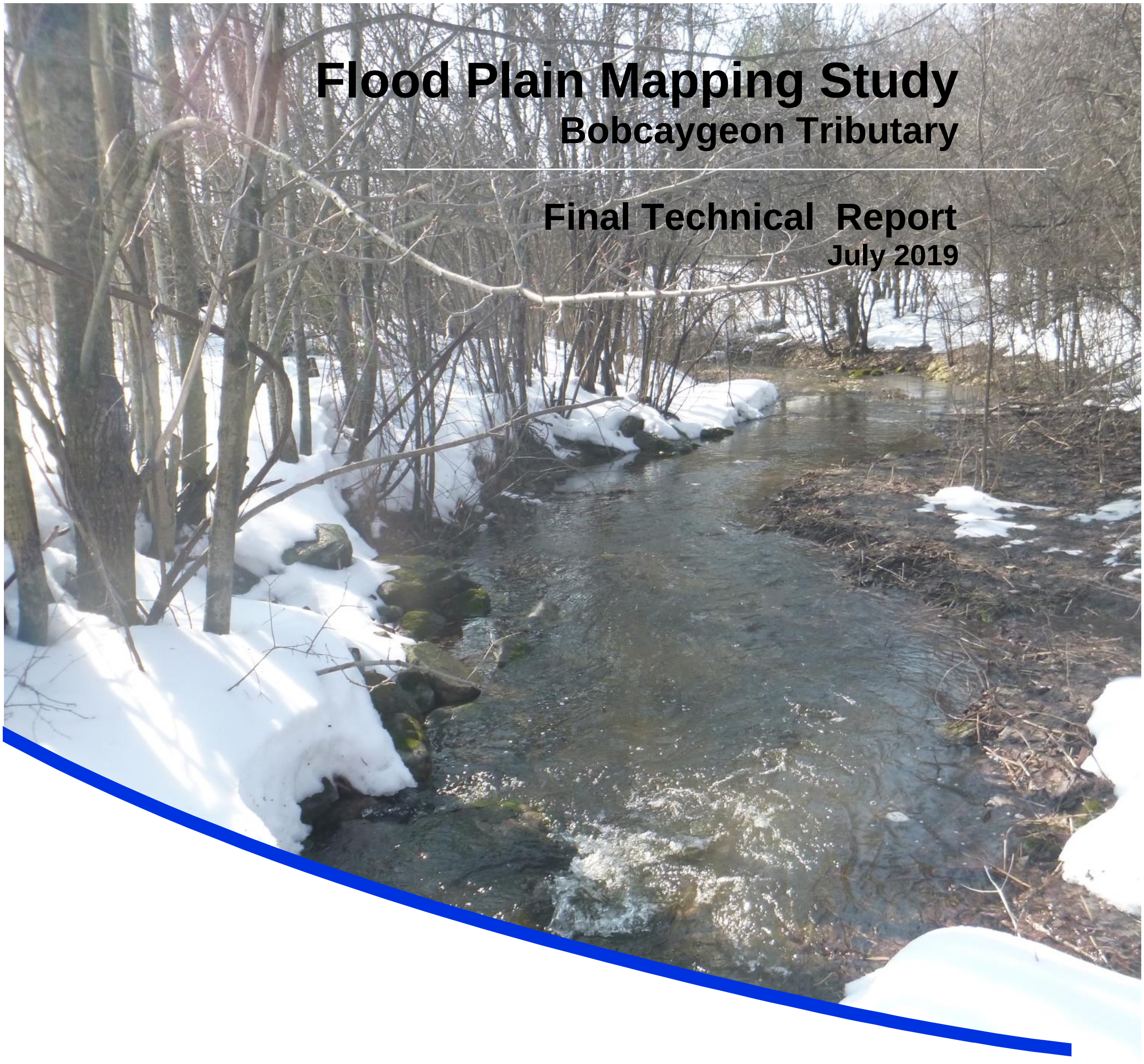

Flood Plain Mapping Study

Bobcaygeon Tributary

Final Technical Report

July 2019

KAWARTHA CONSERVATION

Discover · Protect · Restore

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Executive Summary

The primary goals of this study are to create hydrological and hydraulic models of the watershed and produce floodplain maps for Bobcaygeon Creek. The mapping will allow the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use and identify flood hazards reduction opportunities.

The Bobcaygeon Flood Plain Mapping Study was subject to a comprehensive peer review for core components: data collection, data processing, hydrologic modeling, hydraulic modeling, and map generation. The process was supported throughout by a Technical Committee consisting of technical/managerial staff from Ganaraska Conservation, the City of Kawartha Lakes, and Kawartha Conservation.

Topics discussed in this study include:

Collection of LiDAR and Orthophoto data
Proposed land use
Delineation of hydrology subcatchments
Creation of a Visual OTTHYMO hydrology model
Calculation of subcatchment hydrology model parameters
Derivation of flow peaks at key nodes along the watercourse
Creation of a HEC-RAS hydraulic model
Creation of flood plain maps

Key findings of this study include:
Peak flows from the Timmins Regional storm event exceed peak flows of the 100 year storm, therefore the Timmins Regional storm may be used to define the Regulatory flood event for Bobcaygeon creek watershed

There is only one location (southwest of County Rd. 8 and West St.) where flood waters cannot be contained within the natural valley lands of the creek or are redirected by the limited hydraulic capacity of structures and configuration of roadways. This spilling of the flood water either finds its way back into the creek or spills into the adjacent lands.

Key recommendations of this study:
This study recommends the final floodplain mapping be endorsed and maintained by the Kawartha Conservation Board of Directors and be used to regulate land uses and manage flood hazards within the Bobcaygeon Creek watershed

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1.0 Introduction

1.1 Objective

The objective of this study is to generate updated floodplain mapping for the Bobcaygeon watercourse to protect the public from flooding hazards. This is the fifth flood plain study in a multi-year flood line mapping update project undertaken by Kawartha Conservation and the City of Kawartha Lakes. The mapping will allow the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use and identify flood hazard reduction opportunities.

1.2 Study Process

At the project beginning, the Technical Committee (consisting of one representative from each of the City of Kawartha Lakes, Kawartha Conservation, and Ganaraska Conservation) created quality assurance (Q/A) and quality control (Q/C) standards to be applied to all projects in the multi-year initiative. The Q/A methodology for each component ensures that the project design meets industry standards, and that the work outline and planned deliverables are valid. The three goals of the Q/C component are: that the product is consistent with standards and generally accepted approaches; that the study results meet the Technical Committee's requirements, and that the products and results are scientifically defensible. Each methodology was peer-reviewed for Q/A and Q/C by an external firm or agency. Five separate components of the project were established for Q/A and Q/C:

Elevation data and Orthoimagery

Survey data collection and integration

Hydrology modeling

Hydraulic modeling

Floodplain mapping

For the mapping and air photo portion of the project Q/A, the City of Kawartha Lakes and Kawartha Conservation created a request for proposal (RFP) for geographic data acquisition using LiDAR technology. For the survey data collection and integration, Kawartha Conservation purchased new digital survey equipment and established procedures for survey collection. For the Q/C portion, Ganaraska Conservation's GIS staff performed accuracy checks on the LiDAR-derived project base DEM and the orthoimagery.

For the Q/A portion of the hydrology and hydraulic modeling components, a hydraulic/hydrologic modeling procedures document was created that: established data input parameters to meet municipal and provincial standards; put in place data collection and extraction procedures; and short-listed computer models. The document was peer-reviewed by Greck and Associates and was found to be satisfactory.

1.3 Watercourse Context and Description

Bobcaygeon Creek has two branches. The majority of the watershed flows in the west channel, originating in the rolling farmland northwest of the intersection of County Road 49 and Anderson Road. The channel flows southerly. At Bobcaygeon's urban limits at Bick Street, the channel is more incised. South of North Street, the channel is ill-defined in the wooded rocky areas east and west of West Street where it joins the east branch in the woods north of Front Street West.

The short east branch serves as the outlet for undefined urban runoff east of Head Street. It originates as a poorly-defined channel in the wooded area west of Head Street; flow is directed to this location via a culvert under Head St at the intersection with Prince Street West. Within the woods, flow is in an ill-defined channel.

From the junction, flow is directed within culverts under Front Street West and undergoes a 90° bend to flow east within a man-made channel parallel to the Big Bob Channel of the Bobcaygeon River. Since the river is higher than the land north of the Big Bob channel, the Trent Severn Waterway (TSW) levee ensures flood protection for the low-tying residences. The creek discharges into the river downstream of the TSW dam.

The watershed has a size of 386.5 hectares. The west branch is 5.9km long, and has an average slope of 1%. The east branch is about 0.7km long and has an average slope of 0.85%. Please refer to Figure 1.1.

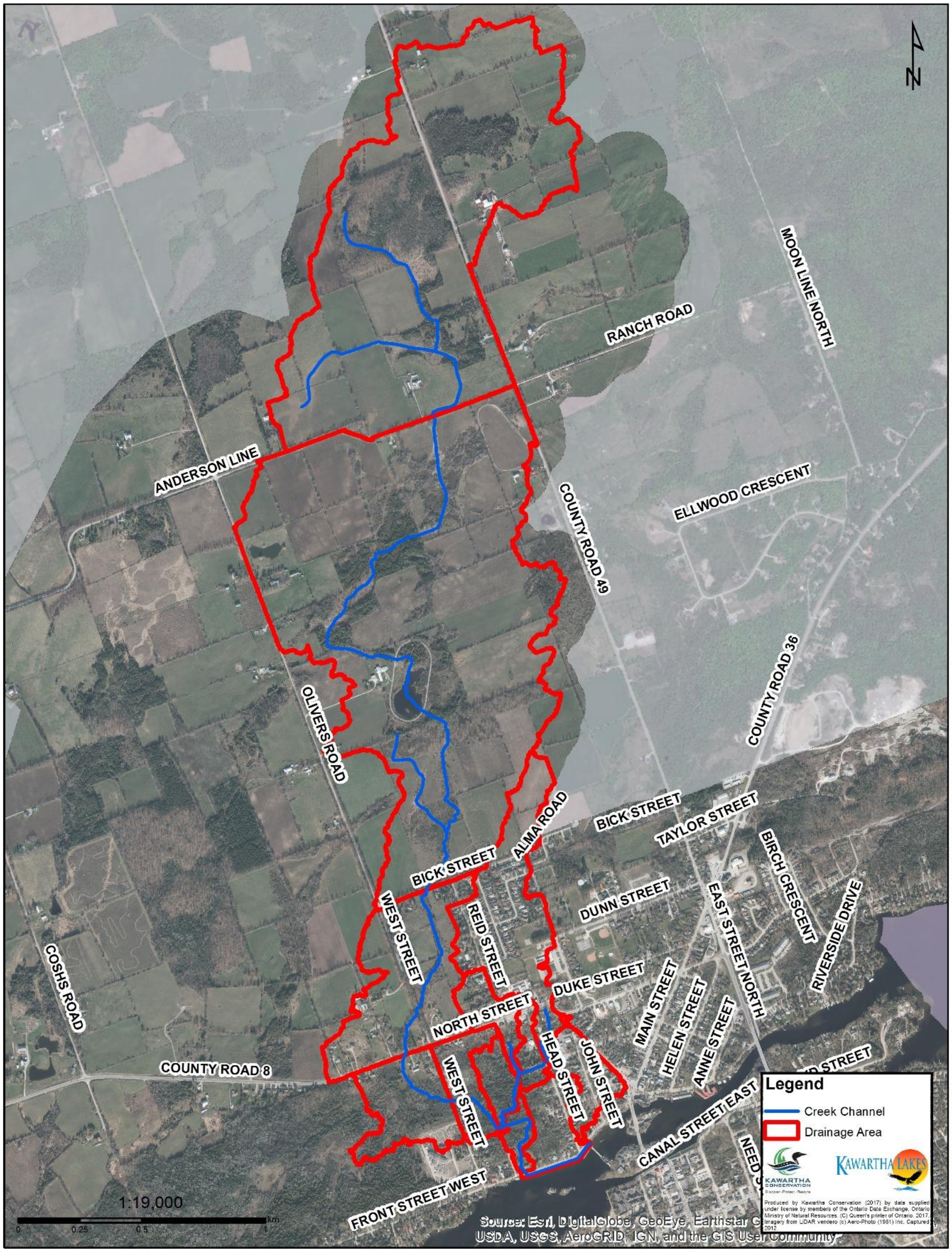

Figure 1.1: Study Area

1.4 Background Information

A 2004 stormwater management report titled *Storm Drainage Report, Northwest Bobcaygeon* by the engineering firm SRM Associates was written for a development parcel near the outlet. The firm calculated existing runoff and creek flows to analyze existing storm sewer infrastructure. The report also modeled future runoff and creek flows to carry out preliminary design of proposed pipes and stormwater management pond(s) for the development. The analyses were based on then-current 1:2000 paper maps provided by the Ontario Ministry of Natural Resources (MNR). The computer model Visual OTT-HYMO was used to simulate 4-hour Chicago design storms using rainfall data from the Atmospheric Environment Services' (AES) rain gauge at the Lindsay filtration plant. No calibration was carried out.

Relevant excerpts are found in **Appendix C**.

1.5 Modeling Approach

Flooding was assessed using standard steady flow methods derived using Visual OTT-HYMO 5.1 (VO5) and HEC-RAS version 5.0.1 (HEC-RAS).

Geographic data (such as subcatchment area, land use, topography, and soil types) was extracted from GIS for each subcatchment to obtain the parameters described in the Hydrology Modeling Parameters Selection document (refer to **Appendix A**), and to calculate values such as imperviousness, SCS Curve Numbers (CN), time to peak (T_p), and time of concentration (T_c).

Runoff hydrographs have been generated for the 2-, 5-, 10-, 25-, 50-year, 100-year storms (6hr SC Type II) and Regional (Timmins) storm.

Sensitivity analyses have been carried to determine the impact of changing model parameters on the calculated flows. The analysis is provided in the report and results are generated in the appendices. No flow monitoring data is available to calibrate the hydrologic model. This approach was peer-reviewed by Greck and Associates Limited in August 2013 and was found to be acceptable, as documented in the separate report titled *Peer Review Services for Terms of Reference of Hydrologic and Hydraulic Assessments, Final Report.*

Unless specified otherwise, default parameters/values were used within VO5 and HEC-RAS.

2.0 Rainfall

When applying flood standards, the Flooding Hazard Limit (or the "Regulatory Floodline") is the greater of the Regional storm, the 100-year, or a documented maximum observed flood event including ice jams. In some instances, it is not unusual to have the 100-year storm exceed the peak flow of the regional storm event, therefore in this study the 100 year and regional storm peak flows were compared.

2.1 Rainfall Data

Rainfall Intensity–Duration–Frequency (IDF) curves provide estimates of the extreme rainfall intensity for different return periods. Rainfall volumes were taken from Lindsay's Atmospheric Environment Services (AES) gauge which was removed from service in 1989. In the initial flood plain study for Ops #1/Jennings Creek, an investigation was carried out to determine the relevancy of using data from this inactive rain gauge. The Peterborough AES rain gauge has a longer time span, and has captured higher rainfall volumes than what was captured by the Lindsay rain gauge. It is unknown whether this increase is attributable to Peterborough's longer period of data capture (36 years, from 1971 to 2006 vs. Lindsay's 24 years, from 1965-1989) or to the effects of climate change.

As outlined in the June 2014 *Flood Plain Mapping Study, Ops #1 Drain/Jennings Creek* report, several rainfall sensitivity analyses were carried out to see the effect on peak flows and associated flood elevations in the Ops #1 drainage basin. The initial analysis adjusted the total Lindsay rainfall volumes +/-10%. The second analyses used the Peterborough AES gauge data. Increasing the Lindsay 100-year rainfall volumes by 10% caused an insignificant increase in flood elevation in the Lindsay commercial district; decreasing the rainfall volume by 10% did not cause an appreciable difference in flood elevation. When the 100-year Peterborough AES gauge data was input to the models, no difference in flood elevations was noted in the Lindsay commercial district. The Lindsay AES gauge data was therefore used for all analyses in the Ops#1/Jennings Creek flood plain study. It was decided that for all subsequent flood plain studies, the Lindsay IDF data would be used for two key reasons: to provide continuity from study to study, and because City of Kawartha Lakes infrastructure has been designed using this gauge data. Details of the Peterborough-Lindsay rain comparison are found in **Appendix G**

Detailed rainfall information is provided in **Appendix G**. Rainfall intensity is calculated by the formula

$I = a/(t+b)^c$, where

I in mm/hr

t in minutes

The City of Kawartha Lakes engineering design standards state the relevant IDF parameters for the gauge are:

Table 2.1: IDF Parameters in the City of Kawartha Lakes' Engineering Standards

Return Period (yr)	a	b	c
2	628.107	5.273	0.78
5	820.229	6.011	.768
10	915.845	6.006	.757
25	1041.821	6.023	.748
50	1139.702	6.023	.743
100	1230.783	6.023	.738

Through the course of the 2013 *Flood Plain Mapping Study, Ops #1 Drain/Jennings Creek* it was discovered that when the a, b, and c parameters listed above were input into the hydrology models, the corresponding total rainfall volumes generated for a 12-hour storm overestimated the measured AES volumes by as much as 25%. As a result, Kawartha Conservation staff re-calculated the a, b, and c parameters (listed below in **Table 2.2**). These values calculate rainfall depths within 1% of the measured volumes shown in **Table 2.3**. These are the values used for the base hydrology scenarios.

Table 2.2: IDF Parameters calculated by Kawartha Conservation

Return Period (yr)	a	b	c
2	808.299	7.413	0.835
5	1248.097	9.760	0.857
10	1486.792	10.44	0.859
25	1917.848	11.842	0.873
50	2142.007	12.182	0.872
100	2465.522	12.897	0.879

Table 2.3: Rainfall Depths from Lindsay AES Station (24 years of data)

Return Period (yr)	6-hour (mm)	12-hour (mm)	24-hour (mm)
2	36.6	39.8	43.6
5	50.8	53.2	56.4
10	60.2	62.2	64.8
25	72.1	73.4	75.4
50	80.9	81.8	83.3
100	89.7	90.1	91.2

Table 2.4, **Table 2.5**, and **Table 2.6** compare the 6-, 12-, and 24-hour volumes using the City's and KRCA's a, b, and c parameters. Details of the a, b, and c parameter recalculations are found in **Appendix G**.

Table 2.4: Comparing 6-hour Rainfall Volumes (City vs. KRCA IDF equations)

Return Period Storm	Rainfall Volumes (mm) Measured	CKL a, b, c	% Diff	KRCA a, b, c	% Diff
2	36.6	37.8	103%	35.0	96%
5	50.8	52.9	104%	47.1	93%
10	60.2	63.0	105%	55.6	92%
25	72.1	75.6	105%	65.6	91%
50	80.9	85.2	105%	73.7	91%
100	89.7	94.7	106%	81.1	90%

Table 2.5: Comparing 12-hour Rainfall Volumes (City vs. KRCA IDF equations)

Return Period Storm	Rainfall Volumes (mm)				
	Measured	CKL a, b, c	% Diff	KRCA a, b, c	% Diff
2	39.8	44.3	111%	39.6	99%
5	53.2	62.5	117%	52.6	99%
10	62.2	75.0	121%	62.1	100%
25	73.4	90.6	123%	72.7	99%
50	81.8	102.4	125%	81.7	100%
100	90.1	114.3	127%	89.6	99%

Table 2.6: Comparing 24-hour Rainfall Volumes (City vs. KRCA IDF equations)

Return Period Storm	Rainfall Volumes (mm)				
	Measured	CKL a, b, c	% Diff	KRCA a, b, c	% Diff
2	43.6	51.7	119%	44.5	102%
5	56.4	73.6	131%	58.5	104%
10	64.8	89.1	137%	68.9	106%
25	75.4	108.2	143%	79.9	106%
50	83.3	122.7	147%	89.9	108%
100	91.2	137.5	151%	98.2	108%

2.2 Design Storms

Design storms are characterized by three elements: total volume, storm duration, and rainfall distribution.

Total Volume

Section 2.1 discussed the volumes collected by the Lindsay AES gauge that are used in this study.

Storm Duration

Watershed drainage areas and the conveyance of flood flows respond differently to different rainfall durations. As such, a variety of rainfall durations (6, 12, and 24 hours) for 2-100 year return periods were tested. For the 100-year event, 4-hour durations were tested. Short duration design storms typically have greater rainfall intensities and lower total rainfall volumes compared to longer duration storms.

Storm Distribution

How the rainfall is distributed over time for a given duration can also influence rates of surface runoff. Various distributions of rainfall have been derived from historical data and are typically tested to examine the watershed's response. It is standard practice to test different design storms to determine the most conservative flows. The most common distributions examined in southern Ontario include the SCS Type II, Chicago and AES.

For over a century, the American Natural Resources Conservation Service has continually refined empirical formulas for the Soil Conservation Service (SCS) method of predicting storms. Their SCS Type II distribution represents a high-intensity storm based on a 24-hour rainfall, and can be used in hydrology studies in Southern Ontario. The bulk of the rainfall occurs in the second half of the storm.

Environment Canada's AES has developed a design storm for southern Ontario. When compared to the SCS distribution, the majority of the rainfall in the AES storm occurs at the beginning of the storm. The Southern Ontario 30% curve is used in this study.

The worst case storm (the duration and distribution producing the highest discharges at key nodes) was selected as the critical event for the watershed. This provides the most appropriate protection for the community of Bobcaygeon. Detailed rainfall information is shown in **Appendix G**.

2.3 Regional Storm

The Timmins storm with a total rainfall of 193mm is the Regional storm event for this part of Ontario. The full storm is defined by Chart 1.04 of the *MTO Drainage Manual*. The Ontario Ministry of Natural Resources (MNR) technical manuals provide a rainfall reduction table for the Timmins storm. Given the size of the Bobcaygeon Creek watershed no areal reduction factors were used. Antecedent moisture content (AMC) condition II, referred to as AMC (II), was applied.

2.4 Snowmelt and Snowmelt/Rainfall Events

These types of analyses were not carried out for this report.

2.5 Climate Change

Climate change considerations were not included within the terms of reference for this study.

3.0 Hydrology Model Input Parameters

3.1 Overview

In 2012, the City of Kawartha Lakes and Kawartha Conservation produced a standardized methodology for undertaking their flood plain mapping studies. This approach was peer-reviewed by Greck and Associates Limited, and their findings concluded the methodology is valid. All parameters and modeling approaches described within this report follow the recommendations presented in **Appendix A** unless otherwise noted. For this study Kawartha Conservation extracted hydrologic parameters from a combination of LiDAR elevation data and pixel-auto-correlated elevation data, Arc Hydro watershed boundaries, Official Plan, Secondary plan, zoning data, and field surveys.

3.2 Digital Elevation Model (DEM)

LiDAR and orthoimagery full-suite remote sensing data were acquired by the City of Kawartha Lakes in 2012. The acquisition included orthoimagery, LiDAR point cloud data, elevation raster tiles, and other geospatial/non-geospatial datasets produced by the vendor. At the time of the acquisition, the *2009 Ontario Guidelines* was the technical document that set geospatial data acquisition specifications in Ontario and defined geospatial data accuracy targets based on levels or risk.

For the Bobcaygeon watercourse watershed, two points per square meter LiDAR data was acquired. ArcGIS version 10.1 computer software programs were to be used to produce a bare earth Base DEM using best available raster and point cloud data from the project LiDAR/ortho acquisition. The Base DEM was produced at a 0.5m cell resolution.

3.3 Subcatchment Discretization

In order to discretize subcatchments, watershed flow paths were generated using ArcHydro version 10.1 software. Surveyed culvert data was merged into the Base DEM to create a hydrologically-conditioned DEM. This allows for flow connections under road barriers to a downstream channel or subcatchment; flow barriers and other impediments were therefore removed from GIS calculations. Critical nodes within the watershed were selected by the engineer as the basis to delineate the initial subcatchments in ArcHydro. ArcHydro is suitable for the delineation of rural subcatchments.

For urban subcatchments the ArcHydro tool cannot account for sub-surface pipe networks nor can it determine overland flow pathways where the topography forms a concave shape. To overcome this gap, field visits were carried out to verify urban subcatchment boundaries. Manual adjustments of the urban subcatchments were carried out under the direction of the engineer and approval of the technical committee. **Figure 3.1** illustrates the creek subcatchments.

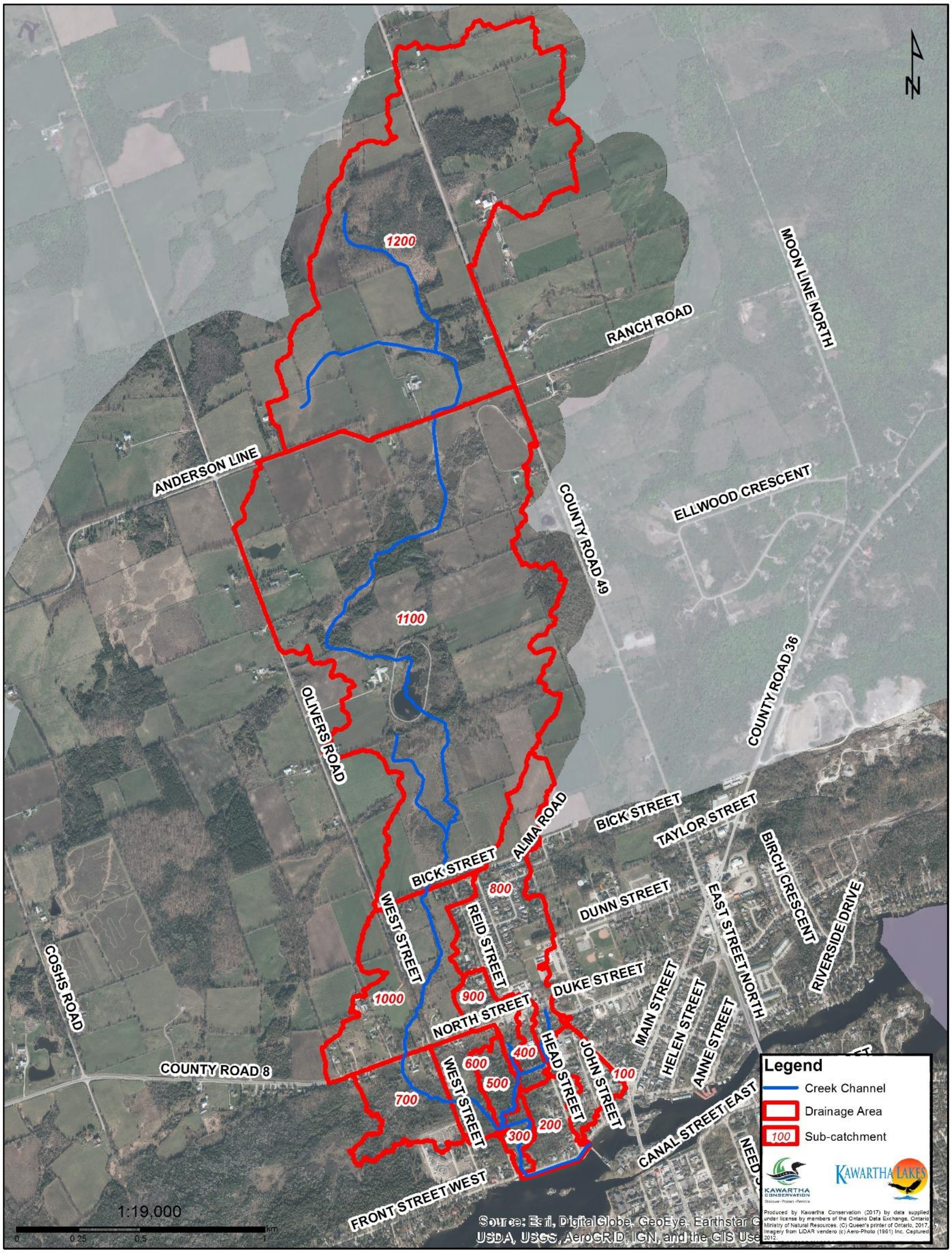

Figure 3.1: Subcatchment Boundaries

3.4 Land Use

The draft April 2013 Schedule 'F-2' Land Use map version from the Secondary Plan Project, Bobcaygeon Settlement Area is the base data referenced for land use patterns. The November 2011 Schedule 'A' zoning map from the Village of Bobcaygeon Zoning By-Law 16-78 is also used for reference.

Land values in the hydrology model do not reflect current land use; instead, the model assumes that all developable areas indicated in the Secondary Plan are fully built out. The rationale for this decision is that the City has approved in principle the proposed land use and therefore the flood lines should reflect the most conservative flood scenario. Copies of the schedules' maps are found in **Appendix B**.

3.5 Rural Subcatchment Properties

The longest flow paths of each rural subcatchment were derived using ArcHydro. In this process, the downstream node was selected, and ArcHydro calculated the longest overland and channel flow paths. **AppendixD** contains of figures showing each subcatchment and their respective lengths.

3.6 Calculation of Slope

For rural subcatchments, spreadsheets were created that calculate channel and subcatchment slopes, based on overland and channel flow data. Details can be found in **Appendix A**.

3.7 CN Value

The Soil Conservation Service (SCS) curve number (CN) is used to determine runoff. **A**ntecedent **m**oisture **c**ondition II (AMC II), was used for the model. For this study, the Kawartha Conservation 2010 ELC (Ecological Land Classification), Secondary Plan and Official Plan (OP) data from the City of Kawartha Lakes, and soil type were queried to extract land use, drainage area, and hydrologic soils group data. A weighted CN (AMC II) value was calculated, as shown in **Appendix A**.

The VO5 program requires that the CN value be transformed to CN* (AMC II). These calculations are included in **Appendix A**. **Figure 3.2** provides soils information while **Figure 3.3** shows the future land use of the watershed based on Secondary Plan data. Spreadsheets with the calculations are provided in **Appendix A**.

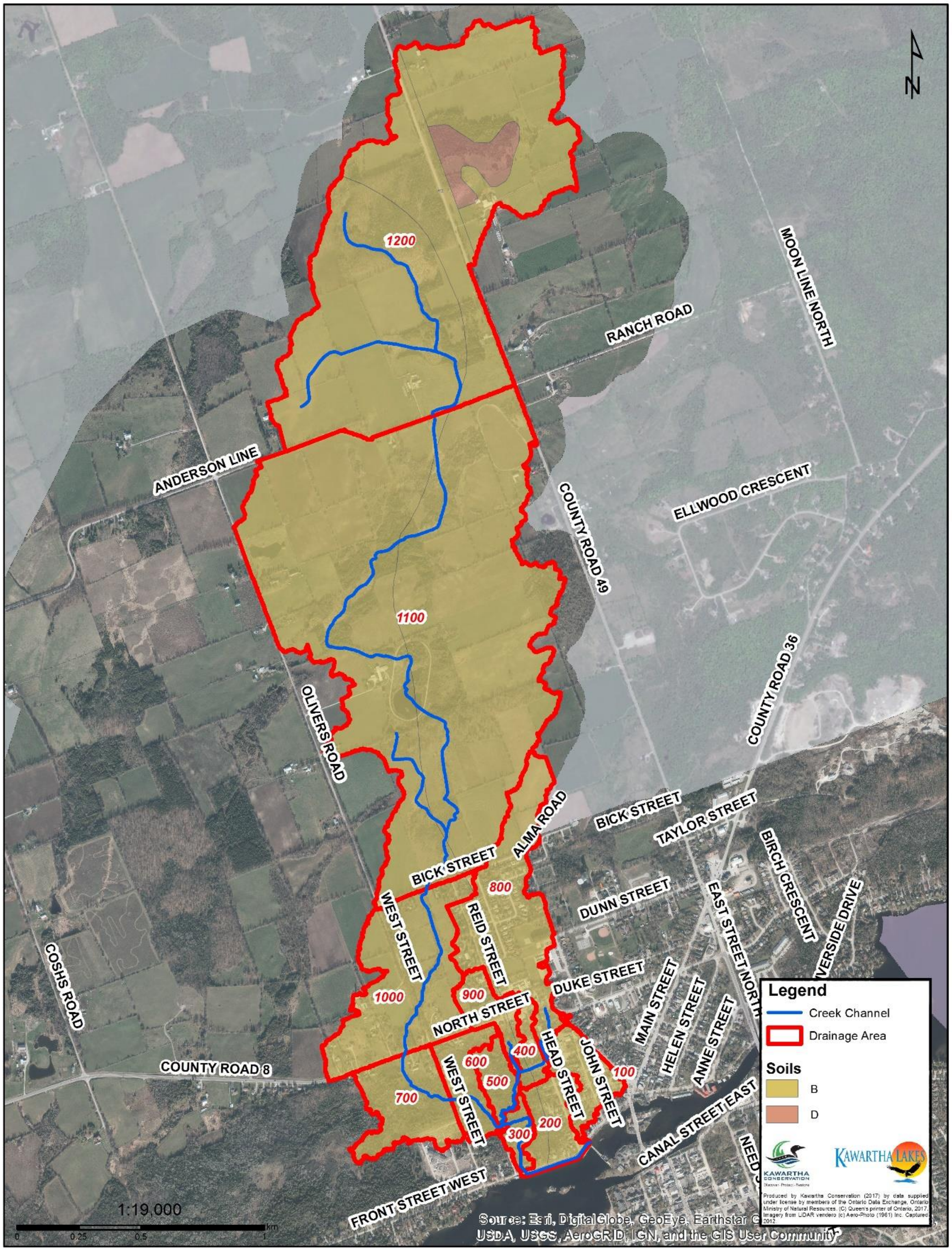

Figure 3.2: Soils

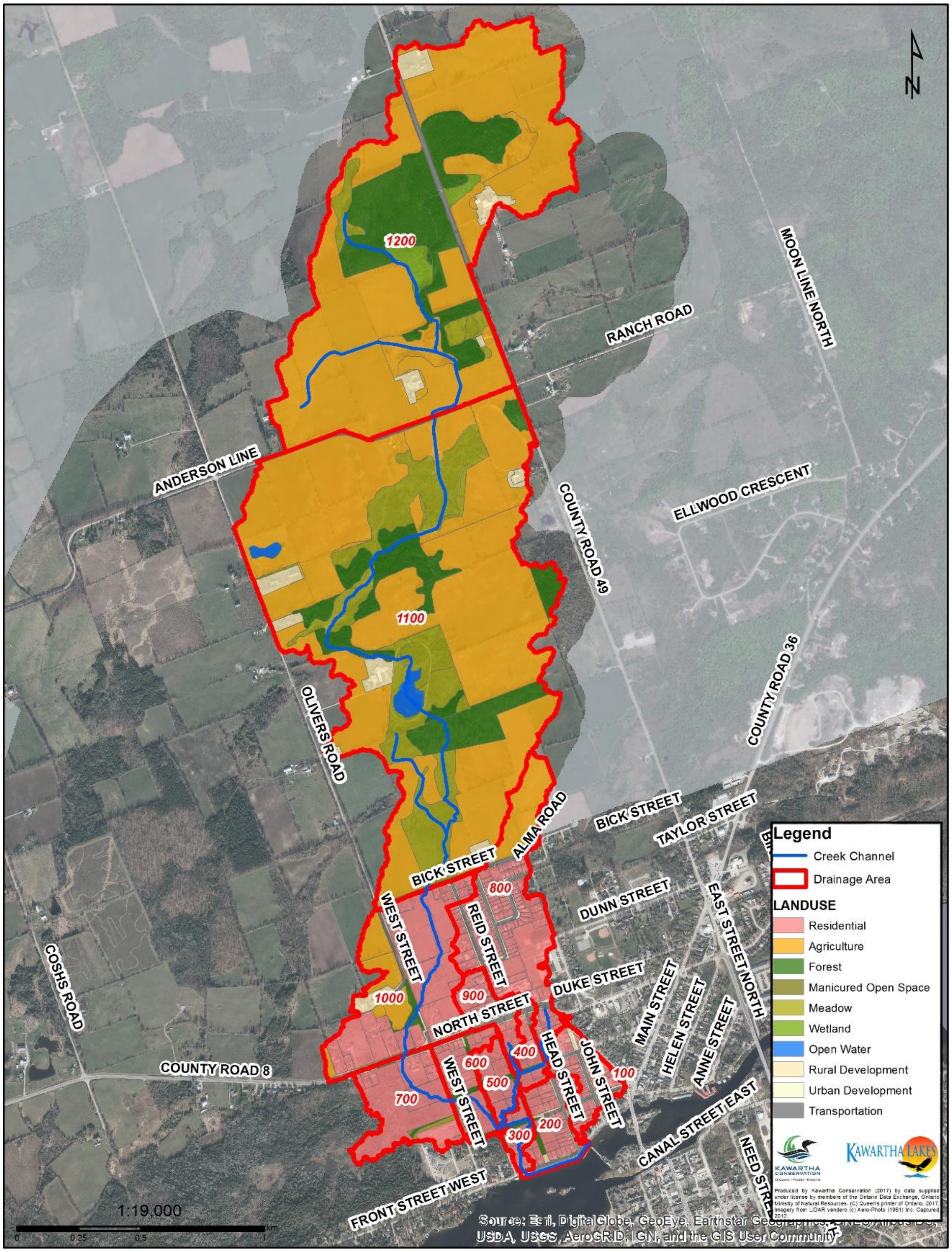

Figure 3.3: Land Use

3.8 Impervious Land Use and Runoff Coefficients

The detailed land use denoted in the Secondary plan and zoning data determine the weighted total impervious area (T_{imp}), directly-connected impervious area (X_{imp}), and runoff coefficient (C) for each subcatchment using the tables from the Hydrologic Parameters List in **Appendix A**.

Subcatchments with a T_{imp} value greater than 20% were modeled with the StandHYD command; otherwise the NashHYD command was used. Spreadsheets with the calculations are provided in **Appendix A**.

3.9 Time of Concentration

Time of concentration (T_c) is a key variable for calculating peak flow in rural subcatchments. This is the time it takes for the flow wave to travel from the hydraulically farthest point of a subcatchment to where it joins the creek.

Time of concentration was calculated using the Airport method for subcatchments with a C value less than 0.4; the Bransby-Williams method was chosen if the C value exceeded 0.4.

The Time to Peak (T_p) is defined by VO5 model via the equation: $T_p = (^2/_3) * T_c$

Time to peak is used in the NashHYD command only. Spreadsheets with the T_c and T_p calculations are found in **Appendix A**, using the flow lengths shown in the subcatchment (1100 & 1200) figures found in **Appendix D**.

3.10 Channel Routing

Channel routing in VO5 accounts for the time lag due to the storage of flows as they are conveyed within the main channel and associated floodplain. One representative cross-section was used for each channel reach. Channel reach and overbank Manning's n values were averaged, as were the channel and overbank slopes. Channel flow routing results in the attenuation (lowering) and a latter (lag) in peak flows.

3.11 Stormwater Management (SWM) Ponds

No SWM facilities are included in the hydrological analyses for several reasons. SWM facilities are designed to control runoff to 100-year levels, whereas the Regulatory event upon which flood plain mapping is based is a greater storm (such as the Timmins storm). Secondly, flood plain mapping is based upon a worst-case scenario where infrastructure such as SWM facilities may fail. Thirdly, since maintenance of private SWM facilities are not the responsibility of the City, there is no assurance they will continue to function as originally designed.

4.0 Hydrologic Model

4.1 Schematic

The information gathered in the preceding sections was used to build a VO5 model of the watershed, as shown schematically in **Appendix F.**

4.2 Calibration

Since no rain or flow gauge data is available for this watershed, no calibration can be performed

4.3 Model Input Data

Channel Flow Length

The input parameters were calculated as described in Section 3 and are summarized in **Table 4.1** below.

Table 4.1: VO5 Model Input Parameters

Catchment	AREA	C	T_p (hr)	CN (II)	CN* (II)	X_{imp}	T_{imp}
100	6.7	0.54	n/a	83	85	0.29	0.56
200	7.1	0.45	n/a	82	82	0.25	0.52
300	2.5	0.45	n/a	79	78	0.25	0.52
400	3.0	0.57	n/a	83	85	0.35	0.57
500	4.0	0.45	n/a	79	78	0.25	0.52
600	6.9	0.45	n/a	80	80	0.25	0.52
700	12.7	0.51	n/a	78	78	0.26	0.52
800	24.6	0.51	n/a	80	80	0.22	0.41
900	5.2	0.51	n/a	80	80	0.32	0.56
1000	28.0	0.43	n/a	76	74	0.17	0.33
1100	164.1	0.34	0.64	72	68	0.01	0.02
1200	121.9	0.34	1.22	72	68	0.01	0.02

4.4 Sensitivity Analyses

The model will be tested for sensitivity in the final report for the following input parameters: Manning's n, CN values, initial abstraction, model time step, removal of channel routing, channel flow lengths, and straight-line overland flow lengths. The Timmins storm model will be modified as outlined below.

- CN* (+/-20%)
- Initial Abstraction (I_a) (+/-50%)
- Time step (DT) (5min/10min)

The results of sensitivity analysis can be located in **Appendix K.**

CN*

Flows at key nodes were investigated to see the impact of changing the CN* value. Increasing CN* by 20% resulted in an average increase in peak flow of 21% at all key flow nodes during the Timmins storm event. Decreasing CN* by 20% resulted in an average decrease in peak flow of 26% at all key flow nodes during the Timmins storm event. Because there is a significant difference in peak flow values as a result of modifying the CN* value, it is imperative to get an accurate CN* value.

CN* is determined by land use and soil type. Soil type information is extracted from the digitized Victoria County soils map originally produced as a joint venture by the Federal Department of Agriculture and the Ontario Agricultural College. Land use is derived from the City of Kawartha Lakes' Secondary Plan and zoning maps as well as the 2010 Ecological Land Classification (ELC) mapping. Aerial orthophotography was reviewed to confirm land use throughout the watershed. This base data is valid, and therefore any calculated value (such as CN*) based on this data truly represents the land.

Initial abstraction (I_a)

Initial abstraction is a parameter that accounts for losses such as infiltration, evaporation, surface depression storage etc. prior to the occurrence of any runoff. This value is typically very small in comparison to the volume of rainfall for a larger storm event and has a larger effect on smaller storm events. Therefore, it is expected that initial abstraction would have little to no effect on a substantial event such as the Timmins storm.

Increasing Initial Abstraction by 50% resulted in an average decrease in peak flow of (<1%) at all key flow nodes during the Timmins storm event. Decreasing initial abstraction by 50% resulted in an average increase in peak flow of (<1%) at all key flow nodes during the Timmins storm event. Therefore, changing the initial abstraction does not result in significantly different flows.

Model Time Step (DT)

The model time step of 1 minute was modified by changing it to 5 minutes and 10 minutes at all subcatchments and channel routing. There was little to no affect on peak flows at all flow nodes during the Timmins Storm Event (less than 0.5%). Therefore, time step has no effect on the regulatory flows.

5.0 Hydrology Model Output

Storm Analyses
Table 5.1 shows the representative peak flows at key flow nodes of the various 100-year storm distributions in effort to determine the critical storm distribution of the watershed.

The 6-hour SCS storm provided the highest peak flow for the 100-year event as per the **Table 5.1** below. Therefore, it can be established that the critical storm distribution is the SCS Type II, 6 hour distribution.

Table 5.1: Comparing 4-hour and 6-hour Peak Flows

Node	4-hr AES	6-hr AES	4-hr SCS	6-hr SCS
Anderson Line	2.5	3.10	2.37	2.15
Bick St	6.85	8.07	6.50	6.09
North St (W of Reid)	7.16	8.66	6.90	6.43
West St	7.34	8.99	7.11	6.61
Junction	9.11	10.68	11.38	12.25
Front St W	9.17	10.73	11.20	11.89
Outlet	9.47	11.00	10.68	10.81

Flow Results
As can be seen in **Figure 5.1** below, the catchments display two distinct hydrological responses closely matching the rainfall pattern of the Timmins storm. The first peak occurs between 2 and 3 hours after the beginning of the storm event for all catchments. The second peak occurs between 6 and 8 hours.

Detail VO5 model output can be found in **Appendix E**.

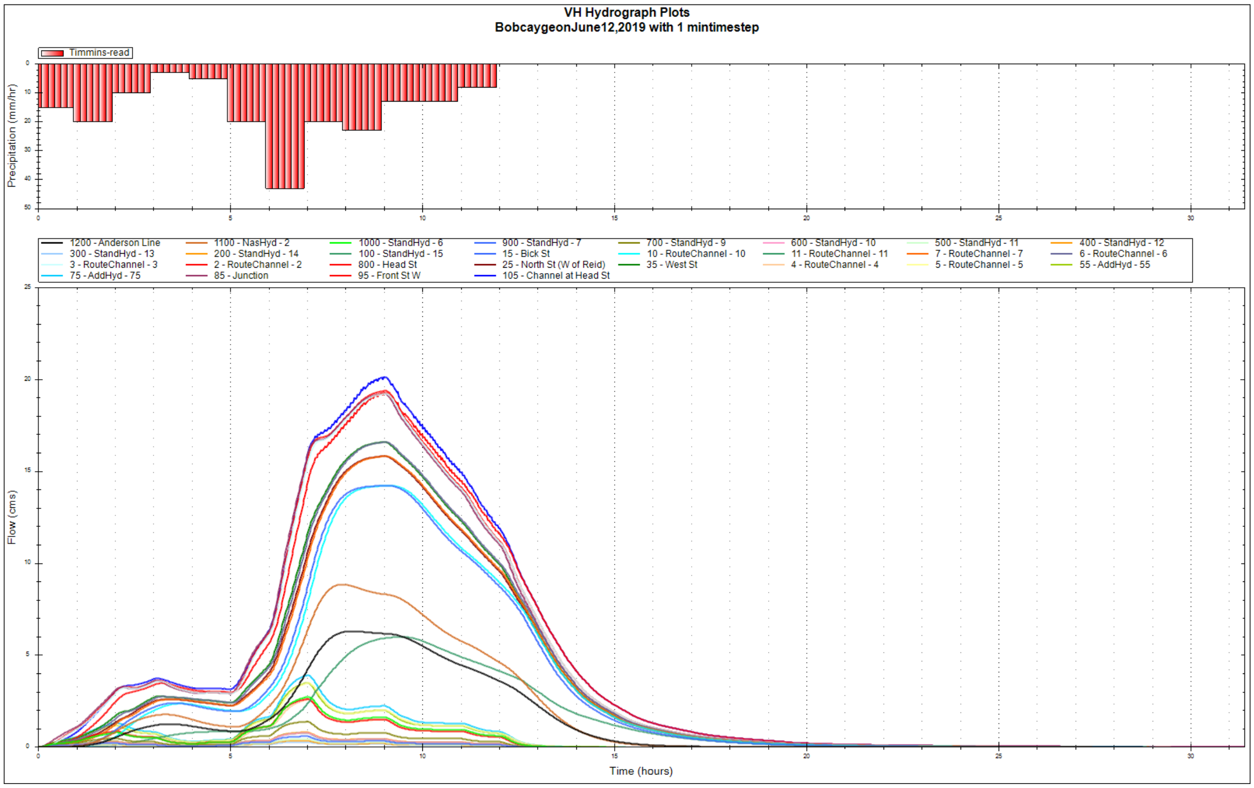

Figure 5.1: Catchment Runoff Comparison

6.0 Conclusions and Recommendations

It is recommended that the peak flows calculated in the VO5 model for Bobcaygeon Creek watercourse be used as input to the hydraulic model, as shown in **Table 6.1**.

Table 6.1: Flows to be Input to Hydraulic Model

Node	Timmins Q_p (m^3/s)	100-year Storm Q_p (m^3/s) 6hr SCS					
		2year	5-year	10-year	25-year	50-year	100-year
Anderson Line	5.98	0.42	0.75	1	1.42	1.74	2.15
Bick St	14.21	1.24	2.24	2.99	4.17	5.07	6.09
North St (W of Reid)	15.82	1.34	2.41	3.20	4.43	5.37	6.43
Junction	19.24	3.02	5.18	6.70	9.03	10.55	12.25
Front St W	19.36	2.91	4.97	6.42	8.65	10.18	11.89

Hydraulic Model Input Parameters

6.1 Overview

The following section presents the setup and findings for the hydraulic analyses. The calculated flood elevations were used to prepare regulatory floodplain maps for the Bobcaygeon Creek watershed. Steady flow hydraulic analyses were completed using GeoHECRAS™ (Civil GEO) software. The procedures used were based on the 2012 City of Kawartha Lakes and Kawartha Conservation standardized methodology for undertaking their flood plain mapping studies.

6.2 Cross-Sections

Cross-section geometric data was extracted using GeoHECRAS™ from the base DEM to ensure geo-referencing in HEC-RAS. Since bathymetric data acquisition was outside the scope of the project LiDAR acquisition, it was necessary to supplement these areas with surveyed data to create accurate river geometry. Bathymetric survey points were taken in-channel up to the top of bank throughout the project area. The surveyed data replaced the DEM-derived elevations within the in-channel portion of the cross-sections generated by GeoHECRAS™. Data sources generated by different entities were placed into the same projection and datum for consistency in processing. Stream crossings were selected based on project orthoimagery, field reconnaissance, and information in previous reports. Full photographic records of all stream cross-sections are found in **Appendix H**.

As per HEC-RAS requirements, all cross-sections are oriented looking downstream. The cross-section nomenclature reflects the distance in metres relative to the initial cross-section. Left overbank, main channel, and right overbank downstream lengths were measured by way of GIS analysis. As per HEC-RAS recommendations, the overbank distances are measured from each overbank centroid.

6.3 Culvert and Road Crossings

Cross-sections are cut at culvert and bridge crossings to accurately represent channel flow. All road crossings are represented by two upstream and two downstream bounding cross-sections. Representative deck elevations were extracted from the base DEM. All culverts and bridges were field-surveyed to ensure accuracy. Invert elevations, height/width dimensions, length, and channel bottom were surveyed with either total station or GPS. All the relevant data and photographs are found in **Appendix I**.

6.4 Manning's n Values

Manning's n values for channel, left and right overbanks were based on recommended values in Table 3-1 of the *HEC-RAS River Analysis System Technical Manual*. The main channel n values are 0.035, and the overbank n values range from 0.02 to 0.08. These values were chosen based on air photo and survey notes/photos. The main channel and overbank lengths were determined by performing measurements in GIS.

6.5 Ineffective Flow Elevations

Ineffective flow areas were introduced at each culvert crossings and selected cross sections to identifies areas which would not contribute to the conveyance of flood flow. Typically, the upstream bounding cross-section at culverts the ineffective elevations was set to the low elevation in the roadway. For the downstream bounding cross-section, the ineffective flow elevations were typically set at a point midway between the low roadway elevation and the culvert obvert elevations.

6.6 Boundary Conditions

For the flow analysis, the downstream boundary condition is the average Bob Lake operating level of 247.70 m, controlled by Parks Canada.

6.7 Expansion/Contraction Coefficients

The model uses the HEC-RAS recommendations of 0.1 and 0.3 for contraction and expansion coefficients, respectively at all normal cross-sections. The values were increased at culverts and bridges and culverts (typically to 0.3 and 0.5, contraction and expansion, respectively) to account for more significant changes in flow conveyance velocity.

6.8 Building Obstructions

Where buildings are located within or between the cross-sections, the cross-section was modified by introducing obstructions to flow. The effect of a building can be felt upstream and downstream of a cross-section. A 1:1 contraction effect was used for a cross-section upstream of a building;

whereby the actual building width is reduced at a 1:1 ratio from each end of the building face. For instance, if a cross-section is 5 m upstream of a 30 m-wide building, the obstruction representing the building in the cross-section is 20 m wide. A 4:1 expansion effect was used for a cross-section downstream of a building. For instance, if a cross-section is 8 m downstream of a 30 m-wide building, the obstruction representing the building in the cross-section is 26 m wide.

7.0 Hydraulic Model

7.1 Schematic

The information gathered in the preceding section was used to build a HEC-RAS model of the watercourse. The geometry of the model is shown schematically in **Figure 7.1**.

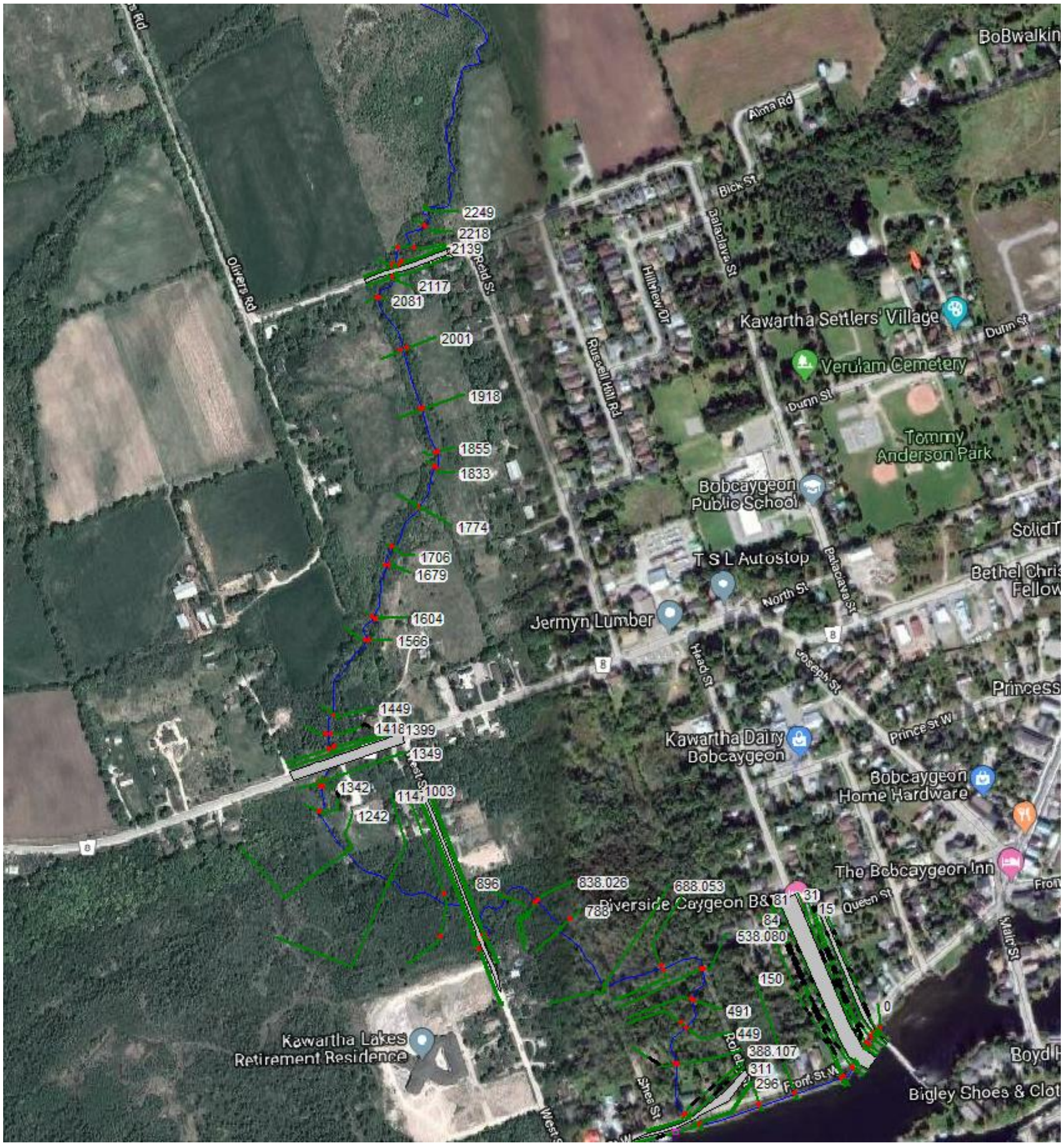

Figure 7.1: Hydraulic Schematic-Bobcaygeon

7.2 Sensitivity Analyses

The hydraulic model was tested for sensitivity to input parameters in the list below. Input parameters were modified by varying degrees as outlined below for the Regional Storm event only (Timmins Event). The increase/decrease in flood elevation from the base scenario were noted to establish a level of confidence in flood elevation estimations. The following parameters were tested for sensitivity:

- Manning roughness coefficient (+/- 20%)
- Peak Regulatory Flow (+/- 30%)
- Downstream Boundary Condition (+/- 1.0 m)

Tabulated results of the hydraulic modelling sensitivity analyses are provided in **Appendix K.**

Manning roughness coefficient (+/- 20%)

Flood elevations throughout the project reach were investigated to determine the impact of changing the Manning roughness coefficient. The Manning's number indicates the friction factor in a cross section. The higher the number, the rougher is the surface against which water flows or instance, a smooth concrete pipe has a manning's n of 0.013 whereas a forest has a Manning's n value of 0.1.

By increasing the Manning's n by 20%, the flow is being subject to a watercourse with greater friction forces acting upon it. It was found that the average increase in the regional water surface elevation throughout the 56 cross sections was 2 cm, and the highest was 35 cm, at cross section 1399.

By decreasing the Manning's n by 20%, the flow is being subject to a watercourse with lower friction forces acting upon it. It was found that the average decrease in the regional water surface elevation throughout the 56 cross section was 1 cm, and the greatest was 8 cm, at cross sections 1918 and 1399.

Due to a minimal affect on the average, overall flood elevation throughout the study reach, it can be determined that the Manning roughness coefficients are acceptable.

Peak Regulatory Flow (+/- 30%)

Flood elevations throughout the project reach were investigated to determine the impact of changing the regional (Timmins Storm) peak flows. This was completed to account for uncertainty and assumptions as per the hydrologic modelling. From the hydrology sensitivity analysis, regional peak flow varied by up to 27%, therefore peak flows within the hydraulic model were varied by +/- 30%.

By increasing the peak flows, it was found that the average increase in regional flood elevation throughout the 56 cross sections was 24 cm, with the highest greatest of 1.43 cm at cross section 1399.

By decreasing the peak flows, it was found that the average decrease in regional flood elevation throughout the 56 cross sections was 8 cm, with the greatest decrease of 43 cm at cross section 1392.

While the flood elevations are somewhat sensitive to the peak flow rate, the variability of 30% in peak flow is also significant. Therefore, with lower assumptions on variability of peak flow, the flood elevations are considered reasonable.

Downstream Boundary Condition (+/- 1.0 m)

A sensitivity analysis was completed by varying the starting water level by +/- 1.0m. For most of the cross sections, the regional flood elevation remained unchanged. When increasing the downstream boundary condition by 1m, nineteen downstream cross sections had a change in flood elevations, with an average of 56 cm through these sections. The limit of this backwater effect ends at cross section 491.

Whereas by decreasing the downstream boundary condition by 1m, only the most downstream two cross section experienced decrease in water level.

Due to the limited effects on flood elevations throughout the entire watershed, the downstream boundary condition is considered acceptable for the study area.

8.0 Hydraulic Model Results

8.1 Creek Flood Results

The resulting flood elevations for the 2 through 100 year events, and Regional storm flood event for Bobcaygeon Creek are listed in **Appendix J**. The regulatory flood elevation is defined as the greater of the 100 year or regional storm flood elevation. For the Bobcaygeon Creek watershed the Regional storm defines the regulatory flood elevation. The Regulatory flood plain extents are illustrated in **Figure 8.1**.

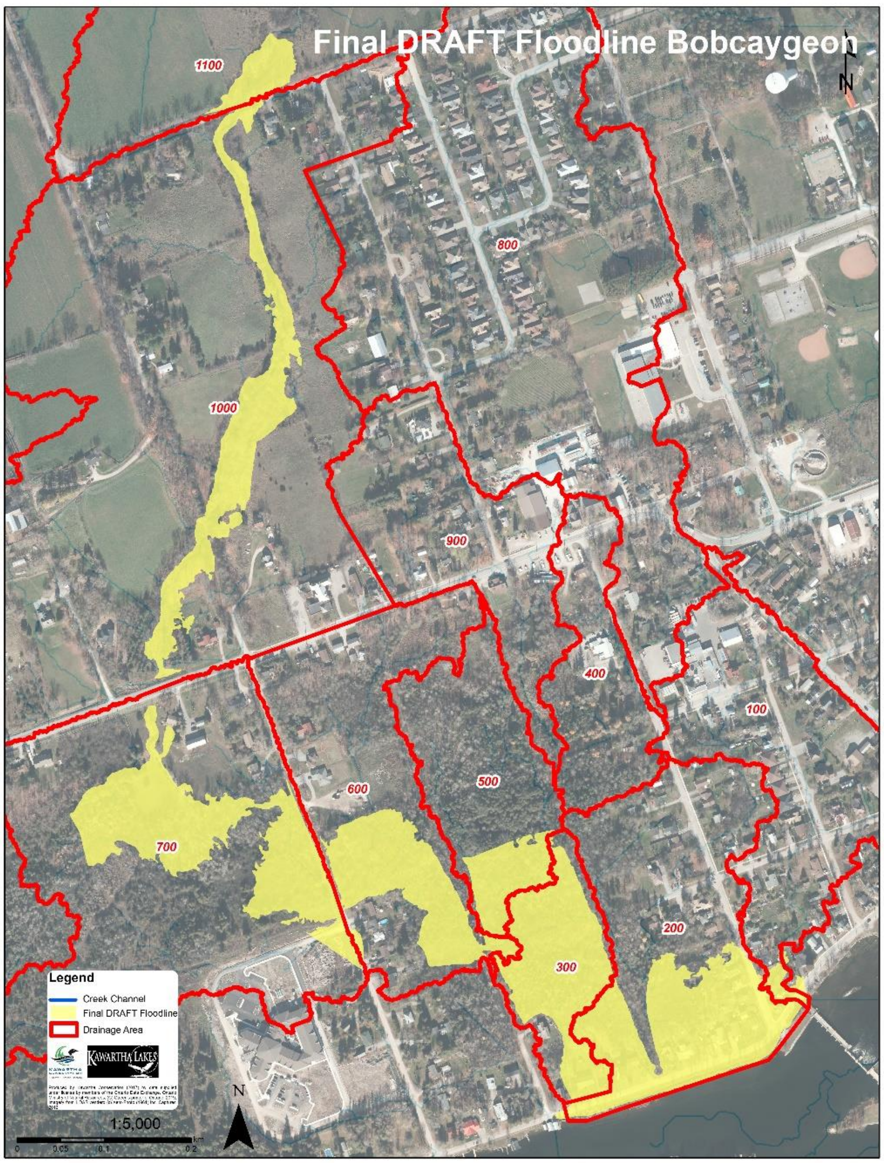

Figure 8.1: Regulatory Floodplain Extents

There is only one location (southwest of County Rd. 8 and West St.) where flood waters cannot be contained within the natural valley lands of the creek or are redirected by the limited hydraulic

capacity of structures and configuration of roadways. This spilling of the flood water either finds its way back into the creek or spills into the adjacent lands.
Further assessment of the spill areas was beyond the scope of the current project.

Figure 8.2 (a &b) shows the profile of the creek and its riverine flood elevations for the major storms i.e. Regulator (Timmins) and 100 year flood events. The profile illustrates structures which have the hydraulic capacity to pass the 100 year and Timmins storm events and other structures which do not provide this hydraulic capacity. The profile also illustrates where road crossing cause backwater effects onto upstream lands during the 100year and Regional storm events. For example, the following profiles for 100 year and Timmins flood events show that one of the culverts (Country Road 8 culvert) can pass both the major storm events, while the other can not and for these structures there is backwater effects. Not all culverts are required to pass the 100 year storm or regional storm event.

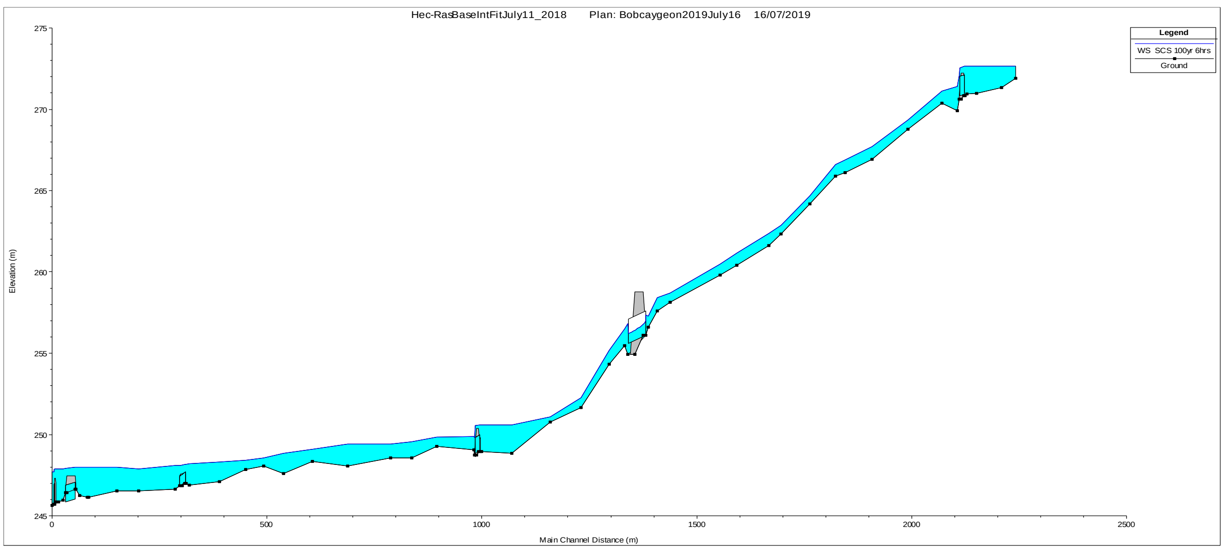

Figure 8.2 (a): Profile of the Bobcaygeon Creek (100 yr)

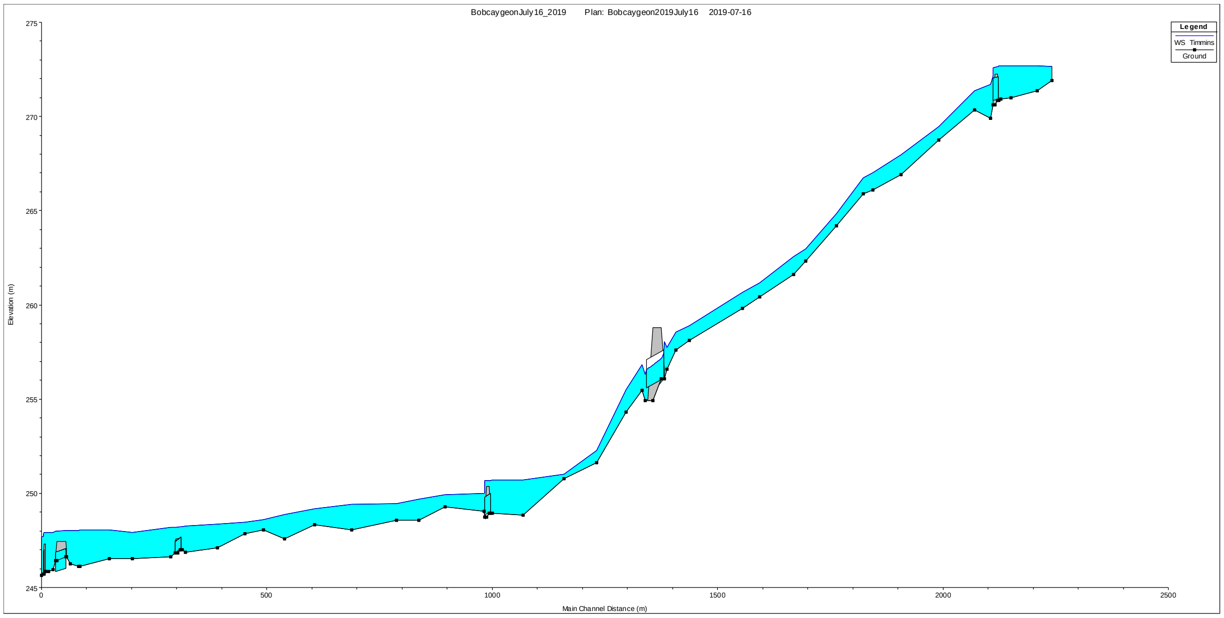

Figure 8.2 (b): Profile of the Bobcaygeon Creek (Timmins)

9.0 Conclusions and Recommendations

The procedures and methodologies for the hydrologic and hydraulic components are based on terms of reference approved by the Technical Committee (consisting of representatives from each of the City of Kawartha Lakes, Kawartha Conservation, and Ganaraska Conservation). Each methodology and procedure were peer-reviewed for quality assurance and control by Greck and Associates Limited and found to be satisfactory.

The mapping will allow the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use and identify flood hazard reduction opportunities. It is recommended that the water surface elevations and flood plain mapping be adopted for current and future planning purposes.

10.0 Limitations of Work

The maps associated with this study have been produced at a strategic, watershed level using an automated mapping process, and minor or local features may not have been included in their preparation. A Digital Terrain Model (DTM) is used to generate the maps. The DTM is a 'bare earth' model of the ground surface with manmade and natural landscape features such as vegetation, buildings, bridges and embankments digitally removed. Therefore, the maps should not be used to assess the flood risk associated with individual properties or point locations, or to replace a detailed local flood risk assessment. The maps associated with this study were produced based on survey data captured prior to, and during the early part of the project. They do not account for changes in development, infrastructure or topography that occurred after the date of survey data capture. The DTM is derived from aerial remote sensing data. The majority of this data is Light Detection and Ranging (LiDAR) data. In areas with no LiDAR data present, the best available DTM was used.

Detailed explanations of the methods of derivation, survey data used, etc. are provided in the relevant reports produced for the project under which the maps were prepared. Users of the maps should familiarize themselves fully with the contents of these reports in advance of the use of the maps.

11.0 Appendices

(Bound in a separate document)

Appendix A:	Modeling Parameters Selection
Appendix B:	Schedule Maps
Appendix C:	Stormwater Management Report (2004) excerpts
Appendix D:	Subcatchment Maps
Appendix E:	VO5 Hydrology Model Detail Output
Appendix F:	Bobcaygeon Hydrology Schematic
Appendix G:	Rainfall Data
Appendix H:	Cross-section Photo Inventory
Appendix I:	Structure Photo Inventory Record
Appendix J:	HEC RAS Output
Appendix K:	Sensitivity Analysis (Hydraulic and Hydrology)