Flood Plain Mapping Study

Sinister Creek

Final Report

February 2016

KAWARTHA CONSERVATION

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KAWARTHA LAKES

About Kawartha Conservation

A plentiful supply of clean water is a key component of our natural infrastructure. Our surface and groundwater resources supply our drinking water, maintain property values, sustain an agricultural industry and support tourism.

Kawartha Conservation is the local environmental agency through which we can protect our water and other natural resources. Our mandate is to ensure the conservation, restoration and responsible management of water, land and natural habitats through programs and services that balance human, environmental and economic needs.

We are a non-profit environmental organization, established in 1979 under the Ontario *Conservation Authorities Act* (1946). We are governed by the six municipalities that overlap the natural boundaries of our watershed and voted to form the Kawartha Region Conservation Authority. These municipalities include the City of Kawartha Lakes, Township of Scugog (Region of Durham), Township of Brock (Region of Durham), the Municipality of Clarington (Region of Durham), Cavan Monaghan, and the Municipality of Trent Lakes.

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1 Introduction

1.1 Objective

The Sinister Creek flood plain study is being conducted to assist the City of Kawartha Lakes in generating accurate flood plain mapping to protect the public from flooding hazards. This is the second flood plain study in a multi-year flood line mapping update project undertaken by Kawartha Conservation and the City of Kawartha Lakes. The objective of the overall study is to generate regulatory flood plain mapping for Sinister Creek. The mapping will allow both the City of Kawartha Lakes and Kawartha Conservation staff to make informed decisions about future land use and identify flood hazard reduction opportunities.

The results of the hydrology modeling work will provide design storm flows for the 2- through 100-year return periods as well as the Timmins Storm, to be used as input to a hydraulic model which will establish Regulatory flood lines within Community of Lindsay. The study area is shown in **Figure 1.1**.

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 Region Conservation Authority (GRCA)) created quality assurance (QA) and quality control (QC) standards to be applied to all projects in the multi-year initiative. The QA methodology for each component ensures a two-fold benefit: that the project design meets industry standards, and that the work outline and planned deliverables are valid. The three goals of the QC component are: that the product is consistent with standards and generally accepted approaches; that the study results meets Technical Committee's requirements; and that the products and results are scientifically defensible. Each methodology was peer-reviewed for QA and QC by an external firm or agency. Four separate components of the project were established for QA and QC:

- mapping and air photos
- survey data collection and integration
- hydrology modeling
- hydraulic modeling

For the mapping and air photo portion of the project QA, 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. The GIS staff from GRCA peer-reviewed the RFP and survey purchase/procedure and confirmed they met industry standards. For the QC portion, Kawartha Conservation Geographic Information System (GIS) staff prepared a report entitled "Quality Assurance and Quality Control Report for Sinister Creek Flood

Plain Mapping Data, 2015" which is included in **Appendix I**. GRCA GIS staff peer-reviewed the geospatial data used for the study and confirmed that it meets the applicable standards.

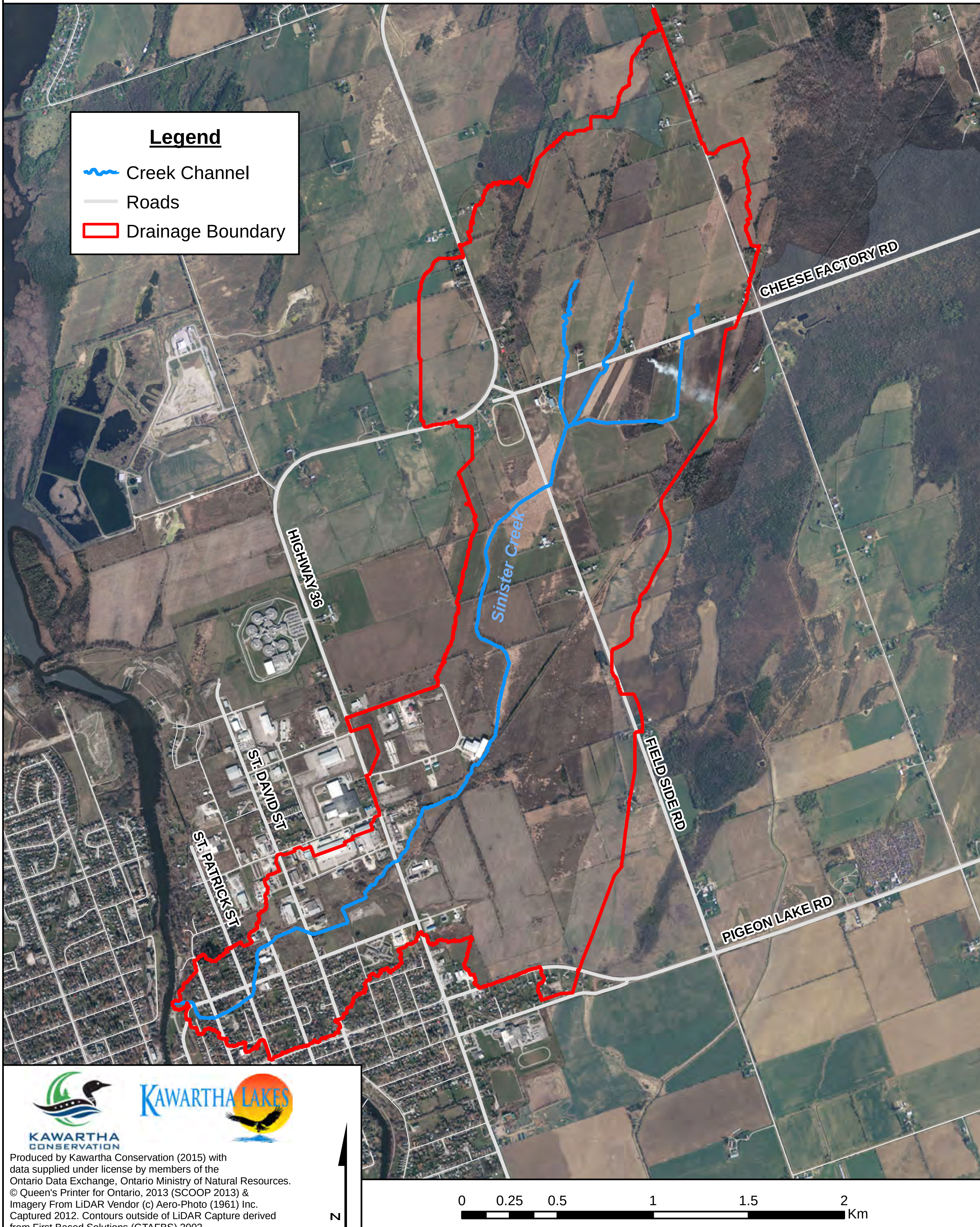
For the QA portion of the hydrology and hydraulic modeling components, a hydraulic/hydrologic modeling procedures document was created that: established data input parameters to meet municipal and provincial standards; put in place data collection and extraction procedures; and short-listed computer models. The document was peer-reviewed by Greck and Associates and was found to be satisfactory. The modeling and flood plain report were peer-reviewed for QC purposes by the water resources engineer at GRCA. The models, report and floodplain maps were found to be satisfactory.

1.3 Watercourse Context and Description

Sinister Creek is a subwatershed of the Scugog River watershed. Sinister Creek originates east of Highway 36, east of the Town of Lindsay. Rural drainage from agricultural lands east of Fieldside Road and other lands adjacent to Highway 36 drain via a series of roadside ditches and tile drains into Sinister Creek. From here the watercourse continues southwest crossing Highway 36 through industrial/commercial lands. The channel continues southwest crossing St. David Street and St. Peters Street, before crossing Colborne Street East and flowing through a residential area. Sinister Creek continues to flow southwest through residential area; crossing St. Patrick Street, St Paul Street and heading northwest back under Colborne Street East before discharging into the Scugog River at Rivera Park. The Scugog River eventually drains into Sturgeon Lake. Please refer to **Figure 1.1**.

The majority of the watershed east of the Town of Lindsay is rural farmland, wetlands, industrial/commercial and residential areas. The watershed has an area of 641 hectares (ha) or 6.4 square kilometers (km^2). The Sinister Creek main channel is about 4.2 km long with an average slope of 0.55%.

Figure 1.1: Sinister Creek Watershed Area



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1.4 *Background Information*

Summary of Previous Flood Plain Mapping Studies:

- Sinister Creek Flood Plain Study, prepared by KRCA, January 1990.
- Sinister Creek Floodplain Report for The Lindsay Non Profit Housing Corporation, prepared by Northern Eagle Engineering, August 1990.
- Partial Environmental Impact Study (EIS) for Flooding and Erosion Hazards, prepared by Jacques Whitford, February 2007 (Tim Horton's development).
- Cut and Fill Balance & SWM Design Brief for 72 St. David Street Storage Warehouse, prepared by C.C. Tatham & Associates Ltd., February 2013..

Kawartha Conservation completed a Flood Plain Study on a small section of Sinister Creek in January, 1990. Northern Eagle Engineering completed a Floodplain Mapping Report for the Lindsay Non-Profit Housing Corporation, dated August 1990, in support of the development of two retirement apartment buildings; one of which straddles Sinister Creek Sinister creek,. The subject development also includes parking areas constructed over of Sinister Creek. The 1990 KRCA study recommended against encasing the creek since the St. Patrick Street crossing was found to overtop and had existing flooding issues. Despite the recommendations of the 1990 KRCA study; a section of Sinister Creek was encased to facilitate parking areas for the two buildings. The encasement of the watercourse is outlined in the report entitled Sinister creek Floodplain Mapping Report for the Lindsay Non-Profit Housing Corporation, prepared by Northern Eagle Engineering dated August 1990.

Jacques Whitford completed a Partial Environmental Impact Study (EIS) for Flooding and Erosion Hazards dated 2007 in support of the Tim Horton's development located at Highway # 36 and Mount Hope Street. C.C. Tatham & Associates Ltd. completed a flood plain assessment and cut/fill balance for the proposed Lindsay Storage Warehouse Facility at 72 St. David Street dated February 2013.

A detailed comparison of previous studies versus the current study will be presented later in this report. Copies of the previous studies are included in **Appendix A**.

The City of Kawartha Lakes recently reconstructed Needham Street and changed the major system drainage area boundary. The Needham Street Storm Catchment Area Drainage Plan East prepared by Jones Consulting Group is included in **Appendix A**.

The City of Kawartha Lakes provided the drainage area boundary for the Ops# 21-74 municipal drain (included in **Appendix A**) adjacent to the Sinister Creek watershed.

The initial study area derived from the geospatial data used for this project was 708 ha. The final watershed area was updated to 641 ha after the drainage areas for the Ops# 21-74 municipal drain and the Needham Street Reconstruction drainage area plan were accounted for in the Sinister Creek watershed area.

1.5 Modeling Approach

A standard steady flow hydrologic modeling method was used to obtain peak flows as input for steady-state HEC-RAS hydraulic models to determine the extent of the subject floodplain for this study. The hydrologic modelling was carried out using Visual Otthymo (V02) v.2.4. Hydraulic modeling was carried out using HEC-RAS v. 4.1.

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

Individual catchments have been refined by desktop review and site visits where applicable.

Runoff hydrographs have been generated for the 2, 5, 10, 25, 50, and 100 year and Regional (Timmins) storms. The source rainfall data utilized for this analysis is from Environment Canada's rain gauge that was historically located at the Lindsay Filtration Plant.

Sensitivity analyses have been carried out to determine the impact of changing model parameters on the calculated flows and will be discussed later in the report. No flow monitoring data was 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.*

1.6 Modeling Assumptions

Where not specified, default parameters/values were used within V02 and HEC-RAS.

2 Rainfall

2.1 Rainfall Data

Rainfall Intensity–Duration–Frequency (IDF) values and curves are used to define the amount of rainfall that will be input into a model. IDF values provide estimates of the extreme rainfall intensity for any given duration corresponding to different return periods. Rainfall volumes are taken from Lindsay's Atmospheric Environment Services (AES) gauge which was removed from service in 1989. Other rainfall stations, such as Peterborough (AES) and Ontario Ministry of Transportation (MTO) were considered while completing the Ops#1/Jennings Creek Flood Plain Analysis in 2014; however it was decided by the technical committee to carry on with the use of the Lindsay station as the values for the Lindsay station are similar to other local station's values. Additionally, use of the Lindsay Filtration Plant values provides continuity as much of the infrastructure in the community has been designed using this curve. Finally, it was felt that this gauge provided the most representative data for the study area.

The Ontario Ministry of Natural Resources (MNR) technical manuals provide a rainfall reduction table for the Timmins storm. For drainage areas larger than 25 km^2, an aerial reduction is applied to the Timmins point rainfall based on 24 hr isohyets as shown in Table D-5 of the MNR manual. Given the size of the catchment no areal reduction factors were used.

Detailed rainfall information is provided in **Appendix C**. 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 shown in **Table 2.1** below:

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

Return Period (yr)	A	B	C
2	628.11	5.273	0.780
5	820.23	6.011	0.768
10	915.85	6.006	0.757
25	1041.80	6.023	0.748
50	1139.70	6.023	0.743
100	1230.80	6.023	0.738

Through the course of the Ops #1 Drain/Jennings Creek flood plain study 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-created the a, b, and c parameters which are listed below in **Table 2.2**; these values provided rainfall depths within 1% of 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	808.3	7.413	0.835
5	1248.1	9.760	0.857
10	1486.8	10.440	0.859
25	1917.8	11.842	0.873
50	2142.0	12.182	0.872
100	2465.5	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

2.2 Design Storms

Three different elements are reviewed regarding rainfall to generate return period events: the total volume of rain, the storm duration, and the rainfall distribution. Rainfall distribution is the specific apportionment of rain over time, or the shape of the storm being considered. The relative importance of these factors varies with the characteristics of a catchment. It is accepted practice to test different design storms to determine the most conservative response of a hydrologic system. It is the intent of this study to use the most conservative of commonly used approaches to ensure the most appropriate protection for the community of Lindsay.

In order to determine conservative catchment response generated by different rainfall storm events, a variety of rainfall durations (4,6,12 & 24 hours) for 2-100 year return periods were tested. Additionally, in order to determine the critical design storm creating the highest peak discharges, different sets of rainfall distribution were tested. The following discusses the rainfall distributions evaluated in this study.

The Soil Conservation Service Type II (SCS) distribution is a rainfall distribution curve which represents high-intensity rainfall rates generally associated to a 24-hr rainfall. For more than a century, the Natural Resources Conservation Service (US) has continued working on the development of empirical formulas to improve the Soil Conservation (SCS) method for predicting storm runoff from design storm events. The SCS method (1973) presents the 24-hr Type I, IA, II, and IIA rainfall time distributions for runoff predictions. The Type II curve is applied to much of the United States, Puerto Rico, and the Virgin Islands. Generally, other distributions are recommended for coastal areas of the country. The Type II distribution is generally tested in hydrology studies undertaken in southern Ontario. The bulk of the rainfall occurs in the second half of the storm.

Environment Canada has developed a design storm for southern Ontario. When compared to the SCS distribution, the majority of the rainfall in the Atmospheric Environment Service (A.E.S.) storm occurs at the beginning of the storm. The southern Ontario 30% curve is used in this study.

The Chicago storm distribution is one of the commonly used distributions for the design and analysis of storm sewer systems within urban areas. The distribution of rainfall is generally in the centre of the storm and the peak of storm is quite intense. Some investigators consider that this distribution yields unrealistically “peaky” hyetographs, especially when a small time step is used.

The worst case storm (the duration and distribution producing the highest discharges at key nodes) is selected as the critical event for the watershed. Detailed rainfall information is shown in **Appendix C**.

2.3 Regional Storm

The Timmins storm with a total rainfall of 193 mm was applied to the Sinister Creek as the Regional storm event. The full storm is defined by Chart 1.04 of the *MTO Drainage Manual*. Antecedent moisture content (AMC) condition II, referred to as AMC (II), was applied. Antecedent moisture content conditions and curve numbers will be discussed further in section 3.6 of this report. An aerial reduction factor was not applied to the Regional model as previously discussed in section 2.1.

2.4 Snowmelt and Snowmelt/Rainfall Events

These analyses were not carried out for this report because there is no recorded data that has captured the runoff from a specified combination of snowmelt and precipitation.

2.5 Climate Change

Climate change considerations were not included within the scope of work or terms of reference for this project at this time.

3 Hydrologic Parameters

3.1 Overview

In 2012, the City of Kawartha Lakes and Kawartha Conservation agreed to produce a standardized methodology for completion of a number of flood plain mapping studies within its watersheds. This approach was peer-reviewed by Greck and Associates Limited, and their findings conclude the methodology is valid. All parameters and modeling approaches described within this report follow the recommendations presented in **Appendix B** unless otherwise noted.

For this study Kawartha Conservation extracted hydrologic parameters from newly acquired LiDAR elevation data, orthoimagery, Arc Hydro watershed boundaries, and field surveys.
As previously mentioned, hydrology modeling was carried out using Visual Othymo (VO2) v 2.4.

3.2 Digital Elevation Model

In order to generate a highly accurate Digital Elevation Model (DEM) for the study area, two points per square meter LiDAR data was acquired. ArcGIS version 10.1 computer software programs translated the collected data points as a Triangulated Irregular Network (TIN) in order to isolate ground elevation points from the full dataset. This resulting data was converted to a 0.5 m raster digital elevation model (DEM), which in turn provides elevation information for the model. LiDAR data was also used in conjunction with Real Time Kinematic (RTK) Global Positioning System (GPS) survey data of culvert locations and invert elevations to create a drainage network.

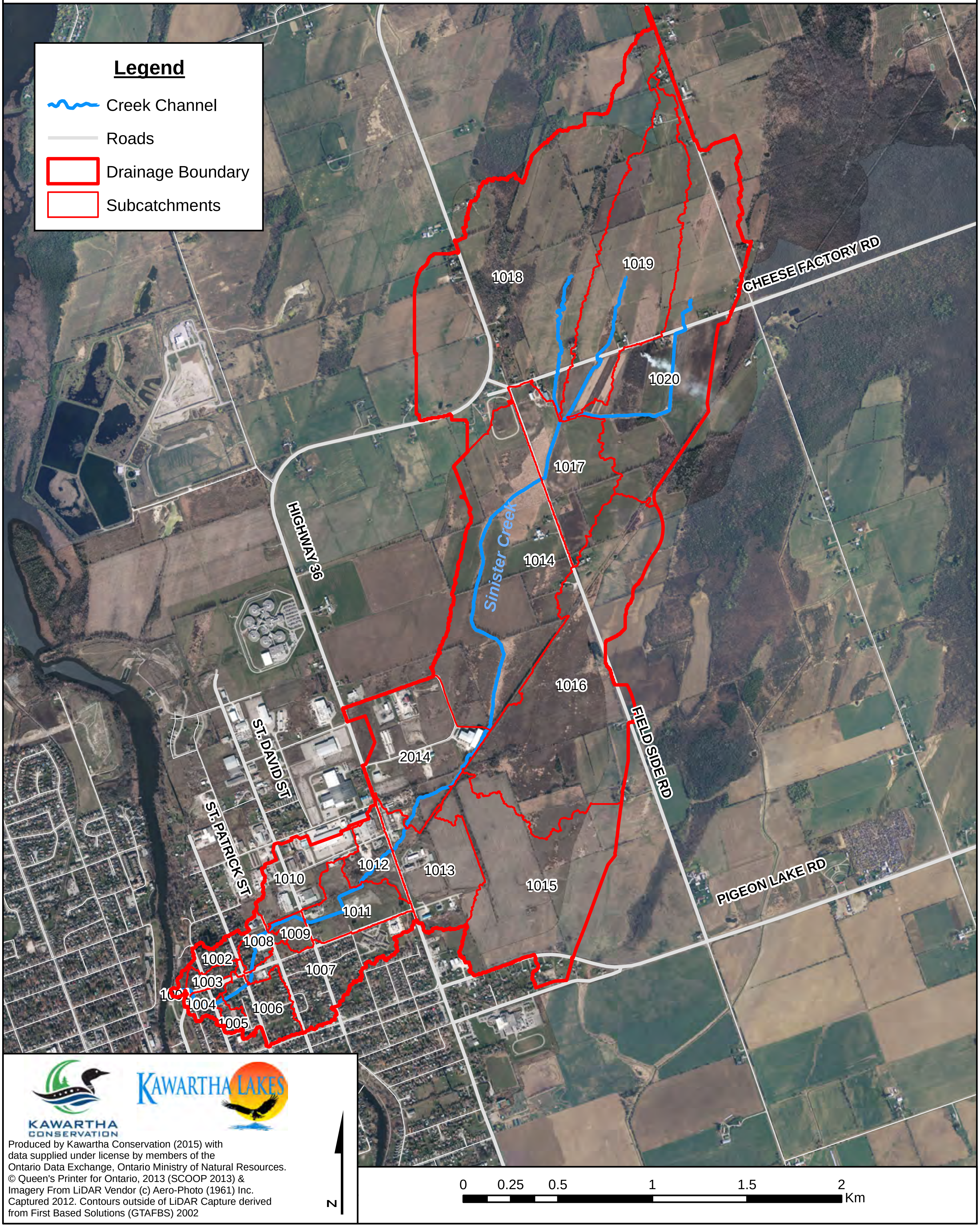
The validity of the DEM was analyzed in the report titled, Quality Assurance and Quality Control Report for Sinister Creek Flood Plain Mapping Data, 2015, prepared by Kawartha Conservation GIS staff and peer-reviewed by GRCA GIS staff.

3.3 Catchment Discretization

In order to discretize catchments, ArcHydro version 10.1 beta software was utilized to generate flow pathways within the watershed using the DEM as input data. The resultant watercourse layer was employed to enforce water routing through roads and other impediments which can act as obstacles to channel flow (i.e. culverts and bridges).

Critical nodes within the watershed were the basis to delineate the initial catchments in ArcHydro. ArcHydro is suitable for the delineation of catchments within rural areas; however in urban areas where a stormwater collection system exists, the ArcHydro tool has deficiencies for including sub-surface pipe networks. ArcHydro also has drawbacks for determining overland flow pathways in urban areas where the topography forms a concave shape. To overcome this gap, desktop review of plans and field visits were carried out to verify and modify catchment boundaries as required. **Figure 3.1** illustrates the catchments.

Figure 3.1: Catchment Boundaries



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3.4 Geometric Properties

The area, main channel length, catchment channel length, and overland flow length of each rural catchment were derived using ArcHydro. In this process, the downstream node is selected by the user, and ArcHydro calculates the longest flow path, both overland and in the channel. **Appendix D** contains a series of figures showing each catchment.

3.5 Calculation of Slope

The slope calculation requires information of the flow paths for overland flow and channel flow within the catchment. In some areas where LiDAR data was not available, Ontario SCOOP data was used to supplement the LiDAR for slope calculations. The SCOOP data was only used in rural areas and was deemed satisfactory to calculate slope for time of concentration (T_c)/time to peak (T_p) calculations in the absence of LiDAR data. Spreadsheets calculating channel and catchment slopes, and individual catchment time of concentration (T_c) and time to peak (T_p) calculations are found in **Appendix E.**

3.6 CN Values

The Soil Conservation Service (SCS) curve number (CN) is used to determine runoff. Users must choose which antecedent moisture condition (AMC I, II, or III) is relevant for the model; AMC II represents a dry soil condition, and AMC III represents saturated soil.

For this study, existing rural land use (based on CN value categories) was digitized from the projects orthophotography, land use zoning from the City of Kawartha Lakes and other GIS data were also queried to extract land use, drainage area, and hydrologic soils group data. A weighted CN (AMC II) value was calculated, using the values found in **Appendix E**.

The VO_2 program requires that the CN value be transformed to modified curve number (CN*). CN* (AMC II) was used for the regional (Timmins) storm and 100 year design storms as per direction from the technical committee. This approach is consistent with MNR guidelines. **Figure 3.2** provides soils information while **Figure 3.3** shows the hydrology land use assumptions for the watershed. These calculations are included in **Appendix E**.

3.7 Percent Impervious

City of Kawartha Lakes GIS data was used to determine the land use for each sub-catchment. The land use of each sub-catchment was determined using draft secondary plan data from the City of Kawartha Lakes.

The detailed land use(s) of each sub-catchment was used to determine the weighted total impervious area (TIMP) and directly connected impervious area (XIMP) using the tables from the Hydrologic Parameters List (**see Appendix B)** for input into V02**.** The percent imperviousness for each sub-catchment area was not calculated by manually digitizing specific impervious areas within GIS due to project budget and scheduling limitations.

The individual look-up tables used to calculate the weighted imperviousness and curve numbers (CN) for each sub catchment are included in **Appendix E.**

3.8 Stormwater Management (SWM) Facilities

No SWM facilities or controls are included in the hydrological model, due to several reasons. The Ministry of Environment (MOE), Kawartha Conservation, and the City of Kawartha Lakes require SWM facilities for quality and quantity control for storm events up to the 100-year return period. However, flood plain mapping is generally based on a Regional event which is beyond the design range of a SWM facility. Secondly, the worst-case scenario is assumed, wherein all structures fail. Thirdly, for private sites having stormwater controls, the City of Kawartha Lakes and Kawartha Conservation have limited ability to enforce regular maintenance or inspection of the facilities and therefore there is no assurance they will continue functioning as designed.

Figure 3.2: Soils

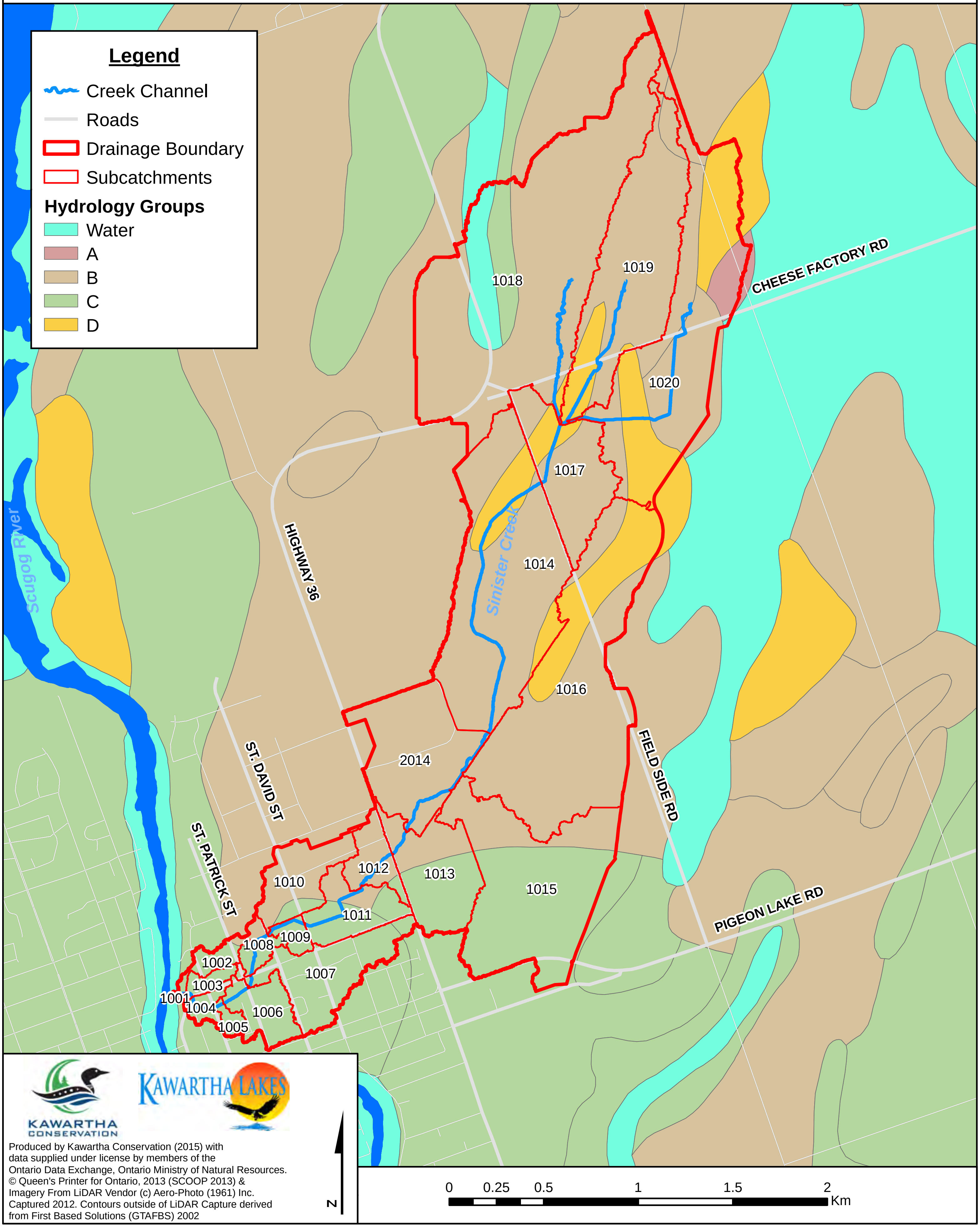

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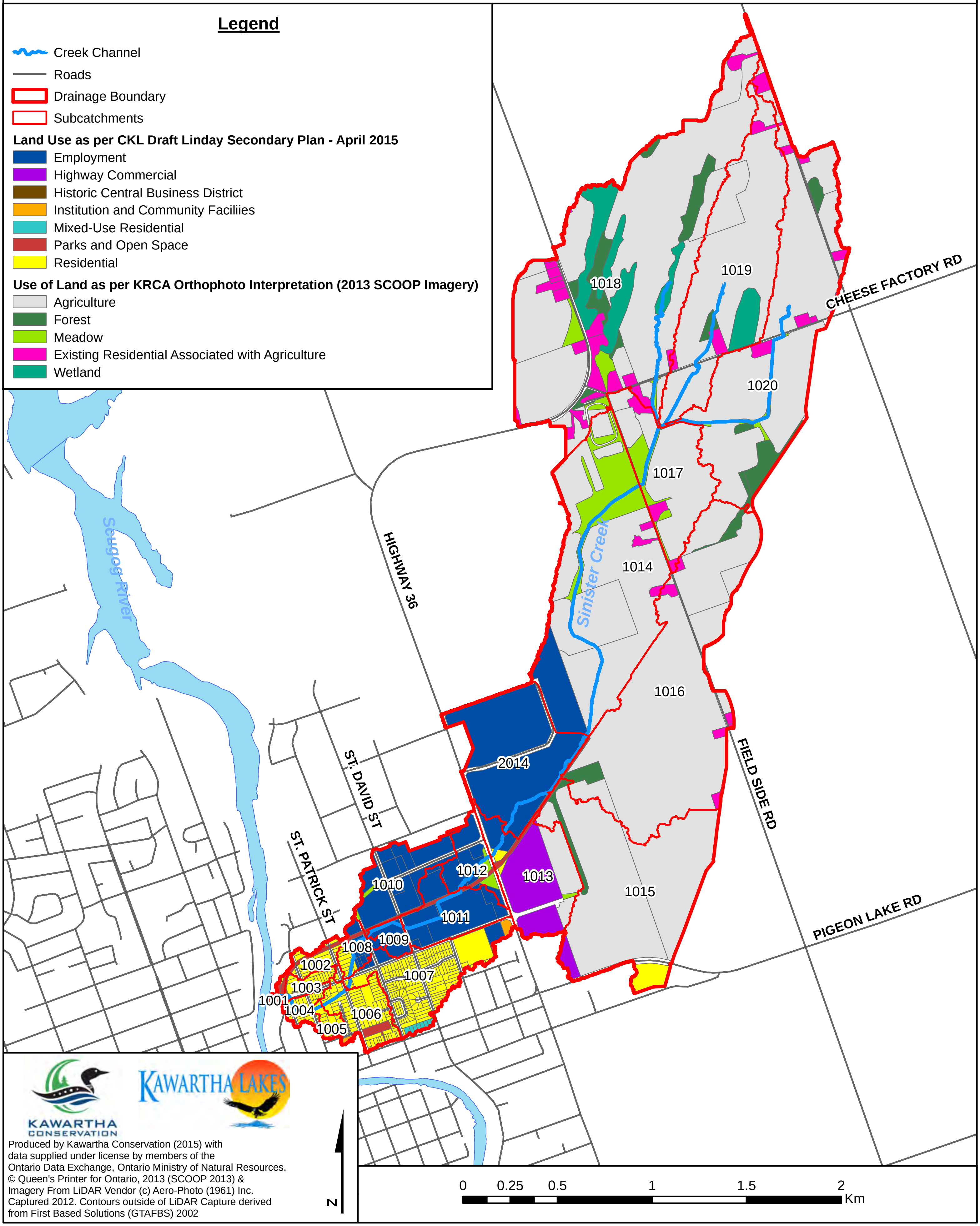
Figure 3.3: Land Use for Hydrology Modeling



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4 Hydrologic Model

4.1 Visual Otthymo (V02)

As mentioned in Section 1.5 of the report; the extent of flooding for Sinister Creek was assessed using a hydrologic model, Visual Otthymo (V02), to determine peak flows for input into the hydraulic model (HEC-RAS).

The regional (Timmins) storm and various 100 year design storms were modeled in V02. The 2, 5, 10, 25 & 50 year return events were also modeled in V02.

The assumed hydrology land use is based on the draft secondary plan land use schedule for areas within the urban settlement boundary. For areas outside of the settlement boundary, the "use of land" was determined through interpretation of the orthophotography by Kawartha Conservation staff. **Figure 3.3** illustrates the assumed hydrology land use for the modeling exercise.

Channel routing was used within the V02 model to account for the lag in timing of the flows being routed through the main channel. Simplified HEC-RAS cross section data was used as input for the route channel command within V02. One representative cross section from HEC-RAS was selected as input into the route channel command for each section of the main channel to be modeled. The HEC-RAS cross sections were simplified for input into V02 due to software limitations. Manning's n values were selected to represent an overall average of the entire length of the channel being modeled in the respective route channel commands. In some instances, the channel routing cross section data had to be manipulated to ensure that the channel routing was effectively conveying the entire flow down the system and to prevent the V02 model from crashing. The route channel length and slope inputs were calculated using surveyed cross section data.

The hydrologic model does not account for any attenuation of flows behind structures (culverts/bridges) since it is assumed that any given structure may not remain in place during a flood event as per MNR flood plain mapping guidelines.

Catchments with TIMP values greater than 20% were modeled as STANDHYD's and catchments with TIMP values less than 20% were modeled as NASHYD's as per the V02 reference manual.

Where not specified, default parameters/values were used in VO2. The VO2 schematic is included in **Appendix F**.

Time of concentration (Tc) was calculated using the Airport Method for catchments with runoff coefficients (RC) less than 0.40 and the Bransby Williams Method for catchments with runoff coefficients greater than 0.40 as per the Hydrologic Parameters List. Time to peak (Tp) was then obtained from the calculated time of concentration (Tp=2/3Tc) for input into the NASHYDs within V02. Tp calculations are shown in **Appendix E**. GIS ArcHydro with engineering oversight was used to determine the source data to calculate Tp.

In some areas where LiDAR data was not available, Greater Toronto Area First Base Solution (GTAFBS) 2002 Ortho-Imagery DEM was used to supplement LiDAR data to create contours. The GTAFBS 2002 data was only used in rural areas (NASHYD's) and was deemed satisfactory to calculate slope for time of concentration (T_c)/time to peak (T_p) calculations in the absence of LiDAR data. This is explained in detail in the report entitled "Quality Assurance and Quality Control Report for Sinister Creek Flood Plain Mapping Data, 2015" included in **Appendix I.** Individual figures for each catchment modeled as a NASHYD are included in **Appendix D**.

Three distinct flow length segments were indentified on the individual catchment figures; overland flow, catchment channel flow and main channel flow lengths. Please refer to the legend on the on the individual catchment figures located in **Appendix D** for more information. For the purpose of the Tc/Tp calculations, only the overland flow length and catchment channel flow length were used for the Tc/Tp calculations. We assumed main channel flow to be instantaneous and therefore was not included in the Tp/Tc calculations. Although the Airport Method is primarily intended for overland flow; we found the results to be reasonable when the catchment channel flow length was included in the total length used for the Tp/Tc calculations.

Modified curve numbers (CN*) were used in V02 as per the V02 reference manual. As mentioned above; CN* (AMC II) conditions were used for the regional (Timmins storm) and 100 year design storms as per direction from the Technical Committee. CN* calculations are included in **Appendix E**.

4.2 Calibration

Since no flow monitoring data exists for this watercourse, no model calibration is possible.

4.3 Schematic

The information gathered in the preceding sections was used to build a V02 model of the watershed, as shown schematically in **Appendix F.**

4.4 Sensitivity Analyses

The model was tested for sensitivity of increasing and decreasing the CN* values.

CN*II was changed +/- 20%. Decreasing CN* by 20% lowers flow peaks by an average of 11% within the entire watershed. Similarly, increasing CN* to 120% of their original value increases flow peaks by an average of 10% within the entire watershed.

The moderate change in peak flows due to this sensitivity analysis indicates that it is important to get an accurate CN* value. Since CN* is a value that is derived directly from measured parameters (land use and soil type), there is confidence that the calculated CN* is correct.

The model time step (DT) was changed by +/- 50%. The default DT in V02 is 10min. Separate scenarios were created to test the models sensitivity using a DT of 5 min and 15 min. There was very little change in the peak flows (<1%). Adjustment of the models time step results in irrelevant changes to the model results. Detail information regarding sensitivity analysis in included in **Appendix E**.

4.5 Hydrology Model Results

The V02 schematic and detailed output from the model are included in **Appendix F**. A summary of the peak flows are presented below in **Table 4.1**. Figure 4.1 shows the key node locations referenced in the hydrology results summary tables.

Table 4.1: Summary of Peak Flows

Nodes	Regional Timmins (m^3/s) CN*II	SCS 100yr 6 hr (m^3/s)	SCS 100yr 12 hr (m^3/s)	SCS 100yr 24 hr (m^3/s)	CHI 100yr 4 hr (m^3/s)	CHI 100yr 12 hr (m^3/s)	AES 100yr 24 hr (m^3/s)	AES 100yr 12 hr (m^3/s)	AES 100yr 6 hr (m^3/s)
118	11.84	6.24	5.19	4.00	5.03	5.59	2.73	4.52	6.40
117	13.14	7.04	5.84	4.49	5.67	6.32	3.05	5.04	7.20
114	16.54	8.20	6.87	5.46	6.49	7.24	3.88	6.33	8.67
116	20.88	10.61	8.88	7.01	8.43	9.39	4.94	8.08	11.11
115	24.08	12.53	10.46	8.16	9.99	11.15	5.69	9.36	13.04
214	25.57	13.02	10.95	8.82	11.78	11.87	6.28	10.04	13.50
113	26.98	13.37	11.31	9.27	16.49	16.71	6.67	10.69	13.92
112	27.41	14.79	11.42	9.44	18.36	18.62	6.81	10.90	14.02
111	28.07	16.56	11.61	9.70	18.85	19.25	7.04	11.19	14.27
109	29.06	18.92	11.95	10.04	20.91	21.34	7.35	11.64	14.65
108	29.18	19.02	12.26	10.12	22.41	22.81	7.41	11.73	14.79
107	30.52	22.57	14.31	10.53	26.59	27.21	7.77	12.32	15.60
106	31.08	24.02	15.11	10.78	29.00	29.76	7.91	12.58	15.94
105	31.18	24.29	15.27	10.87	29.80	30.30	7.94	12.62	15.99
104	31.31	24.61	15.46	11.03	29.74	30.51	7.98	12.69	16.06
103	31.46	24.96	15.72	11.15	30.19	30.99	8.02	12.75	16.15
102	31.67	25.55	16.05	11.33	30.48	31.24	8.08	12.86	16.27
101	31.67	25.64	16.07	11.34	30.47	31.27	8.09	12.87	16.27

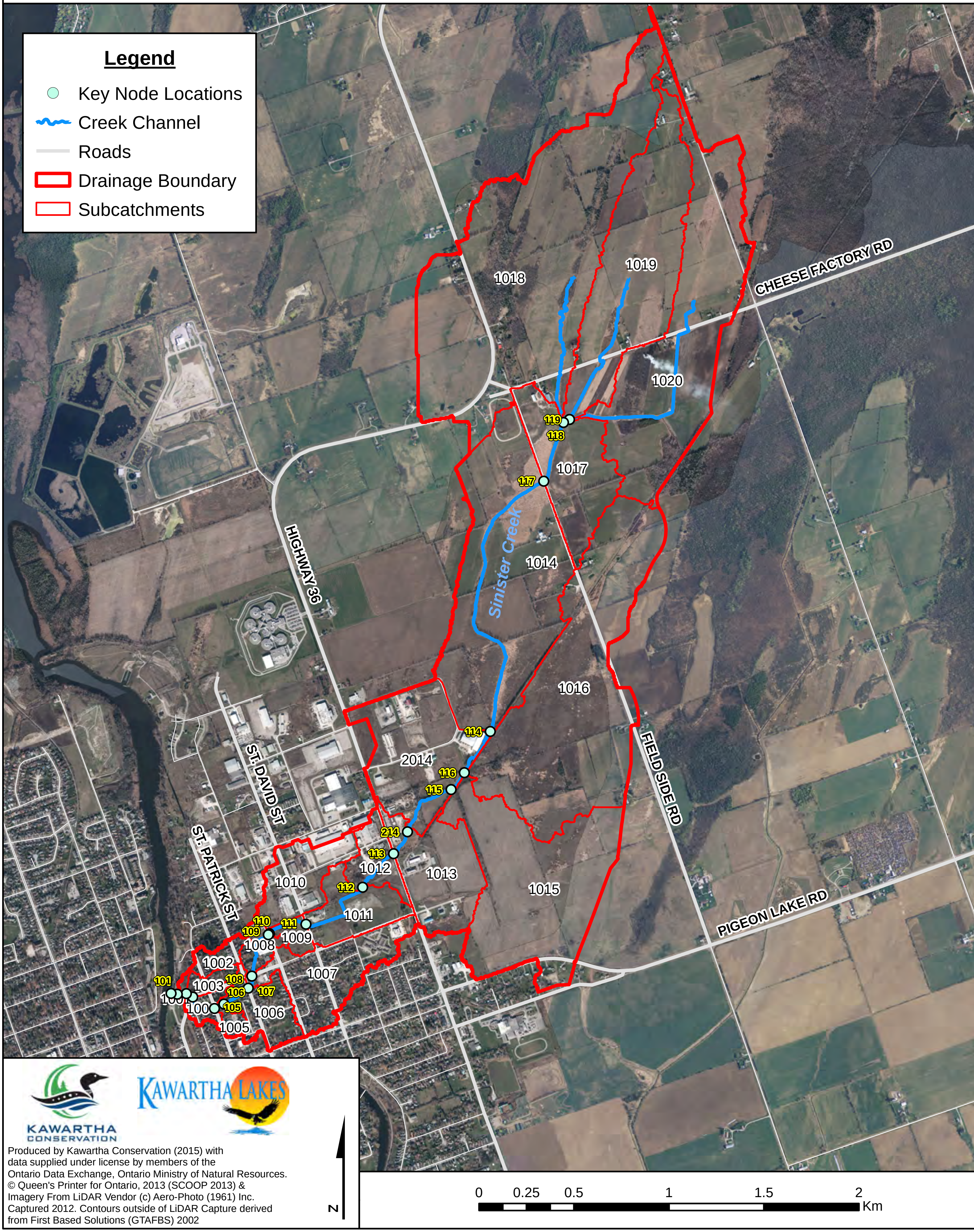
The regional (Timmins) storm produced the highest peak flows and is therefore the regulatory event for the system.

The Chicago design storm is a very “peak” distribution and usually produces the highest peak flows in urban areas. This trend can be seen above as the 12 hr Chicago storm produces the highest peak flows from nodes 113 to 101 (residential/industrial/commercial areas). The AES design storm typically has a “broader” distribution and usually produces higher peak flows in rural areas. This trend can be seen above as the 6 hr AES 100 yr storm produces the highest peak flows between nodes 118 to 214 (upstream rural areas).

It should also be noted that there is minimal difference in rainfall volume between the 6 and 12 hr data from the Lindsay rainfall gauge station.
The 100 yr 12 hr Chicago produced the highest peak flows for the greatest amount of nodes and in the most critical, developed areas; therefore the 100 yr 12 hr Chicago was selected as the most conservative design storm.

The 2, 5, 10, 25, 50 yr return periods are included in the V02 model for the 12 hr Chicago design storm and summary chart is included in **Appendix F**. Regardless, the regional (Timmins) storm produces the highest peak flows and is regulatory event for the system.

Figure 4.1: Key Node Locations



Produced by Kawartha Conservation (2015) with data supplied under license by members of the Ontario Data Exchange, Ontario Ministry of Natural Resources. © Queen's Printer for Ontario, 2013 (SCOOP 2013) & Imagery From LiDAR Vendor (c) Aero-Photo (1961) Inc. Captured 2012. Contours outside of LiDAR Capture derived from First Based Solutions (GTAFBS) 2002

Figure 4.1: Key Node Locations (Zoomed In)

5 Recommendations for Flow Inputs to Hydraulic Model

5.1 Peak Flow Inputs for the HEC-RAS Model

It is recommended that the values from **Table 5.1** be used as input to the HEC-RAS hydraulic model.

Timmins storm provides the highest peak flows and will be the regulatory storm. Refer to **Figure 4.1** for the key node locations.

Table 5.1: Input Flows to Static HEC-RAS Model

Approximate Location	Node	HECRAS Section #	Regulatory (Timmins CN*II)	100 year Chicago 12 hr CN*II
Fieldside Rd	117	4212	13.14	6.32
S/E of Walsh Rd	114	2615	16.54	7.24
S of Walsh Rd.	116	2394	20.88	9.39
E of Verulam Rd.	115	2277	24.08	11.15
E of Verulam Rd.	214	1917	25.57	11.87
Verulam Rd	113	1784	26.98	16.71
Abandoned railway crossing (east)	112	1508	27.41	18.62
St David St	111	1060	28.07	19.25
St Peter St	109	825	29.06	21.34
Colborne St (east crossing)	108	566	29.18	22.81
St Patrick St	107	499	30.52	27.21
Retirement building over creek	106	340	31.08	29.76
St Paul St	105	284	31.18	30.3
Colborne St (west crossing)	104	137	31.31	30.51
Aband. railway berm and crossing (west)	103	88	31.46	30.99
Riveria Park pedestrian bridge	102	30	31.67	31.24
Outlet into Scugog River	101	4	31.67	31.27

The results from the VO2 hydrological model for Sinister Creek are reasonable and the best estimate of peak flows for the system in absence of monitoring data for calibration of the hydrology model.

6 Hydraulic Model Parameters

6.1 Cross Sections

The cross-section geometric data used in hydraulic modeling was extracted from the DEM using HEC-GeoRAS. The use of HEC-GeoRAS ensures spatial referencing of geometry data when imported into HEC-RAS. Cross-sections were cut in the LiDAR-derived DEM. Since LiDAR does not return laser points for any ground below the water surface, it is 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 was fused into the cross-sections generated by HEC-GeoRAS. Data sources generated by different entities were placed into the same projection and datum for consistency in processing.

All cross-sections are oriented looking downstream. The initial cross-section is at the mouth of Sinister Creek where it joins the Scugog River; cross-section nomenclature reflects the distance in meters relative to the mouth of the River. Distances were determined using GIS measurement tools. Left overbank, main channel, and right overbank downstream lengths were measured using GIS. As per HEC-RAS recommendations, the overbank distances were generally measured from each overbank centroid.

Stream crossings have been identified and positioned by reviewing the most recent aerial orthophotography in conjunction with field reconnaissance and information utilized by previous reports. Full photographic records of all stream crossings are found in **Appendix G**.

Where buildings are located within or between the cross-sections, ground elevations were artificially increased by a minimum of 5 m to replicate obstruction to flow.

6.2 Culvert and Road Crossings

Cross-sections were cut at culvert crossings and other restricting structures to accurately represent channel flow. All culvert crossings are represented by two upstream and two downstream bounding cross sections. Representative deck elevations were extracted from the DEM.

All culverts were field surveyed to ensure accuracy. Invert elevations, height/width dimensions, length, and channel bottom were surveyed using either total station and/or RTK GPS survey equipment. All relevant data was noted and photographed, and can be found in **Appendix G**.

The retirement building west of St. Patrick Street that was constructed over Sinister Creek was modeled as a bridge in HEC-RAS.

6.3 Expansion/Contraction Coefficients

The model uses the HEC-RAS recommendations of 0.1 and 0.3 for contraction and expansion coefficients at all normal cross sections. At culvert crossings, the values were increased to 0.6 and 0.8, respectively. The retirement building west of St. Patrick Street that was constructed over Sinister Creek was modeled as a bridge in HEC-RAS with contraction and expansion coefficients of 0.3 and 0.5, respectively.

6.4 Manning's n Values

Manning's n values for channel, left and right overbanks are based on recommended values in Table 3-1 of the *HEC-RAS River Analysis System Technical Manual* and/or the *Hydraulic Modeling Parameters Selections Standard Parameters* document associated with the project (included in **Appendix B).** The main channel n values are generally **.**035 and the overbank n values range from 0.016 to 0.05 and were chosen based on air photo interpretation by the modeller and survey notes/photos.

6.5 Ineffective Flow Elevations

Ineffective flow areas were introduced at all culvert crossings, following the HEC-RAS user manual recommendations. The upstream bounding cross-section has its ineffective flow elevations equal to the top deck elevations, at locations immediately to the left and right of the culvert opening. For the downstream bounding cross-section, the ineffective flow elevations were set at a point midway between the deck and the culvert obvert elevation. The placement of ineffective flow areas for the abandoned railway berm crossing (HEC-RAS structure #77) in the conventional locations yielded unreasonable results. The ineffective flow areas were relocated to the left over bank of section 88 to allow for conveyance of flows that overtop Colborne Street (ineffective flow location was selected based on the low point in Colborne Street). A detailed note was added to section 88 in the HEC-RAS model.

6.6 Boundary Conditions

Mixed flow analyses (including both sub- and supercritical flow regimes) were run for all scenarios in the steady state HEC-RAS model. Normal depth was used for the downstream boundary condition. The slope input for the normal depth boundary condition was calculated between the abandoned railway berm crossing and the creek outlet. Regardless of the downstream boundary condition used, the model defaults to critical depth (discussed further below). The upstream boundary condition was selected as the critical depth method. Detailed sensitivity analysis was conducted on the downstream boundary condition and is discussed further below.

7 Hydraulic Model

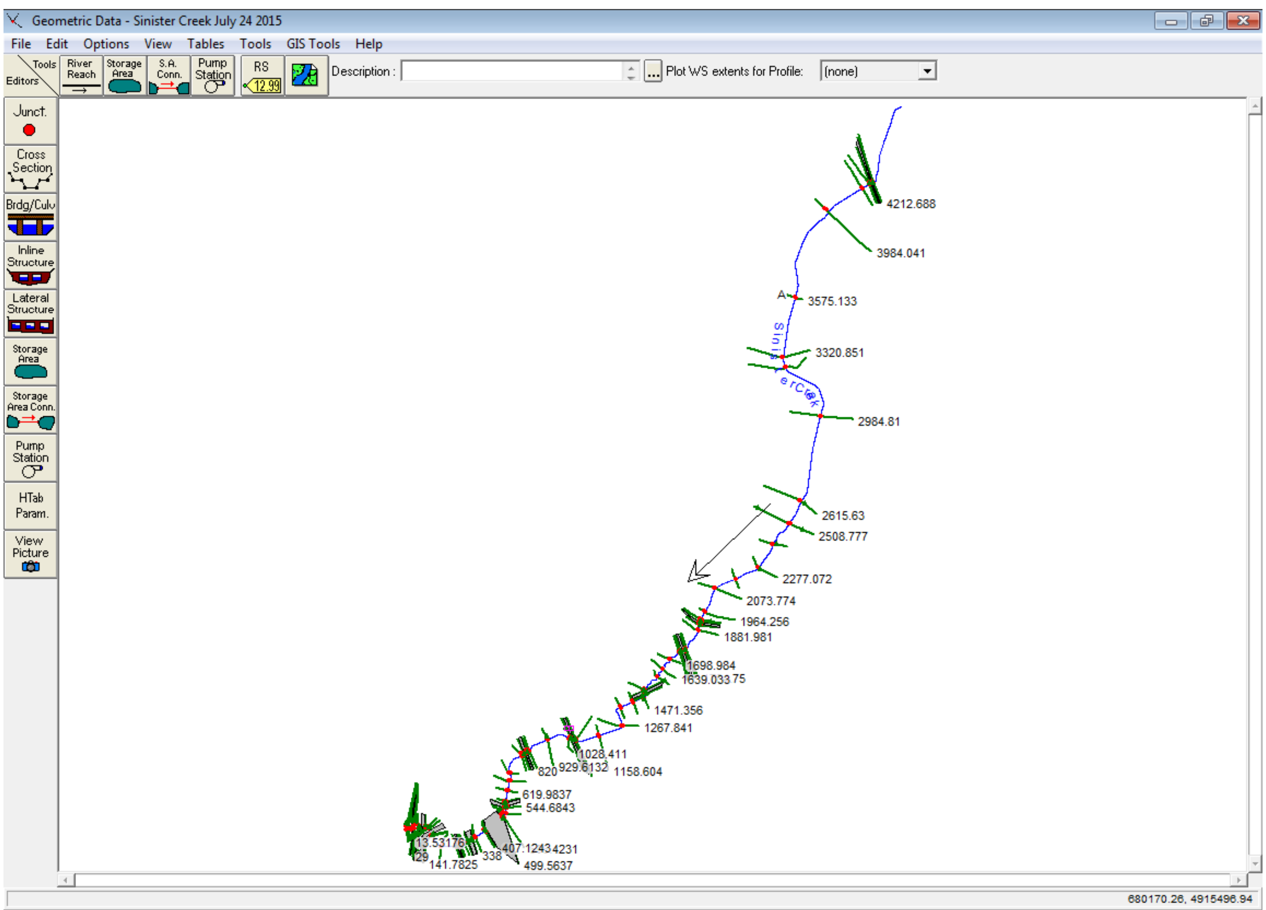
7.1 HEC-RAS

HEC-RAS version 4.1 was used for the hydraulic analysis. MNR policy does not allow flood plains to be reduced due to road/culvert attenuation since any future culvert and/or road improvement would increase the downstream flood plain and there is no guarantee that a roadway would remain in place during a flood event. The road and/or culvert could wash out and the downstream flows would not be attenuated. Therefore a static HEC-RAS model was used to generate water surface elevations for flood lines.

7.2 Schematic

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

Figure 7.1: HEC-RAS Schematic



7.3 Sensitivity Analyses

The HEC-RAS model was tested for sensitivity to the Manning's n and starting water surface elevation. **Appendix H** contains detailed information regarding the sensitivity analysis.

7.4 Increasing Manning's n Value by 20%

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. For 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 numbers by 20%, the flow is being subjected to a watershed with higher friction forces acting upon it. It was found that overall there is generally little impact to the calculated water surface elevations. On average the water surface elevations increased by approximately 5 cm, however there were some locations with greater increases. In some instances the water surface elevations also decreased.

7.5 Decreasing Manning's n Value by 20%

By decreasing the Manning's numbers by 20%, the flow is being subjected to a watershed with lower friction forces acting upon it. It was found that overall there is little impact to the calculated water surface elevations. On average the water surface elevations decreased by approximately 4 cm, however there were some locations with greater decreases. In some instances the water surface elevations also increased.

7.6 Boundary Condition

The model was modified using different starting water surface elevations as boundary conditions. The normal Sturgeon Lake water level of 247.76 m and the recorded 100-year Sturgeon Lake level of 284.4 were used as known water surface elevations. As previously mentioned in Section 6.6, the final HEC-RAS model uses normal depth method for the downstream boundary condition. Regardless of the downstream boundary condition used, the HEC-RAS model defaults to critical depth.

It appears that this is due to the fact that Sturgeon Lake is at too great a distance downstream of the watercourse outlet at the Scugog River. The starting water surface elevation is the controlled Sturgeon Lake water level of 247.76 m. It is noted that Sturgeon Lake is at a point approximately 5 kilometres downstream of the Sinister Creek outlet to the Scugog River. An attempt was made to find a more valid recorded water level for the Scugog River in the vicinity of the outlet. Municipal sewage and water treatment plants are located on the river. It was hoped that City staff would have a record of average water levels in the river that could be input to the model, but Kawartha Conservation was informed that no such recordings are kept by the City of Kawartha Lakes. Kawartha Conservation staff also contacted Trent Severn Waterway and no water surface elevations area available in this area.

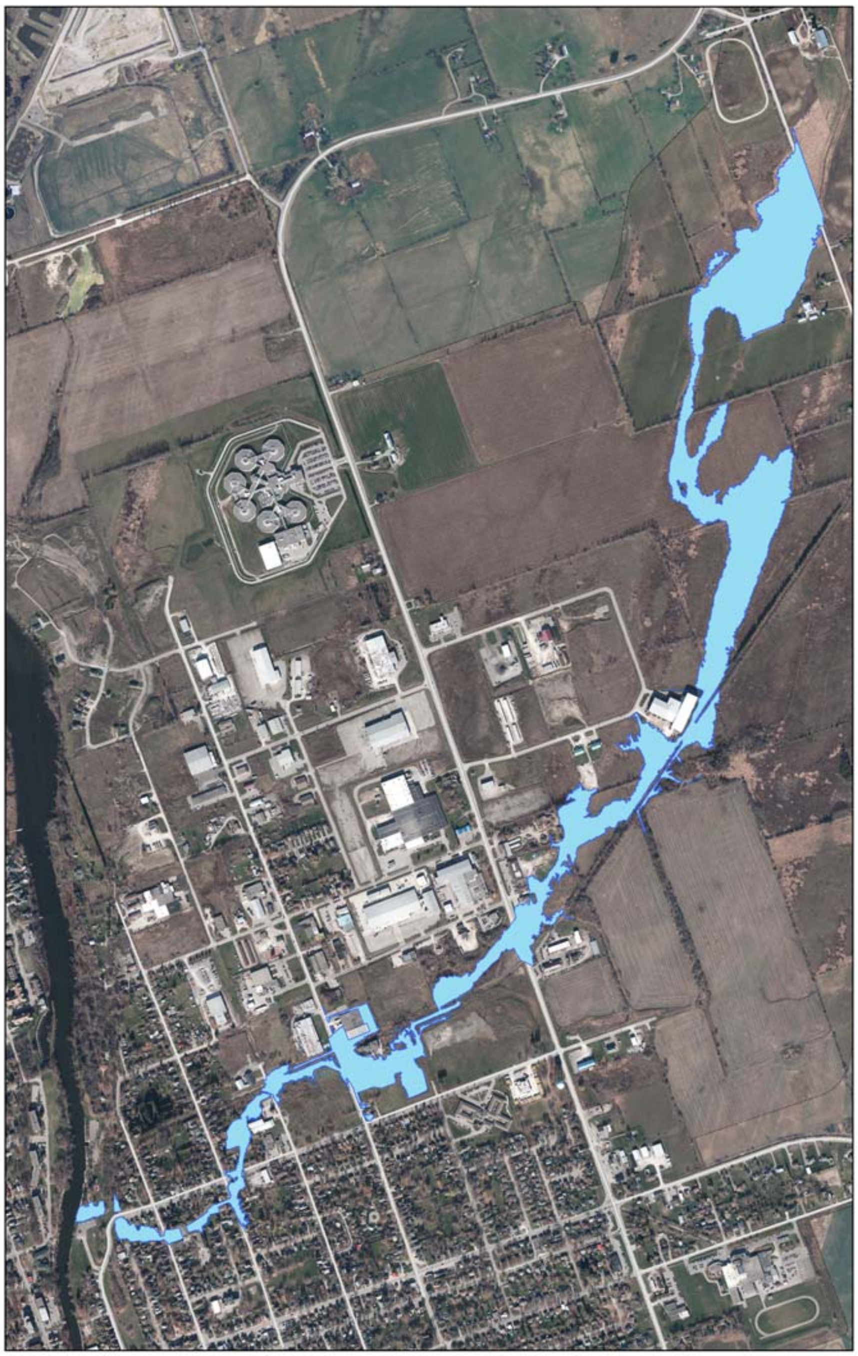
Therefore it was decided to use the normal depth method as the downstream boundary condition.

8 HEC-RAS Model Results

The detailed HEC-RAS model output can be found in **Appendix H**.

The computed water surface elevation from HEC-RAS we input into GIS to create a flood line for the regulatory event (Timmins storm). The extent of the overall flood plain is shown in **Figure 8.1** below.

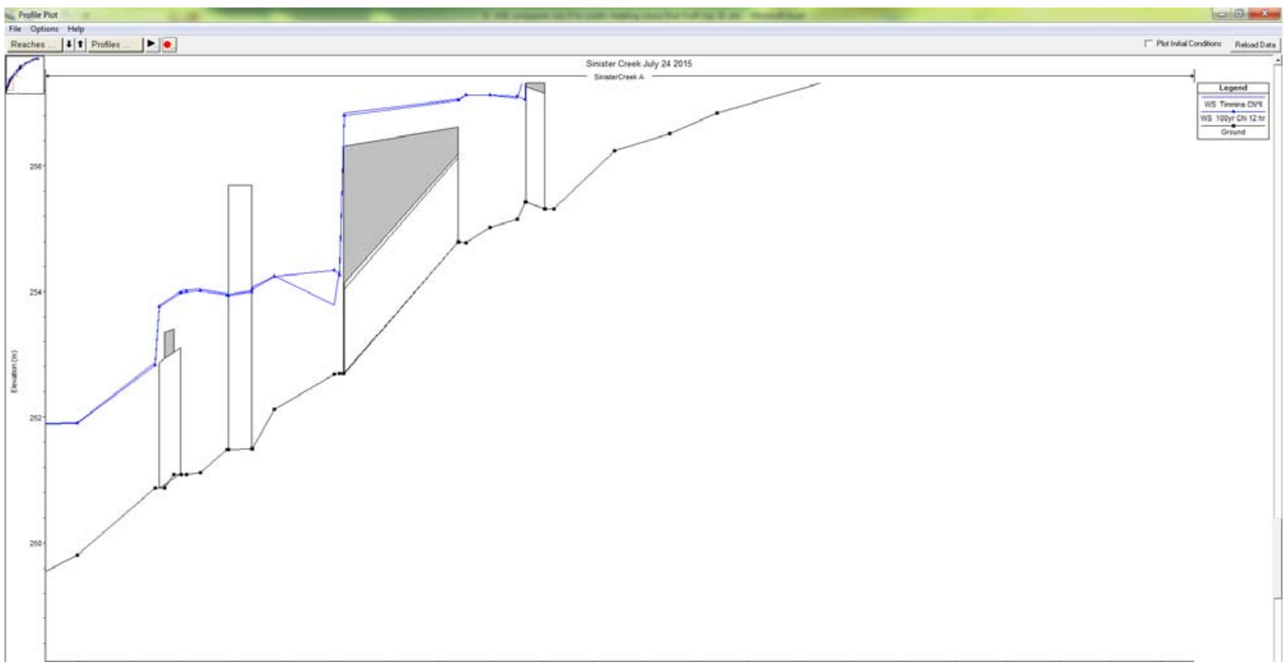
Figure 8.1: Sinster Creek Regulatory Flood Plain Extents



In areas where water will likely flow parallel to HEC-RAS cross sections; "spills" are shown on the flood plain maps due to the one-dimensional, hydraulic modeling approach used for this study.

A hydraulic jump is noted at the outlet of the St Patrick Street culverts, shown in **Figure 8.2** below. The St Patrick Street culverts are approximately 88 m in length. The 100 yr water surface elevation is greater than the Timmins at cross section 403. The Timmins critical water surface elevation (254.13) was selected as the regional elevation for cross section 403.

Figure 8.2: Hydraulic Jump at Section 403



9 Comparison to Previous Studies

The following compares the results of the current flood plain mapping study to previous flood plain mapping studies in the Sinister Creek watershed.

Summary of Previous Flood Plain Mapping Studies:

- Sinister Creek Flood Plain Study, prepared by KRCA, January 1990.
- Sinister Creek Floodplain Report for The Lindsay Non Profit Housing Corporation, prepared by Northern Eagle Engineering, August 1990.
- Partial Environmental Impact Study (EIS) for Flooding and Erosion Hazards, prepared by Jacques Whitford, February 2007 (Tim Horton's development).
- Cut and Fill Balance & SWM Design Brief for 72 St. David Street Storage Warehouse, prepared by C.C. Tatham & Associates Ltd., February 2013.

Copies of the previous studies are included in **Appendix A**.

The current flood plain mapping exercise studied the entire Sinister Creek watershed using a comprehensive approach versus the previous studies that only focused on mapping small sections of Sinister Creek in support of development.

The 1990 KRCA floodplain mapping study and associated 1990 Northern Eagle Study are limited in scope in comparison to this study. The watershed area of the 1990 study only encompassed 528 ha versus 630 ha used in this study. Further, the geospatial data used for the current study is more advanced than the low resolution mapping data available for use in the 1990's. The hydraulic analysis only accounts for 243.5 m of channel length versus 4200 m of main channel length used in this study.

The 2007 study references the 1990 KRCA study. The 2007 & 2013 studies also are very limited in scope in comparison to the current study and only accounts for a small section of Sinister Creek adjacent to the subject development(s).

Table 9.1 below provides an approximate comparison between the regional (Timmins) peak flows and resulting water surface elevations of the current study versus the previous studies. It should be noted that the location of the cross sections and/or flow nodes from the current study are not an exact comparison to the previous studies.

Table 9.1: Approximate Comparison to Previous Studies

KC 2015	KC 2015		1990 Northern Eagle		2007 Jacques Whitford		2013 CC Tatham		Delta Q	% Dif.	Delta W.S.E.
River Stations**	Q (Timmins)	W.S.E.	Q (Timmins)	W.S.E.	Q (Timmins)	W.S.E.	Q (Timmins)	W.S.E.		Q	
	(m^3/s)	(m)	(m^3/s)	(m)	(m^3/s)	(m)	(m^3/s)	(m)	(m^3/s)		(m)
1770.0	Verulam Road Culvert										
1760.4	26.98	266.37			25.3	266.5			1.68	6.2%	-0.13
1699.0	26.98	265.69			25.3	266.06			1.68	6.2%	-0.37
1158.6	27.41	262.19					23.56	262.14	3.85	14%	0.05
1060.2	28.07	262.16					23.56	262.07	4.51	16%	0.09
1053.0	28.07	262.15					23.56	262.07	4.51	16%	0.08
1042.0	St. David Street Culvert										
505.4	29.18	257.12	24.64	257.01					4.54	16%	0.11
499.6	30.52	257.05	24.64	256.94					5.88	19%	0.11
460.0	St. Patrick Street Culverts										
407.1	30.52	254.37	24.64	254.06					5.88	19%	0.31
340.0	31.08	254.07	24.64	253.95					6.44	21%	0.12
338.0	Ret. Building over Creek										
320.4	31.08	253.97	24.64	253.88					6.44	21%	0.09
284.6	31.18	254.01	24.64	253.9					6.54	21%	0.11
274.0	St. Paul Street Culvert										
264.3	31.18	252.87	24.64	253.03					6.54	21%	-0.16

** Approximate comparable XS locations from Current study

The 1990 KRCA flows and water surface elevations were not included in the comparison chart above since the 1990 Northern Eagle study uses the 1990 KRCA study as a base. The 1990 Northern Eagle study represents the flood plain under the developed condition with the building constructed over the watercourse and the associated parking areas where the watercourse was encased underground for approximately 88 m.

The current study's overall watershed area is approximately 20% higher than the 1990 KRCA/Northern Eagle watershed area (at a comparable node). The resulting regional peak flows from the current study are approximately 20% higher than the previous 1990's studies. The above is an overly simplified comparison but it provides additional support of the current study's hydrology results. When comparing the water surface elevations of the current study to the previous studies; the current flood elevations are slightly higher than previous but this is a result of the associated peak flows being slightly higher as discussed above.

10 Conclusions and Recommendations

This report serves as a baseline study for mapping the extents of the regulatory flood plain in the Sinister Creek watershed. The associated regulatory flood plain maps are attached to this study. As per a Technical Committee decision; it's recommended that a one-zone flood plain management policy concept be applied within the regulatory flood plain of Sinister Creek.

Recommendations:

- Install stream flow monitoring gauge for model calibration in the future.
- Incorporate information from this study into emergency response planning, flood forecasting programs and design of future infrastructure.
- Conduct lowest opening elevation surveys for buildings in the flood plain.

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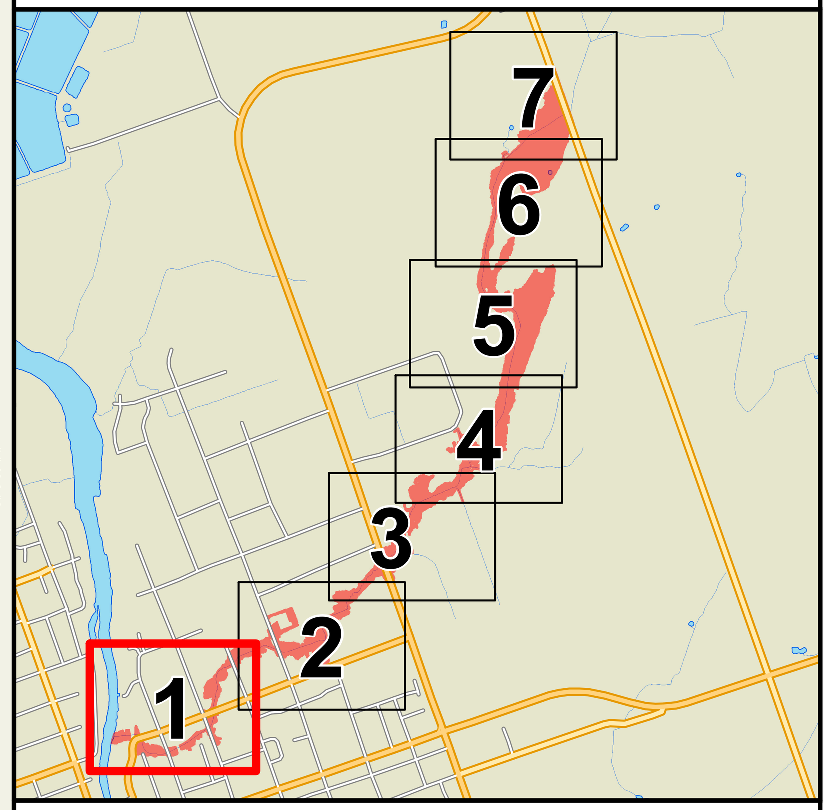
KAWARTHA LAKES

Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

- Main Channel
- Cross Section
- Spills
- Flood Plain
- 0.5 Metre Contour



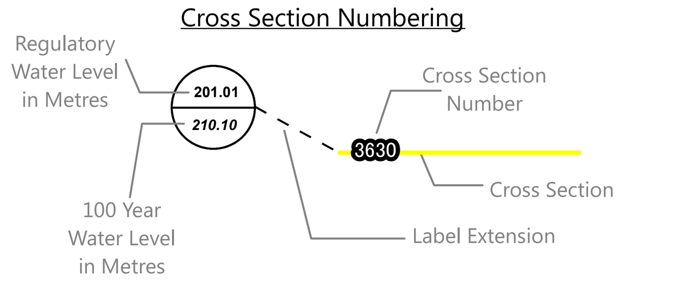
Notes:

1) LiDAR (Light Detection and Ranging) survey data collected November 4th, 5th, 6th, and 7th, 2012 by Aero-Photo (1961) Inc.
2) Contours produced by Kawartha Conservation GIS staff using LiDAR and GTAFBS 2002 data.
3) Field Survey of structures by Kawartha Conservation, using RTK GPS.
4) Orthophotography (16cm) collected November 8th, 2012 Aero-Photo Inc. SCOOP 2013 orthophotography was used to supplement 2012 orthophotography. SCOOP 2013 Copyright Queen's Printer 2013.
5) The flood inundation areas were delineated using the DEM derived from LiDAR by Kawartha Conservation's GIS department.
6)Flood plain modeling was prepared by Kawartha Conservation's engineering department. Input parameters were extracted from base mapping prepared by Kawartha Conservation's GIS department.
7) This map is prepared for use in conjunction with the Sinister Creek Flood Plain Mapping Study, 2015.

REVISIONS

No.	Description	By	Date
1	Final Flood Plain Map	JB	FEB 2016

Cross Section Numbering



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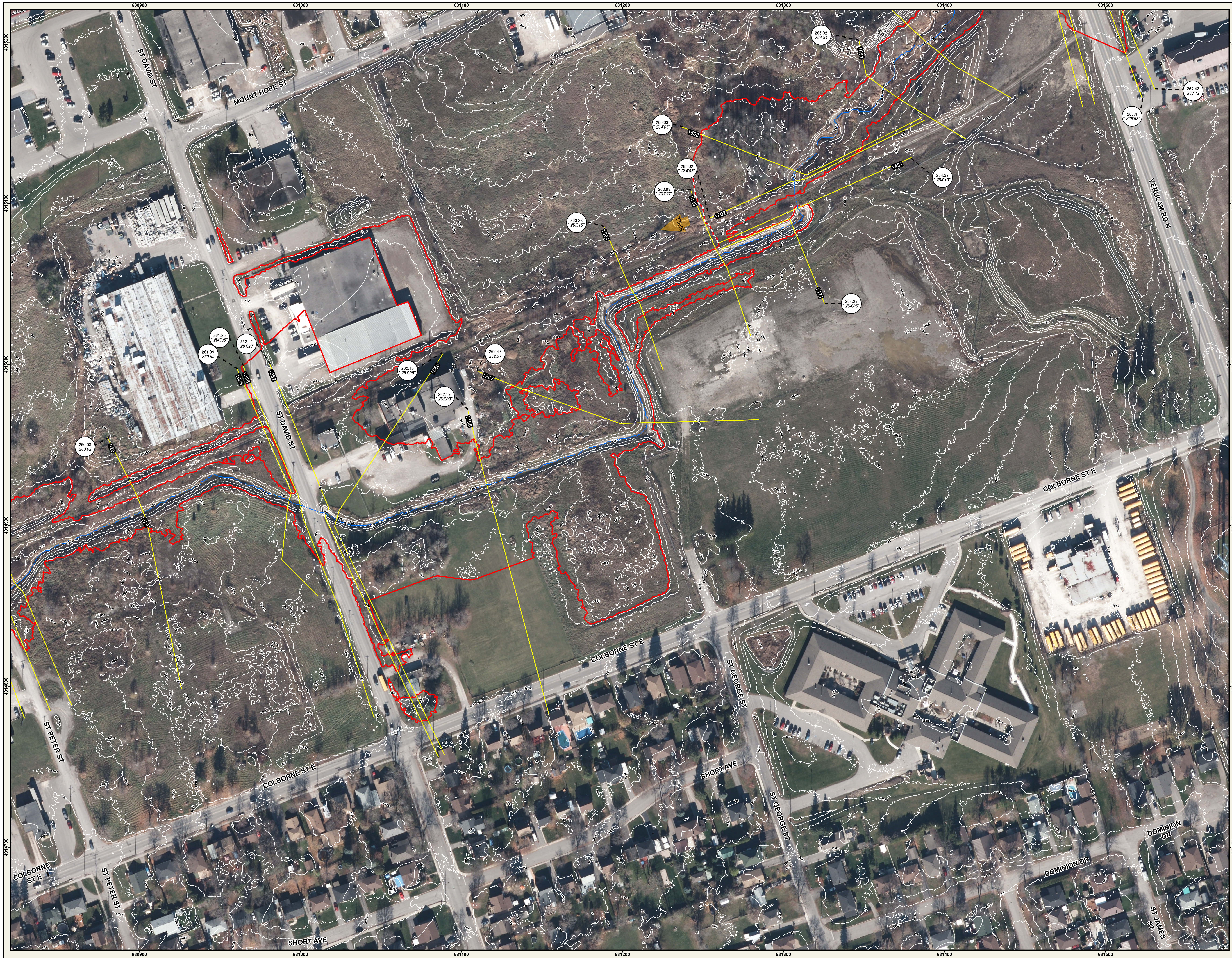
0 25 50 100 Meters

MAP 1



Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

- Main Channel
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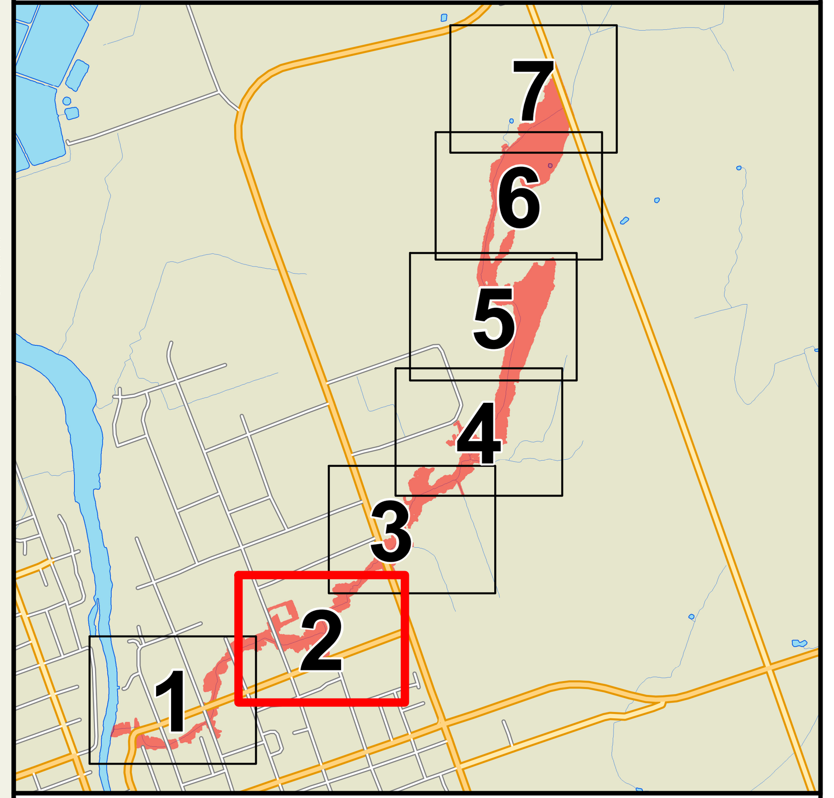
- 0.5 Metre Contour



Notes:

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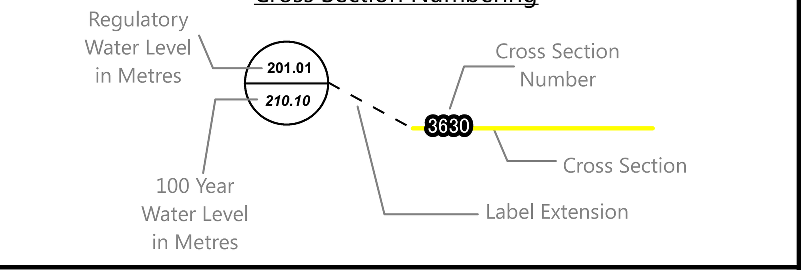
6) Flood plain modeling was prepared by Kawartha Conservation's engineering department. Input parameters were extracted from base mapping prepared by Kawartha Conservation's GIS department.
7) This map is prepared for use in conjunction with the Sinister Creek Flood Plain Mapping Study, 2015.
8) LiDAR data was replaced with site grading information at St. David and Colborne Street as per Cut and Fill Balance & SWM Design Brief for 72 St. David Street Storage Warehouse, prepared by C.C. Tatham & Associates Ltd., February 2013.

REVISIONS			
No.	Description	By	Date
1	Final Flood Plain Map	JB	Feb 2016

Cross Section Numbering



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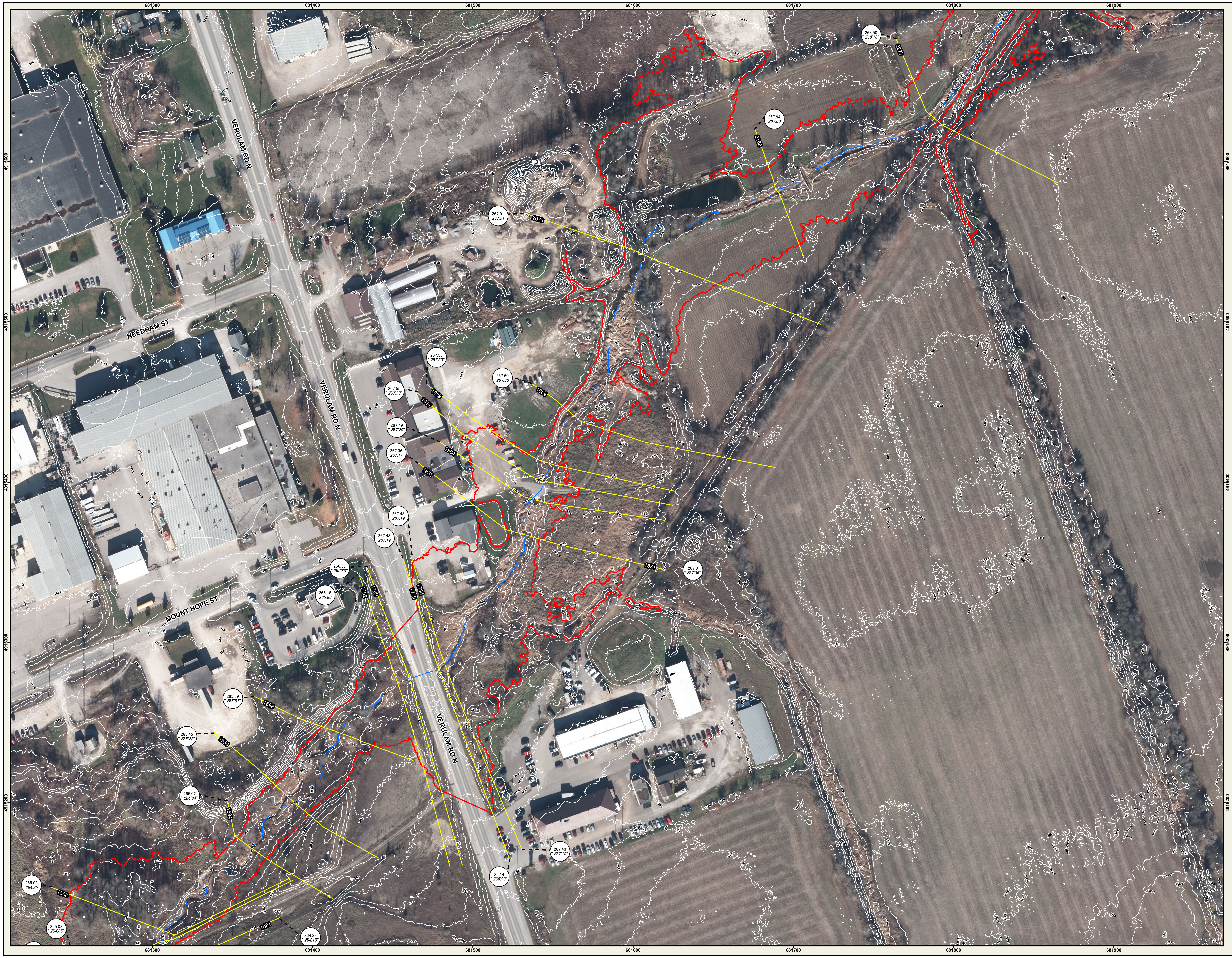
MAP 2



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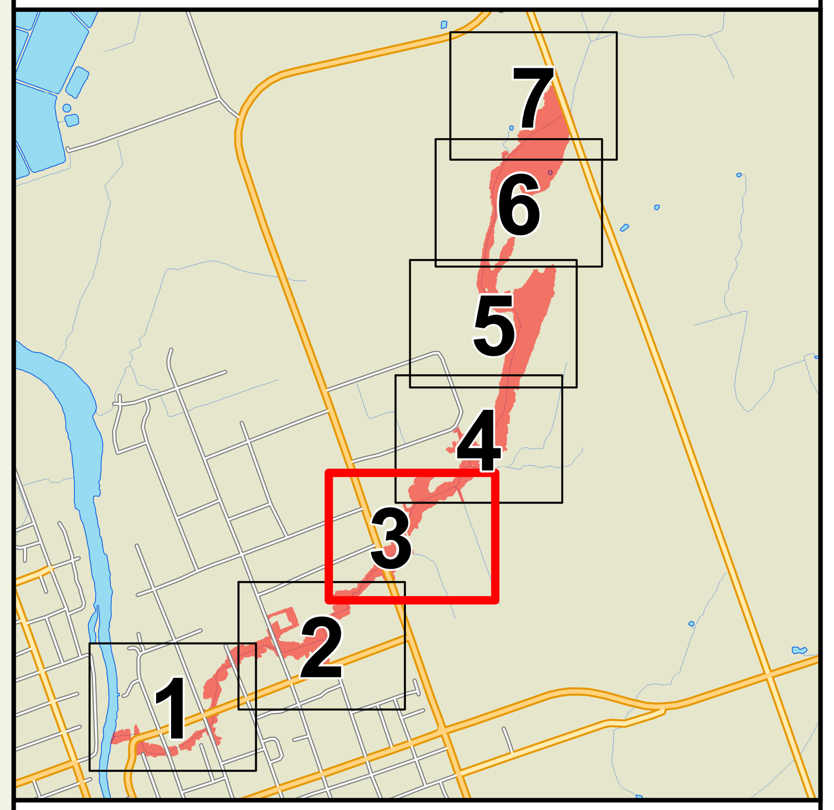
Sinister Creek Flood Plain Mapping City of Kawartha Lakes Printed: February 2016

Legend

- Main Channel
- Cross Section
- Spills
- Flood Plain
- 0.5 Metre Contour



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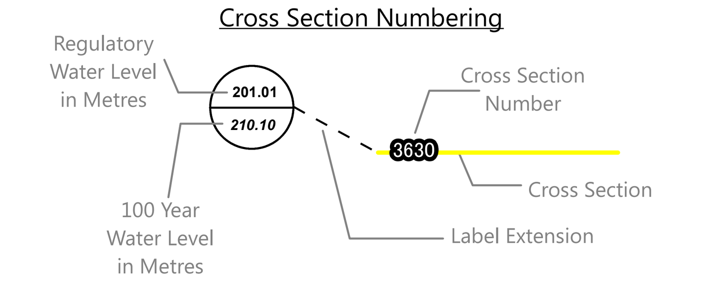
7) This map is prepared for use in conjunction with the Sinister Creek Flood Plain Mapping Study, 2015.

REVISIONS

No.	Description	By	Date
1	Fina Flood Plain Map	JB	Feb 2016

Cross Section Numbering



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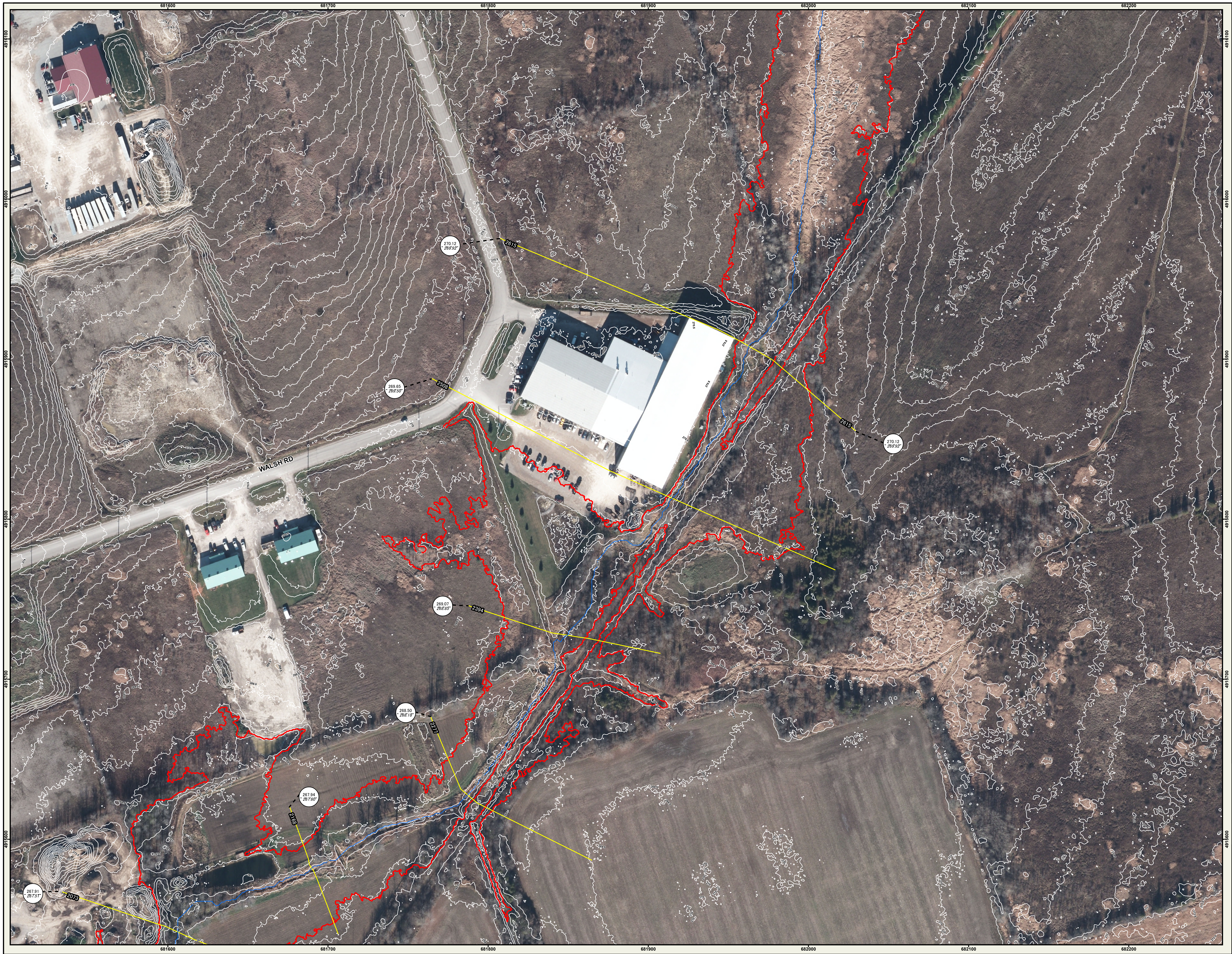
0 25 50 100 Meters

MAP 3



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Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

- Main Channel
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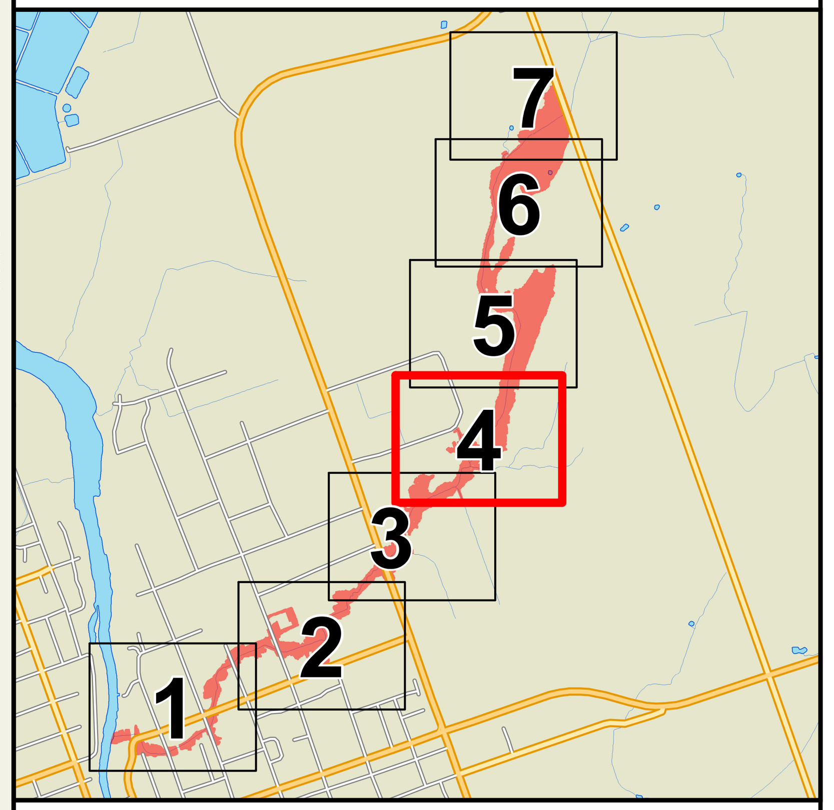

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1) LiDAR (Light Detection and Ranging) survey data collected November 4th, 5th, 6th, and 7th, 2012 by Aero-Photo (1961) Inc.
2) Contours produced by Kawartha Conservation GIS staff using LiDAR and GTAFBS 2002 data.
3) Field Survey of structures by Kawartha Conservation, using RTK GPS.
4) Orthophotography (16cm) collected November 8th, 2012 Aero-Photo Inc. SCOOP 2013 orthophotography was used to supplement 2012 orthophotography. SCOOP 2013 Copyright Queen's Printer 2013.
5) The flood inundation areas were delineated using the DEM derived from LiDAR by Kawartha Conservation's GIS department.
6)Flood plain modeling was prepared by Kawartha Conservation's engineering department. Input parameters were extracted from base mapping prepared by Kawartha Conservation's GIS department.
7) This map is prepared for use in conjunction with the Sinister Creek Flood Plain Mapping Study, 2015.

REVISIONS

No.	Description	By	Date
1	Fina Flood Plain Map	JB	Feb 2016

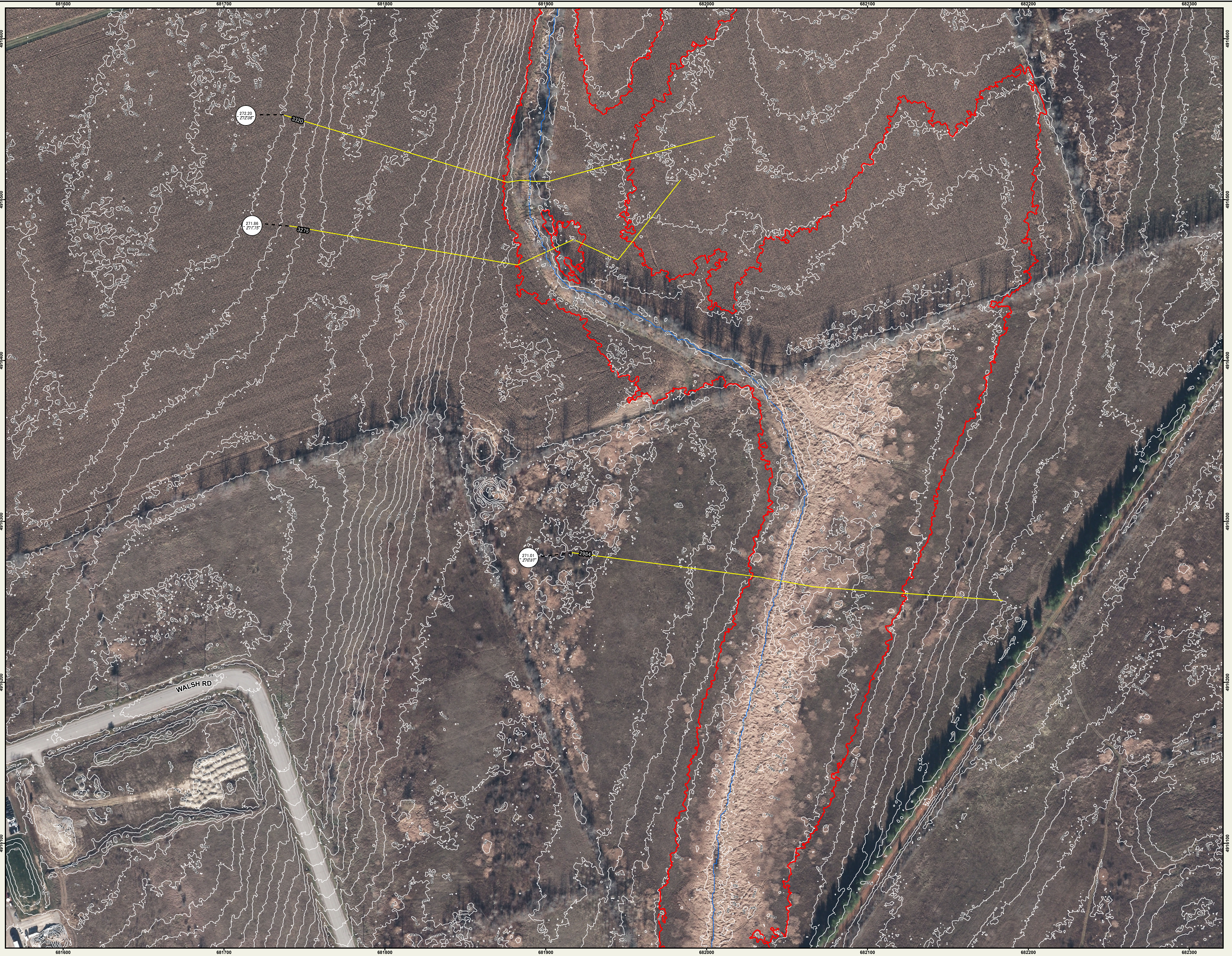
Cross Section Numbering

Regulatory Water Level in Metres — 201.01
100 Year Water Level in Metres — 210.10
Cross Section Number — 3630
Cross Section
Label Extension

1:1,000

0 25 50 100 Meters

MAP 4



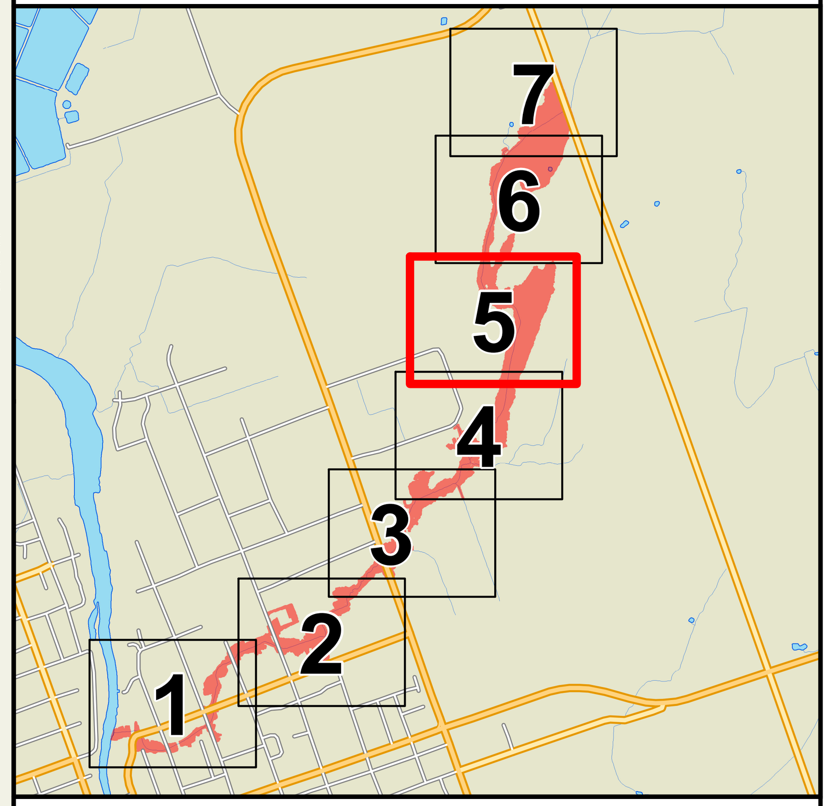
KAWARTHA CONSERVATION

KAWARTHA LAKES

Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

- Main Channel
- Cross Section
- Spills
- Flood Plain
- 0.5 Metre Contour



Notes:

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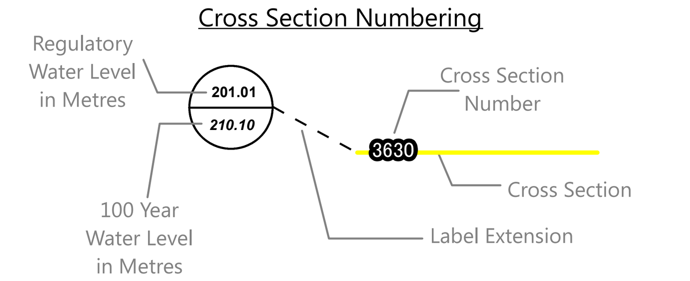
REVISIONS

No.	Description	By	Date
1	Fina Flood Plain Map	JB	Feb 2016

Cross Section Numbering



1:1,000

0 25 50 100 Meters

MAP 5

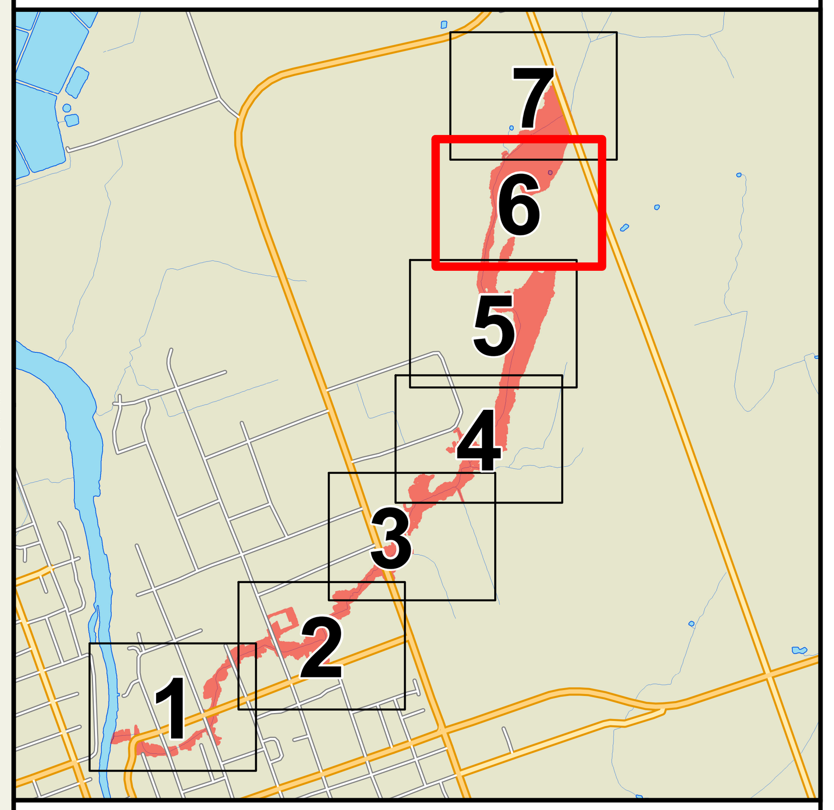
KAWARTHA CONSERVATION

KAWARTHA LAKES

Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

Main Channel
Cross Section
Spills
Flood Plain
0.5 Metre Contour



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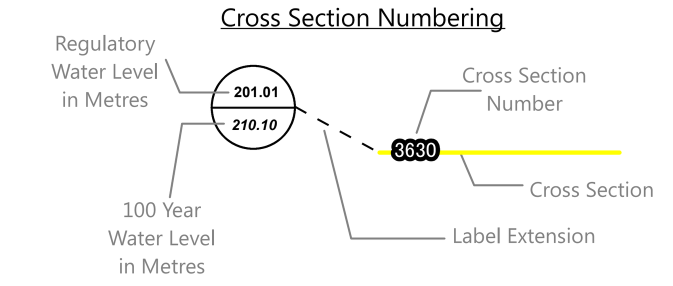
REVISIONS			
No.	Description	By	Date
1	Fina Flood Plain Map	JB	Feb 2016

Cross Section Numbering



1:1,000

0 25 50 100 Meters

MAP 6

Kawartha Conservation

T: 705.328.2271

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277 Kenrei Road, Lindsay ON K9V 4R1

geninfo@kawarthaconservation.com

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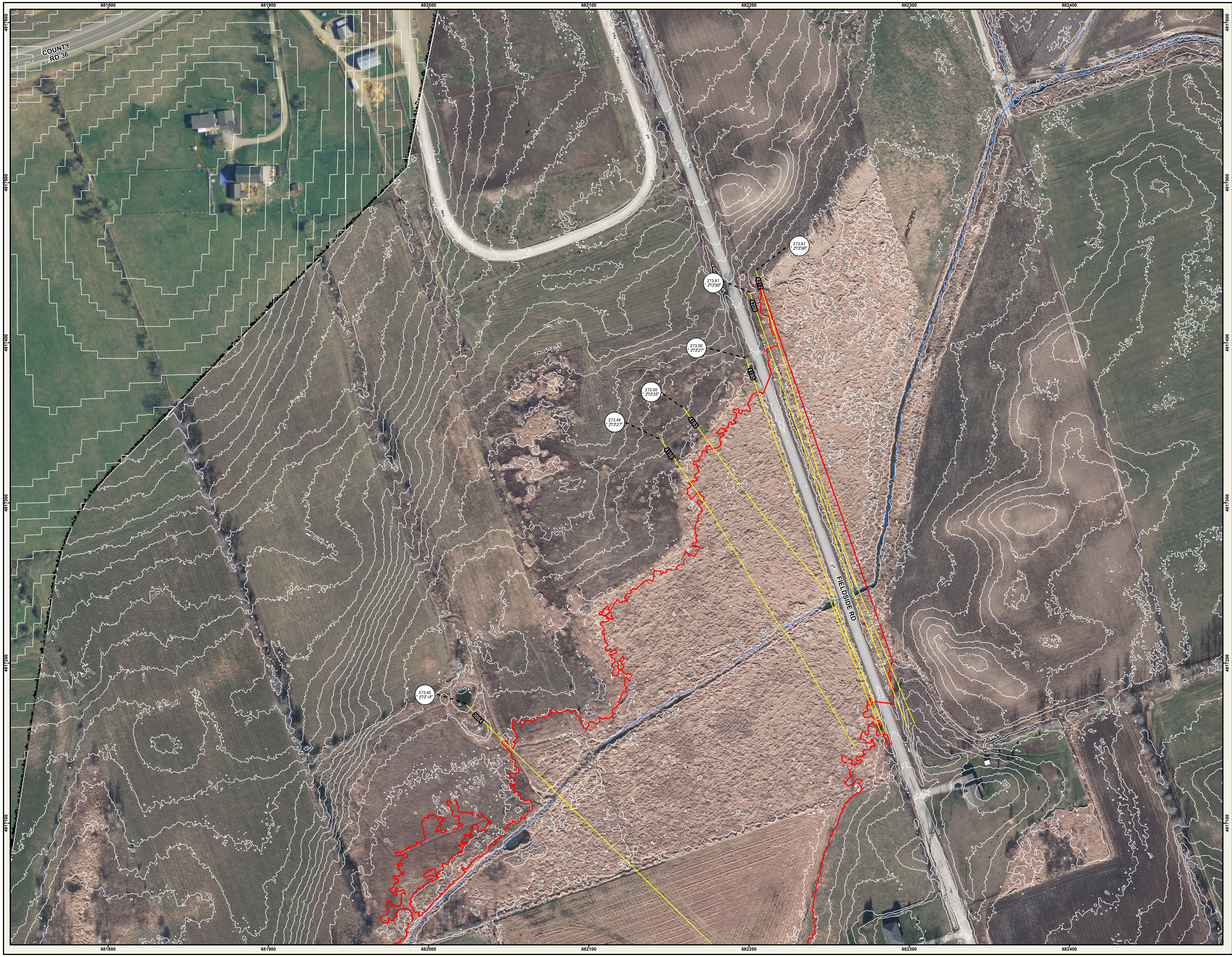
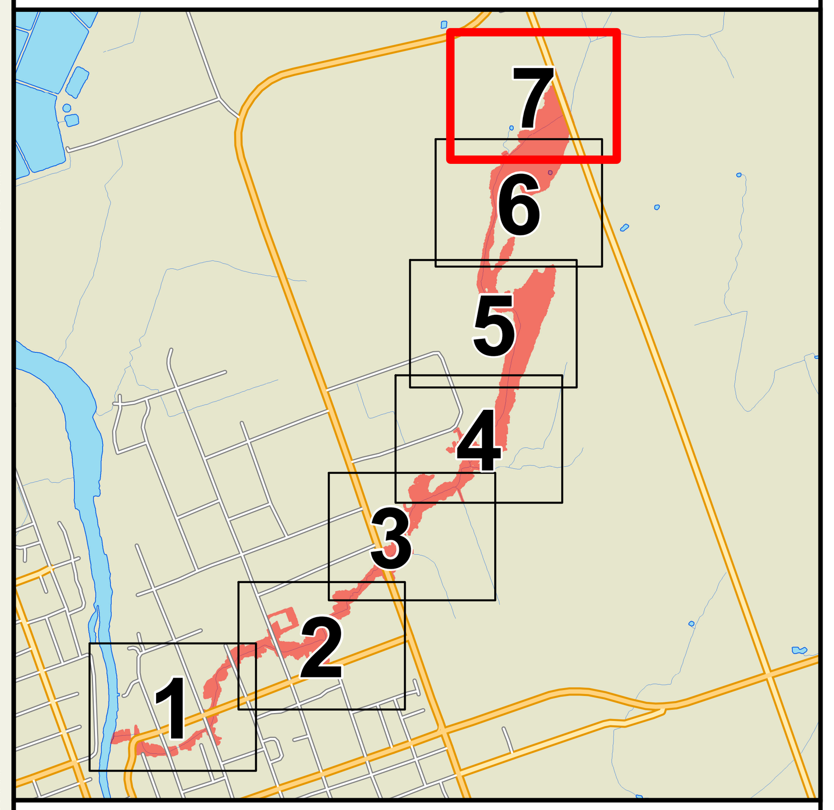


Sinister Creek
Flood Plain Mapping
City of Kawartha Lakes
Printed: February 2016

Legend

- Main Channel
- Cross Section
- Spills
- Flood Plain
- 0.5 Metre Contour



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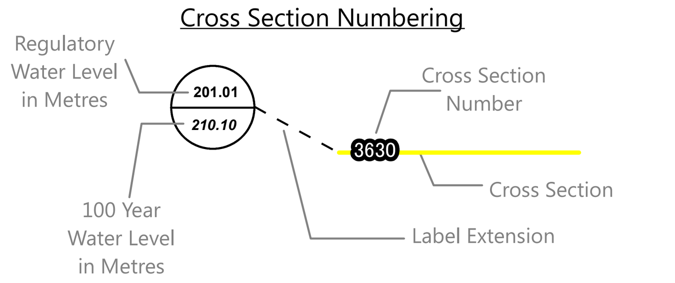
1	Fina Flood Plain Map	JB	Feb 2016

Cross Section Numbering



1:1,000

0 25 50 100 Meters

MAP 7