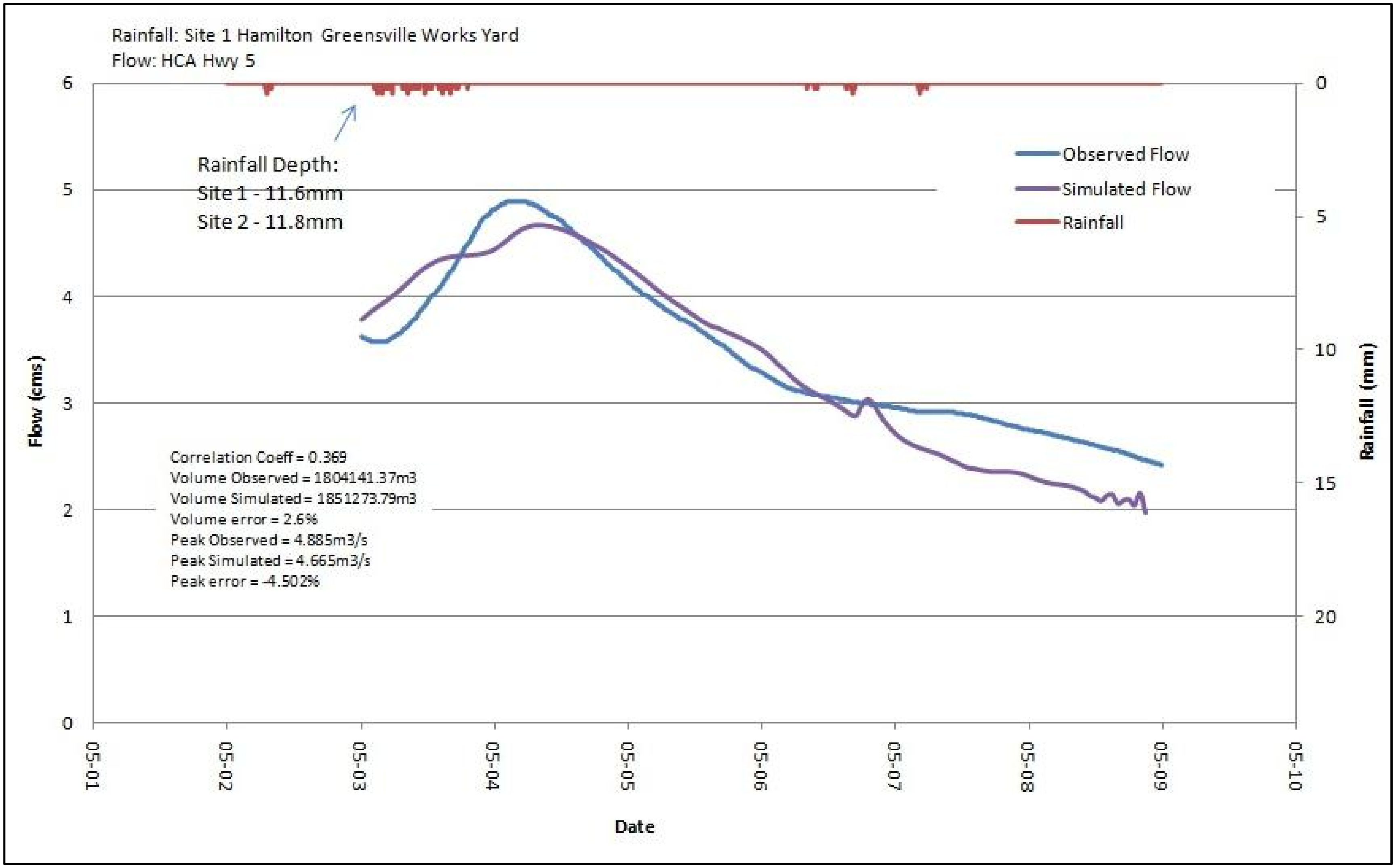


Figure 4.3.8: Calibration May 3rd 2011

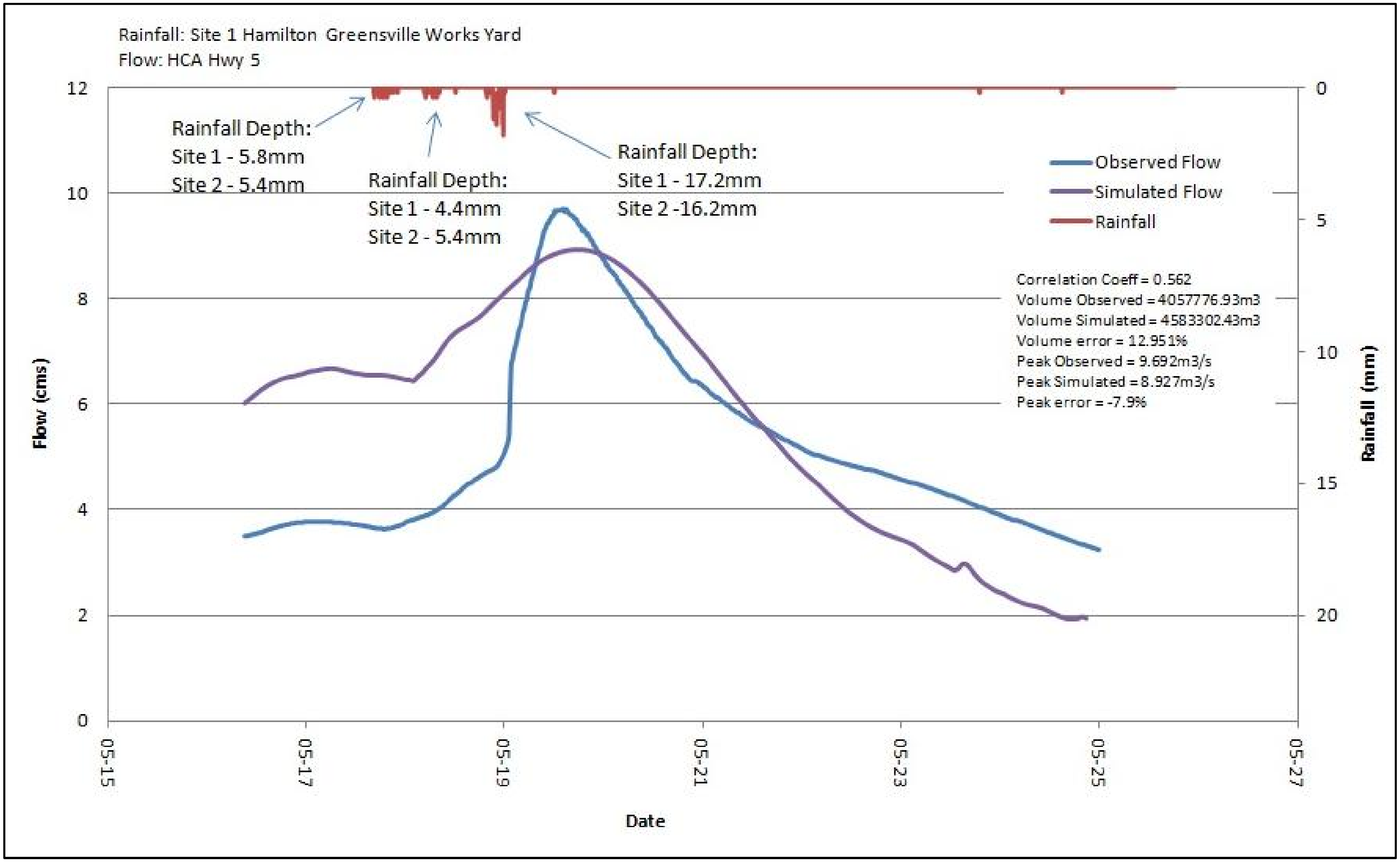


Figure 4.3.9: Calibration May 18th 2011

4.3.3.3 Flood Flow Estimates

By applying the calibrated MIKE 11 model, flood flow rates were established at key locations in the study area (**Table 4.3.4**). These flows include the Regulatory Storm, which is based on Hurricane Hazel, and the 100-year retrun period flow based on the 100-year storm event following rainfall data from the Mount Hope gauge station.

Flow estimates for Hurricane Hazel were estimated by applying the calibrated MIKE 11 model with antecedent moisture conditions adjusted to reflect saturated soils and 72 hours of rainfall recorded during the storm.

Flood flow rates from the previous study (MacLaren Plansearch, 1990) were compared to the flows generated from MIKE 11 results (**Table 4.3.4**). As shown in **Table 4.3.4**, the estimated Regional Flood flow rates at the downstream limit of the Unnamed Tributary within the RSA were found to be slightly higher than those estimated in the previous study (21.5 m^3/s compared to 20.6 m^3/s). Floodline mapping based on these estimates is presented in **Section 4.3.5** (Hydraulics and Floodline Mapping).

Table 4.3.4: Comparison between the Results of MIKE 11 and a Previous Study

Location	Drainage Area* (ha)	Peak Flow Rate (cms) - Regional	Peak Flow Rate (cms) – 100 Year
Mid-Spencer at Westover Road Estimated Flow - Hydrologic Model (Maclaren, 1990)	5862	115.3	12.2
Estimated Flow – MIKE 11	5870	126.2	42.2
Mid-Spencer at HWY 5 Estimated Flow - Hydrologic Model (Maclaren, 1990)	13296	308.9	38.3
Estimated Flow – MIKE 11	13303	258.0	61.2
Unnamed Tributary Estimated Flow - Hydrologic Model (Maclaren, 1990)	215	20.6	3.6
Estimated Flow – MIKE 11	206	21.5	4.1
Confluence at Unnamed Tributary Estimated Flow - Hydrologic Model (Maclaren, 1990)	15357	354.1	51.1
Estimated Flow – MIKE 11	15116	264.0	63.4

4.3.4 Hydrology – Event-Based Model

One key objective of the event-based hydrological model is to estimate surface runoff rates under existing and future conditions (i.e. new development) for the Rural Settlement Area (RSA). Another objective is to propose stormwater management targets related to erosion and flooding, in order to address the impacts resulting from proposed development within the study area.

In this section of the report, surface runoff rates under existing conditions were estimated. Chapter 6 (Impact Assessment) shows the results under future conditions (i.e. development). Stormwater management targets are presented in Chapter 8.

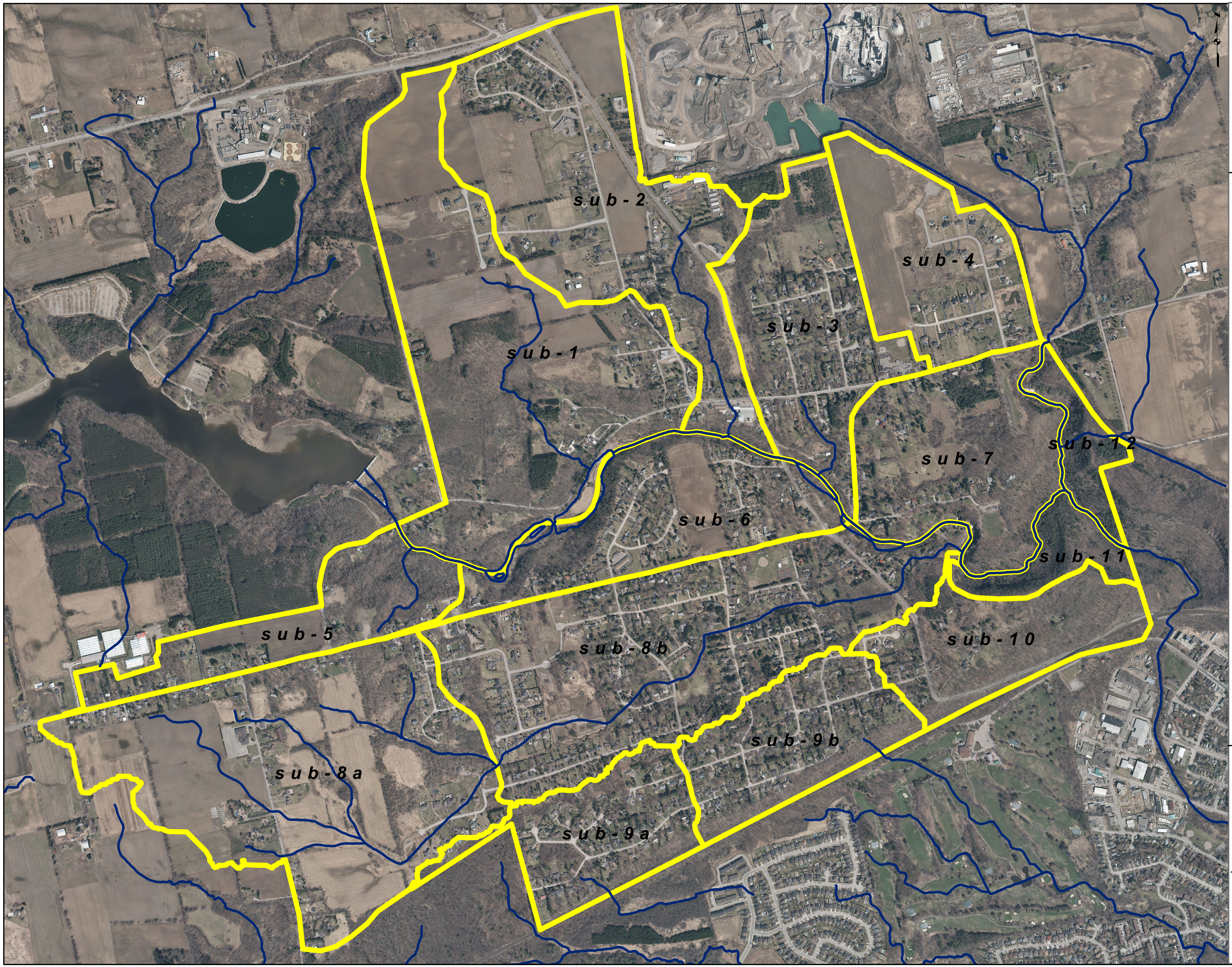
The SWMHYMO hydrologic model was used for the event-based modeling assignment. SWMHYMO is a Windows-based model which is compatible with the widely used OTTHYMO/INTERHYMO hydrologic model format. The catchment delineated as part of the MIKE 11 continuous model (**Section 4.3.3**) were broken down and further refined in order to accurately represent the topography of the Rural Settlement Area while also considering the contrast in land use. **Figure 4.3.10** shows the fourteen (14) delineated subcatchments. Other subcatchment characteristics including topography, Curve Number, and initial abstraction were also added to the SWMHYMO model in order to adequately define the hydrology of the Rural Settlement Area.

IDF curves derived from long-term data at the Mount Hope gauge station were used to estimate runoff rates with return periods between 2-year and 100-year, inclusive. The Regional flood was also incorporated in the event-based model. Various storm distributions from the City of Hamilton's Criteria and Guidelines for Stormwater Infrastructure (2007) were applied. The 6-hr SCS storm distribution was found to produce the highest runoff rates and was therefore used. **Table 4.3.5** presents the results for the subcatchments covering the RSA.

Of particular interest is the Regional Flood flow rate at the downstream limit of the Unnamed Tributary (Catchment 8b). The estimated Regional Flood flow rate using SWMHYMO is 20.2 m^3/s as shown in **Table 4.3.5**. This value compares well with the Regional Flood flow rate estimate from MIKE 11 as shown in **Section 0** (21.5 m^3/s).

Table 4.3.5: Surface Runoff Rates under Existing Conditions within the RSA Study Area

Catchment	Drainage Area	Flow (cms)						
		2-yr	5-yr	10-yr	25-yr	50-yr	100-yr	Regional
1	101.05	0.42	0.90	1.31	1.90	2.40	2.93	10.01
2	81.20	0.97	1.65	2.19	3.06	3.67	4.44	7.59
3	46.90	1.38	2.49	3.35	4.60	5.72	6.73	5.73
4	38.01	0.42	0.76	1.04	1.45	1.81	2.14	3.99
5	29.59	0.44	0.84	1.16	1.63	1.96	2.31	3.16
6	44.25	1.22	2.34	3.23	4.52	5.43	6.52	5.75
7	45.61	1.19	2.48	3.33	4.59	5.66	6.69	6.34
8a	102.05	1.29	2.51	3.47	4.87	5.88	6.95	10.71
8b	95.59	3.19	6.01	8.83	12.81	15.79	18.22	20.21
9a	28.75	1.31	2.47	3.38	4.68	5.58	6.83	4.01
9b	32.20	1.47	2.79	3.82	5.30	6.32	7.72	4.49
10	31.83	0.58	1.23	1.72	2.38	2.90	3.44	4.21
11	10.40	0.73	1.39	1.86	2.48	2.95	3.42	1.51
12	9.68	0.65	1.25	1.68	2.24	2.66	3.09	1.41



Mid-Spencer Creek / Greenville Rural Settlement Area Subwaterhsed Study

Legend

- Watercourses
- Catchment

FIGURE 4.3.10

Rural Settlement Area Subcatchments (Existing Conditions)

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4.3.5 Hydraulics and Floodline Mapping

4.3.5.1 General

This section presents the findings of the hydraulic analysis for the Greenville RSA study area, including the hydraulic model setup and the resulting floodline mapping for an unmanned tributary from Websters Falls to Crooks Hollow Road.

The hydraulic analysis was undertaken using the HEC-RAS hydraulic model (Version 3.1.3) by the U.S. Army Corps of Engineers which computes water surface profiles using the standard step method and routines to analyze bridge and culvert structures.

A base model was assembled using ArcGIS software and the City of Hamilton digital elevation model (DEM). This spatial data was used to define channel cross-section, stream centrelines, and overbank locations. “Low flow” channel dimensions were also coded into the model based on field measurements. Bridge and culvert structures were coded into the model with data collected through field surveys including:

- bridge/culvert dimensions;
- material (i.e. concrete, steel, etc.)
- invert/obvert elevations;
- road profiles

4.3.5.2 Floodline Mapping

The primary function of a floodplain is the conveyance of flood waters during extreme storm events and spring melts. Flood conveyance is dependent upon the shape of the channel and associated floodplain, the flow rate, and the location of structures (buildings, roads, etc.). Floodline mapping was undertaken for this study to identify areas susceptible to flooding under Regulatory Flood conditions. Future urban development is not permitted within the Regulatory Floodplain limits.

As noted earlier, MIKE 11 and SWMHYMO estimates of the Regional Flood flow rate at the downstream limit of the Unnamed Tributary are close and compare well (**Table 4.3.6**).

Table 4.3.6: Comparison between MIKE 11 and SWMHYMO Estmates of the Regional Flood Flow Rate

Location	Regional Flood Flow Rate (SWMHYMO)	Regional Flood Flow Rate (MIKE 11)
Downstream limit of the Unnamed Tributary	20.2 m^3/s	21.5 m^3/s

Regional flood flow estimates, as determined from the MIKE 11 hydrologic analysis (Section 4.3.2) and apportioned based on drainage areas for upstream cross sections, were applied over the appropriate stream reaches to determine water surface profiles for the Unnamed Tributary from Websters Falls to Crooks Hollow Road (**Table 4.3.7**).

Hydraulic model details are provided in **Appendix B**, and the resulting flood profile was used to plot the Regulatory floodplain limits through the study area, as illustrated in **Figure 4.3.11**. Regional Flood estimates and the resulting water surface elevations are summarized in **Table 4.3.7**.

4.3.6 Existing Stormwater Management Facilities

Within the RSA there are three existing stormwater management facilities. The locations are shown on **Figure 4.3.12**. Pond #49 is an assumed wetland located at Oak Avenue and Rosebough Street. Pond #144 is an unassumed wet pond located at Mashboro Ave and Herbert Place. Pond #28 is an assumed wetland located at Ofield Road South and Harvest Road.

Figure 4.3.11

REGULATORY FLOODLINE MAPPING

Table 4.3.7: Regional Flood Estimates and Water Surface Elevations along the Unnamed Tributary

River Sta	Profile	Q Total (m^3/s)	Water Surface Elev. (m)
2261	Regional Flow	16.6	225.46
2223	Regional Flow	16.6	225.4
2193	Regional Flow	16.6	225.4
2181.077	Regional Flow	16.6	225.4
2163.308		Culvert	
2150.26	Regional Flow	16.6	225.35
2106.447	Regional Flow	16.6	224.79
1988.653	Regional Flow	16.6	223.69
1876.627	Regional Flow	16.6	222.07
1766.689	Regional Flow	16.6	221.81
1685.014	Regional Flow	16.6	221.8
1596.124	Regional Flow	21.5	221.63
1513.798	Regional Flow	21.5	220.32
1447.712	Regional Flow	21.5	220.07
1399.952	Regional Flow	21.5	220.06
1385.399		Culvert	
1375.812	Regional Flow	21.5	219.49
1342.405	Regional Flow	21.5	218.36
1270.376	Regional Flow	21.5	218.1
1188.307	Regional Flow	21.5	217.88
1109.68	Regional Flow	21.5	217.49
1067.101	Regional Flow	21.5	217.46
1048.814		Culvert	
1040.061	Regional Flow	21.5	217.11
978.6279	Regional Flow	21.5	215.51
893.6569	Regional Flow	21.5	214.31
811.8255	Regional Flow	21.5	213.22
731.023	Regional Flow	21.5	212.9
714.3663		Culvert	
701.0341	Regional Flow	21.5	212.59
652.4738	Regional Flow	21.5	211.74
566.276	Regional Flow	21.5	211.73
471.2464	Regional Flow	21.5	211.73
407.5992	Regional Flow	21.5	211.73
388.8397		Culvert	
372.6856	Regional Flow	21.5	211.72
319.4237	Regional Flow	21.5	207.03
252.9376	Regional Flow	21.5	206.97
193.9612	Regional Flow	21.5	204.41
134.3451	Regional Flow	21.5	203.27
63.94562	Regional Flow	21.5	196.64
11.67039	Regional Flow	21.5	170.8

Mid-Spencer Creek / Greenville Rural Settlement Area Subwatershed Study

Legend

- Watercourses
- Existing SWM Pond

FIGURE 4.3.12

Location of Existing Stormwater Management Facilities

Aquafor Beech Limited

4.4 Groundwater Resources

4.4.1 Introduction

The goal of the hydrogeology component of the subwatershed study is to establish a conceptual model for the Middle Spencer Creek Subwatershed, identify the key characteristics of the bedrock and overburden systems, how these control groundwater movement, its availability, quantity and quality.

As outlined in the terms of reference, the study should determine if existing uses can be supported by private services, in terms of water quantity and quality. The potential for groundwater to sustain proposed buildout conditions for another 250 residential lots will be considered on Chapter 6.

This will determine the sustainability of groundwater resources in providing drinking water for residents and for future development within the subwatershed, particularly for the population of the Greensville Rural Settlement Area (RSA). In addition, the study will assess the interaction between the groundwater and the surface water to Middle Spencer Creek, thereby assuring its continued ecological function.

Hydrogeology is the study of how water enters and moves below the ground surface. This is an important component of the hydrologic cycle and the water balance. A portion of precipitation infiltrates in the ground and to the water table in what are termed recharge areas. Some of this groundwater may subsequently flow out into low areas, such as streams, that intersect the water table. These are termed discharge zones, supplying a near-constant flow of water (baseflow) to streams.

Layers of soils and rocks through which groundwater moves freely are called aquifers. These are water-bearing zones from which water can be extracted in quantities sufficient to satisfy its intended purpose. Layers in which water cannot move freely are called aquitards. Water may infiltrate slowly through or along aquitards, but does so too slowly to be relied upon as a source of water. What happens to precipitation that falls on the ground is termed the hydrologic cycle, expressed as a water budget.

The approaches used to develop the conceptual model for groundwater were as follows

1. Compilation and interpretation of available information to describe the regional geology and landforms that exercise control of the groundwater

2. Compilation of the Ministry of the Environment database of water wells to determine the aquifers that supply drinking water;

3. Installation of 10 monitor wells by Schlumberger Water Services to examine the subsurface geology (overburden and bedrock) and to determine the hydraulic conductivity (the ease with water moves) and the quality of the groundwater;

4. Installation of 6 hand-driven streambed piezometers in the Middle Spencer Creek tributary in the Greensville RSA for evidence of groundwater discharge;

5. Compilation of precipitation records to determine the relationship between rainfall and groundwater quantity;

6. Review the water quality in residential wells to determine trends over the past 25 years;

7. Install a water level logger in an overburden well adjacent to the Greensville Tributary of Middle Spencer Creek in Rosebough Park;

8. Construct a water budget; and,

9. To identify the Well Head Protection Area (WHPA) for the Greensville municipal well, as determined by Earthfx (2010).

The Middle Spencer Creek subwatershed covers an area of 49.7 square kilometers, approximately 30% of the area of the entire Spencer Creek Watershed. The subwatershed has a (2006) population of 11,829. Particular attention was paid to the Greensville RSA.

The Greensville RSA covers 6.55 square kilometres (655.10 hectares) at the south of the subwatershed, immediately above the Niagara Escarpment. Greensville has a (2006) population of 2,525, second only to Carlisle of the 18 Rural Settlement Areas in the City of Hamilton. Greensville's drinking water is supplied uniquely by groundwater and Greensville has only one municipal supply well.. All sewage is treated by individual on-site septic systems. Greensville has experienced long-standing problems with water quality and water quantity and was subject to a development freeze for this reason.

Middle Spencer Creek flows southwards through the subwatershed, acquiring water from its numerous tributaries and from Westover and West Spencer Creeks. Middle Spencer Creek flows through several sensitive areas, including the Hayesland-Christie Provincially Significant Wetland (PSW) and the Donald Farm Wetland Environmentally Sensitive Area (ESA). Middle Spencer Creek then turns east, flowing through the Christies Valley ESA (the Christie Conservation Area and the Christie Reservoir), through Greensville and over the 22-metre crest of the Niagara Escarpment at Webster's Falls in Spencer Gorge, an ESA and an Area of Natural and Scientific Interest (ANSI).

Compared to other subwatersheds in Ontario, the Middle Spencer Creek subwatershed has a unique topography and several unique landforms (or physiography). Both these features have important consequences for the hydrogeology, particularly the quantity, quality and sustainability of groundwater.

The Middle Spencer Creek Subwatershed has a very steep topography that drops almost 200 metres over a distance of approximately 11 kilometres from northwest to southeast (including the Niagara Escarpment).

Almost half of this change in elevation occurs within the Greensville RSA, in which elevations range from 270 metres above sea level (mASL) to 195 metres mASL at the brow of the Escarpment. This corresponds to a drop in ground surface elevation of 75 metres over a lateral distance of approximately 2,400 metres.

The physiography of the Middle Spencer Creek Subwatershed and the Greensville RSA encompass five distinct landforms, each of which must be incorporated into the conceptual model of groundwater. These landforms are shown in **Figure 4.4.1**and are described as follows (from North to South):

1. The Flamborough Plain is a flat tableland, characterized by shallow soils over a bedrock plain composed of carbonate rocks. The Flamborough Plain is approximately 260 meters above sea level (mASL) and extends almost 3,000 metres in a north-south direction. Land uses are predominantly agricultural and aggregate extraction;
2. The Norfolk Sand Plain is a sand delta derived from post-glacial Lake Warren. It extends to the north boundary of the Greensville RSA;
3. Till Moraines (Waterdown Moraines) and Kame Moraines extend to the Niagara Escarpment and underlie much of the Greensville RSA. The till is composed of silt and sand with some clay, deposited by the receding glacier. The kame moraine is composed of poorly-sorted sand, gravel and silt deposited by streams originating from the base of a stationary and melting glacier. Both the till and kame materials interfinger, such that distinguishing one from the other is difficult. Ground elevations range from 270 mASL to 195 mASL. This is a relatively steep section of the Subwatershed, dropping 75 metres to the southeast over a lateral distance of approximately 2,400 metres;
4. The Niagara Escarpment marks the cliff face of resistant limestone that overlies softer and more easily-eroded shale, attaining heights up to 80 metres; and,
5. The Iroquois Plain is a veneer of sand deposited by post-glacial Lake Iroquois that covers the Dundas Valley and extends from the base of the Escarpment (elevation of 150 mASL) to the southeast extremity of the subwatershed (elevation of 86 mASL).

The surface geology of the Greensville RSA is presented in **Figure 4.4.2** (from OGS, 2011). Much of the Greensville RSA is covered with a layer of sand overlying till. Bedrock is exposed along Middle Spencer Creek and along the Niagara Escarpment.

The bedrock geology consists of a sequence of limestone and dolomite of Silurian age and is shown in **Figure 4.4.3** (Earthfx, 2010).

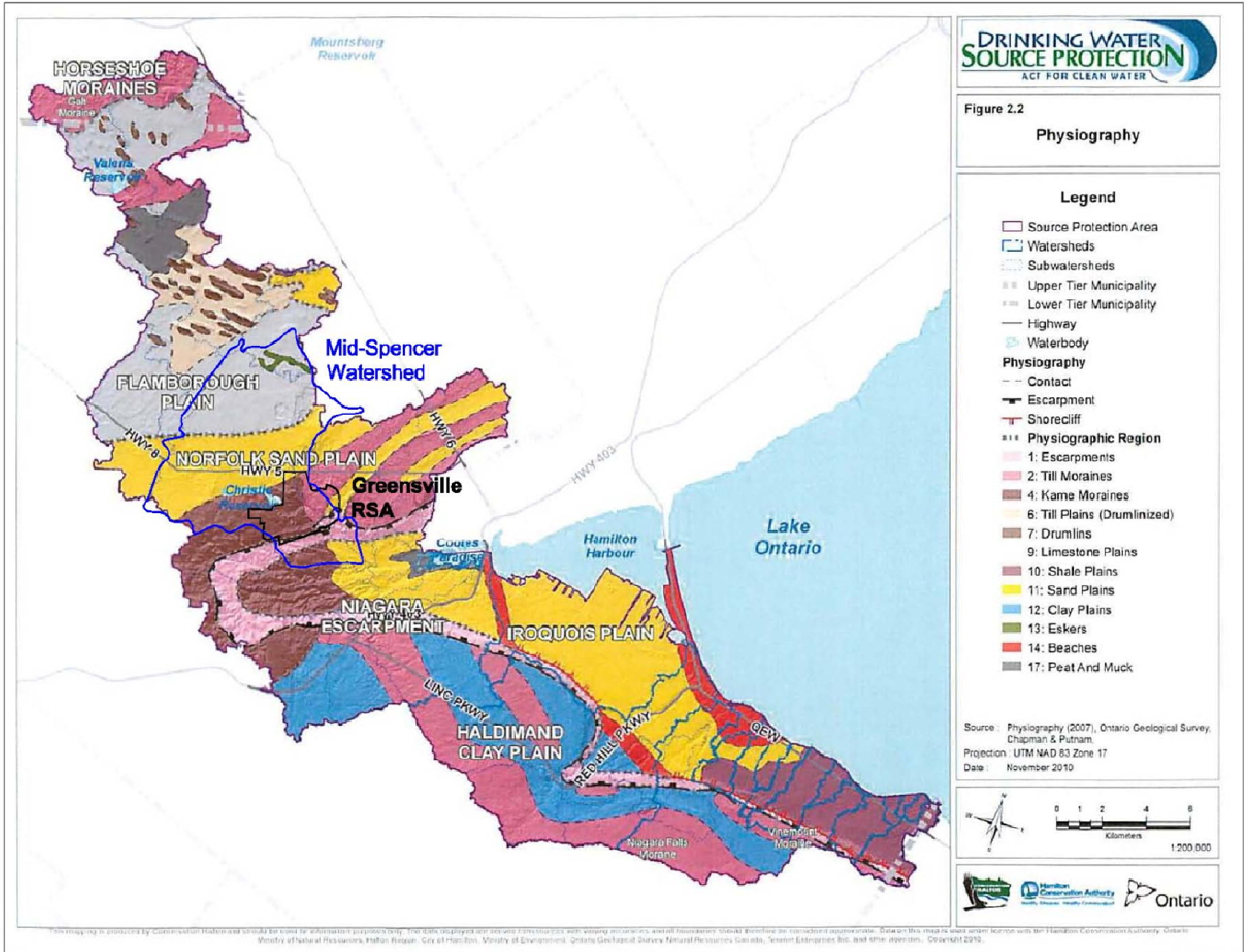


Figure 4.4.1: Landforms in the Middle Spencer Creek Subwatershed and the Greensville RSA

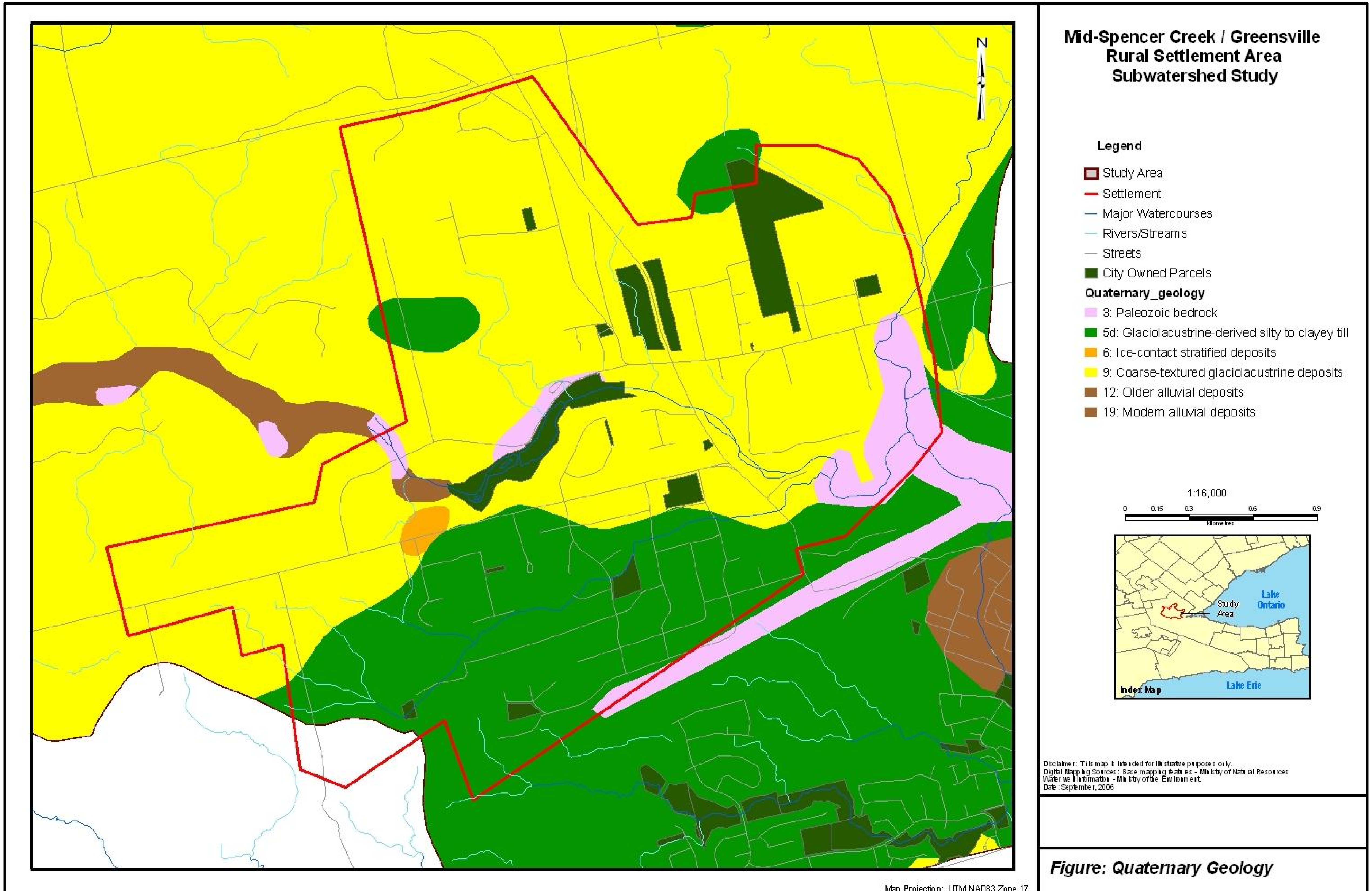


Figure 4.4.2: Surface Geology of the Greensville RSA

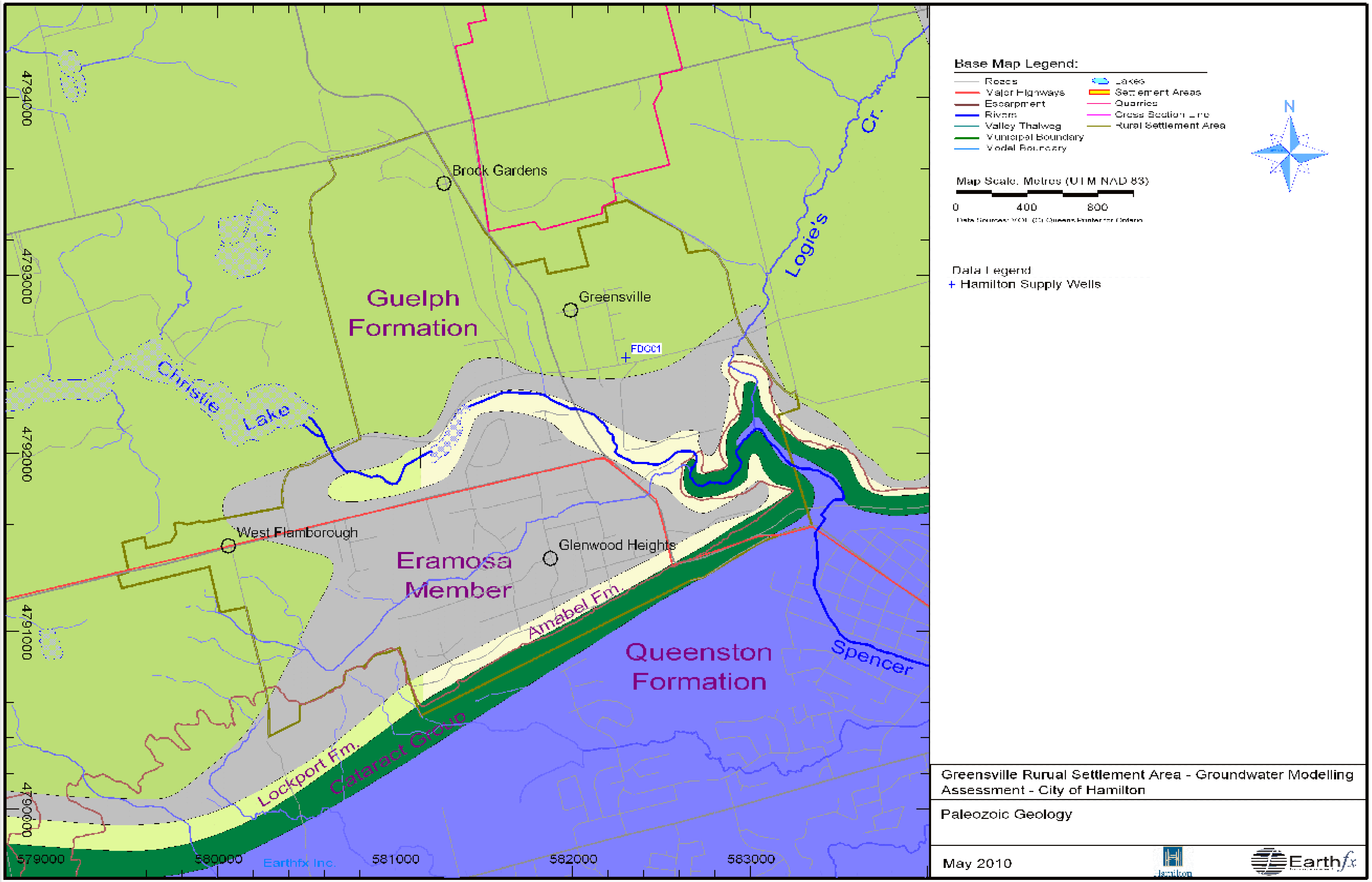


Figure 4.4.3: Bedrock Geology of the Greensville RSA

4.4.2 Hydrogeology and Aquifers

The primary source of information used in developing the conceptual model for the Middle Spencer Creek Subwatershed and the Greensville RSA was the Ministry of the Environment Water Well database, which records all water wells since the mid-1940s. This database, along with geological mapping by the Ontario Geological Survey, provides the 3 dimensions needed to define aquifers and aquitards in soils and bedrock.

The water wells used in the compilation are summarized in **Table 4.4.1**.

Table 4.4.1: Ministry of the Environment and City of Hamilton Water Wells Used

Water Well Data Source	Number of Wells in Source File	Comments
New boreholes drilled	21	Appended
MOEwell_Hamilton_EFX MS Access database	18,695	18,561 wells are MOE WWIS wells
HealthWells_2005 MS Access database	13,551	372 wells are unique to this database and were added to the HealthWells 2005 database..
Monitoring Well Master Data Record MS Excel spreadsheet	35	24 wells were added to HealthWells 2005 database.
Total Number of Wells imported	19,112	
Number of Wells Discarded	2,743	No coordinates, no lithology or no water level or incomplete information
Total Number of Wells used	16,369	

Within the Greensville RSA, there are more than 900 water wells on record. During the compilation, the number of water wells that were added by phase of construction was separated, as shown in **Table 4.4.2**. Most of the water wells serve individual residences. There is one municipal well that serves 36 residences (approximately 108 people as of 2011) in the Village Green area and one communal well (not operated by the City), namely the Briencrest communal well that serves 26 residences on Briencrest, Haines and Kirby Avenues. The locations of the water wells are shown in F**igure 4.4.4** and **Figure 4.4.5**.

Table 4.4.2: New Domestic Water Supply Wells in Greensville RSA

Year	Area	Number of Wells	Municipal and Communal Wells
Pre 1950	Greensville	36	
Pre 1950	West Flamborough	24	
Pre 1950	Bullock's Corners	10	
1950 – 1960	Brock Gardens Phase I	24	
1950 – 1960	Marshboro Drive	25	
1950 – 1960	Grand Vista Phase I	187	
1950 – 1960	Kirby Ave/Briencrest	2	Briencrest communal well (1957)
1950 – 1960	Webster/Short Rd	12	
1950 – 1960	Wesite/Meldrum	24	
1950 – 1960	Steetly/Canada Cut Crushed Stone	2	
1960 – 1970	Rothsay Rendering	5	
1960 – 1970	Brock Gardens Phase II	21	
1960 – 1970	Highway 8 Consents	4	
1960 – 1970	Grand Vista Phase II	106	
1970 – 1980	Kirby/Hunts	36	
1970 – 1980	Village Green	9	Greensville municipal well (1972)
1970 – 1980	Brock Rd Consents	3	
1980 – 1990	Brock Road Commercial/Light Industrial Park	0	
1980 – 1990	Oak Ave Extension	8	
1990 – 2000	Vandenhaar Greenhouse Expansions	1	
1990 – 2000	Weir's Lane Consents	9	
1990 – 2000	Van Every Gardens	1	
1990 – 2000	Briarcliffe Phase I	2	
>2000	Spencer Creek Estates	1	
>2001	Oak Avenue Extensions	1	

>2002	Sun Avenue Estates	0	
2003 – present	Briarcliffe Phase II	0	

The distribution of wells terminated in overburden or bedrock are shown in Figure 4.4.

Figure 4.4.4 for the Mid-Spencer Creek Subwatershed. The distribution of overburden and bedrock wells within the Greensville RSA is shown in **Figure 4.4.5**.

Figure 4.4.6 is a north to south cross-section (BB-5) that illustrates the bedrock topography with a bedrock valley along the trace of Middle Spencer Creek and a blanket of thick overburden (up to 40 metres) in the central portion of the Greensville RSA. Along this section, the majority of the water wells extend 5 metres or so into bedrock.

From the water well database, it is apparent that there are two major aquifers. Approximately 20% of the wells in Greensville tap the overburden aquifer. The overburden aquifer occurs where overburden thickness is greater than 30 metres (**Figure 4.4.6** and **Figure 4.4.7**), clustering mainly along the south margins of a bedrock valley that marks Middle Spencer Creek and south of its tributary.

The remaining 80% of the wells penetrated the bedrock aquifer, the majority ending within the first 5 metres or so into the bedrock.

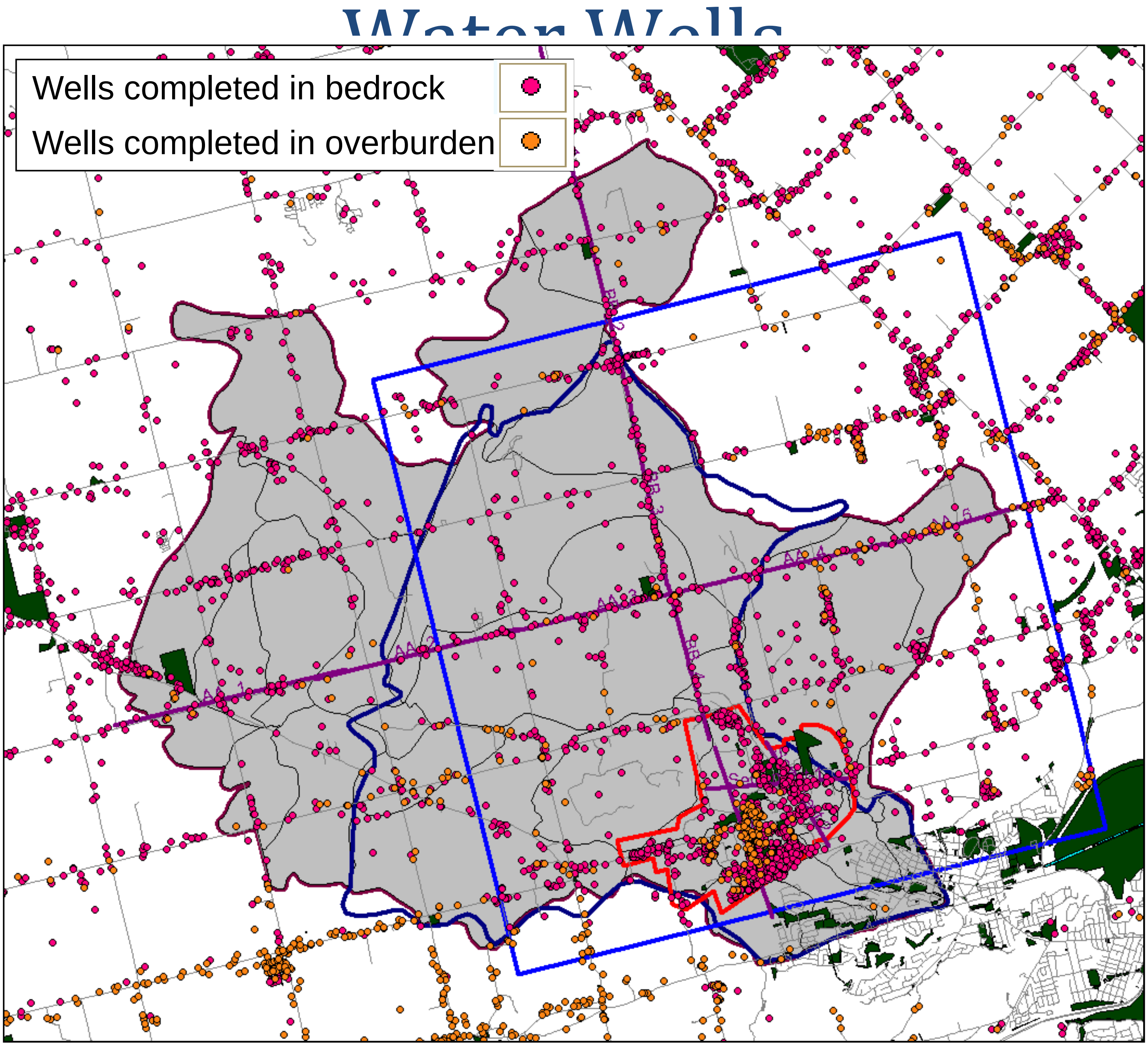


Figure 4.4.4: Water Wells in Overburden and in Bedrock. Mid-Spencer Subwatershed

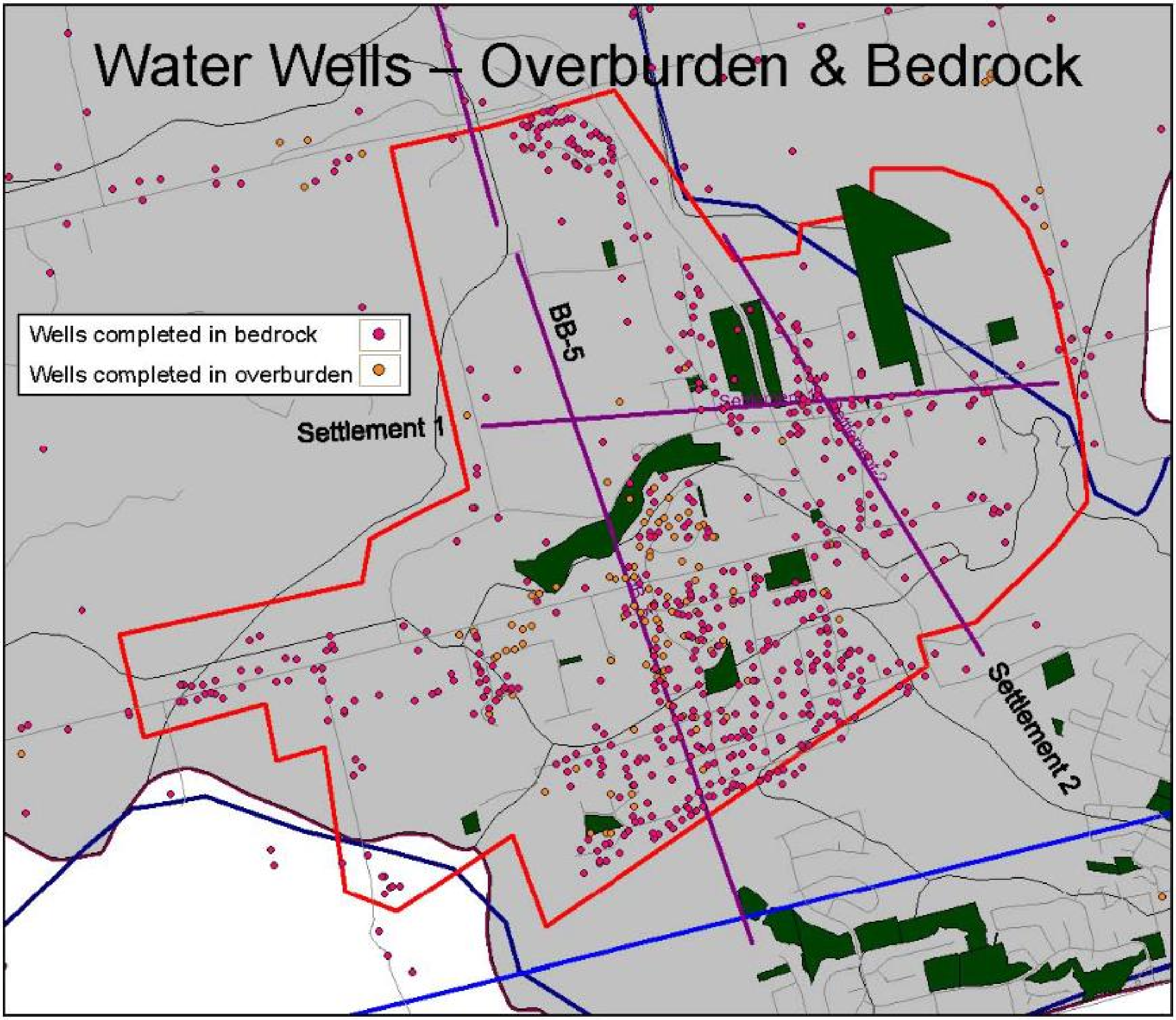


Figure 4.4.5: Water Wells and Cross-section in the Greensville RSA

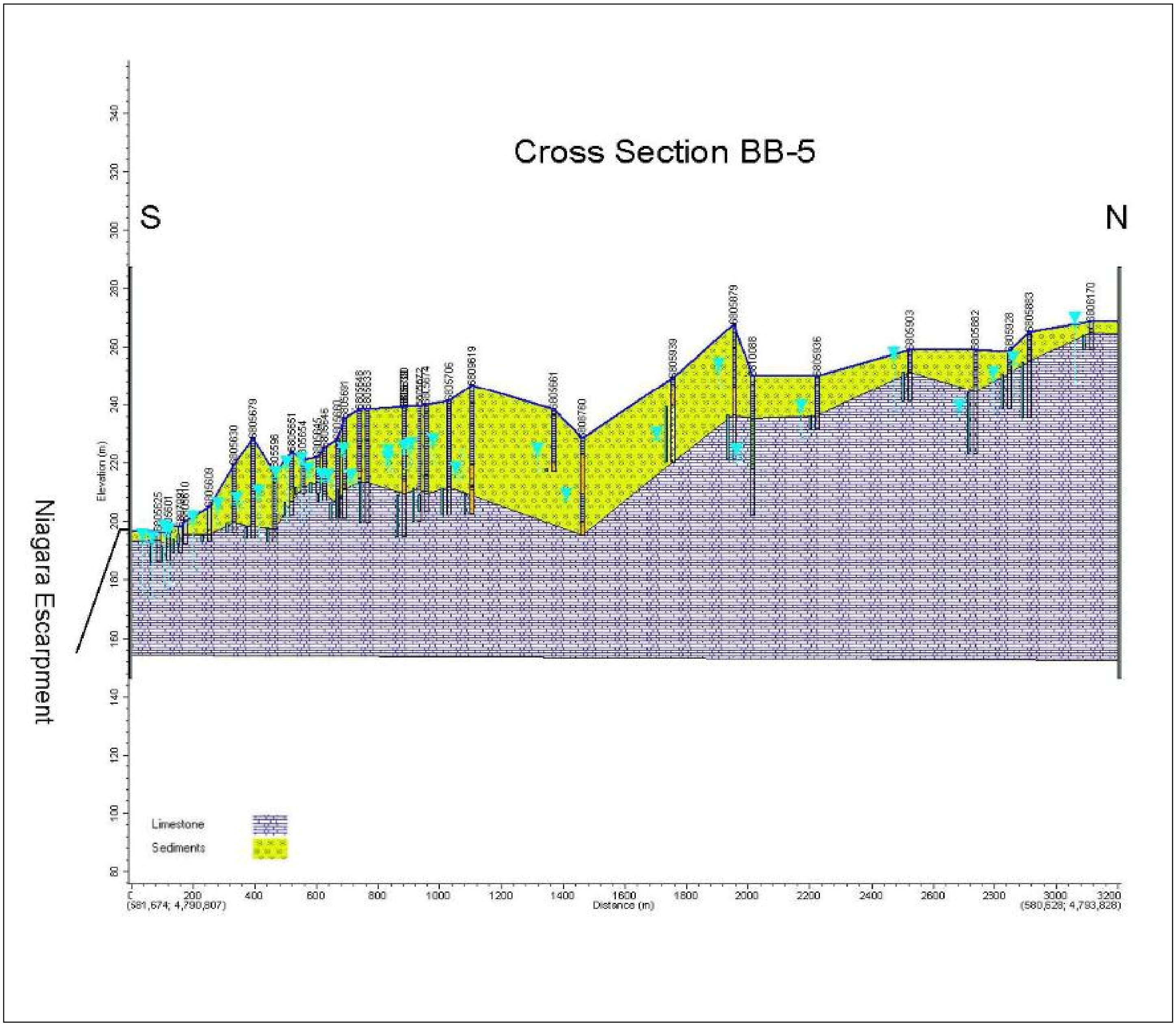


Figure 4.4.6: North-South Cross-Section BB-5, Greensville RSA

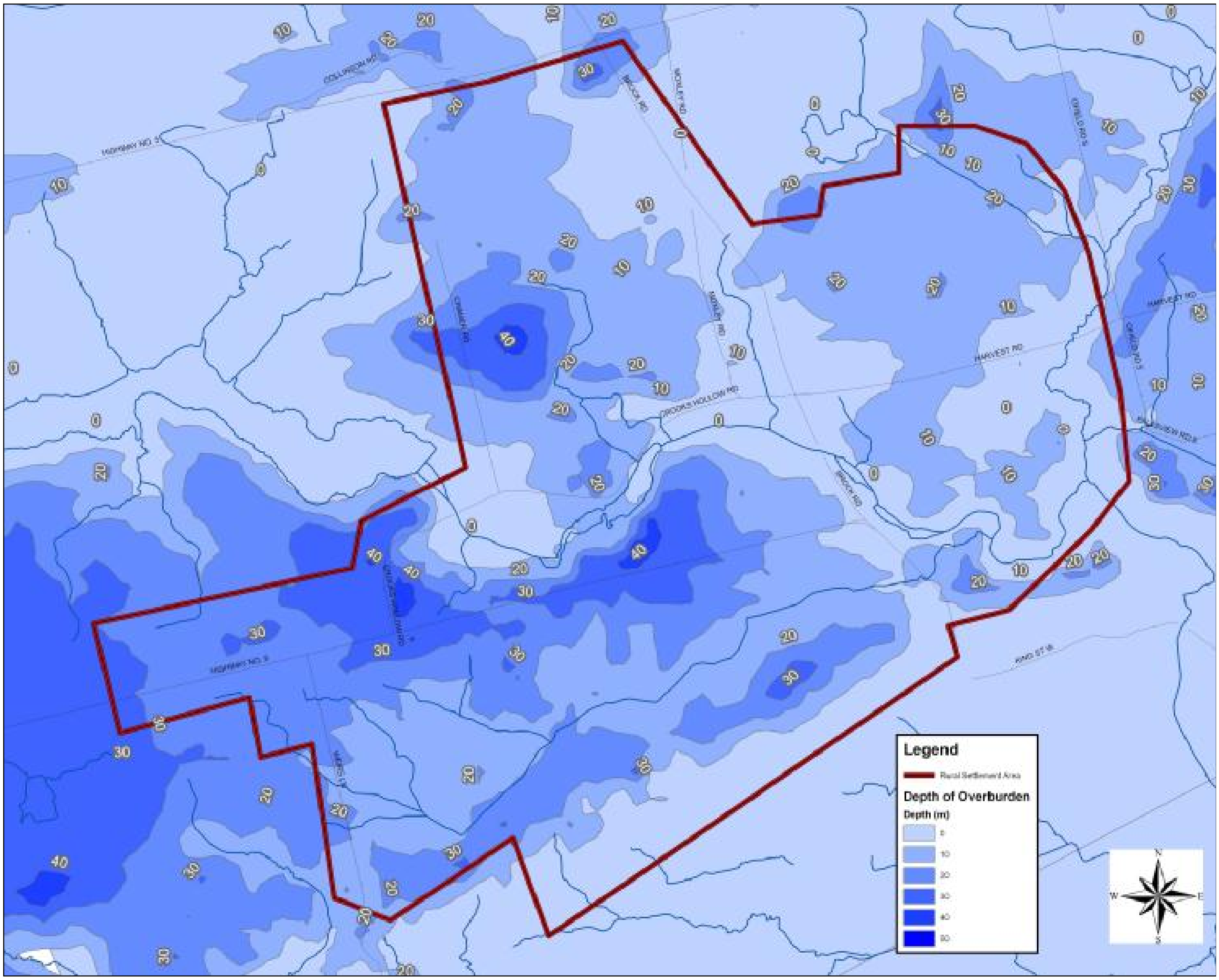


Figure 4.4.7: Thickness of Overburden in the Greensville RSA from Water Wells Records

4.4.3 Detailed Field Work

In 2007, Waterloo Hydrogeologic Inc. (now Schlumberger Water Services) advanced 10 nested monitor wells within the Greensville RSA. The purpose was to examine the nature of the overburden and the underlying bedrock and their hydraulic properties. All wells were screened in both the overburden and bedrock.

The locations of the monitor wells were selected to cover the Greensville RSA in areas that were near to existing or proposed developments, or required additional stratigraphic detail, or that had elevated concentrations of nitrate. The locations were restricted to land owned by the City or the Hamilton Conservation Authority to allow unimpeded access. The monitor well locations, along with the Greensville municipal well and the Briencrest and communal wells are shown in **Figure 4.4.8**, superimposed on a 2005 aerial photograph. The well logs are attached as **Appendix C**.

The overburden consists mainly of silty sand inter-fingering with layers of silt and silty clay. The silty clay layers are referred to as till. North-south and east-west cross-sections are shown in **Figure 4.4.9** and **Figure 4.4.10** showing the interpreted distribution of the silty sand and the silty clay till.

The bedrock was penetrated for a distance of 3 to 6 metres. The bedrock was generally heavily fractured with soil and gravel seams.

Hydraulic conductivity measurements were performed in both overburden soils and in bedrock. The overburden ranged over two orders of magnitude, from a high of 10^{-5} metre/second in sand, 10^{-6} metre/second in silt and 10^{-7} metre/second in silty clay. To put these values into context, a hydraulic conductivity of 10^{-7}metre/second means that water will move several metres per year. A value of 10^{-5} metre/year means that water can move several hundred metres per year, sufficient to serve as an aquifer. This range of values is similar to those measured in the underlying bedrock (WHI, 2007, Tables 4.5 and 4.6).

The water levels in the nested wells showed a consistent downward gradient from overburden to bedrock between December 2006 and July 2007. These data indicate that the overburden aquifer and the uppermost (weathered) bedrock aquifer are hydraulically connected and that infiltrating water can drain from the overburden into the bedrock.

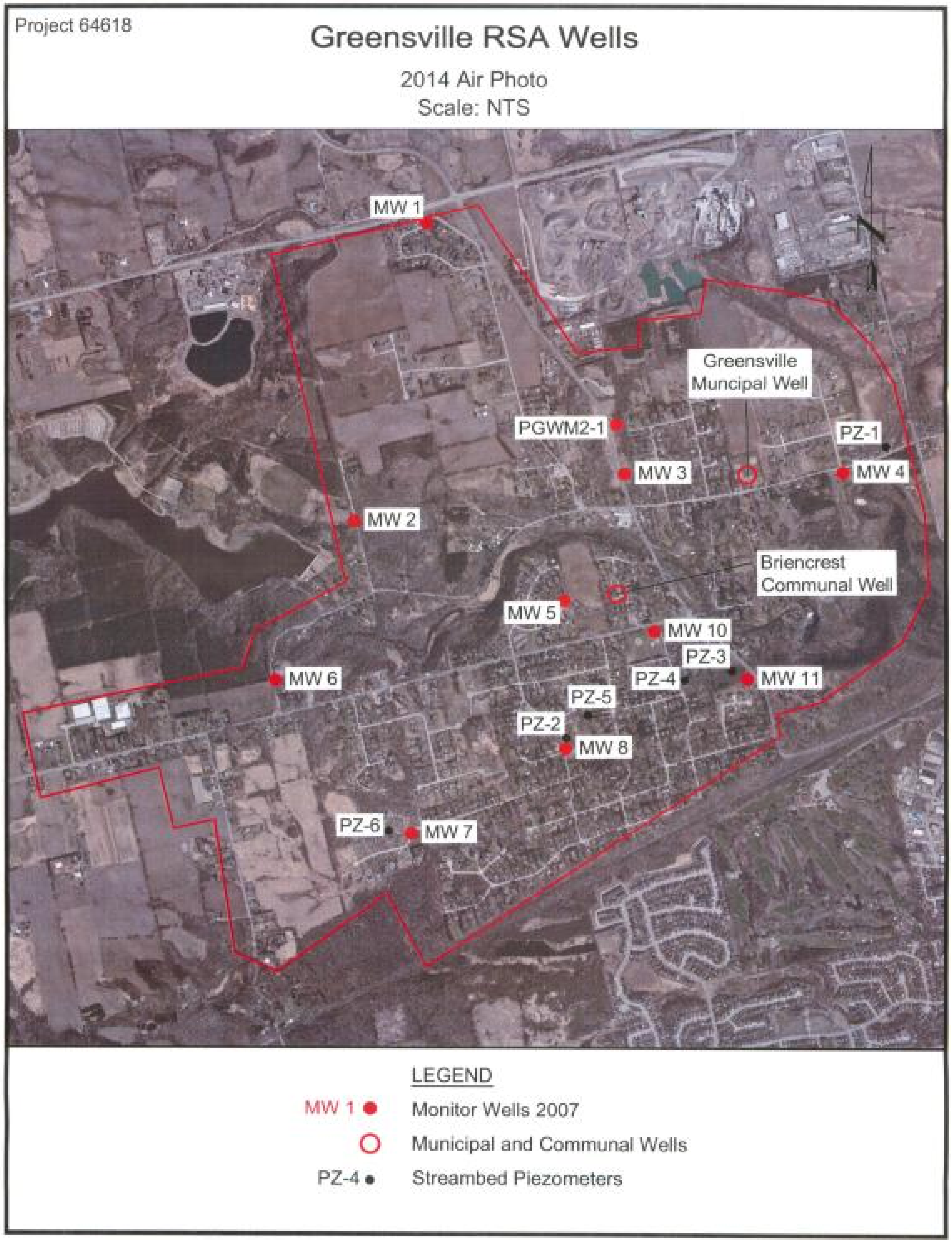


Figure 4.4.8: Locations of 2007 Monitor Wells, Greensville Municipal Well (Drilled 1972, Water Works Approval 1975), the Briencrest Communal Well (1957) and streambed piezometers

Two cross-sections were constructed from the monitor well logs, showing the inferred distribution of kame-derived sand and the sandy silt till (**Figure 4.4.9** and **Figure 4.4.10**).

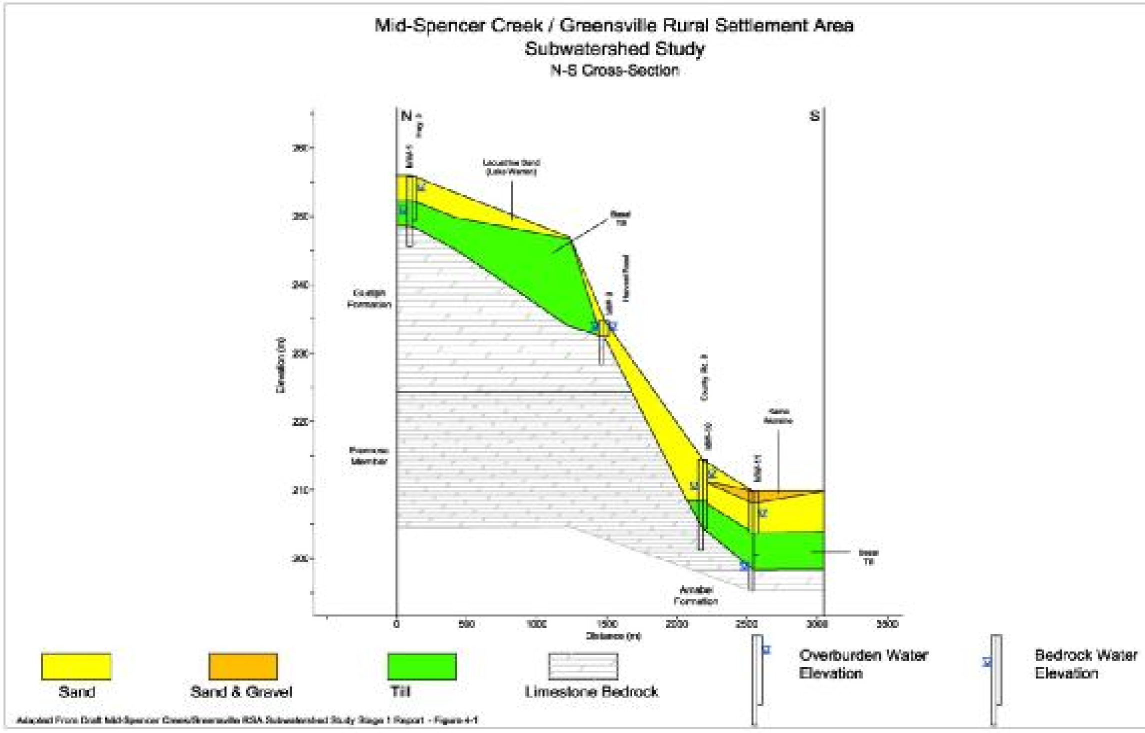


Figure 4.4.9: North-South Cross-Section of Greensville Monitor Wells

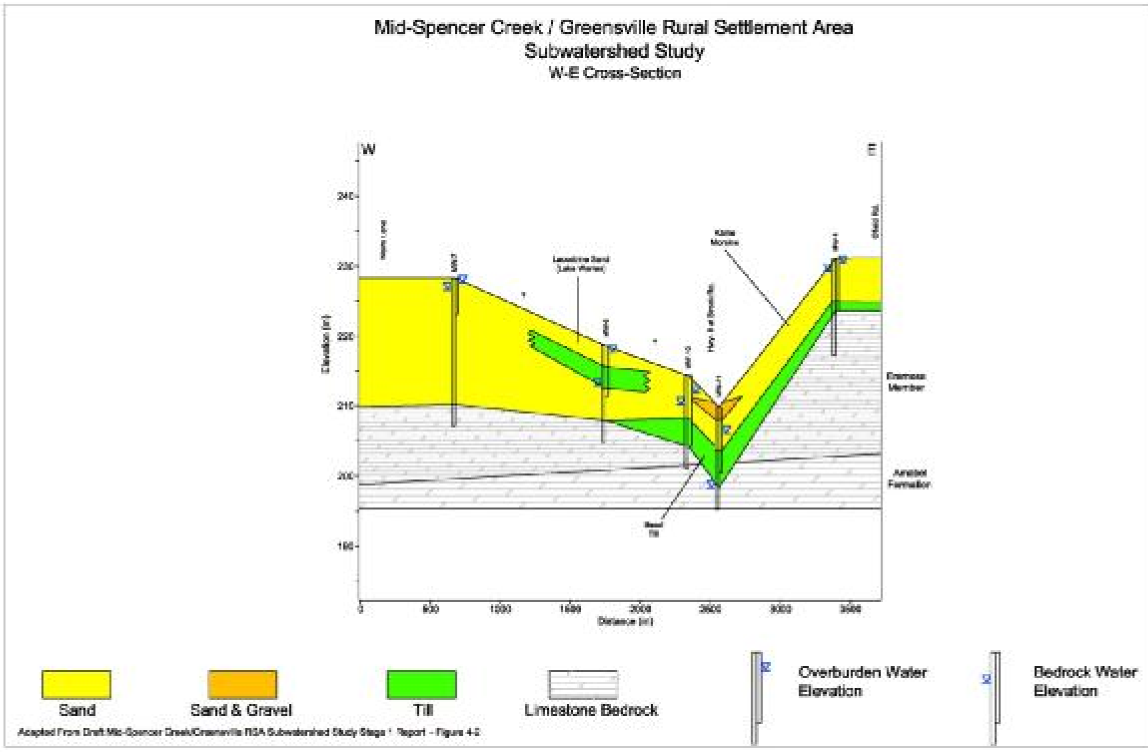


Figure 4.4.10: East-West Cross-Section of Greensville Monitor Wells

The bedrock aquifer is generally found in the uppermost weathered bedrock assigned to (from youngest to oldest): the Guelph, Eramosa or Amabel Formations. Of these, the Eramosa Formation is classed as a regional aquitard, often characterized by poor supply of often sulphurous water. This has been the case in Greensville, where the incidences of sulphur increase with depth into bedrock (see **Figure 4.4.11**).

In total, 64 of the 730 MOE water well records reported high sulphur. Of the 64 high-sulphur wells, 59 are found in areas with low-lying bedrock, suggesting that the Guelph Formation may be thin or absent at these locations. This makes it more likely that sulphurous domestic water wells may have intersected the underlying sulphur-bearing Eramosa Member. Many of these wells were screened at depths of 20 metres below surface or greater.

A positive trend is observed when the well depth is plotted against the percentage of wells with high sulfur at each depth (**Figure 4.4.11**). These data show that high sulphur may be expected in wells at 20 metres or more into bedrock, although it has been observed at shallower depths (Morrison Beatty Ltd., 1988).

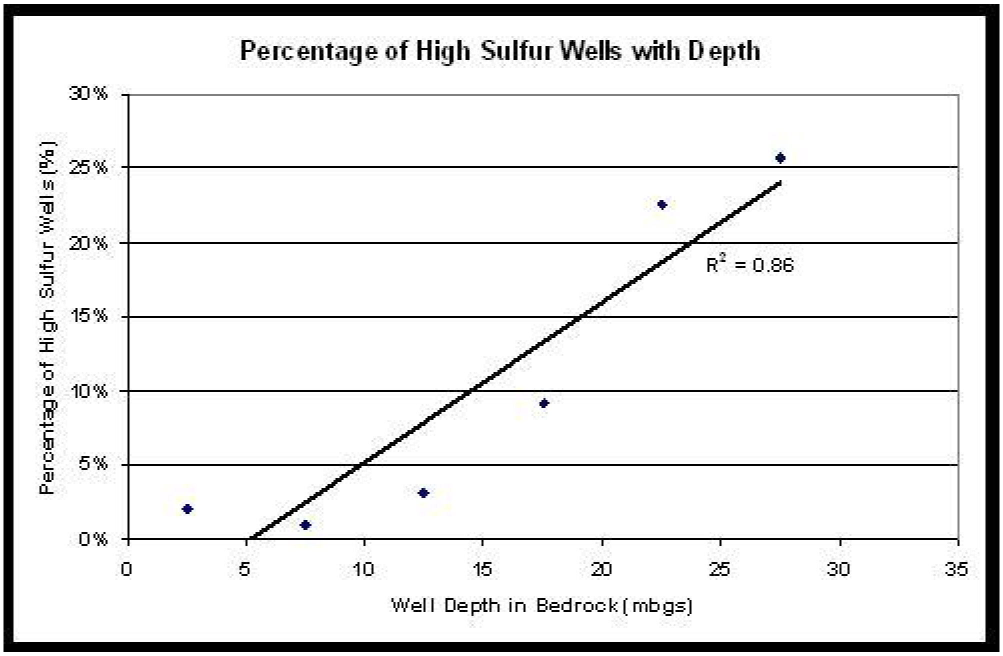


Figure 4.4.11: Incidence of High Sulphur Water in Wells as a Function of Depth

There was concern expressed in the Terms of Reference that some of the bedrock may have open channel created by karst. Karst is defined as a landform that exhibits irregularities in its surface form as a result of rock dissolution, leading to underground rivers and cave structures in limestone environments. An area of Karst topography is found in Stoney Creek and is commonly referred to as the Eramosa Karst.

The Eramosa Karst is considered an area of natural and scientific interest (ANSI). The Eramosa Karst area was transferred to the Hamilton Conservation Authority following its provincially significant status. The Eramosa Karst is approximately 17 km southeast of Greensville.

Two additional Karst areas are found within or close to the City of Hamilton. The first is located near Trinity Church Road, approximately 1 km southwest of the Eramosa Karst area. The second is an area of bedrock solution located 3.2 km southwest of Hayesland, reported to contain foxhole sized cavities and widened joints. The Haysland Karst area is approximately 1 km northwest of Greensville and adjacent to an existing quarry.

Based on the available documentation, surface expressions of karst environments are not recognized or anticipated in the Greensville RSA.

4.4.1 Aquifers in the Greensville RSA

A more detailed examination of the bedrock stratigraphy reveals that the shallow productive aquifer (or hydrogeologic unit – HGU) is found in limestones and dolostones of the Guelph Formation. A second aquifer is associated with the Gasport Formation (aka the Middle Amabel Formation), as illustrated in the section of the Niagara Escarpment in **Figure 4.4.12** (Ontario Geological Survey, from Brunton, 2008). The regional stratigraphic layering is shown in a North-South cross-section that encompasses the Middle Spencer Creek Subwatershed in **Figure 4.4.13** (from Earthfx 2010).

The stratigraphy of the Greensville area was divided by Earthfx (2010a,b) into 10 layers, representing alternating aquifers and aquitards (**Table 4.4.3**). The overburden layers can function both as aquifers (in sand) or aquitards (in clay or till). Of note is the presence of two bedrock aquifers.

The majority of the water wells extend into the uppermost 5 metres or so of the weathered bedrock under the overburden. The weathered bedrock can be assigned to the Guelph Formation, the Eramosa Formations or, near the Escarpment, the Upper Amabel Formation.

There is a deeper and relatively productive aquifer, assigned to the Middle Amabel, including the Gasport Formation.

Sedimentary Geoscience Section (31) *F.R. Brunton*

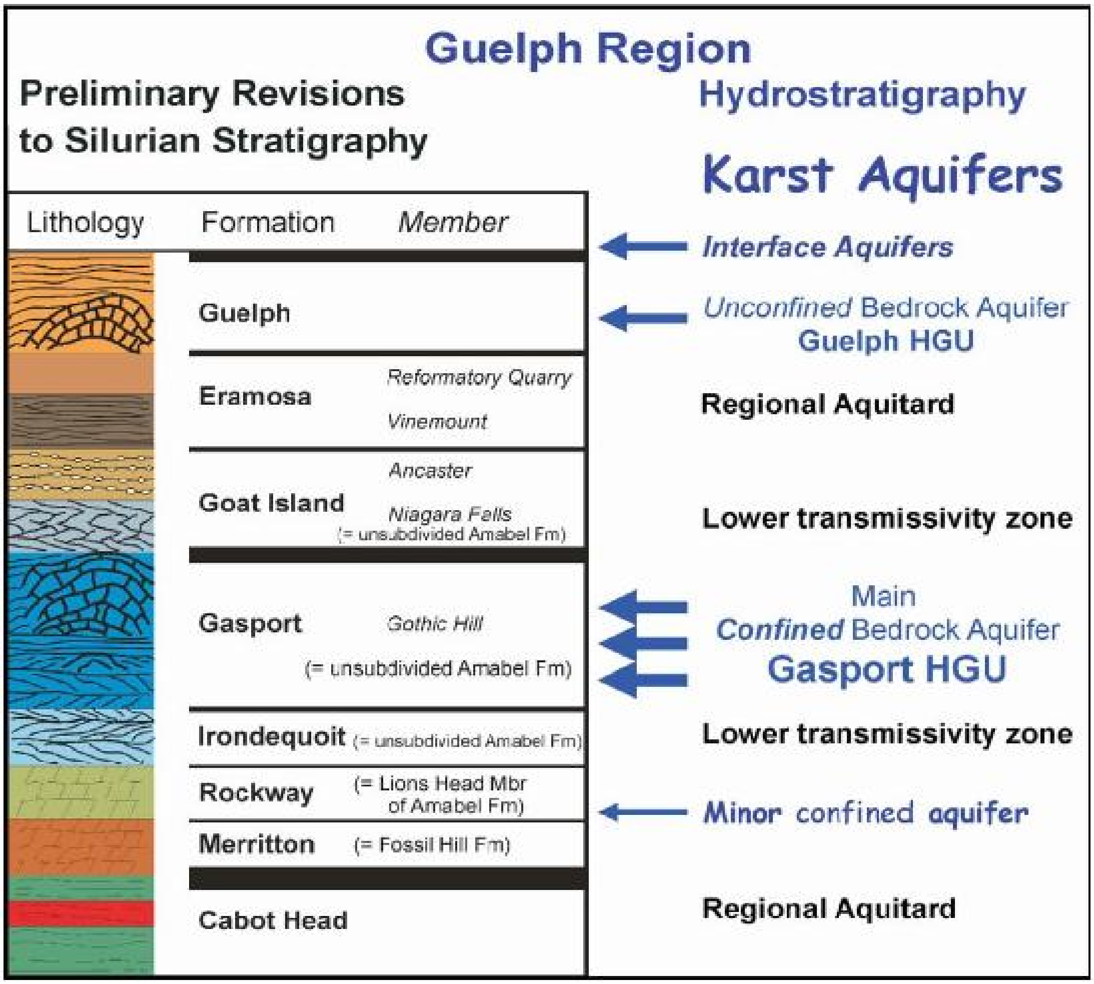


Figure 31.3. Preliminary revised Early Silurian stratigraphy and hydrostratigraphic framework for Guelph region of Niagara Escarpment. The relative thickness of lines separating each formation in right column reflects the significance of the diastem (thicker line reflects greater time break). Key aquitards include the regional Cabot Head Formation shales, the overlying dolostones of the Merritton and Rockway formations, and dolostones and calcareous shales of the Vinemount Member (Eramosa Formation). The Niagara Falls Member of Goat Island Formation is a relatively low transmissivity (reduced hydraulic conductivity) crinoidal grainstone unit. Previous hydrogeology studies have allocated the Irondequoit and Gasport formations and Niagara Falls Member of the Goat Island Formation to the unsubdivided Amabel Formation. Key regional hydrogeologic units (HGU) include the Gasport Formation reef mound and inter-reefal bleached shell coquinas (Gasport HGU) and the overlying Guelph Formation (Guelph HGU); interface aquifers (groundwaters flowing along bedrock surface and within basal unconsolidated sediments) are also regional sources of groundwater (*see* Brunton et al. 2007).

31-6

Source:
Brunton, F.R. 2008. Preliminary Revisions to the Early Silurian Stratigraphy of Niagara Escarpment: Integration of Sequence Stratigraphy, Sedimentology and Hydrogeology to Delineate Hydrogeologic Units; in Summary of Field Work and Other Activities 2008, Ontario Geological Survey, Project Unit 08-004, Open File Report 6226, p.31-6.

Figure 4.4.12: Bedrock Stratigraphy and Aquifer Sections (from Brunton 2008)

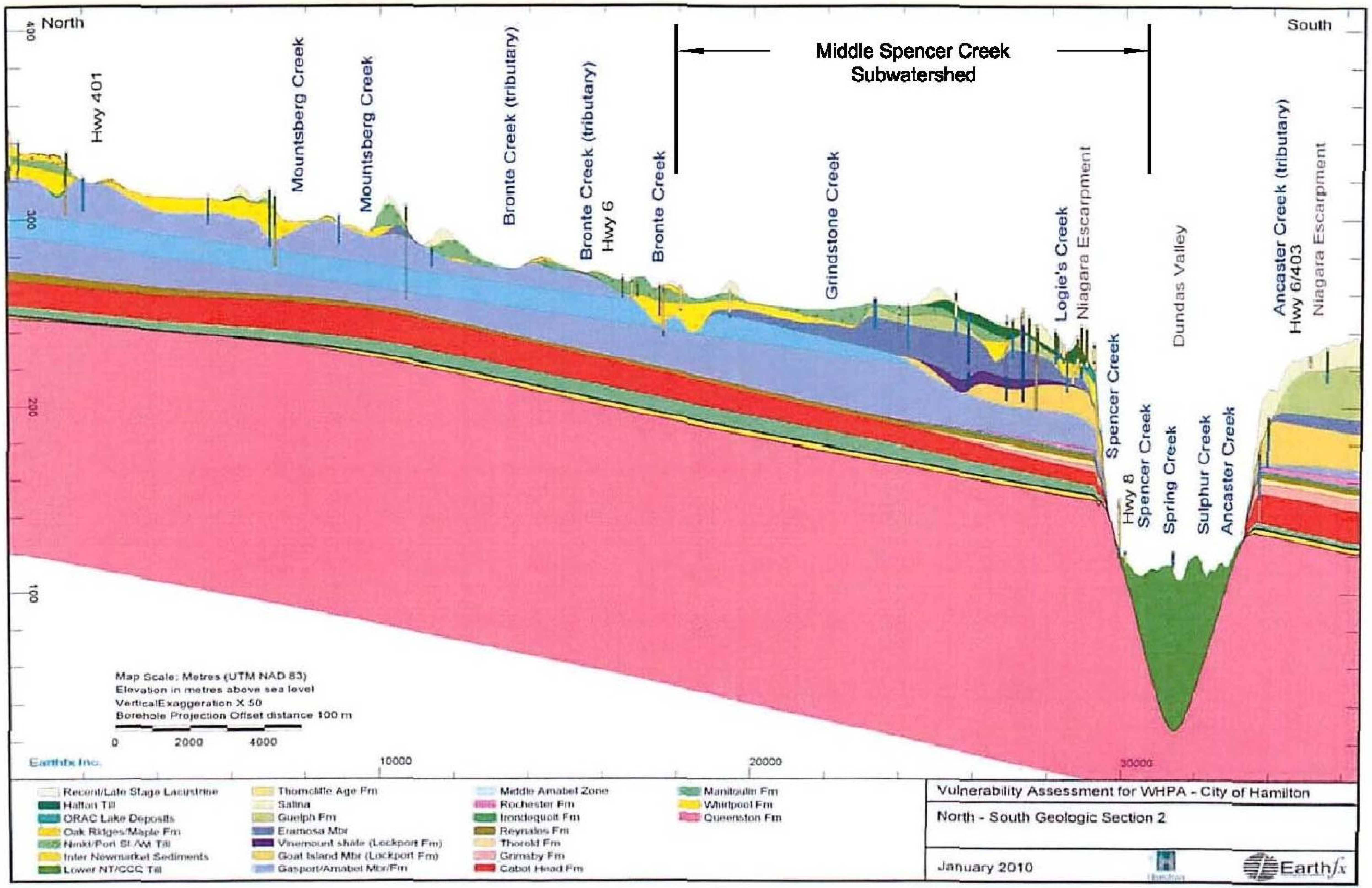


Figure 35: North - south geologic cross section 2.

Figure 4.4.13: Regional North-South Cross-Section Across Middle Spencer Creek Subwatershed (from EarthFx. 2010a,b)

The resulting regional aquifers and aquitards, shown in **Figure 4.4.13** are listed in **Table 4.4.3**.

Based on the EarthFx compilation, a total of ten hydrologic units were selected for numerical modeling in the City of Hamilton. These units are shown in **Table 4.4.3** with their calibrated hydraulic conductivity, their measured hydraulic conductivity and their recognized presence in the Greensville RSA.

Table 4.4.3: Aquifers and Aquitards in the Hamilton and Greensville RSA Areas (EarthFx, 2101a, b)

Layer	Description	Aquifer or Aquitard	Calibrated Hydraulic Conductivty (m/sec)	Present in Greensville?	Measured Hydraulic Conductivity in Monitor Wells (m/s)
1	Surficial Materials	Variable	Variable	Yes	No data
2	Upper Till	Aquitard	2 x 10-7	Yes	2.5 x 10-7
3	**Basal Sand**	**Aquifer**	**1 x 10-4**	**Yes**	**1.4 x 10-5**
4	**Weathered Bedrock**	**Aquifer**	**1 x 10-4 (Guelph)** **5 x 10-6 (Eramosa)** **5 x 10-5 (Amabel)**	**Yes**	**1.5 x 10-6 to 1 x 10-8** **1.1 x 10-7 to 5.3 x 10-7** **1.4 x 10-5 to 3.2 x 10-6**
5	Eramosa	Aquitard	1 x 10-6	Yes – under Guelph	3 x 10-7
6	Upper Amabel/Gas port	Aquitard	5 x 10-6	Yes – under Eramosa	3.2 x 10-6
7	**Middle Amabel**	**Aquifer**	**9 x 10-5**	**Yes**	**1.4 x 10-5**

8	Lower Amabel/Gasport	Aquitard	5 x 10-7	Likely at depth	No data
9	Reyanales to Upper Queenston	Aquifer/Aquitard	1 x 10-8	Likely at depth	No data
10	Unweathered Queenston	Aquitard	2 x 10-9	Likely at depth	No data

The location of the aquifers is particularly significant in the Greensville RSA, where the overburden aquifer can be exploited where overburden thicknesses exceed 30 metres. The bedrock aquifer is found in the uppermost Guelph Formation at the north of the RSA, becoming thinner to the south, with the underlying Eramosa Formation representing a regional aquitard and source of occasional sulphurous water. The uppermost weathered 5 metres of bedrock constitutes an aquifer, whether it is Guelph or Eramosa.

The potential of the deeper aquifer will be considered in Section 6 (Impact Assessment) and Section 9 (Implementation).

4.4.2 Groundwater Flow

Water levels in the 11 monitor wells were recorded in both overburden and bedrock. The gradients are southeast in both overburden and bedrock monitor wells (**Figure 4.4.14** and **Figure 4.4.15**). There is little difference between the gradients on overburden and bedrock monitor wells, confirming both are connected.

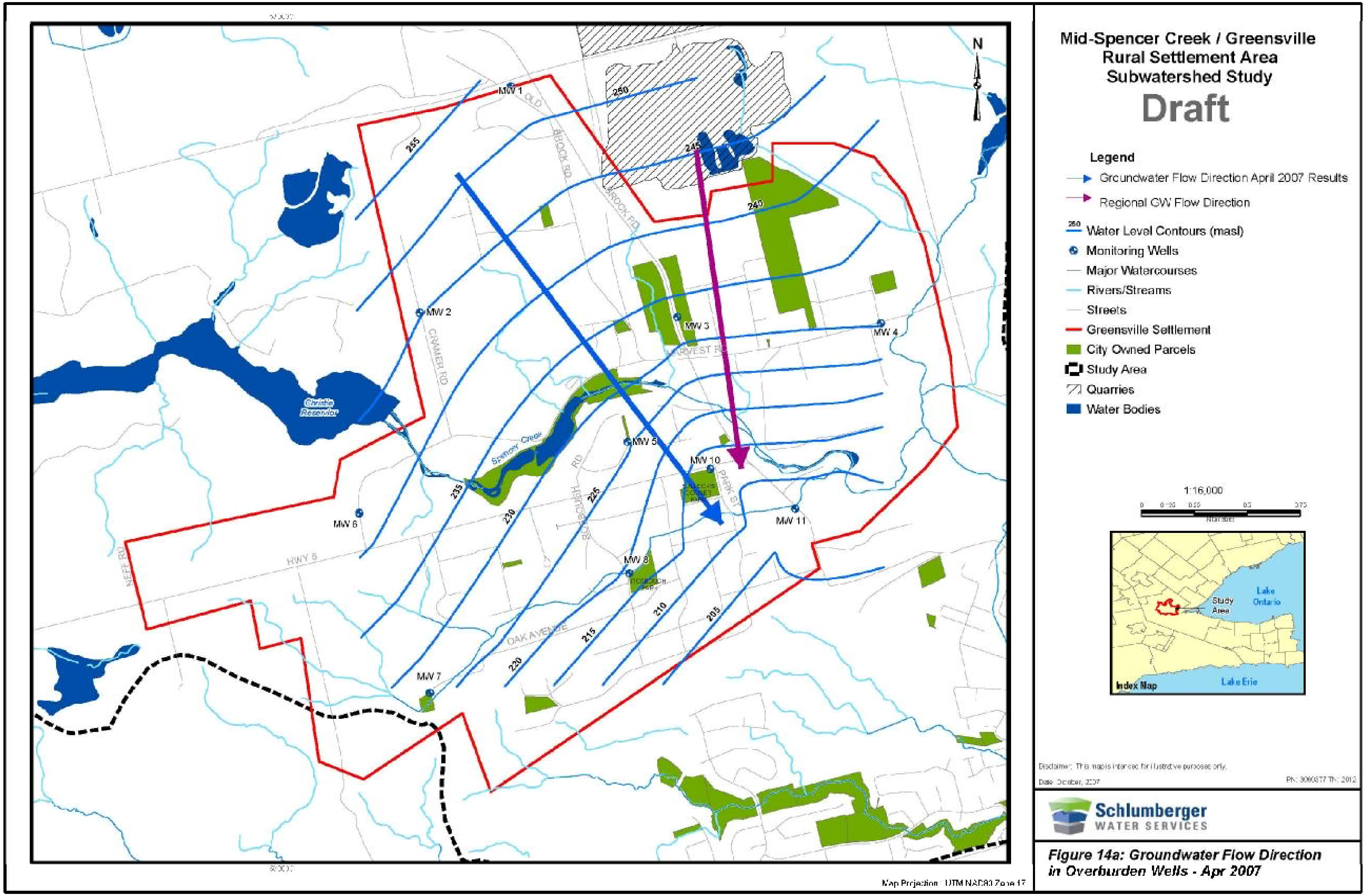


Figure 4.4.14: Groundwater Flow in Overburden Monitor Wells.

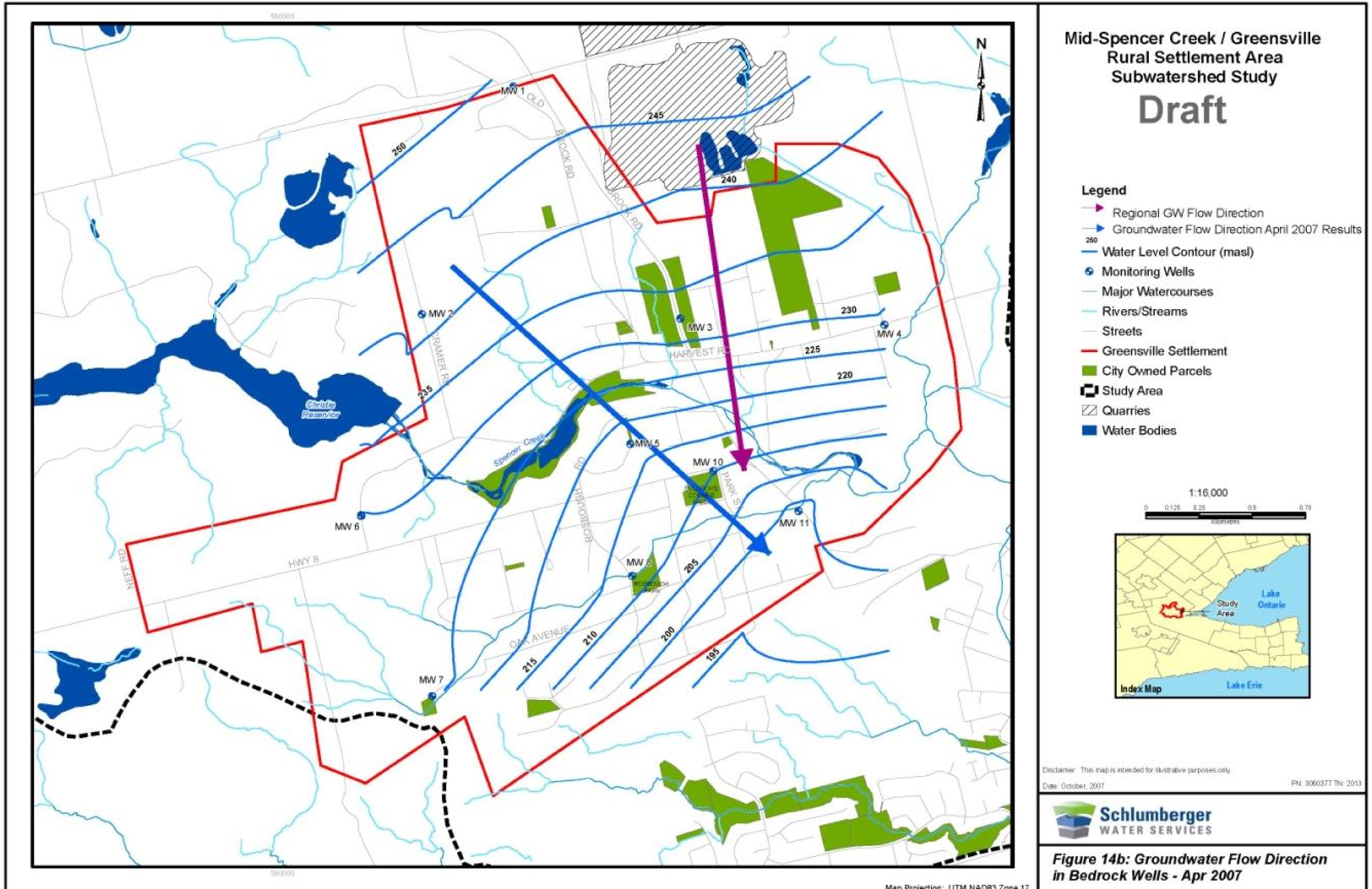


Figure 4.4.15: Groundwater Flow in Bedrock Monitor Wells

4.4.3 Groundwater Recharge and Discharge

Six hand-driven streambed piezometers were installed in the Greensville RSA in May of 2007 to determine if there were upward gradients (indicating the stream was gaining water from the ground) or downward gradients (indicating the stream was losing water into the ground). The piezometers consist of 6" or 12" screen attached to ¾" steel rods. Middle Spencer Creek is mainly on bedrock between Brock Road and Webster's Falls, so the piezometers were placed along the south tributary. The piezometer locations are shown in **Figure 4.4.8** and are described as follows:

- P1 was placed in Logie's Creek, north of Harvest Road
- P2 is located in the tributary at Rosebough Park, east of Rosebough Street
- P3 is located west of Brock Road across from Webster's Falls Road
- P4 is located between Park Avenue and Mountainview Road
- P5 is located west of Mountainview Road
- P6 is located in at the end of Oak Avenue

Table 4.4.4: Water Levels in Piezometers in Greensville RSA

Piezometer	May 15, 2007			July 27. 2007			October 3, 2007		
	Stream	Piezometer water level below stream	Gradient	Stream	Piezometer water level below stream	Gradient	Stream	Piezometer water level below stream	Gradient
P1	Flowing	0.00	↔	flowing	-0.085	↑	flowing	-0.25	↑
P2	Flowing	-0.12	↑	dry	-0.15	↑	dry	0.58	↓
P3	Ponded	0.58	↓	dry	0.875	↓	dry	1.02	↓
P4	Flowing	0.45	↓	trickle	0.5	↓	trickle	0.31	↓
P5	Flowing	0.15	↓	Lost			Lost		
P6	Flowing	0.00	↔	Lost			Lost		

↑ Upward gradient, groundwater discharge (gaining stream)
↓ Downward gradient, groundwater recharge (losing stream)
↔ Neutral gradient, groundwater and stream at same level

The seasonal variation in the shallow groundwater in piezometers installed in watercourses ranged from 0.14 to 0.73 metre between May and October 2007 **(Table 4.4.4**).

The gaining reach noted in piezometer P2 in Rosebough Park was adjacent to a dug well that is used as a water source for a winter skating rink. A pressure logger was installed in the dug well in June 2007 to monitor the water level with reference to the stream for close to one year. The results (**Figure 4.4.16**) indicate that the stream is gaining water (as baseflow) after significant rainfalls and throughout the winter months. The maximum seasonal fluctuation in the shallow groundwater at this location was 1.4 metre, approximately the same as the fluctuations noted in the streambed piezometers.

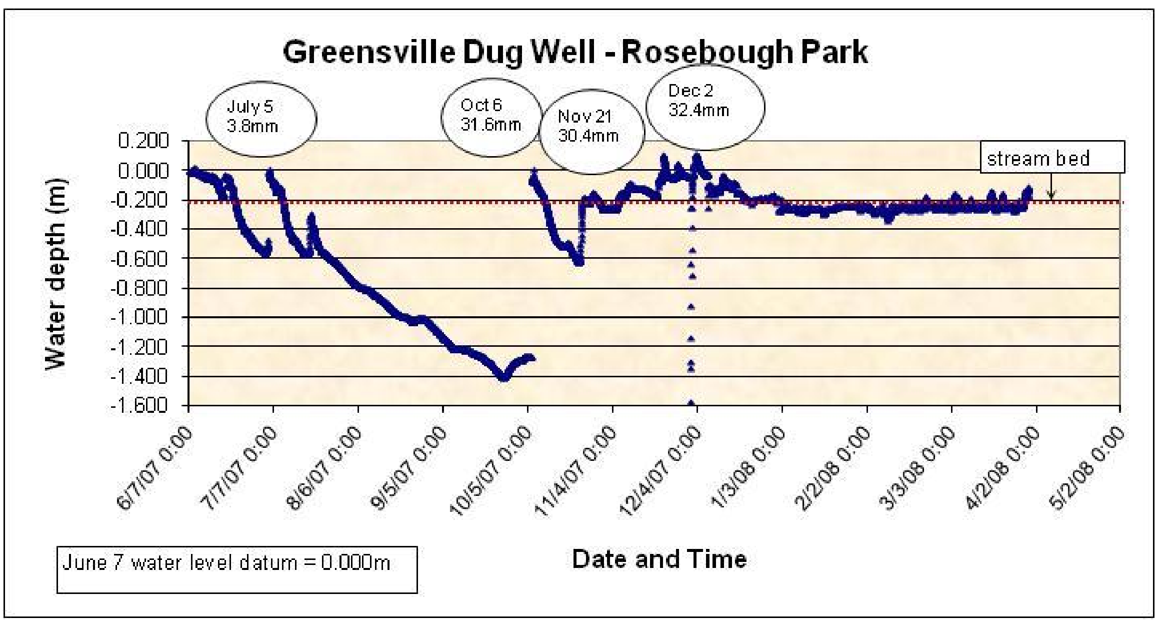


Figure 4.4.16: Water levels in a dug well in Rosebough Park Compared to Middle Spencer Creek

Groundwater elevations in the 10 monitor wells installed in the Greensville RSA in December 2006 were monitored between December 2006 and September 2013 (no water level data) and are summarized in **Table 4.4.5**.

Table 4.4.5: Groundwater Elevations in Monitor Wells 2007 – 2010

Well#	Dec. 15, 2006	Jan. 31, 2007	Apr.7, 2007	July 3, 2007	July 31, 2007	Oct. 3, 2007	Aug., 2010	Oct., 2010	Maximum Difference (m)	Gradient
MW-1D	250.40	255.78	248.82	248.05	247.85	-	247.44	247.05	8.73	↓
MW-1S	253.74	253.15	253.27	252.66	252.35	-	252.73	252.63	1.39	
MW-2D	241.86	242.24	242.32	241.28	241.58		--	-	1.04	↓
MW-2S	244.86	244.93	245.19	245.29	245.22		-	-	0.43	
MW-3S	233.17	233.34	233.38	dry	dry	dry	dry	dry	>0.71	↓
MW-3D	233.17	233.41	233.52	233.06	232.96	-	231.82	231.71	1.81	
MW-4D	228.19	228.53	229.25	228.55	227.79	-	228.73	228.59	1.06	↓
MW-4S	229.11	230.24	230.35	229.80	229.56	-	229.93	229.80	1.24	
MW-5D	215.88	216.28	216.47	215.90	215.90	-	214.73	214.54	1.93	↓
MW-5S	225.32	225.56	225.69	225.05	224.64	-	223.79	224.00	1.90	
MW-6D	229.19	228.87	229.80	228.96	228.57	-	227.80	227.89	1.39	↓
MW-6S	242.11	242.68	242.78	242.62	242.85	-	242.08	241.96	0.82	
MW-7D	226.27	226.61	226.44	225.47	225.01	-	224.26	223.71	2.90	↔
MW-7S	226.24	227.45	227.55	226.23	225.56	-	225.60	225.16	2.39	
MW-8D	236.96	236.55	236.94	235.99	235.24	235.23	235.77	235.37	1.57	↓
MW-8S	242.95	-	-	243.14	242.78	-	-	-	0.36	

Well#	Dec. 15, 2006	Jan. 31, 2007	Apr.7, 2007	July 3, 2007	July 31, 2007	Oct. 3, 2007	Aug., 2010	Oct., 2010	Maximum Difference (m)	Gradient
MW-10D	210.06	210.02	210.14	208.68	208.46	-	207.49	207.23	2.91	↓
MW-10S	211.58	211.54	211.83	210.93	210.65	-	210.41	209.66	2.17	
MW-11D	197.38	198.17	198.35	198.06	198.07	-	-	-	0.97	↓
MW-11S	205.40	205.98	206.05	205.83	205.48	-	-	-	0.65	

↑ Upward gradient, confined bedrock aquifer under overburden
↓ Downward gradient, unconfined overburden and bedrock aquifer
↔ Neutral gradient, both overburden and bedrock aquifers at same level

With the exception of MW-1D (located at the north extremity of the RSA on Old Brock Road), the fluctuations in water levels over a 4-year period ranges between 0.4 and 2.9 metres. This range of fluctuations similar to that observed in the streambed piezometers.

4.4.4 Groundwater Quantity and the Water Balance

The year 2007 was marked by numerous complaints regarding wells running dry. This section will examine the causes by means of a water balance and annual precipitation records.

The water balance is a concept based on the hydrologic cycle. Precipitation falling on the ground can be returned to the atmosphere by evaporation and plant transpiration (collectively called evapotranspiration), or soak into the ground (as Infiltration) or run along the surface of the ground (as Runoff).

In general, more than half of the annual precipitation returns to the atmosphere as evapotranspiration (or ET). The remainder, called the water surplus, is partitioned between the portion that soaks into the ground as Infiltration or recharge (INF) and the remainder that flows across the ground surface as runoff (RO).

In addition, there is a contribution of groundwater that flows downhill into the area of interest (GW_{in}) and the amount that subsequently flows out of the area (GW_{out}).

At its simplest, the water balance is a measure of how precipitation (P) is distributed between evapotranspiration (ET), infiltration (INF) and runoff (RO). This is expressed as:

$$P = ET + INF + RO \ (+ GW_{in} - GW_{out})$$

A water balance was calculated using the Thornthwaite and Mather (1957) empirical formula based on the average monthly precipitation and temperatures for the period 1971-2000 at the Hamilton Airport in **Table 4.4.6** for a fine sandy loam soil with deep-rooted vegetation (e.g. soy, soy or shrubs) and shallow-rooted vegetation (e.g. turf).

Table 4.4.6: Calculation of Evapotranspiration (ET) and Water Balance for a Silt and Fine Sand Loam in Greensville for different vegetation Cover

Month	Average Precipitation (mm)	Average Temperature (^{o}C)	Potential ET (mm)	Actual ET for silt loam, deep-rooted vegetation (mm)	Actual ET for sand loam shallow-rooted vegetation (mm)
January	65.8	<0	0	0	0
February	55.3	<0	0	0	0
March	74.9	<0	0	0	0
April	78.0	6.3	30.24	30.24	30.24
May	75.6	12.9	79.38	78.60	78.60
June	83.9	18.0	115.20	112.90	109.90
July	86.5	20.8	135.45	123.50	109.50
August	80.6	19.8	118.8	103.60	89.60
September	82.1	15.5	81.12	81.12	81.12
October	72.5	9.10	39.90	39.9	39.90
November	78.6	3.3	12.15	12.15	12.15
December	76.6	<0	0	0	0
TOTALS	910.4			582	551
WATER SURPLUS				328.4	359.4
INFILTRATION (0.6 of surplus)				197.0	215.6
RUNOFF (by				131.4	143.8

difference)					

* Infiltration calculation is based on hilly ground (0.1) + sandy loam soil (0.4) + cultivated ground (0.1)

A recent study by Earthfx (2015) using GSFLOW with PRMS and MODFLOW sub-models determined the actual evapotranpiration (AET) to be 576 mm/year. consistent with the above estimates of 551 and 582 mm/year.

Within the Greensville RSA (655.1 hectares = 6,551.000 m^3), assuming that 80% of the area is pervious and 20% is impervious, the annual quantities of water partitioned between evapotranspiration, infiltration and runoff are shown in **Table 4.4.7**.

Groundwater inflows from the north were estimated by means of Darcy's Law, using the measured hydraulic conductivities, head differences, gradients and porosities in the 10 monitor wells drilled by WHI (Schlumberger Water Services, 2008).

The average daily use of water by urban residents is calculated to be 285 litres per day per person (Environment Canada. 2005). The average value for infiltration from the Thornthwaite calculation (210 mm/year) is similar to the value proposed in the Tier 1 and Tier 2 Water Budget for the Mid-Spencer Creek Subwatershed (230 mm/year) from the Halton-Hamilton Source Protection (2010).

The volume of streamflow infiltrated in the ground (from "losing" streams) is considered to be low, given that the fraction of baseflow to total flow in Middle Spencer Creek is greater than 50% (Earthfx, 2010a, Table 5) and the fact that some of the streambed piezometers indicated both "gaining" and "losing" losing conditions. For these reasons, the contribution of streamflow infiltration was set at a nominal 1000 m^3/year and is discounted.

Table 4.4.7: A Simplified Water Budget for the Greensville RSA (Precipitation Only)

Annual Precipitation in cubic metres (m3)	Annual Evapo-transpiration on 80% Pervious Ground (m3)	Annual Infiltration on 80% Pervious Surfaces (m3)	Groundwater inflow from North (m3)	Total Groundwater recharge from infiltration and inflows from the north of the RSA (m3)	Annual Runoff on 80% Pervious Ground + 20% Impervious Surfaces (m3)	Annual Volume of Water used by residents @ 285 L/day (m3)	Annual Volume returned to ground by Septic Systems, assuming 85% of use (m3)
5,964,030	2,947,950	1,100,568	810,620	1,911,188	1,922,325	262,663	223,264

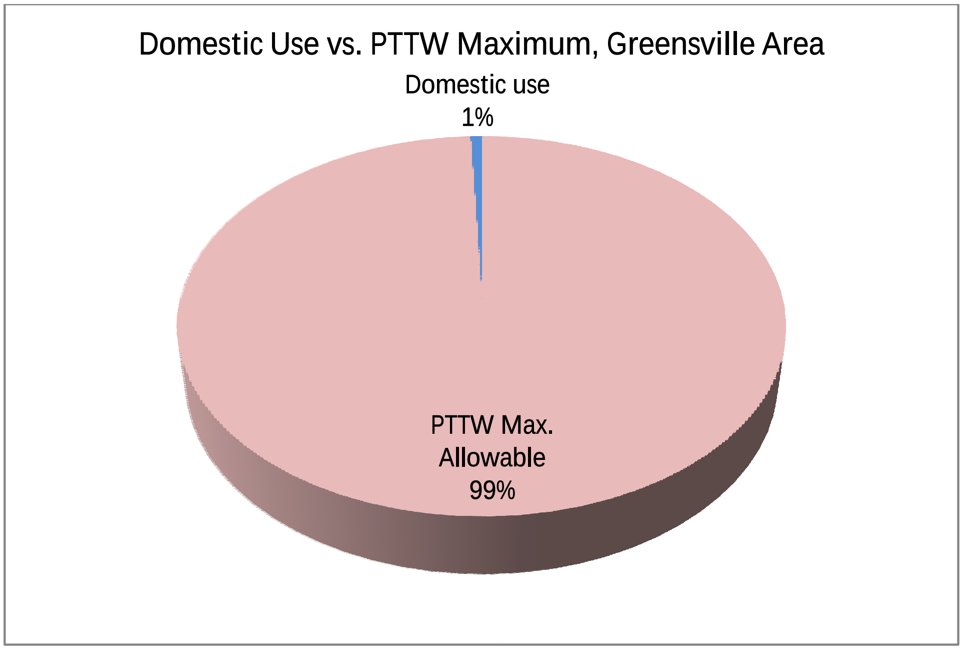
By this calculation, the residents of Greensville use approximately 14% of the available annual groundwater recharge from both infiltration and inflows from north of the RSA. The volume of groundwater flowing into the RSA from the north is subject to large uncertainties, but appears to be marginally less than the infiltration figure.

Permits to Take Water (PTTW) from groundwater sources have been controversial, particularly when residential wells run dry. There are several PTTW in and north of Greensville for food processing and quarry de-watering. These are listed in **Table 4.4.8**. It must be emphasized that these values are maximum amounts permitted. The actual amounts are unknown, but are generally much lower than the permitted amounts.

As shown in Figure 4.4.17, the total water demand in Greensville represents 1% of the maximum permitted groundwater withdrawls for industry and quarry dewatering.

Table 4.4.8: Industrial/Commercial Permits to Take Water in the Greensville Area

PTTW Number	**Name**	**Valid until**	Permitted Withdrawal (m3/year)	Average withdrawals (2007-2012)
	Flamboro Quarry	N/A	6,388,230	1,076,750
98-P-2050 (application)	Lafarge Canada - South Quarry	Renew to 2018	5,737,800	1,477,520
98-P-2051 (application)	Lafarge Canada - North Quarry	renew to 2018	18,398,190	4,325,615
N/A	Lafarge Canada – Railway Cut	N/A	6,412,320	3,896,375
69-P-0323 (renewal)	Rothsay – Well #1	Renew to 2020	191,151	47,852
00-P-2629	Rothsay – Well #2	Renew to 2020	66,430	13,177
80-P-2013 (renewal)	Rothsay – Well #3	Renew to 2020	66,430	13,177
2476-9F5KM6	City of Hamilton (Greensville Well	N/A	71,686	14,929
Total PTTW			37,273,108	10,865,393
Greensville RSA Total Domestic Water Demand			262,663	262,663
Greensville RSA Domestic Water Demand as a % of PTTW withdrawals			1.0%	2.0%



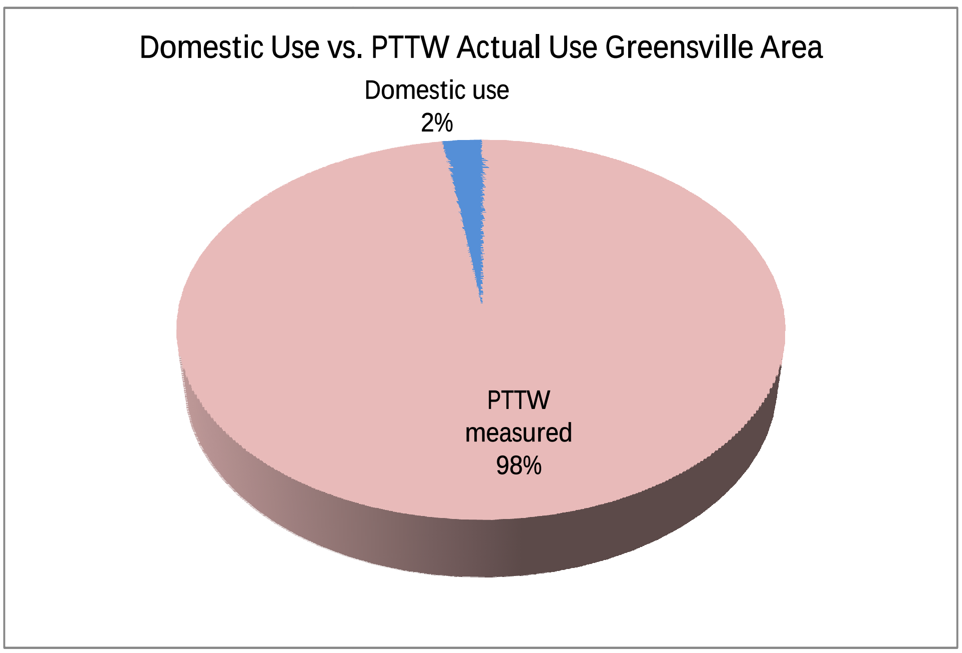


Figure 4.4.17: Groundwater Withdrawals in the Greensville Area PTTW and Domestic Wells

The effect of the variability of annual precipitation was examined to determine its impact on groundwater resources. The precipitation records for the Hamilton Airport are available for the years 1977 to 2011 (**Figure 4.4.18**). In 2007, precipitation was only three-quarters of the long-term average of 910.4 mm/year. That year a number of wells in Greensville ran dry. Precipitation for the years 2008 to 2011 returned to above the long-term average.

The water budget for the annual precipitation expected for a normal year (910.4 mm) was presented in **Table 4.4.6**, in which an infiltration rate of approximately 210 mm/year would be expected. The effect of a dry year (2007, with 702.2 mm precipitation) and the following wet year (2008, with 1,107.3 mm precipitation) are considered. **Table 4.4.9** shows equivalent calculations for normal, dry and wet years. It is apparent that 2007 was characterized by a 15% reduction in groundwater recharge, whereas 2008 was characterized by a 51% increase in groundwater recharge when compared to a "normal" year.

It is concluded that the natural variability of annual precipitation has a profound effect on the sustainability of groundwater resources. This effect will be exacerbated with development due to the increase in impervious surfaces (roads, driveways, roofs). If 20% of the developed lots are covered with impervious surfaces, the potential for groundwater recharge will be correspondingly lowered, unless infiltration targets are implemented.

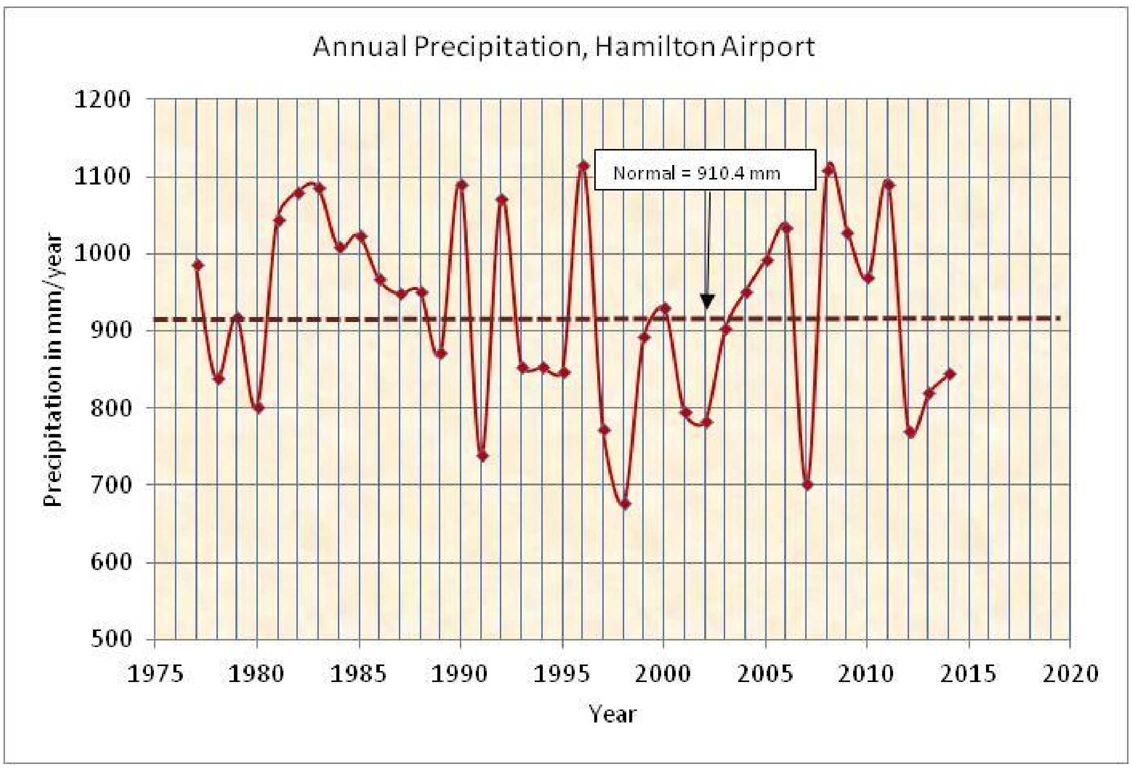


Figure 4.4.18: Annual Precipitation Records (1977-2014) for the Hamilton Airport

Table 4.4.9: Calculation of the Water Balance for Greensville for a normal year (1977-2000), a dry year (2007) and a wet year (2008) using records from the Hamilton Airport. Calculated for a fine sandy loam (water retention = 150 mm)

Month	Precipitation in a normal year (mm)	Actual ET for deep-rooted vegetation (mm)	Precipitation in a dry year (2007) (mm)	Actual ET for deep-rooted vegetation (mm)	Precipitation in a wet year (2008)	Actual ET for deep-rooted vegetation (mm)
January	65.8	0	82.8	0	47.4	0
February	55.3	0	60.2	0	117.6	0
March	74.9	0	56.0	0	95.4	0
April	78.0	30.24	56.8	23.52	64.2	43.68
May	75.6	78.60	28.6	74.60	68.4	64.26
June	83.9	112.90	32.6	80.60	103.4	118.4
July	86.5	120.50	39.2	64.20	148.6	135.45
August	80.6	98.60	41.0	54.00	108.4	113.40
September	82.1	81.12	52.6	56.60	109.1	81.12
October	72.5	39.90	68.6	57.00	53.8	37.05
November	78.6	12.15	66.8	7.29	82.8	7.29
December	76.6	0	117.0	0	111.8	0
TOTALS	**910.4**	574.0	**702.2**	417.8	**1107.3**	600.7
WATER SURPLUS	336.4		284.4		506.6	
INFILTRATION (0.6 of surplus)	**201.8**		**170.6**		**304.0**	
RUNOFF (by difference)	134.6		113.8		202.6	

4.4.5 Water Quality

The Greensville RSA has had a long history of water quality problems. Coliform bacteria and fecal bacteria (*E. Coli*) in wells have been documented in studies done in 1983, 2005 and 2008. The number of unsafe wells in each of the studies in summarized in **Table 4.4.10**. Unsafe water is defined as containing >10 CFU/100 mL of total coliform bacteria or the presence of any E. coli (or fecal coliform in earlier studies). These criteria have not changed for all three sampling events.

Table 4.4.10: Number and Percentage of Unsafe Wells in 1983, 2005 and 2008

1983	2005	2008
54 of 425 (12.4%)	17 of 169 (10%)	3 of 30 (10%)

A second water quality concern was nitrate in groundwater. The drinking water standard for nitrate is 10 mg/litre and is based on the known health effects of consuming water with elevated nitrate. Excessive levels of nitrate in drinking water have caused serious illness. The most serious is Methemoglobinemia in infants (aka Blue Baby Syndrome), due to the conversion of nitrate to nitrite by the body, which can interfere with the oxygen-carrying capacity of the child's blood. This can be an acute condition in which health deteriorates rapidly over a period of days. Symptoms include shortness of breath and blueness of the skin.

The two main sources of nitrate are agriculture (manure and fertilizers) and septic systems. Septic systems contribute approximately 40 gram of nitrate per person per day.

Figure 4.4.19 illustrates the distributions of nitrate in Greensville wells from studies done in 1983, 2005 and 2008. The data are reported as percentages of affected wells to permit a direct comparison.

The proportion of wells with detectable nitrate concentrations increased between 1983 and 2005. In 1983, 68% of wells had nitrate concentrations less than 5 mg/L, but by 2005, this fell to 29%. In 2008, the proportion of wells with less than 5 mg/L nitrate was again over 60% although none of the 30 sampled wells had nitrate concentration in excess of the drinking water standard of 10 mg/L.

The long-term nitrate concentration in groundwater in the Greensville municipal well (FDDG01) has been compiled for the years 2003 through 2013 in **Figure 4.4.20**. The steady-state nitrate concentration is approximately 6 mg/L. The 2008 survey also included a sample of water from the Briencrest communal well collected from a home on Kirby Avenue, which returned a nitrate concentration of 2.5 mg/litre.

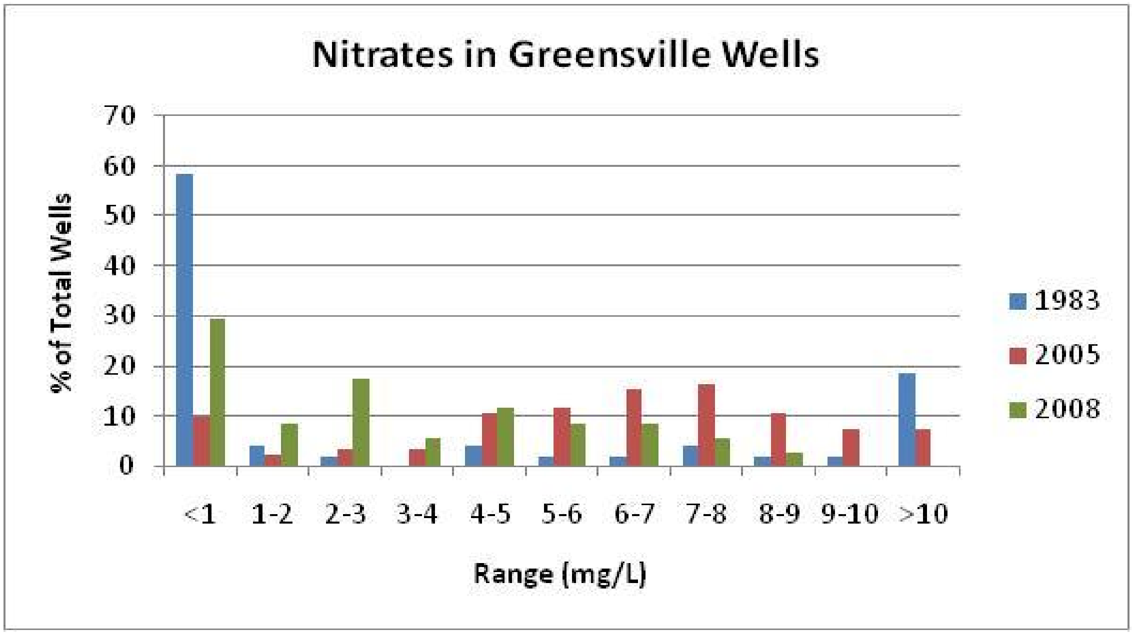


Figure 4.4.19: Nitrate Concentrations in Greensville Well Water (1983 – 2008)

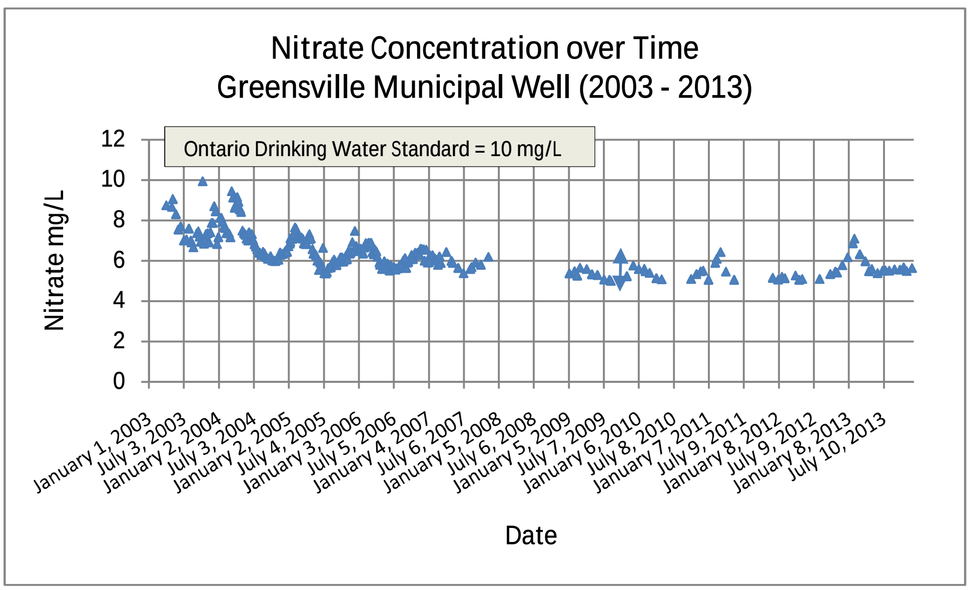


Figure 4.4.20: Nitrate Concentrations in the Greensville Municipal Well (2003 – 2012)

The ten monitor wells in the Greensville RSA were sampled for nitrates in 2007 as part of this study and again in 2010 by SNC Lavalin (2010). The results are summarized in **Table 4.4.11**.

Table 4.4.11: Greensville RSA Monitor Wells – Nitrate Concentrations 2007 - 2014 (mg/L)

	Jan. 30 – Feb. 8, 2007	April 17, 2007	Aug. 1, 2007	Aug. 4, 2010	Oct.14, 2010	**Sep. 24-26, 2013**
	This study			**SNC-Lavalin Inc.**		**City of Hamilton**
MW1-S	1.0	0.57	0.94	0.7	1.2	0.31
MW1-D	0.7	1.79	2.38	0.84	0.77	0.13
MW2-S	0.3	0.59	0.48	-	-	3.95
MW2-D	0.6	0.55	0.08	-	-	0.18
MW3-D	2.3	2.97	3.18	2.83	2.17	2.33
MW4-S	4.5	9.59	5.91	4.26	4.07	5.10
MW4-D	0.5	1.49	2.21	1.29	0.96	0.80
MW5-S	0.6	<0.05	0.13	0.43	<0.1	0.05
MW5-D	0.4	<0.05	<0.05	0.03	0.02	<0.05
MW6-S	<0.1	<0.05	<0.05	<0.02	<0.02	<0.05
MW6-D	0.6	0.56	0.53	0.02	0.02	<0.05
MW7-S	0.1	0.57	0.32	0.1	0.09	0.07
MW7-D	<0.1	0.21	<0.05	-	<0.01	0.10
MW8-S	-	-	0.06	<0.01	<0.01	<0.05
MW8-D	0.6	<0.05	<0.05	0.09	<0.05	0.10
MW10-S	0.8	1.33	0.74	0.9	0.46	0.18
MW10-D	1.7	2.74	2.9	2.39	1.83	1.56
MW11-S	1.2	0.63	<0.05	-	-	0.74
MW11-D	0.9	0.33	<0.05	-	-	<0.05

With the exception of MW-4S, located in Spencer Gorge parking lot off Harvest Road, the results are consistently lower than 3 mg/litre). Since the monitor wells were installed on public lands, the low nitrate concentrations at these undeveloped locations indicate that the problem with elevated nitrate in groundwater is localized to developed areas.

The problem with nitrates was further examined by considering that most of the groundwater extracted by residents is returned to the ground through the septic systems. We have assumed that 85% of the daily water use is returned to the ground by the on-site septic system. The percentage of water that is returned to the ground by residential septic systems would be approximately 17% of the total potential infiltration from precipitation (**Table 4.4.12**). It is emphasized that this excludes groundwater inflows from the north.

Table 4.4.12: Water Budget for Greensville RSA Including Groundwater Inflows from the North

Annual precipitation (P, m^3/year)	Potential Total Infiltration on 80% pervious surfaces in the Greensville RSA in m^3/year	Volume of septic effluent infiltrated, assumed to be 85% of water used by 2, 525 residents. (m^3/year)	Total Recharge from precipitation and septic systems (m^3/year	% of total recharge that originates from septic systems
5,963,120	1,100,568	223,264	1,323,832	17%

This simple calculation emphasizes that up to 1 out of every 6 litres of groundwater within the Greensville RSA could come from someone else's septic system.

The promotion of infiltration of precipitation is essential to the long-term sustainability of water quality, especially with regards to nitrate. Nitrate (like chloride and sodium) is a conservative substance, meaning that its concentration in groundwater is reduced principally by dilution.

4.4.6 Source Water Protection and Well Head Protection Area (WHPA)

The Clean Water Act (2006, Section 22) mandated a Tier 1 water budget evaluation and a groundwater and surface water quantity stress assessment (WQSA). The Tier 1 report identified the Middle Spencer Creek Subwatershed as having both a Moderate groundwater quantity stress and a municipal drinking water system. As such, a Tier 2 water budget and WQSA was completed (Hamilton Region Conservation Authority, 2010). The Tier 2 study confirmed the moderate stress level in the subwatershed and concluded that there were no components of the water stress that could be improved. A Tier 3 (complex water budget) incorporated three key areas of concern, namely water withdrawals from quarry operations, the cumulative impact of private well water takings and other water uses (e.g. the Rothsay rendering plant located 1.5 km northwest of the Greensville municipal well) and water quantity risk assessment was recommended for several reasons, including the fact that portions of the Middle Spencer Creek Subwatershed may draw water from the adjacent Logie's Creek and Grindstone Creek Subwatersheds. The Tier 3 risk assessment (EarthFX, 2014, 2015) addresses the possibility that a municipal groundwater supply (i.e. the Greensville municipal well) may not have sufficient water quantity to service existing and future populations (Halton-Hamilton Source Protection Committee, 2012). This study looked at a variety scenarios, some of which are beyond the scope of this study. Factors which were taken into consideration included future increases in water demand, build-out of the quarries and changes in land uses. Details of the findings are provided in Chapter 5 of the Earthfx Risk Assessment Report. The Tier 3 modeling improves the representation of groundwater recharge (using the PRMS sub-model) and the surface water flow system. The objective is to present state-of-the-art modeling to improve the management and protection of water resources.

The study entailed a Well Head Protection Area (WHPA) around the Greensville Municipal Well, developed by EarthFx (2010a,b) which is reproduced in **Figure 4.4.21** from the Source Water Protection Assessment Report (2012). The aquifer vulnerability and contributions from agricultural nitrate sources are shown in **Figure 4.4.22** and **Figure 4.4.23**, respectively.

The WHPA shows the times-of-travel (ToT), whereby a virtual particle of water is tracked backwards in time from the well to its point of recharge at surface over a length of time (2, 5 and 25 years). The 2-year time-of-travel for the municipal well extends north and west as far as Old Brock Road. The higher vulnerability area extends north as far as the Lafarge South Quarry

The vulnerability of the well recharge areas (**Figure 4.4.22**) was calculated using a Surface to Well Advection Time (SWAT), which is based on the actual travel time of a contaminant from surface to the well, The classification is as follows:

- Areas of High Vulnerability have travel times less than 5 years;
- Areas of Medium Vulnerability have travel times between 5 and 25 years; and,
- Areas of Low Vulnerability have travel times greater than 25 years.

Finally, **Figure 4.4.23** illustrates the potential for nitrate affecting the Greensville municipal well from agricultural inputs, based on the number of Nutrient Units (NU) per acre. As an example, a free stall Jersey milking cow would have a NU of 1.

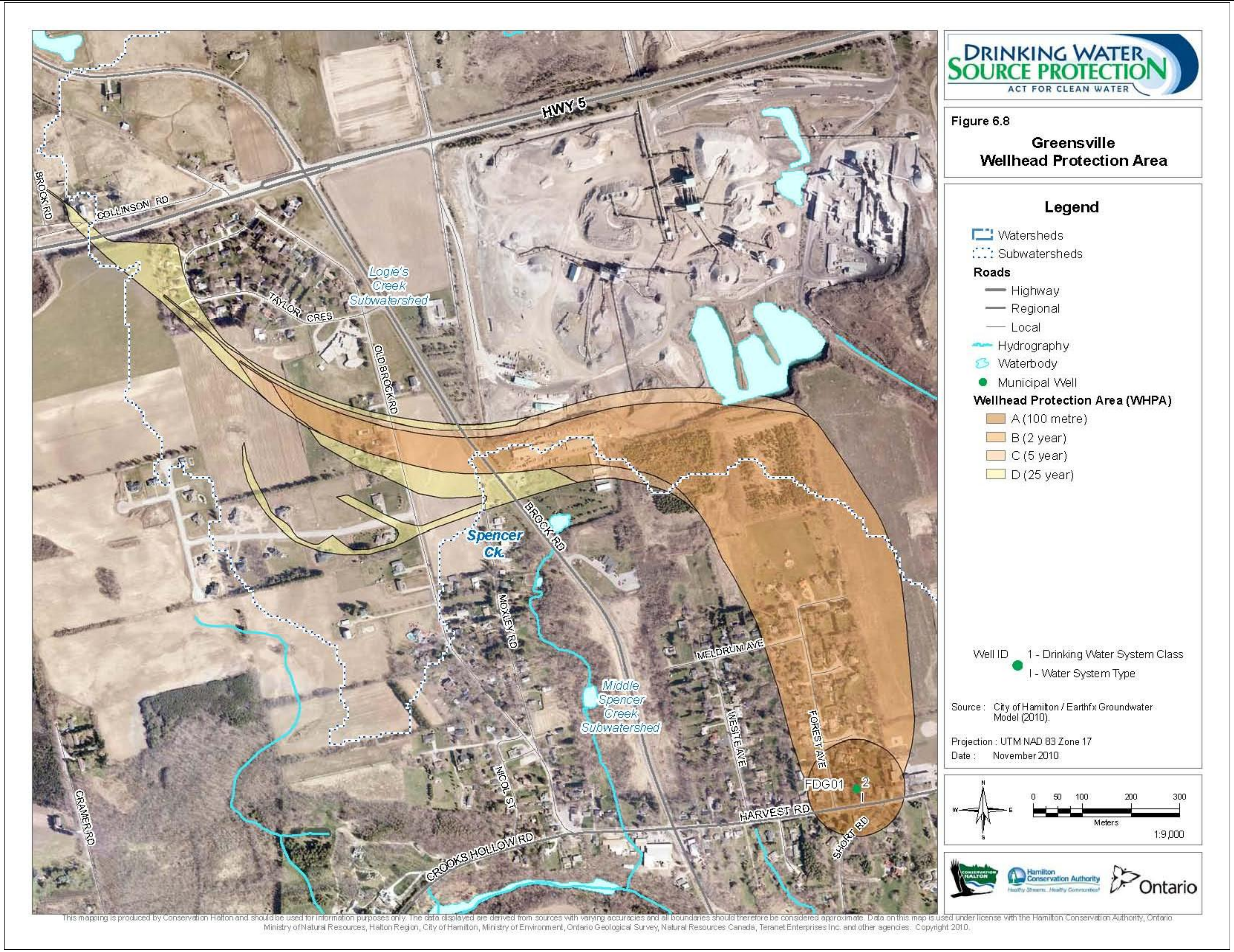


Figure 4.4.21: Well Head Protection Area for the Greensville Municipal Well

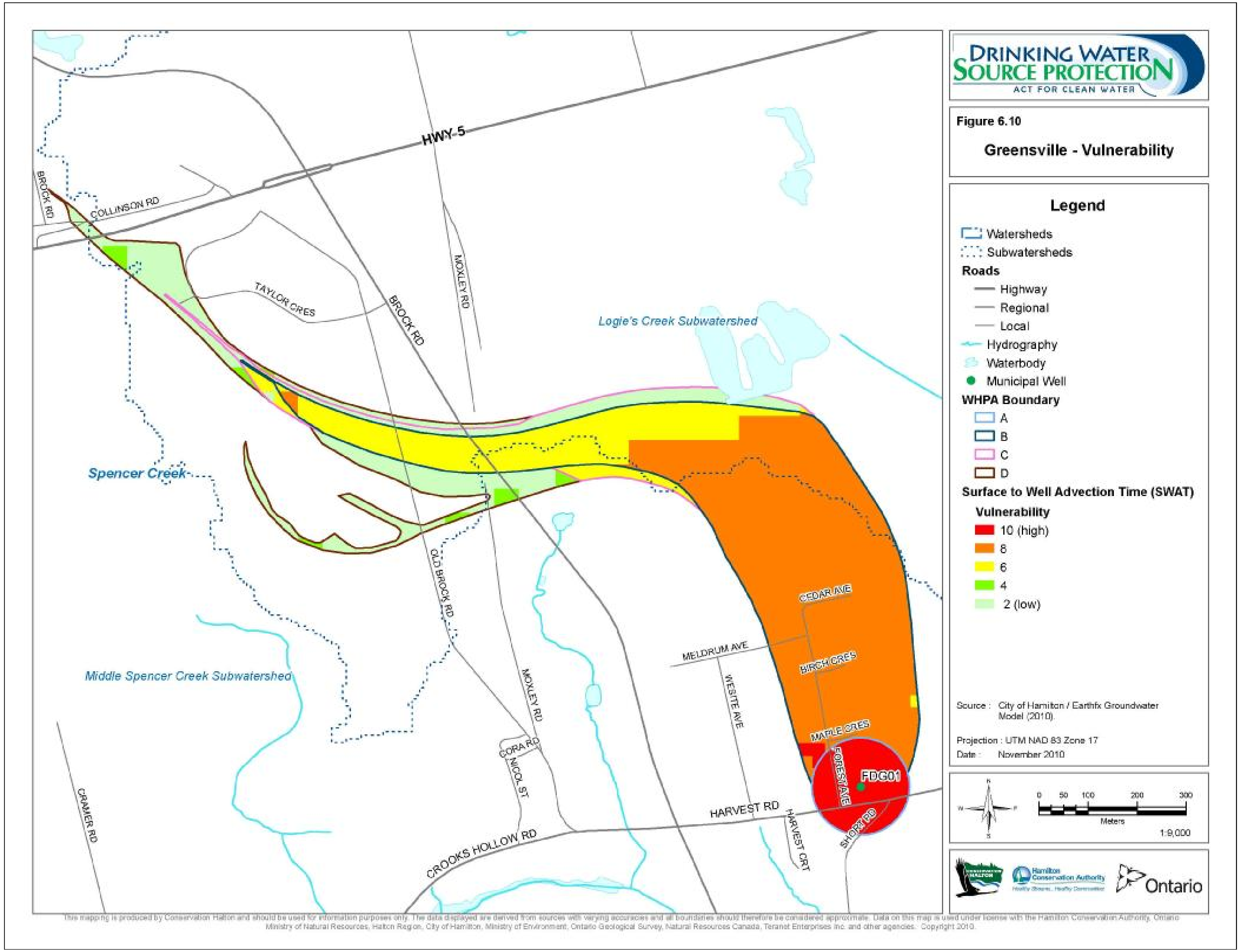


Figure 4.4.22: WHPA and Vulnerability of the Greensville Municipal Well

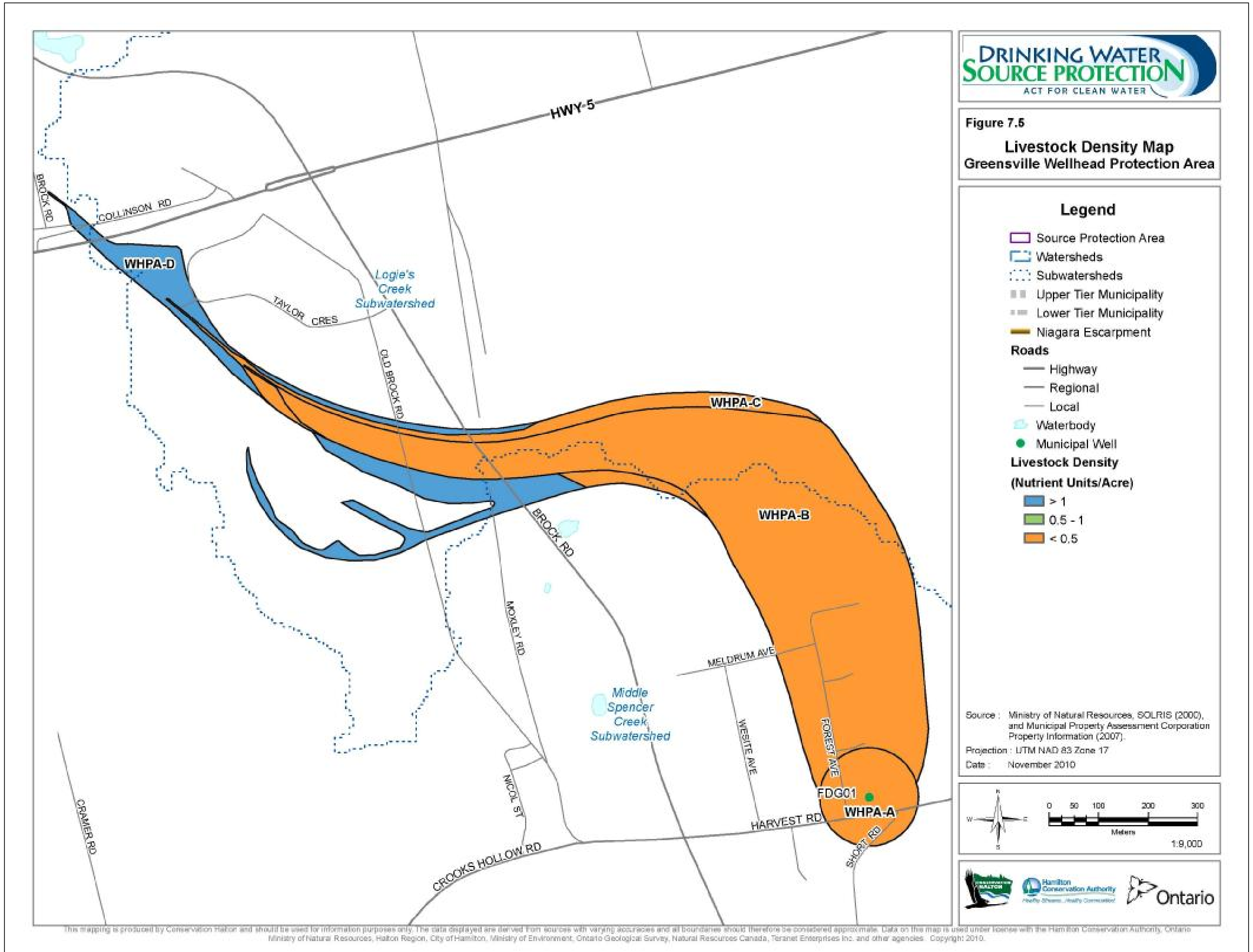


Figure 4.4.23: Nutrient Units within the WHPA for the Greensville Municipal Well

4.4.7 Summary and Conclusions

The Greensville RSA has a (2006) population of 2,525 in 925 homes with private septic systems. There are 900 recorded water wells, including the Greensville Municipal well that serves 36 homes (approximately 108 people) and the Briencrest Communal well (owned by the Infrastructure Ontario and managed by the Ontario Clean Water Agency) that serves 26 homes (approximately 75 people). The remainder of the population obtains water from individual wells.

There are two main aquifers in the RSA, namely an overburden sand aquifer (generally exploited where overburden depths are ≥30 metres) and a bedrock aquifer (the Guelph and/or upper Eramosa Formations) that is mainly productive in the upper 5 metres or so). Approximately 80% of the wells extend into the bedrock aquifer and the remaining 20% are located in the overburden aquifer. Throughout most of the RSA, it appears that both aquifers are hydraulically connected. Over the south half of the RSA, the bedrock consists of the Eramosa Member dolomite, which is often sulphur-bearing at depths greater than 5 metres. A deeper bedrock aquifer (the Gasport or Middle Amabel Formation) has been recognized, although few wells extend to it, except near the Niagara Escarpment.

A conceptual model of the recognized overburden and bedrock aquifers is presented in a block diagram in **Figure 4.4.24**.

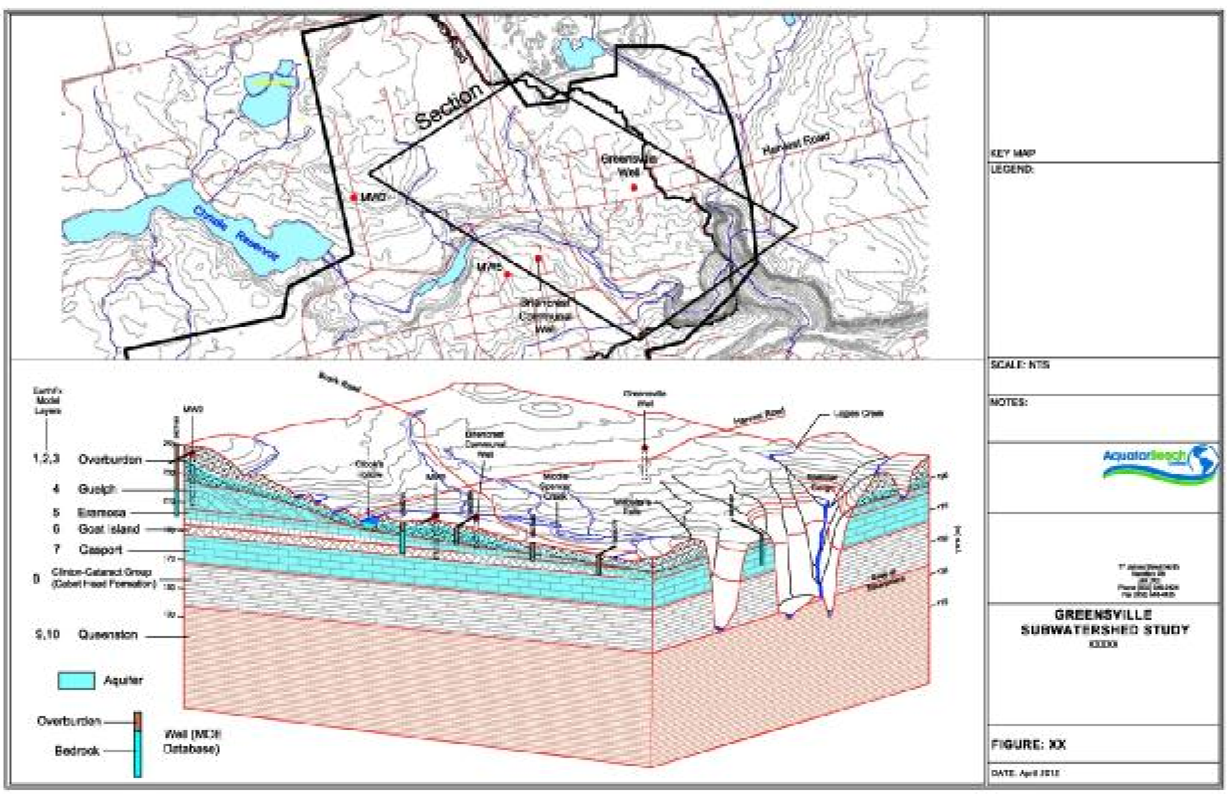


Figure 4.4.24: Conceptual Block Diagram of Greensville RSA Showing Recognized Aquifers

The groundwater gradients show a flow from northwest to southeast across the RSA towards the Niagara Escarpment.

Under existing conditions, the following two issues are addressed:

Water Quantity: in 2007, a number of wells that ran dry, mainly in the northern half of the RSA; and

Water Quality: Up to 10% of the wells are deemed unsafe due to bacteria. Nitrate concentrations are commonly elevated, although below the Drinking Water Standard of 10 mg/litre.

The main conclusions of the study regarding water quantity in Greensville are:

1. Current domestic water demand by Greensville residents (262,663 cubic metres per year) represents 12% of the available recharge from infiltration of precipitation and groundwater inflows from the north. Approximately 85% of the water used by residents is returned to the ground through individual on-site septic systems.

2. The volume of residential water that is returned to the ground via septic systems represents approximately 17% of the total recharge within the RSA. In other worlds, 1 out of every 6 litres of groundwater in the RSA may be derived from septic systems.

3. The maximum volume of groundwater that can be extracted under existing Permits to Take Water (PTTW) in, and north of, the RSA is 100 times greater than the water extracted by residents. The actual average volumes extracted are much lower than the permitted volumes. Between 2007 and 2012, the average PTTW withdrawals were less than 30% of their permitted maxima.

4. From the experience in 2007, it appears that the problems of water supply and wells running dry were due to a year where precipitation was less than 75% of its long-term average. Since 2008, the annual precipitation has been above average. The increase of groundwater recharge going from a dry year to a wet year can almost double, as shown in **Table 4.4.9**.

5. The Source Water Protection Assessment Report and Tier 1 water quantity stress assessment (WQSA) indicates that the Middle Spencer Creek Subwatershed has a moderate stress levels and a municipal water supply system. A Tier 2 confirmed the Middle Spencer Creek Subwatershed was moderately stressed with the PRMS model. The Tier 3 assessment upgraded the model, reflecting the complexity and variability of the groundwater – surface water interactions.

6. A vulnerability assessment and a delineation of the Well Head Protection Area (WHPA) were completed in 2010 for the City of Hamilton and the Greensville RSA. The WHPA for the Greensville municipal well is mainly contained within the RSA and the elevated vulnerability of the well to contamination at surface (including septic system) extends almost 900 metres north of the municipal well to the limit of the RSA.

7. Water quality concerns are principally due to incidences of bacterial contamination in the short term and to elevated nitrate in the longer term. It is noted that 10% of the water wells are unsafe to drink, including the Briencrest communal well.

8. Nitrate is elevated in many wells, although that number of wells that exceed the Ontario Drinking Water Standard of 10 mg/litre has decreased since 1983. The nitrate content of the Greensville municipal well has remained at <6 mg/litre since 2007.

9. With reference to the WHPA and long-term nitrate monitoring in the Greensville municipal well, it appears that nitrate contributed from north of the RSA is minor (less than 2 mg/L), due to the low contribution from agricultural sources. It appears that both bacteria and nitrates are derived from within the RSA, mainly from septic systems.

10. In 2004, the Hamilton-Halton Watershed Stewardship Program conducted a septic system awareness survey. Based on 992 responses, it was determined in 2004 that 56% of the respondents from Greensville had septic systems older than 25 years and some were older than 50 years. In a 2008 follow-up survey in the Greensville RSA, 35% of respondents had not had their septic tanks pumped in more than 6 years and 13% had never pumped their tank. Failing septic systems are a major contributor to bacteria in groundwater.

11. The importance of preserving and enhancing infiltration of precipitation is emphasized with nitrate, as the only mechanism available for reducing the concentration of nitrate in groundwater is by dilution. The long-term implications of the Water Quantity Stress Assessment (WQSA) by the Hamilton Conservation Authority and the 2012 Assessment Report of the Halton-Hamilton Source Protection Committee will be discussed further in Chapter 6.

4.5 Fluvial Geomorphology

4.5.1 Introduction

Fluvial geomorphology is the study of the processes associated with streams and rivers, including stream hydraulics and sediment movement. Variables that influence the morphology of a stream include discharge, velocity, sediment load and size, channel slope, and the width and depth of the channel. A change in one of these variables will eventually alter another variable causing the channel to adjust.

Land-use changes within a watershed can alter the amount of surface runoff and the amount of sediment reaching a stream. This can result in erosion and flooding problems, as well as poor aquatic habitat. Channel restoration works can mitigate the impacts of land-use change, through natural channel design or other river engineering approaches.

Study Objectives

Within the overall study goal of responsible environmental and economical management of water resources, the objective of the fluvial geomorphology component is to characterize stream and river channels, particularly with respect to erosion and channel stability. As such, detailed geomorphic assessments of watercourses have been completed within Greenville Rural Settlement Area (RSA) and general geomorphic assessments have been completed for the surrounding Middle Spencer Creek subwatershed. Specifically within the Greensville RSA, detailed geomorphic assessments include field sites for watercourses draining each of the three Major Development Areas (A, B, and C), including Middle Spencer Creek, Logies Creek, and the Greensville Tributary, respectively. Assessment of erosion and channel stability for stream reaches was completed using Rapid Geomorphic Assessment protocols (RGA – MOE, 1999). As well, detailed assessments within selected reaches included surveys of channel geometric properties (e.g., width, depth, gradient) and assessment of boundary materials (e.g., bed and banks). General geomorphic assessments for Middle Spencer Creek beyond the Greensville RSA identified and classified reaches based on dominant channel boundary materials (i.e., a key factor for interpreting potential channel erosion processes).

In addition to defining the existing stream morphology conditions, fluvial geomorphology is an important component for evaluating other natural features and functions within the study area. As such the results of the geomorphologic field investigation, when combined with results from other study disciplines (e.g., biology, hydrology, hydrogeology, water resources engineering), provides a thorough subwatershed perspective. Within the Greensville RSA, the geomorphic assessments provide a basis for recommendations with respect to development constraints (for sensitive stream reaches), mitigation of existing erosion problems, and opportunities for stream restoration which will improve future channel stability, protect infrastructure and property, and enhance ecological habitat.

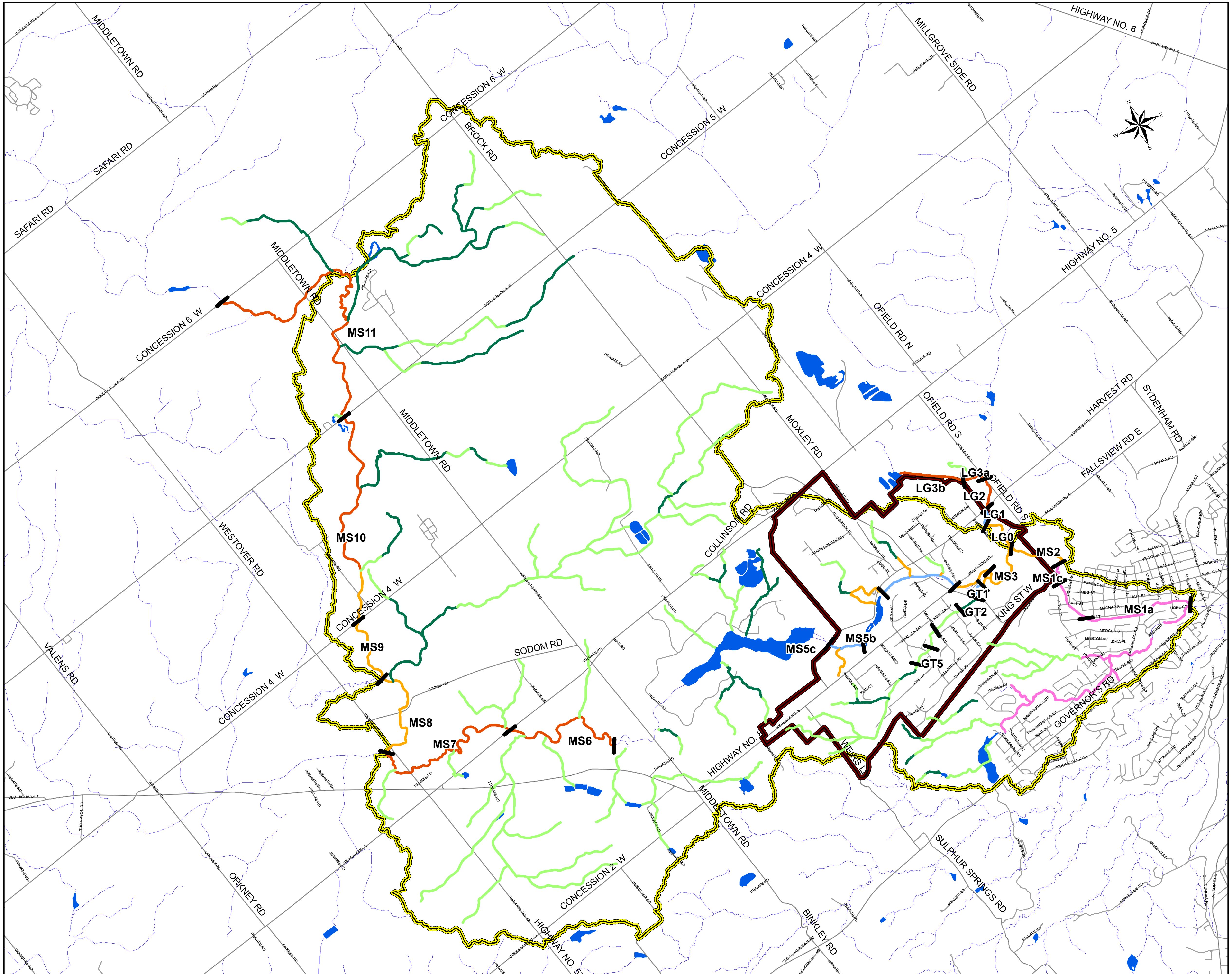
4.5.1.1 Location and General Description of the Mid-Spencer Creek Subwatershed

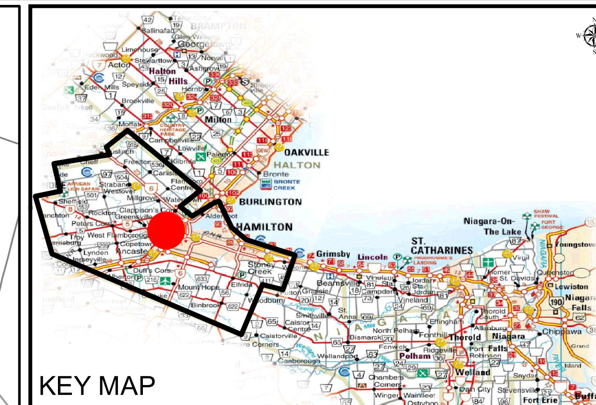
The Middle Spencer Creek Subwatershed Area begins near the confluence with Flamborough Creek and drains approximately 231 km^2 into the upper basin of Hamilton Harbour (Cootes Paradise). Catchments, which include Flamborough Creek, Westover Creek, West Spencer Creek, and Logies Creek, drain directly into the Middle Spencer Creek Watershed. The Upper Spencer Creek flows into the Middle Spencer Creek near the confluence with Flamborough Creek. Land-use within this watershed is classified as rural, with residential development located at the downstream limit of the watershed, within the Greensville Rural Settlement Area and the Town of Dundas.

The morphology of Middle Spencer Creek is controlled by the surrounding geology and the areas of urban development in the lower limits of the watershed. The channel throughout the watershed can be generally characterized based on boundary conditions as either hardened (urban), bedrock controlled, or alluvial (coarse or sandy) (**Figure 4.5.1**). The tributaries within the headwaters flow through wooded/forested swamps, agricultural land, and landscaped properties. The morphology of Middle Spencer Creek is also influenced by the Christie Dam and reservoir and the smaller Crooks Hollow Dam and Reservoir (now removed) (**Figure 4.5.2**). Dams and reservoirs can affect the morphology of the channel due to sediment impoundment upstream and controlled discharge from the reservoir. Downstream channel responses typically include degradation/incision, coarsening or fining of surface grain size distributions, and lateral adjustments (Grant et al., 2003). Middle Spencer Creek is classified as a sandy alluvial system upstream of Christies Dam and a coarse alluvial system with local bedrock controls downstream of the Dam (ultimately falling into the bedrock gorge).

The study area, and specifically the Greensville RSA, is composed of three catchments which include the Middle Spencer Creek and the two main tributaries, Logies Creek and the Greensville Tributary, which flow into it (**Figure 4.5.2**). The boundary conditions along Logies Creek transition from a sandy to coarse alluvial system in upstream reaches, to a bedrock controlled channel downstream (refer to **Figure 4.5.1**). The upper portion of the Greensville Tributary consists of landscaped grass swales and wooded area swales, transitioning to coarse alluvial systems, and bedrock controlled channels in the downstream section (refer to **Figure 4.5.1**).

Confluences for Logies Creek and the Greensville Tributary with the Middle Spencer Creek are located downstream of the waterfalls that exist for all three watercourses as the channels flow over the escarpment. Middle Spencer Creek becomes extensively modified below the escarpment as it flows through the Town of Dundas. The lower reaches of Spencer Creek transition from the Bedrock Controlled gorge to dominantly Hardened Urban Channel conditions within the Town of Dundas.





LEGEND:

- Mid-Spencer Creek Subwatershed Boundary
- Reach Break **LG3a** Reach ID
- Bedrock Controlled
- Coarse Alluvial
- Hardened - Urban
- Sandy Alluvial
- Tributary - Grass - Agricultural - Landscaped Swale
- Tributary - Wooded Area Swale - Riparian Wetland
- Rural Settlement Area

NOTES:

0 0.5 1 2
Kilometers

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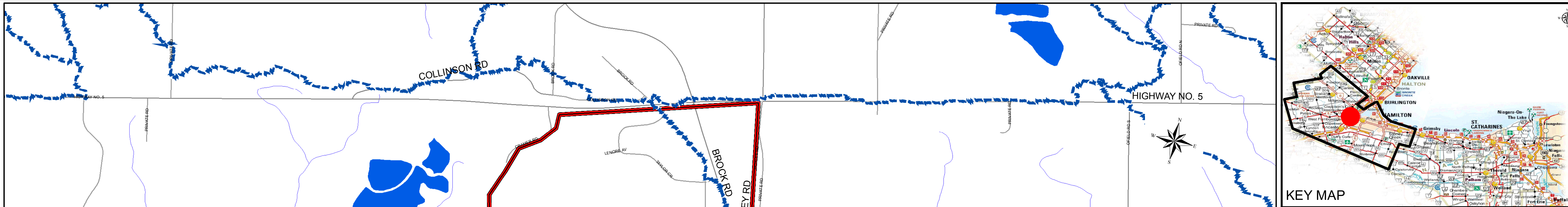
Fax: (905) 546-4435

GREENSVILLE SUBWATERSHED STUDY

Geomorphic Characteristics

FIGURE: 4.5.1

DATE: February 2016



LEGEND:

- Subwatershed Boundary
- Rural Settlement Area
- Site Specific Assessment
- Reach Breaks **LG3a** Reach ID

Geomorphic Site Priorities

- High Priority
- Moderate Priority

NOTES:

0 0.5 1
Kilometers

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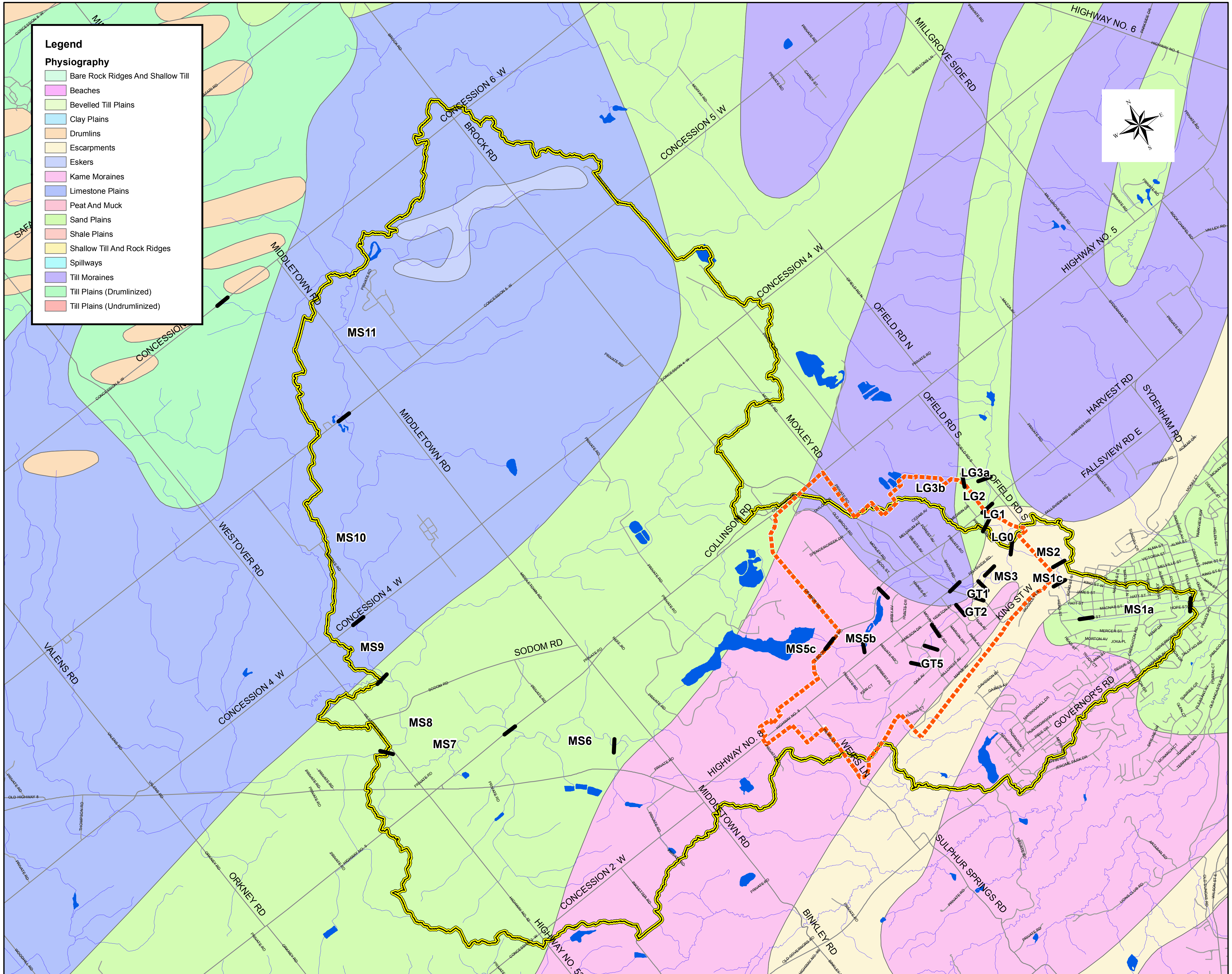
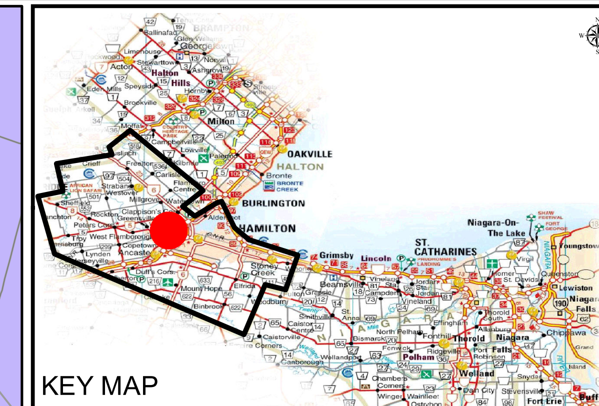
GREENSVILLE SUBWATERSHED STUDY

Geomorphic Characteristics

FIGURE: 4.5.2

DATE: February 2016





KEY MAP

LEGEND:

Mid-Spencer Creek Subwatershed Boundary

Rural Settlement Area

Reach Breaks

NOTES:

0 0.5 1 2 3

Kilometers

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GREENSVILLE SUBWATERSHED STUDY

Physiography

FIGURE: 4.5.3

DATE: February 2016

4.5.1.2 Drainage Characteristics and Surface Geology

4.5.1.2.1 Logies Creek

Logies Creek, within the former municipal boundary of Flamborough, has a drainage area of 13.3km^2 (Hamilton Conservation Authority, 2009). Only a small portion of the watercourse is within the study area of the Greensville Rural Settlement Area. The southernmost extent reaches Spencer gorge south of Harvest Road and the confluence of Logies Creek with Middle Spencer Creek is approximately 4km downstream of Christie Lake Reservoir (Hamilton Conservation Authority, 2009).

The surface geology of Logies Creek varies from upstream to downstream within the study site as the channel transitions from an alluvial system to a bedrock controlled watercourse **(Figure 4.5.3**). The upper reaches are dominated by silty and sandy loam sediments, but as the watercourse flows closer to the edge of the escarpment coarser grained particles dominant. Once the watercourse flows over the escarpment at Tew's Falls it becomes completely bedrock controlled.

4.5.1.2.2 Greensville Tributary

Greensville Tributary catchment is within the Greensville Rural Settlement Area and has a drainage area of 2.1km^2. The headwaters for this watercourse begin just west of Weirs Line and the watercourse enters into the Middle Spencer Creek east of Brock Road, just downstream of Webster's Falls.

Similar to Logies Creek, the surface geology of the Greensville Tributary transitions from fine and coarse textured soils to a bedrock system. The upstream reaches are dominantly silty and sandy loam but as the watercourse flows towards the edge of the escarpment, coarser material is present and the bedrock is exposed **(Figure 4.5.3**).

4.5.1.2.3 Middle Spencer Creek

The portion of Spencer Creek that falls within the study area begins just downstream of the Christie Lake Dam and Reservoir and this Dam controls the flow rate for the downstream watercourse. The drainage area for this section of Middle Spencer Creek is 83.9 km^2.

Dominant soil textures found within this portion of Middle Spencer Creek are sandy and silty clay loams. The watercourse is predominantly a coarse-grained alluvial system with bedrock exposed immediately downstream of the Christie Lake Dam, and increasing bedrock control as the watercourse approaches the escarpment and bedrock gorge **(Figure 4.5.3**).

4.5.2 Methodology

In order to determine existing conditions within the specified watercourses and assess the channel stability, Detailed Geomorphic Assessments were completed at three sites (i.e., draining each of the three Major Development Areas of the Greensville RSA), including detailed channel surveys and Rapid Geomorphic Assessments (RGA, MOE, 1999).

4.5.2.1 Rapid Geomorphic Assessments (MOE, 1999)

Rapid Geomorphic Assessments were conducted along the watercourses during the reconnaissance level field walks. These field walks through the channel were conducted to collect data in order to characterize the current geomorphic state and to aid in the selection of sites for the detailed geomorphic assessments. This process uses visual indicators to determine whether the stream is stable or in adjustment. Stability is determined by adjustments in slope, either an increase (aggradation) due to sediment deposition or a decrease (degradation) due to bed erosion. It also considers an increase in the bank to bank width (widening) and indicators suggesting a change in the planform regime (planimetric form adjustment). Evidence of aggradation, degradation, channel widening, and planimetric form adjustment are determined using the form in **Appendix D**.

4.5.2.2 Detailed Geomorphic Assessments

Detailed geomorphic assessments were conducted on all 3 watercourses, one site per watercourse. In addition to the RGA, each geomorphic assessment involved a detailed survey of the field sites shown in **Figure 4.5.2**. This allowed for documentation of stream sections that are suitable for long term monitoring. These sites were then surveyed using a Total Station in order to determine the geometric properties of the channel (e.g., width, depth, gradient). The following data was collected at each site: planimetric form, longitudinal profile, channel cross sections, bank and bed material composition, and photographic documentation

4.5.2.2.1 Logies Creek

A number of limitations contributed to the site assessment location for Logies Creek. Only a small portion of the Logies Creek Watershed is actually within the Greensville Rural Settlement Area and further limitations included channel geology and channel alterations. The downstream reaches are completely bedrock controlled and the upstream reach has been historically modified through channelization and at times flows through landscaped properties. The site assessment was chosen within an alluvial section of Logies Creek that does not show evidence of significant historic modifications or erosion problems and therefore provides suitability for long term monitoring of channel adjustment. This section is located ~100m upstream of Harvest Road (**Figure 4.5.2**).

4.5.2.2.2 Greensville Tributary

The detailed geomorphic assessment along the Greensville Tributary was completed both upstream and downstream of Brock Road, where the channel is highly controlled by the hydraulics of the road culvert (aggradation upstream; degradation downstream). A poorly defined channel flows through a wooded area in the upstream reach and appears to be impacted by an under-sized culvert at the Brock Road crossing. Downstream of the crossing, the channel becomes entrenched and steep eroded banks are present. While highly modified, this site represents the most worthwhile location for monitoring in terms of potential adjustments to future land uses, and in terms of potential opportunities for improving watercourse conditions. By comparison, residential development in the upper portion of this watershed has led to direct modifications of the watercourse through landscaped properties, therefore making most reaches undesirable for monitoring.

4.5.2.2.3 Middle Spencer Creek

The upper portions of Middle Spencer Creek within the Greensville Rural Settlement Area contain the Christie's Lake Dam and Reservoir, and formerly contained the Crook's Hollow Dam and Reservoir (now removed). Evidence of a historical dam/weir was also identified during the reconnaissance field walk, a few hundred meters upstream of Brock Road. These features will have an impact on the morphology of the channel and therefore do not provide ideal locations for long term monitoring. The field site for the detailed geomorphic assessment was chosen downstream of Brock Road due to the fact it is dominantly alluvial and locally has minimal impacts from historic dams and existing infrastructure. Further downstream the channel flows through a Conservation Area and over the escarpment into a bedrock controlled valley.

4.5.3 Existing Conditions

4.5.3.1 Stream Reach Delineation and Rapid Geomorphic Assessment Results

Documentation of existing channel conditions was conducted during the geomorphic field assessment and by using the Rapid Geomorphic Assessment Protocol. Field walks which ere completed in 2007, also allowed stream reaches to be delineated by key factors that include hydrology, channel gradient, geology, valley setting, sinuosity, and riparian vegetation. These reaches therefore display similar channel characteristics, functions, and processes which can be used as a guide for management objectives and restoration opportunities.

The Rapid Geomorphic Assessment protocol was applied to all reaches within the Greensville Rural Settlement Area except reaches that were completely bedrock controlled or altered through channelization and landscaping. Based on the Rapid Geomorphic Assessment results, the reaches are classified as 'stable', 'transitional', or 'in-adjustment', refer to **Table 4.5.1** for descriptions of classifications.

Table 4.5.1: Rapid Geomorphic Assessment Descriptions Based on Index Value

Stability Index Value	Stability Class	Description
0 – 0.25	Stable	Channel morphology is within the expected range of variance for stable channels of similar type. Channels are in good condition with minor adjustments that do not impact the function of the watercourse.
0.25 – 0.40	Transitional	Channel morphology is within the expected range of variance but with evidence of stress. Significant

		channel adjustments have occurred and additional adjustment may occur.
0.40 – 1.0	In Adjustment	Metrics are outside of the expected range of variance for channels of similar type. Significant channel adjustments have occurred and are expected to continue.

(MOE, 1999)

4.5.3.1.1 Logies Creek

Fieldwork completed along Logies Creek resulted in the watercourse being divided into 5 reaches (refer to). Fieldwork protocol documented the existing conditions and provided insight into existing form and process for Logies Creek. The results of the Rapid Geomorphic Assessment for each reach are within **Table 4.5.2** and detailed descriptions of each reach are discussed in Section 4.5.3.1.1.1.

Table 4.5.2: Reach Breaks and Rapid Geomorphic Assessments for Logies Creek

Reach ID ~ Length (m)	Location	Rapid Geomorphic Assessment Score	Dominant Form/Process	Classification
L-0 484m	Confluence with Mid-Spencer Creek to just upstream of Tews Falls	N/A	Completely Bedrock Controlled	N/A
L-1 232m	Just upstream of Tews Falls to Harvest Road	0.52	Evidence of Aggradation and Evidence of Degradation	In Adjustment
L-2 383m *Contains Detailed Field Site	Harvest Road to confluence adjacent to Ofield Road	0.36	Evidence of Widening	Transitional
L-3a 279m	Confluence adjacent to Ofield Road to channelized section	N/A	Landscaped Yards and Channelized	N/A
L-3b 633m	Channelized section to Quarry outlet	0.23	Minor Evidence of Aggradation and Planimetric Form Adjustment	Stable

Note: RGA Scores 0 - 0.25 = Stable; 0.25 – 0.40 = Transitional; 0.40 – 1.0 = In Adjustment (MOE, 1999)

4.5.3.1.1.1 Reach Descriptions – Existing Conditions

Logies Creek Reach L-0

Reach L-0 (**Figure 4.5.4**) begins at the confluence to Mid-Spencer Creek and ends at Tews Falls, which drops 41m over the Niagara Escarpment (Hamilton Conservation Authority, 2009). This step-pool system is completely bedrock controlled and the bed of the creek is lined with large boulders and cobbles. The riparian zone consists of wooded area with deciduous trees, shrubs, and herbaceous vegetation. Large woody debris and leaning trees are present at various locations across the channel. The watercourse is confined within a valley system and for a large portion of the reach the channel banks are continuous with the valley slopes. At these locations, an unstable channel bank could cause an unstable valley slope, resulting in mass movement and large woody debris within the channel. Due to the fact that this reach is completely bedrock controlled, no Rapid Geomorphic Assessment was conducted.

Logies Creek Reach L-1

Reach L-1 (**Figure 4.5.5**) of Logies Creek begins just upstream of Tews Falls and ends at Harvest Road. This alluvial reach has poorly sorted coarse material along the bed varying in size from boulders, cobbles, gravels, and fines. Indicators of channel adjustment through aggradation is present with evidence that the watercourse is depositing sediment in the overbank zone, as well as slugs of sediment deposited on the bed in the form of lobate bars. Riffle and pool morphology is present along this reach but it is variable and not well defined. The riparian zone consists of herbaceous vegetation, shrubs, and deciduous trees. Steep banks composed of fine sediment, are partially vegetated and exposed roots are visible through the majority of the reach. A suspended armor layer, consisting of larger particles, is present within the bank and a terrace has cut through older bar material. These features are indicators of degradation occurring within the reach. Knickpoints and erosion along the bed exposing the overburden/bedrock are also indicating that the channel is adjusting through degradation. This can also be identified by the exposed footings present at the bridge within the reach. The Rapid Geomorphic Assessment classifies this reach as ‘in adjustment’. While this reach may be moderately sensitive to future development, the existing channel is already experiencing significant adjustments due to natural processes and historic land use changes.

Logies Creek Reach L-2

Reach L-2 (**Figure 4.5.6**) of Logies Creek begins at Harvest Road and ends at the confluence adjacent to Ofield Road. The channel is a well defined, low to moderate sinuous meandering channel with pools and riffles present. The channel bed is lined with cobbles and small boulders, as well as unconsolidated fines which cause the water to become turbid when disturbed. The coarse material along the bed is embedded and siltation in the pools indicates that sediment deposition is occurring throughout the reach. Bank vegetation consists of deciduous trees and herbaceous vegetation. Channel adjustment through widening has been identified through bank instability causing bank vegetation to be deposited within the channel resulting in large organic debris jams. As a result of aggradation, the channel is adjusting its planimetric form through the creation of flood chutes and the channel thalweg not in alignment with meander geometry. The Rapid Geomorphic Assessment classifies this reach as ‘transitional’. This reach is considered moderately sensitive to future development, and given its transitional stability it is considered the most appropriate location for monitoring.

Logies Creek Reach L-3a

Reach L-3a **(Figure 4.5.7**) of Logies Creek begins at the confluence adjacent to Ofield Road and ends within a channelized section. This section of the watercourse flows through a cornfield and a landscaped yard, providing little diversity of native species in the riparian zone and also affecting the canopy cover over the channel. No Rapid Geomorphic Assessment was completed for this reach.

Logies Creek Reach L-3b

Reach L-3b (**Figure 4.5.8**) of Logies Creek begins within the channelized section and ends downstream of the quarry. This entrenched reach has been channelized and the bed morphology varies from a poorly defined pool-riffle form to low bed relief form. The stream bed composition consists of poorly sorted, unconsolidated fine sediment with few cobbles present. Deposition of unconsolidated fines has been identified within the pools, providing evidence of aggradation. The planimetric form of this channel has been historically altered through the channelization of the watercourse and evidence of adjustment is occurring through poorly formed bars and a thalweg alignment that does not follow the geometry of the channel. The stream banks are composed of fine material with local coarse fill and the riparian vegetation is deciduous and herbaceous vegetation. The Rapid Geomorphic Assessment classifies this reach as ‘stable’, however, the reach exhibits evidence of significant human modification and few natural geomorphic features exist.

Figure 4.5.4 (Left): Logies Creek Reach L-0

Figure 4.5.5 (Right): Logies Creek Reach L-1

Figure 4.5.6 (Left): Logies Creek Reach L-2

Figure 4.5.7 (Right): Logies Creek Reach L-3a

Figure 4.5.8: Logies Creek Reach L-3b

4.5.3.1.2 Greensville Tributary

Greensville Tributary has been divided into 6 reaches after completion of fieldwork along the watercourse. Fieldwork also provided insight into existing form and process for Greensville Tributary. The results of the Rapid Geomorphic Assessment are within **Table 4.5.3** and detailed descriptions of each reach are discussed in Section 4.5.3.1.2.1.

Table 4.5.3: Reach Breaks and Rapid Geomorphic Assessments for Greensville Tributary

Reach ID ~ Length (m)	Location	Rapid Geomorphic Assessment Score	Dominant Form/Process	Classification
GT-0 160m	Confluence with Middle Spencer Creek to the Waterfall	0.21	Evidence of Degradation and Widening (minor evidence of aggradation)	Stable
GT-1 200m *Contains Detailed Field Site (downstream)	Waterfall to Brock Road	0.31	Evidence of Degradation and Widening (minor evidence of aggradation and planimetric form adjustment)	Transitional
GT-2 240m *Contains Detailed Field Site (upstream)	Brock Road to Downstream of Park Ave	0.38	Evidence of Planimetric Form Adjustment and Aggradation (minor evidence of widening)	Transitional
GT-3 385m	Downstream of Park Ave to Mountain View Road to	N/A	Landscaped yards	N/A
GT-4 237m	Mountain View Road to Grandview Court	0.18	Evidence of Aggradation and Planimetric Form Adjustment	Stable
GT-5	Headwater channels	N/A	Variable definition and vegetated swales	N/A

Note: RGA Scores 0 -0.25 = Stable; 0.25 – 0.40 = Transitional; 0.40 – 1.0 = In Adjustment (MOE, 1999)

4.5.3.1.2.1 Reach Descriptions – Existing Conditions

Greensville Tributary Reach GT-0

Reach GT-0 of Greensville Tributary (**Figure 4.5.9**) begins at the confluence with Middle Spencer Creek and ends at the waterfall downstream of Brock Road. This is a bedrock channel that contains poorly sorted coarse material, varying in size from boulders, cobbles, gravels, and fines, along the reach bed. Multiple knickpoints and a waterfall are present within this reach and the channel has worn into undisturbed overburden/bedrock. These features, as well as exposed bridge footings and an undermined vertical bank protection structure, indicate that the channel is adjusting through degradation. The wooded area, consisting of deciduous trees, shrubs, and herbaceous vegetation, surrounds the channel on both sides of the watercourse. Evidence of bank instability is present through exposed tree roots and scour along the toe. Fracture lines on top of the bank were also noted in number of locations and private properties exist at the top of bank. Some alluvial material/fill is present in the banks at the upstream end of the reach. The Rapid Geomorphic Assessment classified this reach as 'stable', primarily due to limited rates of adjustment from bedrock control.

Greensville Tributary Reach GT-1

Reach GT-1 of Greensville Tributary (**Figure 4.4.10**) begins at the waterfall and ends at Brock Road. Various sizes of bed material exist along the channel bed ranging in size from small boulders, cobbles, gravel, to fines. The bed material is poorly sorted along this reach and bed morphology is also poorly defined, changing from a pool-riffle form to low bed relief form. This entrenched reach has exposed bridge footings, undermined structural features along the bank, and a large scour pool downstream of the Brock Road culvert indicating that degradation is the dominant process occurring in the reach. Bank instability, in the form of exposed tree roots and scour at the toe of the bank, is present throughout the reach along the steep banks. Riparian vegetation is dominated by deciduous trees and herbaceous vegetation, but landscaped yards exist beyond the top of bank. The Rapid Geomorphic Assessment classifies this reach as 'transitional', but the channel is highly controlled by landscaped and armoured banks, and by the significant hydraulic effects of the culvert at Brock Road (**Figure 4.5.2**).

Greensville Tributary Reach GT-2

Reach GT-2 of Greensville Tributary (**Figure 4.5.11**) begins at Brock Road and ends downstream of Park Ave. An undersized culvert exists at the Brock Road crossing. Fieldwork identified this section of Greensville Tributary as a poorly defined channel with some local standing pools and minimal flow. Poorly sorted, loose, unconsolidated material is present along the bed, as well as deposited within the pools. Good floodplain access for channel flows indicates that the reach is not entrenched, but there is evidence that the watercourse is depositing sediment in the overbank zone, indicating aggradation. Numerous indicators that the channel is adjusting its planimetric form due to aggradation are present within this reach. Poorly formed bed morphology is present within the channel, as well as flood chutes and bifurcation of the channel. Deciduous and coniferous trees and herbaceous vegetation surround the channel providing a large canopy over it. Numerous locations of large organic debris within the channel are present. The Rapid Geomorphic Assessment classifies this reach as 'transitional', however, the apparent long-term effects of aggradation due to backwater from the Brock Road culvert are considered to be significant.

Greensville Tributary Reach GT-3

Reach GT-3 of Greensville Tributary (**Figure 4.5.12)** is located between Park Ave and Mountainview Road. Good floodplain access indicates that the channel is not entrenched but there is an abundant amount of herbaceous vegetation within the channel indicating a low energy gradient and suggesting it is vegetation controlled. Fine sediment dominants the channel bed material but coarser particles can be found at the road crossings. The channel banks are mostly root bound soils and the watercourse flows through landscaped yards. No Rapid Geomorphic Assessment was completed for this reach.

Greensville Tributary Reach GT-4

Reach GT-4 of Greensville Tributary (**Figure 4.5.13**) begins at Mountainview Road and ends at Grandview Court. The channel is variably defined and locally marshy, and dominated with herbaceous vegetation within the channel, suggesting a low energy gradient. Poorly sorted bed sediment can be found in pools and has caused coarse material to be embedded in riffles. Deposition of sediment by the watercourse was identified in the overbank zone. The riparian buffer consists of landscaped yards with manicured lawns, deciduous and coniferous trees, and herbaceous vegetation. The Rapid Geomorphic Assessment classified this reach as 'stable'; however, stability is largely controlled by the local effects of vegetation control and the maintenance of landscaped yards.

Greensville Tributary Reach GT-5

The upper reaches of the Greensville Tributary (**Figure 4.5.14**) are classified as headwater streams. No Rapid Geomorphic Assessment was completed for this reach due to the fact that the channels have variable definition and morphology is classified as vegetated swales.

Figure 4.5.9 (Left): Greensville Tributary Reach GT-0

Figure 4.5.10 (Right): Greensville Tributary Reach GT-1

Figure 4.5.11 (Left): Greensville Tributary Reach GT-2

Figure 4.5.12 (Right): GreensvilleTributary Reach GT-3

Figure 4.5.13 (Left) : Greensville Tributary Reach GT-4

Figure 4.5.14 (Right): Greensville Tributary Reach GT-5

4.5.3.1.3 Middle Spencer Creek

Middle Spencer Creek, within the Greensville RSA, has been divided into 4 reaches. Existing conditions were recorded during completion of fieldwork and provided insight into existing form and process for the watercourse. The results of the Rapid Geomorphic Assessment are in **Table 4.5.4** and detailed descriptions of each reach are discussed in Section 4.5.3.1.3.1.

Table 4.5.4: Reach Breaks and Rapid Geomorphic Assessments for Middle Spencer Creek

Reach ID ~ Length (m)	Location	Rapid Geomorphic Assessment Score	Dominant Form/Process	Classification

MS-3 763m	Confluence with Logies Creek to Webster Falls	N/A	Completely Bedrock Controlled	N/A
MS-4 490m	Webster Falls to Highway 8	0.31	Evidence of Degradation	Transitional
MS-5a 961m *Contains Detailed Field Site	Highway 8 to Crooks Hollow Dam	0.46	Evidence of Aggradation and Degradation (minor evidence of widening and planimetric form adjustment)	In Adjustment
MS-5b 504m	Crooks Hollow Dam to Downstream of Crooks Hollow Road	0.32	Evidence of Aggradation (minor evidence seen of planimetric form adjustment, widening, and degradation)	Transitional
MS-5c 152m	Crooks Hollow Road to Christie Dam	N/A	Bedrock Channel	N/A

Note: RGA Scores 0 -0.25 = Stable; 0.25 – 0.40 = Transitional; 0.40 – 1.0 = In Adjustment (MOE, 1999)

4.5.3.1.3.1 Reach Descriptions – Existing Conditions

Middle Spencer Creek Reach MS-3

Reach MS-3 of Middle Spencer Creek (**Figure 4.5.15**) begins at the confluence with Logies Creek and continues to Webster's Falls, flowing through the Webster's Falls Conservation Area. The bed of the channel is bedrock with varying sizes of coarse material. Bed morphology is an irregular step-pool morphology with multiple knickpoints, including a large waterfall that exists along the reach. Similar to Reach L-0 of Logies Creek, channel banks are continuous with the valley banks through the majority of the reach due to the confined valley system. These locations could be more prone to mass movement and large woody debris entering the watercourse if the channel banks become unstable. The riparian zone is a wooded area consisting of deciduous trees and herbaceous vegetation. No Rapid Geomorphic Assessment was completed along this reach due to the fact that it is completely bedrock controlled.

Middle Spencer Creek Reach MS-4

Reach MS-4 of Middle Spencer Creek (**Figure 4.5.16)** is located between Webster's Falls and Highway 8. The majority of this reach flows through the Webster's Falls Conservation Area. Near the Falls a pedestrian bridge over the channel and a stone wall along the right bank exist.

The channel boundary is dominantly bedrock, but also consists of coarse material ranging in size from cobbles, gravels, and fines. Numerous locations exist where the channel has worn into the undisturbed overburden/bedrock. Erosion along the moderate to steep bank slopes is present in the form of exposed tree roots and fallen/leaning trees. There is also a suspended armor layer, composed of coarse material visible within the bank. Herbaceous vegetation and deciduous trees dominant the riparian zone for this reach. The Rapid Geomorphic Assessment classifies this reach as 'transitional', which is at least partially associated with natural processes of degradation as the watercourse approaches the bedrock gorge.

Middle Spencer Creek Reach MS-5a

Reach MS-2 of Middle Spencer Creek **(Figure 4.5.17)** begins at Highway 8 and ends at Crooks Hollow Dam. The poorly sorted bed substrate is composed of cobbles and small boulders, with gravel and fine sediment. The morphology of the channel is a poorly formed riffle-pool formation. The presence of lobate bars and medial bars indicates that the flow is unable to transport the sediment, possibly due to channel widening, and therefore deposits the sediment along the bed. This channel has a high width to depth ratio and deposition of sediment in the overbank zone was identified. Other identifiers of adjustments in sediment deposition and transport that cause planimetric form change are the formation of an island and the bifurcation of the channel in a number of locations. A number of grade control features exist within this reach. The upstream end of this reach is Crooks Hollow Dam and further downstream an old dam/weir present. The old dam/weir is not channeling spanning and therefore may only act as a localized confinement instead of a grade control structure. Evidence of degradation can be found throughout the reach. An exposed pipe is present along the bed and areas where the channel has worn into the undisturbed overburden/bedrock are present. A terrace has cut through older bar material and a suspended armor layer composed of larger particles is visible within the bank. Locations exist where the channel banks are continuous with the valley banks and an unstable channel bank could result in an unstable valley slope. Deciduous trees and herbaceous vegetation dominate the wooded area in the riparian zone and private properties exist at the top of bank. Bank instability has been noted in exposed tree roots along the bank, leaning or fallen trees, and large organic debris within the channel. A local erosion site has been identified upstream of Brock Road along the left bank (looking upstream, see(**Figure 4.5.2**). The Rapid Geomorphic Assessment classifies this reach as 'in adjustment', which in additions to watershed conditions is interpreted to be due to abundant sediment supply, moderately high channel gradients, and the existing and historic effects of dams and grade control structures.

Middle Spencer Creek Reach MS-5b

Reach R-5b of Middle Spencer Creek **(Figure 4.5.18)** starts at Crooks Hollow Dam and ends downstream of Crooks Hollow Road. Poorly sorted substrate material consists of various sizes of particles from fines to small boulders. Lobate and medial bars along the bed indicate that the channel is unable to transport the sediment load and adjustment through aggradation is occurring. The increase in sediment deposited along the bed results in planimetric form adjustment, such as the island present, as the channel attempts to increase the bed slope and sediment transport rate.

Evidence of channel bed lowering was identified by the partially exposed bridge footings and the numerous knickpoints present. This reach contains poorly formed bed morphology and is adjusting from riffle-pool morphology to a low bed relief form. The wooded area surrounding the channel is composed of herbaceous vegetation and deciduous trees. The Rapid Geomorphic Assessment classifies this reach as 'transitional', stating that the morphology is within the expected range of variance but there is evidence of stress.

Middle Spencer Creek Reach MS-5c

Reach MS-5c of Middle Spencer Creek **(Figure 4.5.19)** begins at Crooks Hollow Road and ends at Christie Dam. This is a bedrock channel that has various sizes of coarse material along the bed and multiple knickpoints are present within this reach. No Rapid Geomorphic Assessment was completed at this site due to the bedrock control.

Figure 4.5.15 (Left): Middle Spencer Reach MS-3

Figure 4.5.16 (Right): Middle Spencer Reach MS-4

Figure 4.5.17 (Left): Middle Spencer Reach MS-5a

Figure 4.5.18 (Right): Middle Spencer Reach MS-5b

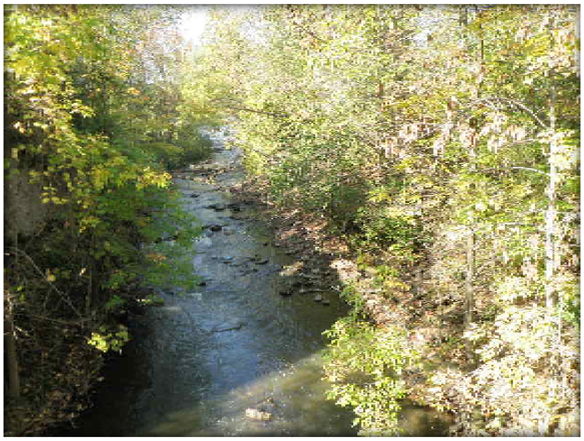

Figure 4.5.19: Middle Spencer Reach MS-5c

4.5.3.2 Detailed Geomorphic Assessments

4.5.3.2.1 Existing Conditions

Detailed geomorphic assessments along Logies Creek, Greensville Tributary, and Middle Spencer Creek allowed for documentation of geometric properties of the channel. Determination of the existing planimetric form, longitudinal profile, cross sections, and bed and bank material composition for these sites provides the basis for long term monitoring and restoration opportunities.

4.5.3.2.1.1 Logies Creek

Completion of a detailed field site investigation provided the planform, bankfull geometry, and bed morphology properties for the Logies Creek site (site summaries are within **Appendix E**). The Logies Creek field site exhibits a curved to locally sinuous planform with irregular development of meander bends (partially due to influence of vegetation and large woody debris) (**Figure 4.5.20**). The average width of the channel is 4.01 m and the average bankfull depth is 0.74 m, representing a relatively narrow and deep cross-section with a low width-to-depth ratio (w/d = 5.65). The total survey length of the field sites is about 75 m with an average channel gradient of 0.28 %. Riffles and pools are locally developed, but formation and maintenance is irregular due to the influence of woody debris and irregular meander bend development. The average riffle pool spacing is 8.0 m and the average riffle gradient is 2.69%.

Substrate materials are dominantly gravel and sand, with cobbles also representing the coarsest fraction (greater than ~D_{90}). The average grain size of the substrate (D_{50}) is 25 mm, or coarse gravel. Due to the irregular development of the bed morphology and the loose nature of the substrate, the channel is not considered a threshold channel and critical erosion thresholds for the channel are recommended to be based on the D_{50} grain size, rather than the coarse fractions (e.g.,

D_{84}). Bank materials are dominated by sandy loam with low to moderate cohesion from clay fractions. Although bank materials are locally exposed due to bank erosion, vegetation in the form of long grasses, herbaceous species, and tree rooting do locally provide some protection (**Figure 4.5.21**).

The selected field site on Logies Creek within Reach LG-2 represents the section of the watercourse which is considered "closest" to a natural equilibrium with the prevailing hydrology and sediment supply, despite the "Transitional" classification and local effects of large woody debris. While historic land uses locally and within the watershed have likely impacted the channel at this site, it is considered the best location for monitoring development impacts within the watershed upstream. In addition to managing future land use change impacts on hydrology and sediment supply in the watershed, specific opportunities for stream restoration on Logies Creek within the Greensville RSA include:

- Replacement and realignment of the Harvester Road culvert between Reaches LG-1 and LG-2.
- Advocate for naturalized channel conditions within private yards, Reaches LG-2 and LG-3a.
- Consider future options for naturalization of Reach LG-3b in development plans.

Figure 4.5.20 (Left): Logies Creek Detailed Site

Figure 4.5.21 (Right): Logies Creek Detailed Site

4.5.3.2.1.2 Greensville Tributary

Completion of a detailed field site investigation provided the planform, bankfull geometry, and bed morphology properties for the Greensville Tributary site (refer to **Appendix E** for site summary). The Greensville Tributary field site exhibits a straight to locally curved planform which is significantly controlled by the culvert at Brock Road. The planform downstream of the road culvert exhibits a slight sinuosity due to alternating bank erosion processes (**Figure 4.5.22**).

Upstream of the road culvert the average width of the channel is approximately 5.16 m and the average bankfull depth is 0.37 m, representing a moderate width-to-depth ratio (w/d = 14). By comparison downstream of the road culvert the average width of the channel is approximately 9.96 m and the average bankfull depth is 1.76 m, representing a low width-to-depth ratio (w/d = 6) associated with a locally high degree of channel entrenchment. The total survey length of the field sites is about 140 m (approx. 93 m upstream and 47 m downstream of the road centerline) with an average channel gradient of 2.0% (very low gradient upstream, high gradient through the crossing, and moderate gradient downstream). Riffles and pools are poorly developed upstream of the road due to dominantly fine grained aggradation and a low channel gradient (**Figure 4.5.23**). The bed morphology is partially developed downstream of the road with low-relief riffles and pools due to higher degrees of erosion and bedload transport. A significant scour pool is maintained immediately downstream of the road culvert which has exposed undisturbed glacial material.

Substrate materials upstream of the road are dominantly fine grained sands, silts, clays, and organic mud (due to long-term aggradation upstream of culvert and low channel gradient). Downstream of the road the substrates are much coarser consisting of mostly gravel, with some cobble sized material. The average grain size of the substrate (D_{50}) downstream of the road is 26 mm, or coarse gravel. The channel sections upstream and downstream of the road are not considered to be threshold channels, with high potential for erosion upstream (under increased flows or channel gradients) and high existing erosion processes downstream.

As such, critical erosion thresholds for the channel downstream of the road are recommended to be based on the D_{50} grain size, rather than the coarse fractions (e.g., D_{84}). Upstream of the road, critical erosion thresholds are not appropriate as the entire channel and floodplain would be very susceptible to watershed changes in hydrology. However, the backwater effects of the existing road culvert are expected to support continued aggradation rather than erosion. Improvements to the culvert size and flood conveyance recommended below will require special consideration the channels vertical alignment (i.e., long profile) and boundary materials potentially some distance upstream and downstream of the road crossing. Bank materials downstream of the road are dominated by gravel, loam, and clay loam, with moderate to high cohesion from clay fractions where gravel is absent. Banks downstream of the road are steep and actively eroding, with sediment inputs resulting in local bar accumulations within the channel. Persistent erosion due to hydraulic conditions downstream of the culvert is expected to sustain channel degradation and lateral planform adjustments into the future.

The selected field site on the Greensville Tributary spans both Reach GT-1 and GT-2, and thus represents two distinct channel conditions which are strongly influenced by the low capacity design of the Brock Road culvert. While this field site represents heavily modified channel conditions, by comparison with the other reaches of the Greensville Tributary it is the least influenced by artificial landscaping, vegetation, and bedrock controls. The selected field site represents the location of the highest potential for natural alluvial-channel processes and the most significant opportunity for stream restoration (and enhanced flood conveyance) along the watercourse. In addition to managing future land use change impacts on hydrology and sediment supply in the watershed, specific opportunities for stream restoration on the Greensville Tributary within the Greensville RSA include:

- Replacement and realignment of the Brock Road culvert between Reaches GT-1 and GT-2 (**Figure 4.5.2**). This option will require special consideration of culvert size (i.e., flood conveyance) and for the vertical and horizontal realignment of the existing channel, particularly upstream of Brock Road. Vertical realignment of the channel may require either large areas of sediment removal (and vegetation) with replacement of some coarse grained boundary material; or else a hardened drop structure of armourstone immediately upstream of the road (with intermediate option of an engineered boulder-type step-pool channel).
- Advocate for naturalized channel conditions within private yards, all reaches.

Figure 4.5.22 (Left): Greensville Tributary Detailed Site

Figure 4.5.23 (Right): Greensville Tributary Detailed Site

4.5.3.2.1.3 Middle Spencer Creek

Completion of a detailed field site investigation provided the planform, bankfull geometry, and bed morphology properties for the Middle Spencer Creek site (site summaries are within **Appendix E**). The Middle Spencer Creek field site exhibits a straight to slightly curved planform with lateral floodplain processes including vegetated bar/island formation, channel bifurcations, abandoned channels, and evidence of avulsions (more prominent in Reach MS-5a upstream and downstream of the survey site) (**Figure 4.5.24**). The average width of the channel is 11.97 m and the average bankfull depth is 0.50 m, representing a relatively wide and shallow cross-section with a high width-to-depth ratio (w/d = 25.99) (**Figure 4.5.25**). The total survey length of the field sites is about 100 m with an average channel gradient of 1.04%. Riffles and pools are poorly developed as the high gradient and high bedload sediment supply maintain a relatively consistent riffle-run bed morphology, with local bar-pool bedforms. The local riffle gradients are as high as 4.37% and the riffle spacing is estimated at ~7m, but these parameter estimates are not considered relevant to the prevailing bed morphology. The high channel gradient, high width-depth ratio, and high degree of floodplain access are consistent with expectations for dynamic channel and floodplain processes which result from moderate to high levels of coarse bedload transport (and relatively low storage volumes of fine-grained materials in the floodplain). This has produced a quasi-braided type channel pattern, which is the product of, or is at least emphasize by, historic and existing dams within Reach MS-5a and upstream.

Substrate materials are dominantly cobble with some gravel and minor sand fractions. The average grain size of the substrate (D_{50}) is 70 mm, or small cobbles. Due to the apparent mobility of the coarse bed material and poorly developed bed morphology, the channel should not be considered a threshold channel and critical erosion thresholds for the channel are recommended to be based on the D_{50} grain size, rather than the coarse fractions (e.g., D_{84}). Bank materials are dominated by gravel and thin accumulations of loam, with low to moderate cohesion from clay fractions. Although trees, shrubs, and grasses provide some protection on semi-stable banks and bars within the floodplain, the high stream energy of the reach is capable of local bank erosion and floodplain avulsions due to bar flow deflections and/or floodplain chute formation.

The selected field site on Middle Spencer Creek within Reach MS-5a represents the section of the watercourse which is considered to be the least impacted by local dam effects, despite the "In Adjustment" classification and widespread channel dynamics due to bedload transport. While historic land uses locally and within the watershed have likely impacted the channel at this site, it is considered the best location for monitoring development impacts within the watershed as currently exhibits the most stable alluvial cross-sections within the reach (i.e., dominantly single channel, lacking fully active channel bifurcation or floodplain chute). Other sections of Reach MS-5a have multiple dynamic channels and/or local influences of historic dams (or grade controls). In addition to managing future land use change impacts on hydrology and sediment supply in the watershed, specific opportunities for stream restoration on Middle Spencer Creek within the Greensville RSA include:

- Stabilize bank along south valley wall immediately upstream of Brock Road.
- Mitigation or removal of old dam and weir structures in the channel, Reach 5a specifically.

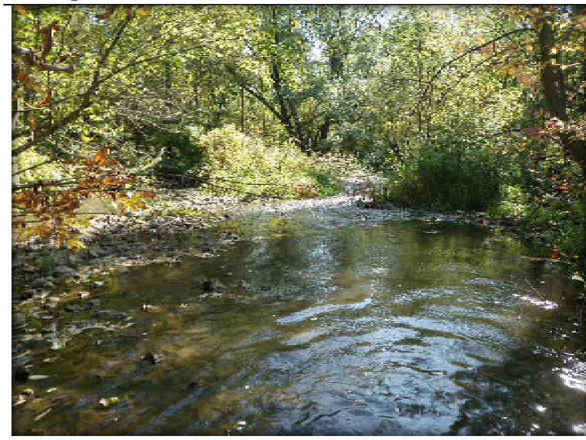


Figure 4.5.24 (Left): Middle Spencer Creek Detailed Site

Figure 4.5.25 (Right): Middle Spencer Creek Detailed Site

4.5.4 Conclusions and Recommendations

The objective of the fluvial geomorphology component is to characterize stream and river channels, particularly with respect to erosion and channel stability. General and detailed geomorphic assessments of watercourses have been completed within Middle Spencer Creek watershed and Greenville Rural Settlement Area (RSA), respectively. Specifically within the Greensville RSA, detailed geomorphic assessments include detailed field sites for watercourses draining each of the three Major Development Areas (A, B, and C), including Middle Spencer Creek, Logies Creek, and the Greensville Tributary, respectively. Assessment of erosion and channel stability for stream reaches was completed using Rapid Geomorphic Assessment protocols (RGA – MOE, 1999).

Middle Spencer Creek which receives tributary runoff from Development Area A, and specifically within Reach MS-5a, is considered to be fluvially dynamic with respect to bedload transport and lateral stability, however it is unclear to what degree this is the product of existing and historic dams and grade control structures within the channel (wholly or partially). While the current mobility of the bed material produces a largely unstable channel pattern within the floodplain of Middle Spencer Creek within Reach MS-5a, the main branch is not expected to be sensitive to hydrological (or sediment supply) changes from the small tributaries draining Development Area A. Bedrock controlled reaches downstream such as MS-4 and MS-3 (gorge) are also not expected to be sensitive to development impacts in terms of fluvial geomorphological processes.

Logies Creek, and specifically its west branch upstream of Ofield Road, receives runoff from Development Area B. Reaches LG-1 and LG-2 specifically are considered to be moderately sensitive to development related impacts due to erodible alluvial boundary materials and existing signs of stress and adjustment. Although Reach LG-1 is currently considered to be in adjustment, channel instability could be increased by significant changes to the hydrology or sediment supply. Reach LG-1 is considered to be in a transitional condition relative to historic land use changes, and is the most important reach in terms of managing and monitoring the land use changes upstream in the watershed. Portions of Reaches LG-2 (upstream) and LG-3a are maintained with artificial or landscaped banks within private properties, so monitoring or predicting channel stability locally under these conditions is not feasible. Reach LG-3b is the product of significant historic modifications and Reach LG-0 is entirely bedrock controlled (and relatively insensitive to fluvial impacts in the watershed).

The Greensville Tributary receives runoff from Development Area C, and conveys flows through an existing residential area. As such, from a fluvial geomorphology perspective managing, predicting, and/or monitoring of channel stability and erosion are not feasible. In particular, locally variable modifications and maintenance of channel boundaries (banks and beds) within landscaped yards or along heavily vegetated channels does not allow for generalized assessments of fluvial processes and reach scale channel stability. These conditions overshadow the geomorphic assessments of Reaches GT-3 to GT-5 of the Greensville Tributary. Reaches GT-1 and GT-2 are, however, considered to be moderately sensitive to watershed land use changes which might change the hydrology and sediment supply. This said, existing conditions at the transition between GT-1 and GT-2 (at Brock Road) are highly controlled by the hydraulics of the undersized culvert at the road. While it is recommended that the culvert at Brock Road be replaced, special considerations for channel restoration are required to deal with a reasonably long history of aggradation and degradation, upstream and downstream of the road respectively. Bedrock control at Reach GT-0 downstream is expected to limit any potential development impacts in terms of fluvial geomorphological processes.

Within the Greensville RSA, the completed geomorphic assessments have identified an number of opportunities to mitigate historic impacts and/or restore stream forms and functions from both geomorphological and ecological perspectives (see **Figure 4.5.2** for restoration options).

High Priority Restoration Options

- Greensville Tributary – Replacement of culvert at Brock Road (see discussion Section 4.5.3.2.1.2)
- Middle Spencer Creek – Stabilize bank upstream of Brock Road (see discussion Section 4.5.3.2.1.3)

Moderate Priority Restoration Options

- Logies Creek – Replacement of culvert at Harvester Road (see discussion Section 4.5.3.2.1.1).
- Logies Creek – Consider restoration options for naturalization of Reach LG-4b
- Middle Spencer Creek – Removal dam structures, Reach MS-5a (see discussion Section 4.5.3.2.1.3)