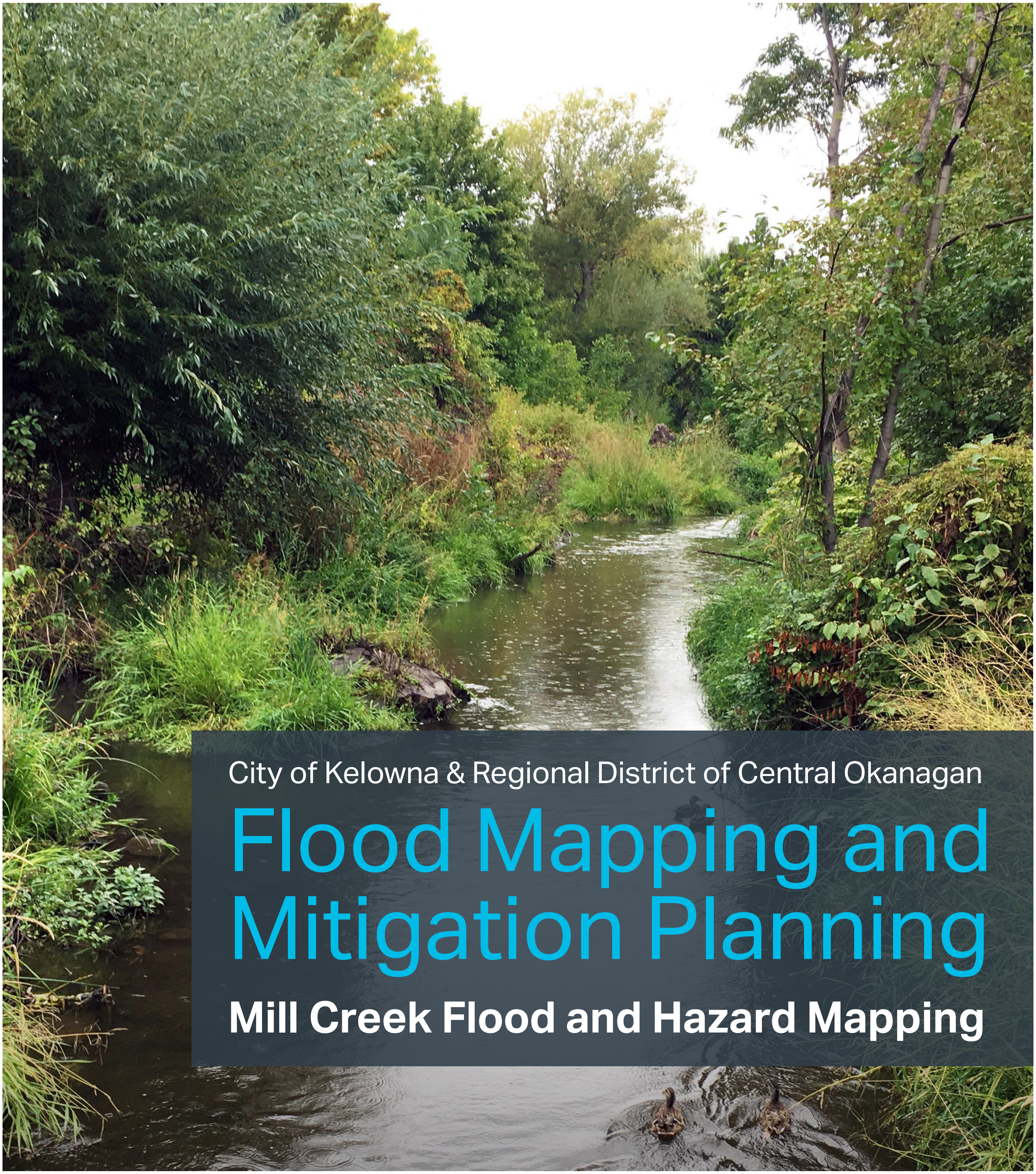

City of Kelowna & Regional District of Central Okanagan

Flood Mapping and Mitigation Planning

Mill Creek Flood and Hazard Mapping

Prepared by:
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Date Prepared: May 2020

Project #: 60613804

AECOM

Regional District of Central Okanagan

City of Kelowna

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Revision History

Rev #	Date	Revised By:	Revision Description
0	March 18, 2020	Graeme Billay	Draft
1	May 5, 2020	Graeme Billay	Final

AECOM Imagine it. Delivered.

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Robinson Puche
Infrastructure Planner
City of Kelowna
1435 Water Street
Kelowna BC, V1Y 1J4
Canada

May 5, 2020

Project #
60613804

Dear Mr. Puche:

Subject: City of Kelowna
Flood Mapping and Mitigation Planning
Mill Creek Flood and Hazard Mapping

We are pleased to submit the final Mill Creek Flood and Hazard Mapping report. We have incorporated your comments received through the review of the draft report.

Thank you for the opportunity to collaborate with you on this project and we trust that the enclosed document meets your expectations. If you have any questions or require information, please call.

Sincerely,
AECOM Canada Ltd.

Marcel LeBlanc, P.Eng.
Water Resources Market Sector Leader, Water,
Western Canada
Marcel.leblanc@aecom.com

GB:blb

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AECOM: 2015-04-13

Authors

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Water Resources Engineer-in-Training

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Stamp

Executive Summary

AECOM has assessed the flood hazards within the Lower Mill Creek basin within the City of Kelowna. The work is supported in part by the federal Disaster Mitigation and Adaptation Fund (DMAF) as well as by the Union of BC Municipalities (UBCM) to the Regional District of Central Okanagan (RDCO) through the Community Emergency Preparedness Fund (CEPF) under the Flood Risk Assessment, Flood Mapping and Flood Mitigation Category. The limits of the study area include Mill Creek downstream of Spencer Road and the stormwater infrastructure that is part of the Mill Creek drainage basin. AECOM, the City of Kelowna, and the Regional District of Central Okanagan acknowledge that the project occurs on the traditional territory of the Syilx/Okanagan Peoples. The objective of the study was to develop flood depth and hazard maps indicating the extents of flooding due to overtopping of the banks of Mill Creek. Additional modelling was conducted which included the underground stormwater infrastructure to be utilized in future stormwater planning exercises, allowing for dynamic interaction of both underground and overland hydraulics.

Previous reports of flooding within the Mill Creek basin were utilized for comparison purposes as well as setting model parameters for the present study. Hydrologic information was provided by previously developed models of Mill Creek which incorporated climate change impact factors. Stormwater infrastructure data was provided via the City's online tools and topographic data was provided by the Okanagan Basin Water Board (OBWB). The elevation reference frame of the topographic data required that all of the City's stormwater infrastructure which was included in the present work be modified to reflect the national vertical datum standard. It should be acknowledged that all results within this report (unless stated otherwise) reference the national vertical datum and that a conversion is necessary to translate it to the datum used by the City of Kelowna's infrastructure databases.

The main conclusions drawn from the mapping are:

- Marshall Street and Rowcliffe Avenue is the first point of flooding Downstream of Highway 97 during the simulation followed by locations near Springfield Road, Pacific Community Park/Lindahl Street, and Burne Avenue/Copeland Place.
- Overtopping of Mill Creek near Springfield Road may result in widespread, but relatively shallow, flooding towards important civic locations such as A.S. Matheson Elementary School and Kelowna General Hospital.
  - No flooding in these areas occurred in 2017 as a result of sandbag and Tiger-dam placement, according to the City.
- Flood extents are drawn along Enterprise Way but was not observed in the 2017 aerial imagery, potentially as a result of sandbag placement. The presence of debris during the 2017 flood event may have also played a role in backing up water in this area.
- Flood maps agree well with observed flooding near Kelowna Springs and Shadow Ridge golf courses.
- Good agreement between mapped and observed flooding within the Kelowna airport parking lot was found, as well as in areas east of the airport.

A number of flood mitigation measures were discussed at a conceptual level. The models developed in this report provide a good starting point for assessing specific structural and non-structural measures. Examples of measures included locally raising or constructing dikes at existing locations such as along Enterprise Way or near Springfield Road and non-structural measures such as identifying which parts of the basin exhibit flooding in the model first to enable emergency response planning.

Recommendations were also described which would improve the accuracy of these models and support future flooding and stormwater assessments based on their use, these include;

Areas where additional mesh refinement may benefit modelled results are areas around:

- Enterprise Way
- Springfield Road

With regard to the integrated stormwater model; the same type of mesh refinement could be made to improve overland flooding accuracy. Aside from that, further recommendations include:

- Manually delineating subcatchments, which should be done during any future update of the model.
- Addition of stormwater infrastructure under Highway 97 (if any), and other locations as needed.
- Updated survey data around the Mill Creek diversion to Mission Creek to correct inconsistencies between modelled and as-built geometry.

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Appendices

1. Introduction

1.1 Background

As part of the Regional Growth Strategy (Bylaw No. 1336, Adopted – June 23, 2014), a Regional Floodplain Management Framework was developed for the Regional District of Central Okanagan (RDCO). This framework is split into three phases, the first of which has been completed. The first phase of the framework was intended to better understand the risks associated with the watercourses within the region and to scope the priorities of Phase 2. The results of Phase 1 have indicated Mill Creek and Mission Creek to be of the highest priority based on a preliminary flood hazard risk assessment. AECOM, the City of Kelowna, and the Regional District of Central Okanagan acknowledge that the project occurs on the traditional territory of the Syilx/Okanagan Peoples.

The City of Kelowna received federal funds under Infrastructure Canada's Disaster Mitigation and Adaptation Fund (DMAF) to support the development of long-term mitigation planning for Mill Creek and to begin the conceptual analysis of a number of flood mitigation projects. For the present work, additional funding from the Union of BC Municipalities (UBCM) to the Regional District of Central Okanagan (RDCO) through the Community Emergency Preparedness Fund (CEPF) under the Flood Risk Assessment, Flood Mapping and Flood Mitigation Category was received to provide information regarding the extents and associated hazards of flooding within the Lower Mill Creek basin. It will also support the update to emergency planning management and development criteria, such as Flood Construction Level (FCL) or Minimum Building Elevation (MBE) in flood-prone areas.

In 2017, Mill Creek flooded as a result of a combination of high lake levels, rapid snowmelt, and steady rainfall and caused extensive damage to the City of Kelowna. The following year record high flows were also recorded along the Creek. Although this event was less costly than in 2017, it underlies the need for a more detailed hydraulic model of Mill Creek to better inform flood mitigation activities within the City's Mill Creek basin.

A number of previous models have been developed for the City of Kelowna and Mill Creek. These include stormwater management-based models (SWMM) of various basins within the City and a HEC-RAS model of Mill Creek. Many of the stormwater basin models are now in need of updating. These models are also 1-dimensional, meaning that they lack the complexity to investigate overland flooding as a result of large rainfall events or under-sized pipe networks. The interaction of the underground stormwater network and Mill Creek is also not accounted for in any great level of detail. A more integrated approach to modelling the City's stormwater network is required to achieve a better understanding of its shortcomings.

1.2 Study Objectives

The objectives of this study are two-fold; firstly, to develop flood extent and hazard maps of overland flooding within the City as a result of spring freshet flows in Mill Creek. These maps will delineate areas of the City at greatest risk to flooding and help identify the volumes of water which may need to be managed in order to reduce the damage caused by severe spring-time flood events. The second objective is to deliver a fully integrated stormwater model, incorporating both underground stormwater infrastructure as well as the Mill Creek channel itself along with other overland flow paths. This integrated major-minor stormwater system model will allow for hydraulic interaction between overland flow paths and the underground pipe network. The need for two separate models will be outlined in greater detail in Section 5.1.

The integrated stormwater model is to be considered a "living" model, with its intent to be modified, updated, and maintained for future stormwater modelling efforts. This integrated model will also be capable of investigating different flooding scenarios and the mitigative impacts of specific flood management efforts. To support this, the models will be coupled 1D-2D models. The 1-dimensional component representing the main channel of Mill Creek and underground stormwater network, and the 2-dimensional component providing for the ability to model overland flooding. More on these technical details will be discussed in Section 5.

Given the experience the City has with previously developed stormwater models, the hydraulic software program PCSWMM has been chosen as the preferred tool. PCSWMM is a SWMM-based hydraulic program which can handle the modelling of systems such as rainfall-runoff processes, stormwater sewers and ponds, sanitary sewers, etc. It is based on the Environmental Protection Agency's Stormwater Management Model (EPA-SWMM) and is widely used in the industry. PCSWMM builds upon EPA-SWMM by providing a much more modern, user-friendly, graphical user interface that is more integrated with GIS capabilities. These GIS-based features will be heavily utilized alongside the City's GIS OpenData database.

1.3 Scope of Work

The scope of work involves the following activities:

1) Reviewing past reports and hydraulic model results for the City of Kelowna's Mill Creek basin.
2) Collecting GIS data from the City and other stakeholders for the purpose of model development.
3) Conducting a site visit of the Mill Creek basin.
4) Developing a coupled 1D-2D rainfall-runoff model of the Lower Mill Creek basin within the City of Kelowna.
5) Developing a Mill Creek-only model to investigate flooding at a greater level of spatial detail.
6) Develop flood mapping criteria to be adopted for the study.
7) Produce flooding depth maps for the design events (20-year and 200-year return periods) considering climate change impacts on the design flow events.
8) Generate flood hazard maps for the design event (200-year return period).
9) Outline baseline hydrologic inputs for future model runs to support the "living model" approach for subsequent concept design and modelling of flood mitigation infrastructure.
10) Identify potential flood mitigation measures to be examined in future studies.
11) Develop a draft and final report documenting the findings of the study.

Each of the above tasks will be discussed in the following sections.

1.4 Steering Committee

A steering committee consisting of the following designates from the following parties was assembled:

- Robinson Puche – Project Manager for the City of Kelowna,
- Luke Dempsey – Secondary contact for the City of Kelowna,
- Rod MacLean – City of Kelowna,
- Janelle Taylor – Primary contact for Regional District of Central Okanagan,
- Todd Cashin – Regional District of Central Okanagan, and
- Marcel LeBlanc – Project Manager for AECOM.

The role of the steering committee was to provide direction to the technical team, and to review and monitor progress relative to the scope of work, budget and schedule established for the project.

2. Study Area

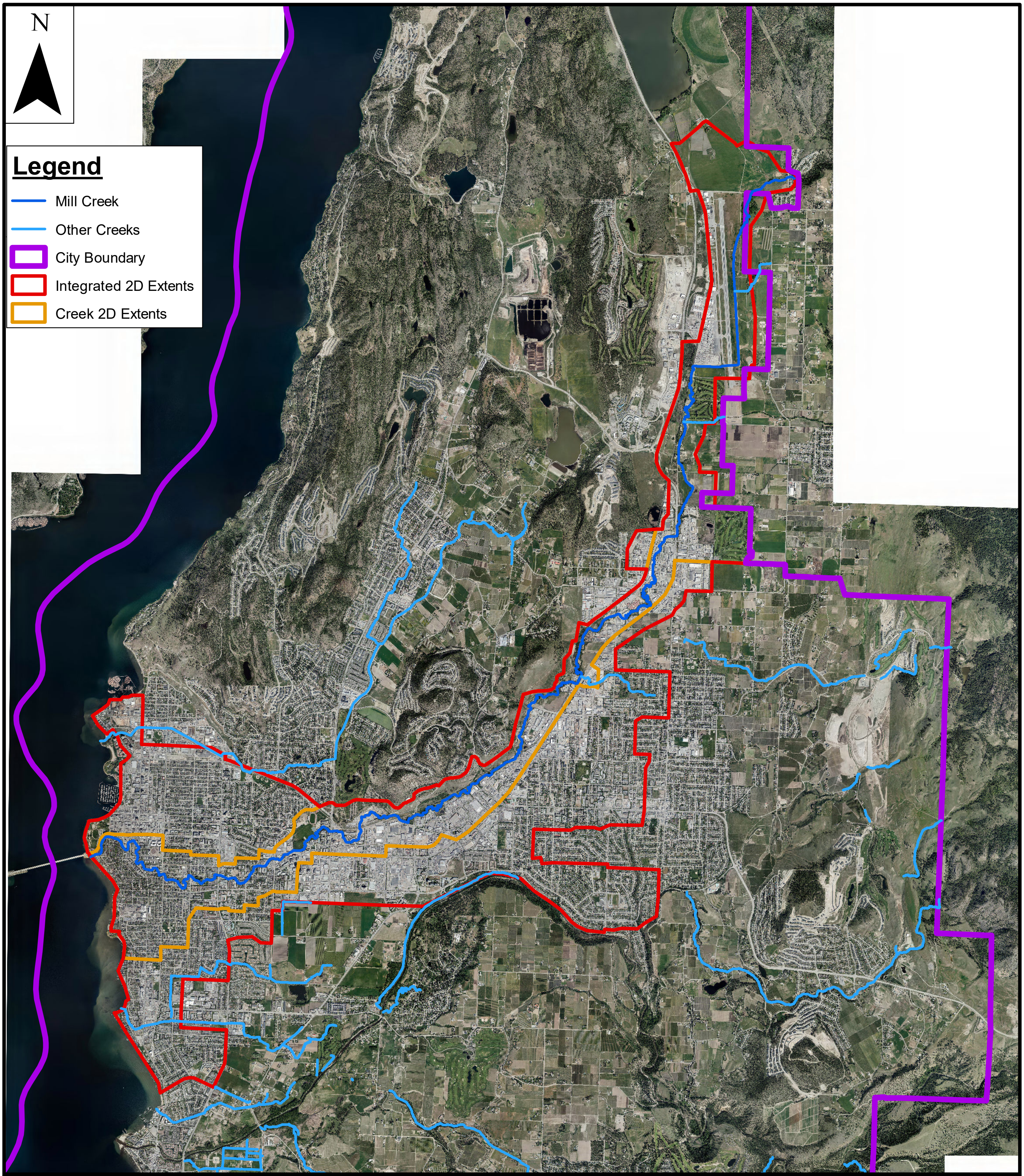
The Mill Creek watershed is approximately 222 km^2 upstream of Okanagan Lake. Within the lower basin, below Spencer Road, there are three other tributaries of Mill Creek that will be considered within our modelling work as shown in Table 2-1.

Table 2-1: Lower Mill Creek Tributaries

Description	Approximate Location		Watershed Area (km^2)
	Easting (m)	Northing (m)	
Whelan Creek	329572	5536606	25.0
Scotty Creek	328865	5534695	39.6
Gopher Creek	327331	5530983	16.1

The study area is approximately 22.6 km long from Spencer Road to Okanagan Lake and is heavily urbanized. The land use immediately around Mill Creek spans all types of agricultural, residential, commercial, and industrial zones. The creek capacity also shrinks as it approaches downtown leaving no room for flooding to occur without impacting the City of Kelowna and its residents.

The study reach begins upstream of Kelowna International Airport and Shadow Ridge Golf Course before making its way through the industrial areas around Adams Road. It primarily follows the northern edge of the industrial areas until it crosses Highway 97 near the Parkinson Activity Centre. The final sub-reach of Mill Creek meanders through downtown Kelowna before discharging into Okanagan Lake. The average slope of the entire study reach is approximately 0.0049 m/m. There are 91 bridge and culvert crossings within the study reach and multiple outfalls into the creek from the City's stormwater network. See Figure 2-1 for the study area and Figure 2-2 for the Lower Mill Creek profile.



City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804	Figure 2-1
SCALE:	1:75,000	Study Area
DRAWN:	B. TROITSKY	
APPROVED:	-	
PROJECTION:	UTM ZONE 11N	REV NO.: SHEET
DATE:	2020-04-24	0 : 1/1

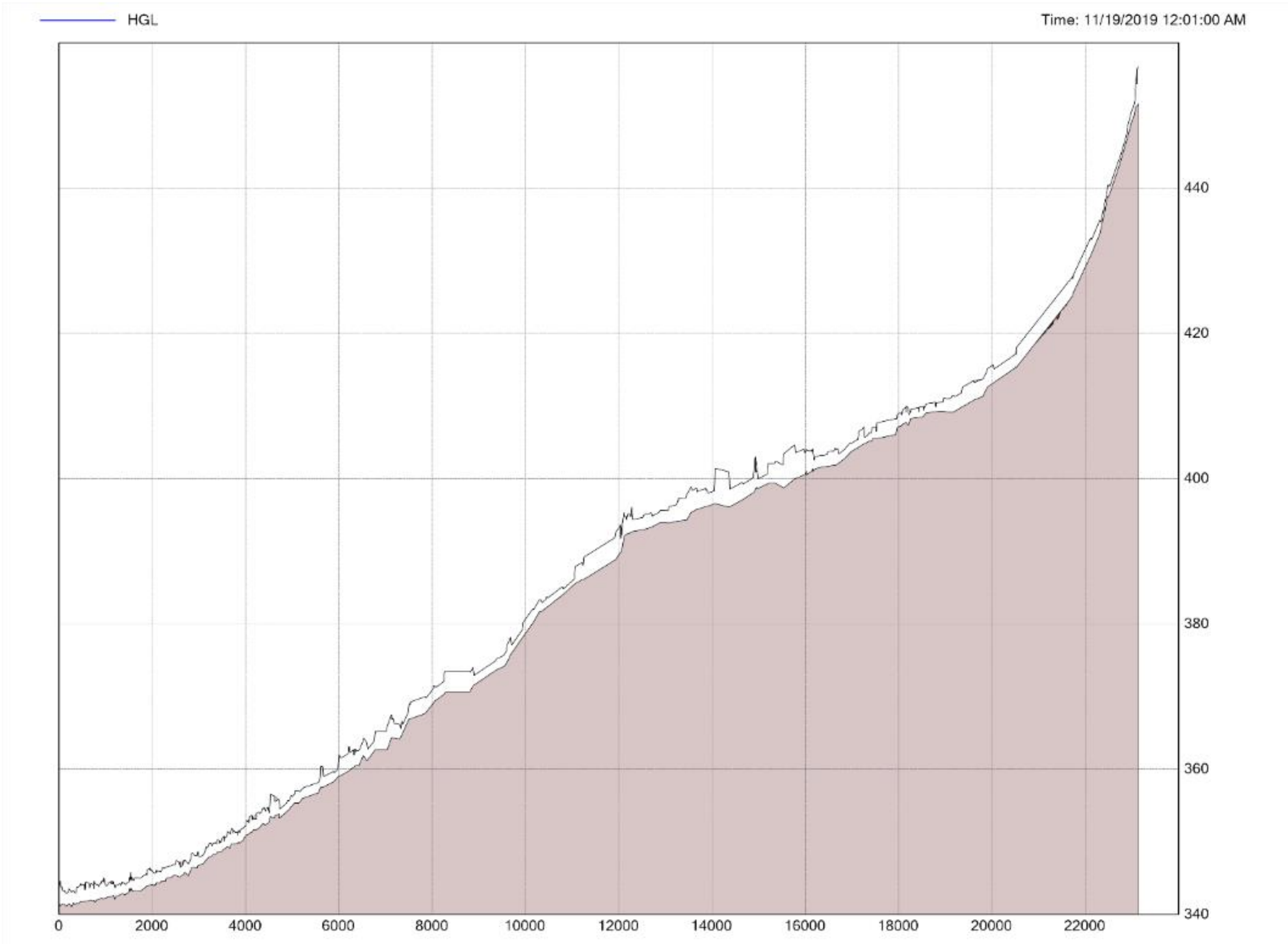


Figure 2-2: Lower Mill Creek Profile

3. Review of Historical and Existing Data

3.1 General

Given Mill Creek's significance within the City of Kelowna, especially since the severe flooding events of 2017 (and to a lesser degree, 2018), a review of recent reports and historical data was reviewed prior to developing the PCSWMM model. The following sections detail the existing information available to develop the model and provide context for interpretation of results.

3.2 Existing Reports

The recent Kelowna Flood Risk Assessment by Associated Engineering (AE, 2019) outlined the procedure by which an existing HEC-2 model of Mill Creek was georeferenced and updated within HEC-RAS. Along with this hydraulic model a HEC-HMS hydrologic model was developed to determine the inflow hydrographs along the creek. A number of scenarios were run for varying lake levels and creek flow rates. Following this report, the main scenario which will be discussed in more detail below included the 200-year Mill Creek hydrographs with an Okanagan Lake level associated with a 5-year return period.

City Bylaws, specifically Schedule 4 and Schedule 5, were used to determine rainfall parameters for use in the integrated stormwater model. Intensity-Duration-Frequency (IDF) curves were pulled from these bylaws and adjusted to include a 15% increase to account for climate change and to build the design storm hyetographs. In the model, this is a 15% increase in the rainfall intensity.

Stormwater basin plans were also used to import elements of previous SWMM-based models that may not appear in the GIS database. It is important to note that many of these basin plans were developed by the City in the early 2000's, therefore, they were used only to supplement the GIS database of the present PCSWMM models where required.

3.3 Existing HEC-RAS Model

A previously developed HEC-RAS model has recently been updated by Associated Engineering (2019). The model update included georeferencing the stream centerline and cross-section locations. Along with the georeferencing, cross-section geometry was updated to include LiDAR acquisition by the Okanagan Basin Water Board (OBWB), which was flown in 2018. This is the same topographic information made available to AECOM at the time of this project's initiation.

The primary need for this existing HEC-RAS model was to derive main channel bathymetry and bridge and culvert geometry for use in the current PCSWMM model. There are 91 bridge and culvert crossings and a total of 322 surveyed cross-sections in the HEC-RAS model. It is assumed for the purpose of this project that the main channel bathymetry and bridge and culvert crossing data is the most accurate and up-to-date information available. The model extents, which will also coincide with the PCSWMM model extents, begins approximately 35 m upstream of Spencer Road and ends at Okanagan Lake.

Further to developing the Mill Creek component of the PCSWMM model, the existing HEC-RAS model will be used to calibrate hydraulic losses at bridge and culvert crossings. HEC-RAS has specific code to account for head losses at these structures as well as handle overtopping flows during flooding events. PCSWMM models these properties differently and will therefore be compared against the HEC-RAS model results during model calibration and validation. With the updated Mill Creek alignment and cross-sections, the HEC-RAS model geometry could be imported into PCSWMM.

3.4 LiDAR and GIS Data

A fundamental piece of data which allows for creation of 2D hydraulic models is LiDAR (Light Detection and Ranging). This information was collected for the Okanagan Basin Water Board and provided to AECOM by the City of Kelowna. The LiDAR dataset provides a continuous digital elevation model (DEM) which is used as a reference surface for modelling overland flooding and setting manhole rim elevations. The LiDAR data was flown in 2018 and was processed into a 1m x 1m DEM. Water surface elevations from the PCSWMM models will be compared against this surface to develop depth and hazard maps.

The City of Kelowna's OpenData website was the primary source of the stormwater infrastructure data that was used to build the integrated PCSWMM model. This information included stormwater mains (pipe diameters, material, inverts, lengths, etc.), storage structures (ponds and detention tanks), manholes, drywells, catchbasins, outfalls, etc.

An important difference in the vertical reference datum of the LiDAR data and the City's GIS database is discussed in Section 0.

3.5 As-Built Data

During PCSWMM model development, significant use of as-built data facilitated the inspection of GIS-imported elements of the stormwater network. These records were at times incomplete or contradictory to the GIS database provided on the City of Kelowna's OpenData website. In these instances, proper engineering judgment was used to determine the best course for correcting the stormwater components in question, keeping in mind the intended use of the model to adequately portray the hydraulic conditions of the stormwater network within a reasonable degree of accuracy.

3.6 Historical Flow, Rainfall, Okanagan Lake Water Levels, and Flood Data

The City of Kelowna in the lower Mill Creek basin has historically been at risk to flooding of Mill Creek primarily driven by snowmelt in the upper watershed coupled with rainfall. For the present study, hydrology data had been provided by the City along with a report (AE, 2019) which discussed the development of the input hydrology. This report provided the Water Survey of Canada (WSC) gauge stations that were used to develop the peak flow rates and inflow hydrographs; Daves Creek near Rutland (WSC 08NM117), Bulman Creek at the Mouth (WSC 08NM145), and Kelowna (Mill) Creek Near Kelowna (Lower Station, WSC 08NM053).

In 1996, one of the largest recorded streamflow events occurred in May and June (WSC station 08NM053). The peak maximum daily flow observed was 14.4 m^3/s. The streamflow data and available meteorological data made this a suitable calibration event for the developed design storm hydrographs (AE, 2019).

Given that Okanagan Lake is downstream of the study area, it will act as a natural boundary condition for the PCSWMM models. According to AE (2019), Okanagan Lake levels were their highest ever recorded and achieved an elevation of 343.51 (CGVD2013 datum) on June 8, 2017. Although this elevation was significant, no joint probability analysis was conducted to determine the likelihoods of very high Okanagan Lake levels coupled with very high flood flows in Mill Creek. The provided HEC-RAS model uses the 5-year return period water level of 342.91 m as the boundary condition. The present study will adopt this value for all Mill Creek flood scenarios, but a discussion regarding results of a separate model run which included the 2017 lake level is given in Section 6.4.2.

4. Field Reconnaissance

On September 17, 2019, AECOM visited Mill Creek to assess its main channel, the floodplain areas, and key hydraulic structures along the creek within the study limits. Three AECOM staff attended the visit along with two City of Kelowna staff. Specific points of interest that were observed were the dikes west of Adams Road in the North Industrial Area, the Mill Creek diversion to Mission Creek, a number of culvert and bridge crossings, as well as previously effected areas near Okanagan Lake. See Appendix A for a summary report of the filed visit.

5. PCSWMM Model Development

5.1 Model Setup

5.1.1 Model Structure

The Mill Creek basin within the City of Kelowna is heavily urbanized and is prone to significant amounts of flooding. Due to the relatively small channel capacity and the large freshet flow conditions that can arise in the uplands of the watershed, Mill Creek may overtop and flood the urban areas. Complicating this problem is the fact that several stormwater outfalls also discharge into Mill Creek. When Mill Creek water levels increase, surcharging is experienced by the underground stormwater infrastructure making large parts of the City susceptible to flooding under even small rainfall events. The interconnectivity between the open channel of Mill Creek and the underground stormwater infrastructure and the need to understand the hydraulic factors contributing to urban flooding is one of the reasons why an integrated dual-drainage (major and minor systems) model is needed. That is – a model capable of dynamically simulating the hydraulic conditions within the City's stormwater network directly connected to Mill Creek via outfalls.

The use of the hydrologic and hydraulic modelling software program PCSWMM was determined to be an acceptable compromise between model performance, intended use, and price. With PCSWMM, the interplay of creek hydraulics and the underground stormwater network will be investigated. In addition, to account for the great complexity of flood flows in an urban environment, a coupled 1D-2D model has been developed. This ability to examine in more detail the hydraulic characteristics of the basin comes with some trade-offs. It requires a balance of computation time and level of detail. Models of this type, with 2D domains, significantly increase the computational requirements of the computer running the model. These runtimes are directly related to the 2D mesh resolution which will be discussed in more detail below. To balance the need for accurate flood mapping and to provide for a tool that also allows for examining the stormwater network as a whole, two models were developed.

Alongside this integrated major-minor stormwater model, a second PCSWMM model was developed to study the effects of flooding caused only by the overtopping of Mill Creek. The decision to split the work into two models came as a result of inefficiencies in the integrated model. These inefficiencies stem directly from the creation of the 2D mesh which represents the domain of overland flooding. More on how this mesh is developed will be discussed below; however, it was because of increasingly long runtimes of the integrated model that the need for a Mill Creek-only model was realized. The benefit of having two separate models is that the creek-only model, with a smaller overland area being studied, can have a finer mesh resolution and the hydraulics of the flood can be more accurately modelled. It is this model which will provide for flood depth and hazard maps, and the integrated model, covering a larger overland area with a lower-resolution mesh, will be used as the main stormwater model which can be used to test what-if flooding scenarios and identify areas of the City whose stormwater networks are the most prone to flooding.

5.1.1.1 Coupled 1D-2D Modelling

Within a traditional 1D SWMM model, pipes and open channels are modelled as conduits with breaks in geometry or hydraulic conditions represented at junctions (manholes, catchbasins, ponds, outfalls, changes in cross-section, etc.). These types of models are difficult to estimate extents of flooding and hazard levels due to the necessity of 1D models to have flow paths pre-defined by the modeller given the topographic data available. This can lead to potential inconsistencies in a large model and large degrees of uncertainty given the branching flow paths most streets afford, as well as the low relief of the City of Kelowna as you approach Okanagan Lake. The overland flow paths which must be assumed to be constant for all flooding events may, in fact, differ from one flood event to another. Furthermore, a 1D model does not give spatial variation in velocity since this data can only be estimated along the conduits which have been defined as flow paths.

Given the above deficiencies of a 1D model for this application, a coupled 1D-2D model was accepted as the most accurate way to model overland flooding. In a 1D-2D model, the underground stormwater conduits and main channel of Mill Creek remain 1D elements; however, the high-resolution LiDAR data is leveraged to provide the modeller with the ability to represent overland flow in two-dimensions. In this way, when Mill Creek spills its banks and underground stormwater infrastructure surcharges into the streets, the 2D computational domain allows for the flooding waters to flow over land and in whichever direction gravity takes it. No assumptions are needed with respect to flow paths and the benefit of high-resolution LiDAR data can truly be utilized. As well with 2D modelling, spatial data such as depth and velocity can easily be extracted from whichever part of the flooded area is of interest to develop hazard maps and identify zones of interest or concern.

As there are many benefits to utilizing the 2D components of stormwater models such as PCSWMM, there are some drawbacks that need to be addressed throughout the model-building process. These include compromising between reasonable model runtimes and the spatial resolution of results. Some of the optimization parameters are a function of the duration of design storm events and some are a function of 2D domain resolution. The hydrologic component of the model will be discussed in more detail below. This section will concern itself with the generation of model geometry, the computational mesh, and the inclusion of available spatial data.

5.1.1.2 Model Extents

The focus of this study is Mill Creek and its related stormwater network within the City of Kelowna. An earlier HEC-RAS model recently updated with new geometry represents the limit of available data and the ultimate extents of the current models. These extents begin approximately 35 m upstream of Spencer Road and terminate at Okanagan Lake downstream.

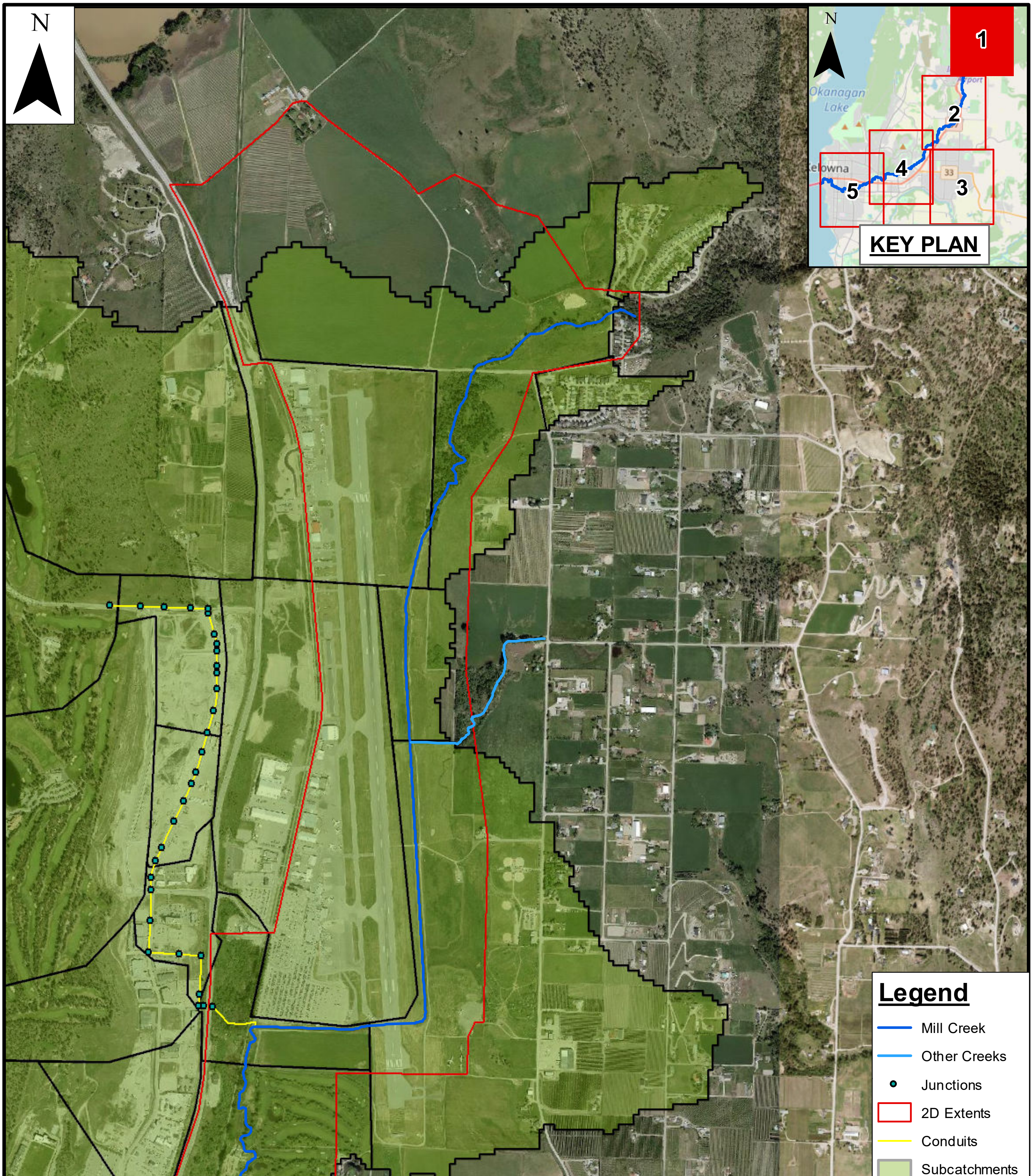
The integrated stormwater model is the larger of the two models developed because it includes much of the City of Kelowna's underground stormwater infrastructure. Nearly 2400 stormwater conduits are included in the model, representing almost a quarter of the City's total stormwater network (from the City's GIS database). As will be described in the section below, the size of the area serviced by these utilities necessitates a very large 2D computational domain. As the computational mesh gets larger, the mesh resolution needs to be lowered in order to maintain computational efficiency.

Pipes which were directly connected to Mill Creek or in very close proximity were included in the integrated model. Those pipes which were not connected and removed from the model are considered to have very limited impact on overland flooding. It was noticed that in certain parts of the City's network, GIS-based information was not available. This was determined by inspecting the location of catchbasins in the GIS database and realizing that they did not appear to outlet into any stormwater pipe. These areas typically existed far enough from Mill Creek that their omission likely has little impact on the results of the flooding extent. Nonetheless, as this model is utilized in the future, it is expected that some of these areas can be filled-in with the required data by field survey or a more detailed look at the City's record drawings that have not yet been translated into GIS features. Other potential GIS data that was not included in the model was any stormwater infrastructure along Highway 97. It is presently uncertain as to what infrastructure exists under the highway, but the area covered by the highway which contributes to runoff is still captured by a subcatchment and routed to the nearest stormwater manhole or, potentially, creek node. This is conservative, since actual runoff would enter a storm pipe and then into the creek or other storm network. Future updates to the model should take this potential stormwater infrastructure into account.

Given that Mill Creek provides an outlet for much of the City's stormwater network, certain elements were simplified at the extremities of the watershed in order optimize the model for it's intended function; to examine the hydraulic interaction of the underground network within Mill Creek, particularly during periods of flood events. This simplification is mostly confined to four areas; the first area being the subcatchments around Fascieux Creek and Munson Pond. These areas are a significant distance away from Mill Creek itself; however, stormwater pipes near Mill Creek are designed to spill water into the networks which run south towards Fascieux Creek and eventually into Okanagan Lake. Fascieux Creek and the stormwater network that connects it to Mill Creek was added to the model but the subcatchments were broadly delineated at a low level of detail, they were simply needed to account for inflow to the creek which may provide boundary conditions for the inflows spilling over from closer to Mill Creek.

The Gopher Creek subcatchment and the Rutland neighbourhood was simplified to focus on flows that route into the Gopher Creek diversion, a 450 mm to 900 mm storm sewer that takes overland inflows from Gopher Creek at Springfield Road and from portions of the Rutland neighbourhood and outlets at Chichester Wetland. The Gopher Creek subcatchment is an important inflow point that discharges towards Mill Creek and therefore it was included in the model. However, the need for simplification of the storm network in this area was to limit the extent of the 2D mesh.

Another area with contributions to Mill Creek inflows is from the hills in the Tower Ranch area. Overland flow paths and estimates of the two stormwater ponds were added to the model to provide for flow routing from these subcatchments towards Mill Creek. Finally, the fourth area which was simplified because of its proximity to Mill Creek was the developed area West of Kelowna International Airport. A single storm pipe network was added to the model to route runoff from the developed area towards Mill Creek.



City of Kelowna
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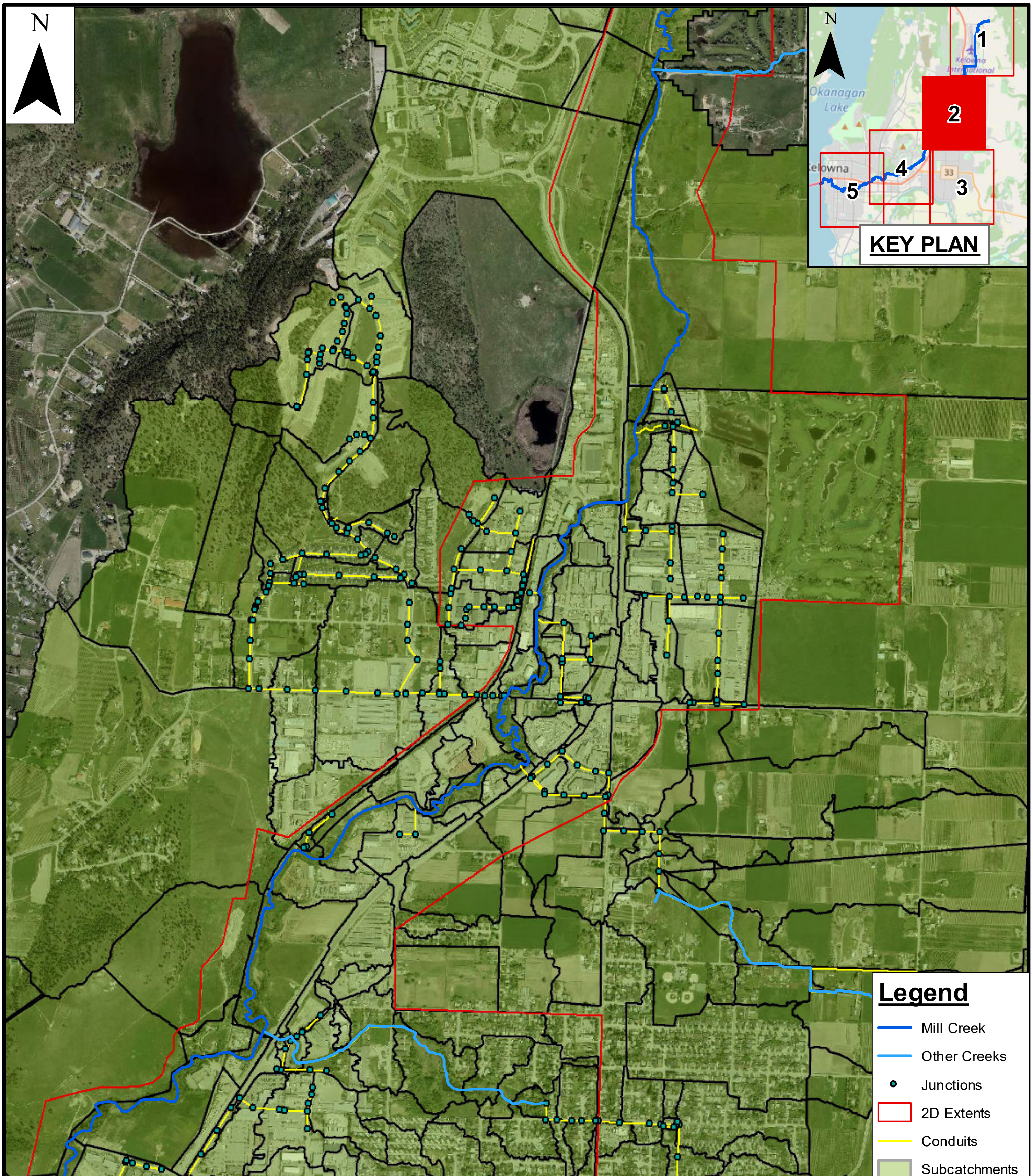
PROJECT NO.	60613804	Figure 5-1-1
SCALE:	1:20,000	Model Limits
DRAWN:	B. TROITSKY	
APPROVED:	-	
PROJECTION:	UTM ZONE 11N	REV NO. / SHEET
DATE:	2020-04-24	0 / 1/5



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PROJECT NO.	60613804
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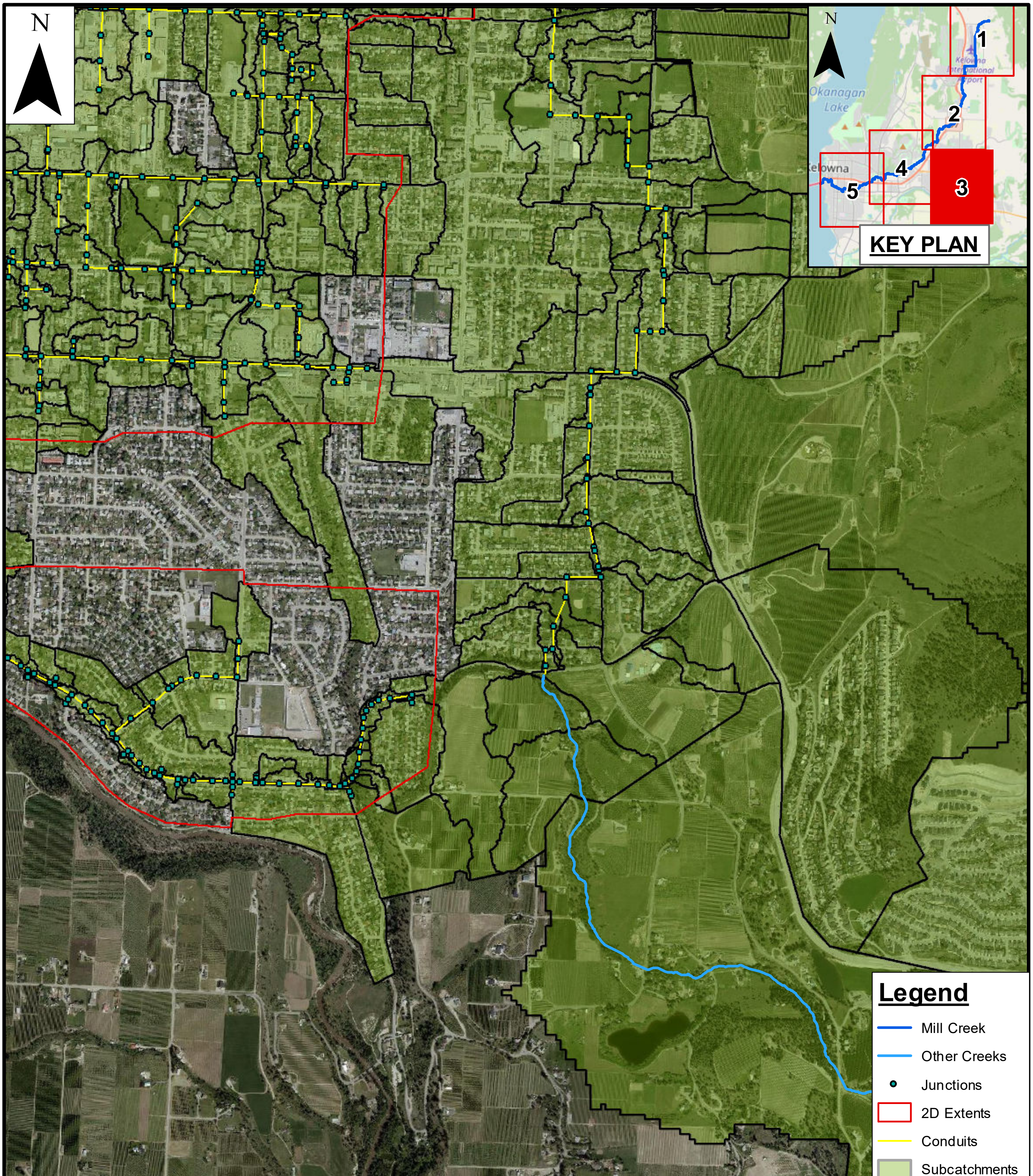
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 5-1-2

Model Limits

REV NO.	SHEET
0	2 / 5



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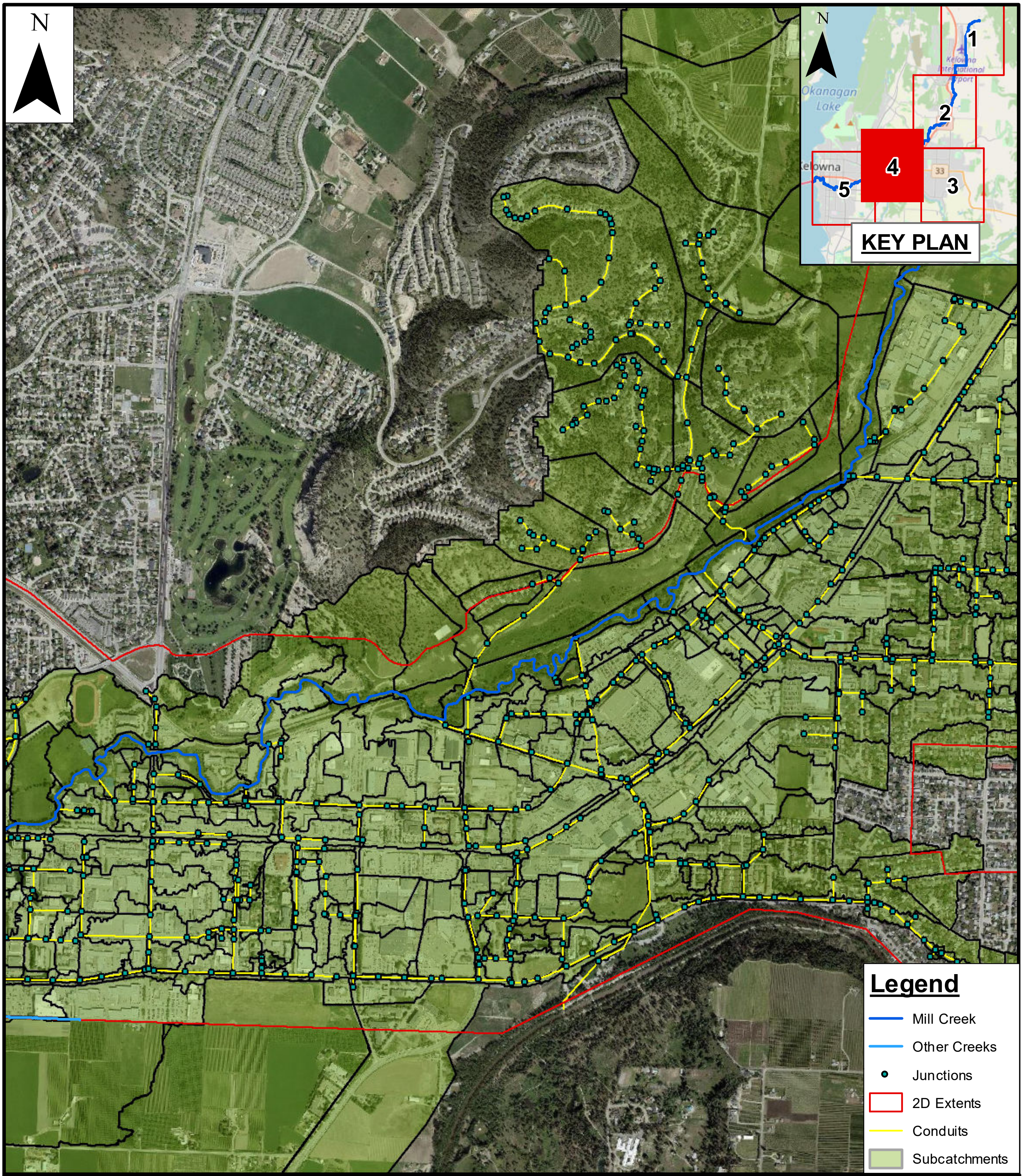
PROJECT NO.	60613804	Figure 5-1-3
SCALE:	1:20,000	Model Limits
DRAWN:	B. TROITSKY	
APPROVED:	-	
PROJECTION:	UTM ZONE 11N	REV NO. / SHEET
DATE:	2020-04-24	0 / 3 of 5



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Regional District of Central Okanagan

PROJECT NO.	60613804	Figure 5-1-4
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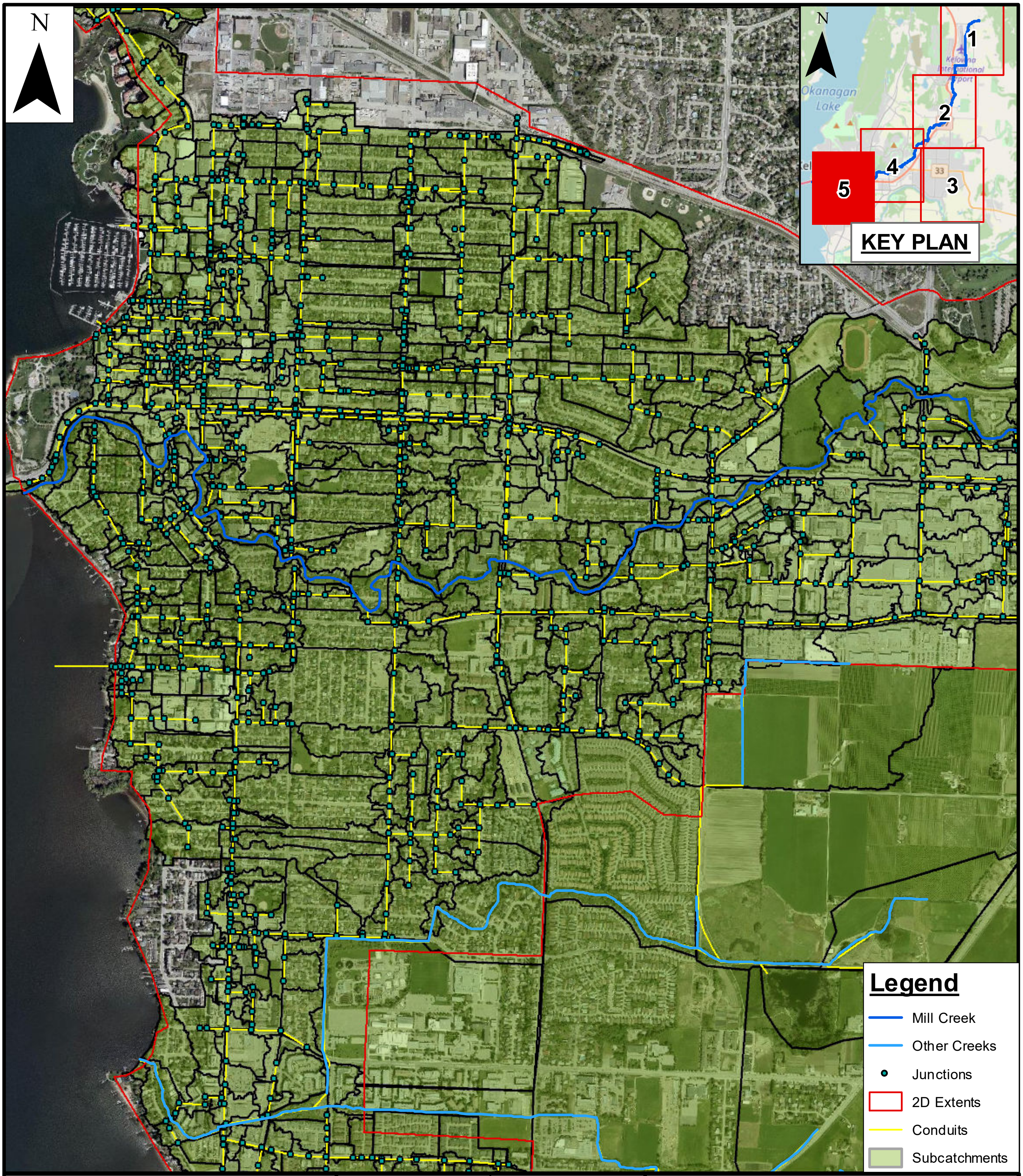
APPROVED:	-	
PROJECTION:	UTM ZONE 11N	REV NO. 0
DATE:	2020-04-24	SHEET 4/5



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PROJECT NO.	60613804
SCALE:	1:20,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 5-1-5

Model Limits

REV NO.	SHEET
0	5/5

5.1.1.3 Generating the 2D Computational Mesh

The 2D computational mesh is one of the main features of these models, at the same time it is also the limiting factor in its development, ultimately governing the extents of the model and level-of-detail available for examining overland flooding. Unfortunately, it is in this capacity that PCSWMM runs into computational limits. The 2D mesh generated by PCSWMM is an extension of the link-node network and it's recommended that this mesh does not exceed 100,000 nodes. The creek-only model has approximately 178,000 nodes and the integrated stormwater model has around 84,000 nodes.

The creek-only model covers a smaller total area but has a more refined 2D mesh. The area within 10m of the creek has a mesh resolution of 5 m, and the remaining 2D area has a mesh resolution of 10 m. See Figure 5-2 illustrating the difference in mesh resolutions. The integrated model has a constant mesh resolution of 20 m and covers a much larger area. This lower resolution mesh limits the detail one can obtain about sub-20m overland flow paths and the Mill Creek floodplain will also have lower levels-of-detail. This is necessary in order to encompass the entire stormwater network surrounding Mill Creek. The lower resolution mesh is also necessary to limit model runtimes to something reasonable that can be used to test what-if scenarios and conduct concept designs. As will be discussed in Section 5.3, the creek-only model takes several days to run on a moderately powerful computer, and this is simply too long for practical purposes. That is why the creek-only model was used for the generation of flood depths and hazards and not to be used as the primary future modelling tool. As a result of the differing mesh resolutions, it is expected that certain inconsistencies would arise in the model results, particularly in the extents of overland flooding due to Mill Creek. These will be discussed in greater detail in Section 5.3. It is expected that as future projects arise and utilize the integrated model, greater levels-of-detail and higher mesh resolutions be considered on the basis of the level-of-detail required for the particular scope of work.

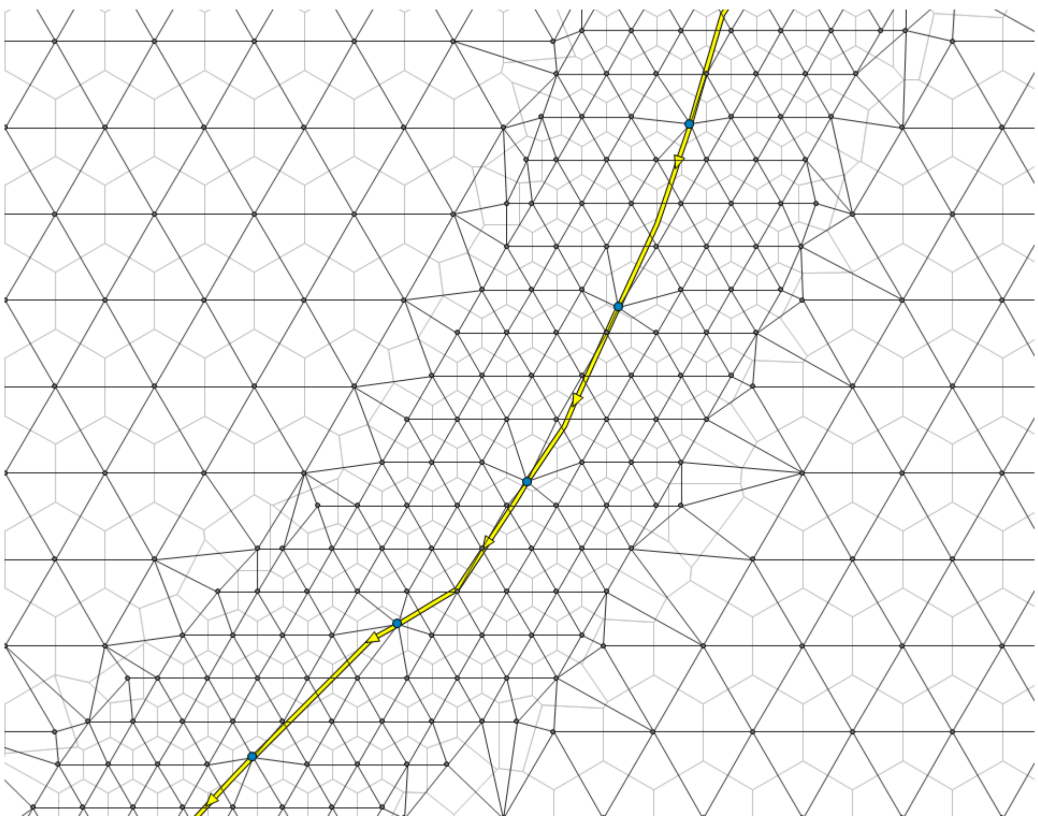

Figure 5-2: Comparison of 5 m and 10 m Mesh Resolution

5.1.2 Data Sources

Given that a brand-new model had been developed from the ground up, a significant amount of data was required. The existing data described in Section 2 was heavily utilized.

The main structure of the integrated model consists of data gathered from the City's OpenData database. This GIS information consisted mainly of shapefiles of various stormwater-related infrastructure as discussed previously. The data coordinate system was projected on horizontal datum NAD83 UTM Zone 11. To follow the standard guidelines by the federal Government of Canada, the existing GIS data was re-projected to NAD83 UTM Zone 11 CSRS (Canadian Spatial Reference System) and would then match the exact coordinate system of the LiDAR data. This adjustment is mostly organizational to maintain a consistent coordinate system across the model's dataset, follows best practices, and codes this information into the metadata of the GIS shapefiles for record. This was done for all GIS-related data which was used to build the PCSWMM model.

5.1.2.1 Vertical Datum Transformation

A brief discussion is required regarding the vertical reference frame the spatial data is projected on. It was mentioned in the previous section that the horizontal reference frame was adjusted to align with the LiDAR data which was flown in 2018 and national standards. This provided a consistent system for the PCSWMM model. The required adjustment in the vertical plane; however, is more complicated.

The LiDAR data which was provided to the City by the Okanagan Basin Water Board (OBWB) for AECOM to utilize in the modelling was produced referencing the most recent Canadian vertical datum CGVD2013 (Canadian Geodetic Vertical Datum of 2013). This posed an issue given that the invert elevations of the storm mains in the City's database are referencing the older Canadian vertical datum CGVD28 (Canadian Geodetic Vertical Datum of 1928).

A vertical datum is the reference for all elevation data and until 2013, CGVD28 was the predominant datum across Canada. With the introduction of CGVD2013, the country is in a state of transition between the two datums and some provinces, including British Columbia, still currently consider CGVD28 the official datum. The City of Kelowna's as-built drawings certainly reference the old vertical datum, however the LiDAR data provided for use in the current modelling exercise references the newer datum. Therefore, a transformation from one system to another is required. The challenge is that (to the best knowledge of the authors of this report at the time of writing) there is no tool to conveniently transform raster datasets (such as the LiDAR data in DEM format) from one vertical datum to another. There is; however, a tool provided by Natural Resources Canada which can batch convert data in point format from one datum to the other. This tool is linked to from the Government of BC's website (https://www2.gov.bc.ca/gov/content/data/geographic-data-services/georeferencing/geoid-model-data). Given that the simplest way to convert datums would be from the GIS-based information from the City to the LiDAR dataset vertical datum, and that in the future it is expected that the Province of BC will adopt CGVD2013 as the provincial standard and be in keeping with the national standards, a conversion was made for all GIS or as-built elevations from the CGVD28 vertical reference frame to CGVD2013.

In order to bring the invert elevations of the stormwater mains to reference the newer vertical datum, coordinates were calculated for each end of a pipe segment and an invert elevation was matched to those points. After building a database of easting, northing, and elevation data representing the location and elevation of each pipe inlet and outlet invert, the Natural Resources Canada tool GPS-H was used to convert the invert elevations to reference CGVD2013 with respect to the location of the pipe ends on the geoid model, as the vertical transformation is not a constant value but varies across the country.

The range of elevation corrections were between 0.199 m and 0.277 m and is in the range of expected values given by the Province of BC (https://www2.gov.bc.ca/gov/content/data/geographic-data-services/georeferencing/vertical-reference-system). All data is now correctly projected in both the horizontal and vertical reference frames and is ready to be imported into the PCSWMM model. It is acknowledged that the City still officially recognizes CGVD28 as the official datum and that a transformation of vertical data or results of the modelling will be required to be in line with City records.

5.1.2.2 Input from Previously Developed HEC-RAS Model

In 2019, a Mill Creek HEC-RAS model update was conducted by Associated Engineering in the report titled Kelowna Flood Risk Assessment (AE, 2019) to replace old topographic data with the latest LiDAR information. This also involved georeferencing the model. PCSWMM's built-in capacity to import HEC-RAS geometry was utilized to develop the 1D elements of Mill Creek. Imported elements include the creek centerline, cross-section locations, and bridge and culvert crossings.

The HEC-RAS model was a 1D representation of the main channel and overbanks. Since the current PCSWMM model is a coupled 1D-2D model, the overbank geometry from the HEC-RAS elements could be removed from the conduit data within PCSWMM such that the imported geometry was only representing the main channel. The overbank elevations would then be assigned to 2D nodes connected to the computational mesh which would route the flow overland in the event of flooding.

HEC-RAS handles bridge and culvert crossings with specific calculation routines which are not implemented within the SWMM5 engine. Since there is a difference between the way HEC-RAS and PCSWMM handle the hydraulics around these crossings, a comparison was made between the two models to ensure hydraulic losses have been adequately captured in the PCSWMM model. This will be discussed further in Section 5.3.

5.1.3 Scope of the Models and Intended Function

To summarize the scope and intended function of each PCSWMM model; the Mill Creek-only model consists of Mill Creek itself with all of the bridge and culvert crossings, (as well as the Mill Creek diversion to Mission Creek) from just upstream of Spencer Road to Okanagan Lake. It includes a 2D mesh which covers the floodplain as delineated from Mill Creek overtopping flows without any interaction with the stormwater network within the City of Kelowna. In general, it is expected that storage afforded by the underground network is minimal and its exclusion allows for a more refined 2D mesh, providing more accurate flood depths, extents, and estimates of flood hazard within the City. It is this model which is used to produce the flood depth and hazard maps presented in Section 6.

The intent of providing a second, larger PCSWMM model is to provide a tool, which is expected to be updated, maintained, and refined over time, for the purpose of general stormwater modelling during design rainfall and flooding scenarios. This model incorporates storage nodes, stormwater pipes, manholes, overland flow networks, and the same Mill Creek elements as the creek-only model. It has, based on model performance, a lower resolution 2D mesh which covers a larger area than the Mill Creek-only model. A trade-off in 2D resolution and flood extent accuracy is required in order to provide for a more comprehensive model of the City's interconnected stormwater system, which includes both major (overland) and minor (underground) networks. Areas of the stormwater network have been simplified at the extremities of the model as an attempt to limit the area covered by the 2D mesh to improve runtimes and usability.

5.2 Hydrology

As previously stated in Section 3.2, Associated Engineering's 2019 report included a flood assessment of Mill Creek. Along with the hydraulic model of the Creek, hydrology inputs were constructed using the HEC-HMS software program. This program modelled the entire Mill Creek watershed and was calibrated to the 1996 flood event as measured at the Water Survey of Canada gauge station 08NM053. A series of design flood hydrographs for several subcatchments of the Mill Creek watershed were derived and used as inputs to the hydraulic model. The present modelling exercise has adopted these design hydrographs as inputs to the Mill Creek component of the PCSWMM models. These hydrographs included streamflow for the 5-, 10-, 25-, 50-, 100-, and 200-year return periods.

One notable change that has been made to the way in which these inputs are applied to the PCSWMM models is the exclusion of the Gopher Creek hydrograph. Unlike other inflow points to Mill Creek, Gopher Creek enters the City of Kelowna from the southeast, under Springfield Road. The creek is diverted from its natural path into the City's stormwater network. This series of underground pipes drain north and outlet into Chichester Wetland Park before flowing under Highway 97 into Mill Creek. Due to the nature of the stormwater network's attenuation of any extreme flood event within the Gopher Creek subcatchment, it is unlikely that these flows would contribute substantially to flood flows in Mill Creek. The Gopher Creek subcatchment is also smaller than the others whose inflows more directly enter Mill Creek and is more heavily developed. As a result, the Gopher Creek subcatchment will be treated as a PCSWMM-element whose hydrograph will be generated using the City's IDF parameters similar to the way in which the rest of the City will be treated. It will only be included in the integrated stormwater PCSWMM model.

A 20-year hydrograph was also developed for each of the three main inflow points to support flood mapping to meet Health Act requirements for septic systems (discussed in Section 6). Upon observing the hydrographs developed for the HEC-RAS modelling, it was found that the 10- and 25-year hydrographs were identical for both Whelan and Scotty Creeks. The possible reason for this is that they were chosen to remain the same to support the calibration of Mill Creek flows observed at WSC 08NM053. As a result, the 20-year hydrographs for both of those creeks will remain coincident with the 10- and 25-year hydrographs. The 25-year Mill Creek inflow hydrograph applied at the upstream-most junction of the model was reduced by 5% to generate the 20-year inflows. This number was arrived at by interpolating a peak flow rate for the 20-year flood event between the 10- and 25-year peak flows given in the AE (2019) report. Other hydrographs for different return periods appear to be incomplete, it is unknown at the time of writing this report why that is the case, but it could be due to calibration issues within the HEC-HMS model. If other return periods need to be modelled, hydrologic estimates may need to be updated.

5.2.1 Design Discharge Estimation

The Mill Creek inflow hydrographs provided in the existing HEC-RAS model were used as inputs to the PCSWMM models. Hydrographs for Mill Creek at Old Vernon Road, Whelan Creek at Old Vernon Road, and Scotty Creek at Old Vernon Road were used. The Gopher Creek at Springfield Road hydrograph was omitted from the present PCSWMM model as previously discussed.

For the integrated stormwater model, subcatchments were delineated to receive rainfall events that would route into the stormwater system. If the storm mains within the system surcharge at manhole locations, the water is transferred into the 2D domain and overland flooding will be governed by the 2D mesh. Due to the low-resolution of the mesh itself, certain low-flow channels may not be properly represented, such as gutters and roadside ditches; however, locations of the storm network can still be identified as having low capacity and the general direction of overland flooding can still be discerned. Should greater level-of-detail be needed for sub-sections of the stormwater network, local areas of the mesh may be refined for greater accuracy. Sub-models may also be built based upon the main integrated model to improve computational efficiency for smaller areas.

Given the large area covered by the integrated 2D model, the subcatchments were delineated using LiDAR data and PCSWMM's built in Watershed Delineation Tool (WDT). This provided a "first pass" of subcatchment delineation across the City and was further improved by manual alterations of the subcatchment boundaries. In lieu of specific prescriptions of subcatchment infiltration and roughness values, these parameters were derived by inspection of previous City of Kelowna basin plans, specifically, the Central Area Drainage Plan Report (2009). In this report hydrologic classification codes were given to various land uses and parameters were associated with them (percent imperviousness, depression storage, etc.). The City's "Zoning" GIS layer was used to associate areas of the City with a specific hydrologic classification code (HC1-4). These land use zones within the GIS layer are described in the City's zoning bylaw Section 1. These zones and sub-zones were merged together into four types to match with the four HC zones. Since many of the subcatchments encompassed more than one HC zone, GIS was again utilized to perform an area-weighted analysis on the various subcatchment parameters to come up with the final values. Tables indicating the various zones and HC parameters are given in Table 5-1, and Figure 5-3 illustrates the areas covered by each of the City's land use/HC zones.

Table 5-1: Hydrologic Classification (HC) Zones

			Depression Storage (mm)	
	Land Use Type	**% Imperviousness**	Impervious	Pervious
HC1	High Density Commercial, Industrial, or Residential	95	8.5	5
HC2	Medium Density Residential Strata	50	1.5	8
HC3	Low Density Residential	80	1.5	5
HC4	Rural	5	1.5	10

Similar to the 2008 report, manning's n roughness coefficients for impervious and pervious areas are 0.015 and 0.025 respectively.

The City of Kelowna's bylaws (Schedule 4 and 5) were used to create design rainfall scenarios. Two different rainfall distributions were assessed, the Chicago distribution and the distribution from AE (2019) which was applied to the Brandt's Creek PCSWMM model. The AE (2019) report developed design rainfall distributions using IDF data at the Kelowna A station (1123970) which included climate change impact factors based on EGBC (2018) recommendations. This type of rainfall was compared against a 6-hour Chicago storm distribution. It was found that the peak rainfall generated by the Chicago distribution caused flooding in most pipe networks even under the 5-yr design event. This flooding was minor, but it is suspected that the distribution developed by AE (2019) is better suited to the Kelowna area. This distribution is less "peaky" and therefore led to significantly less flooding during the 5-year event. Figure 5-4 illustrates the difference between the overland flooding extents of surcharging stormwater conduits under a 1:10-year, 6-hour Chicago storm distribution when climate change impact factors are considered.

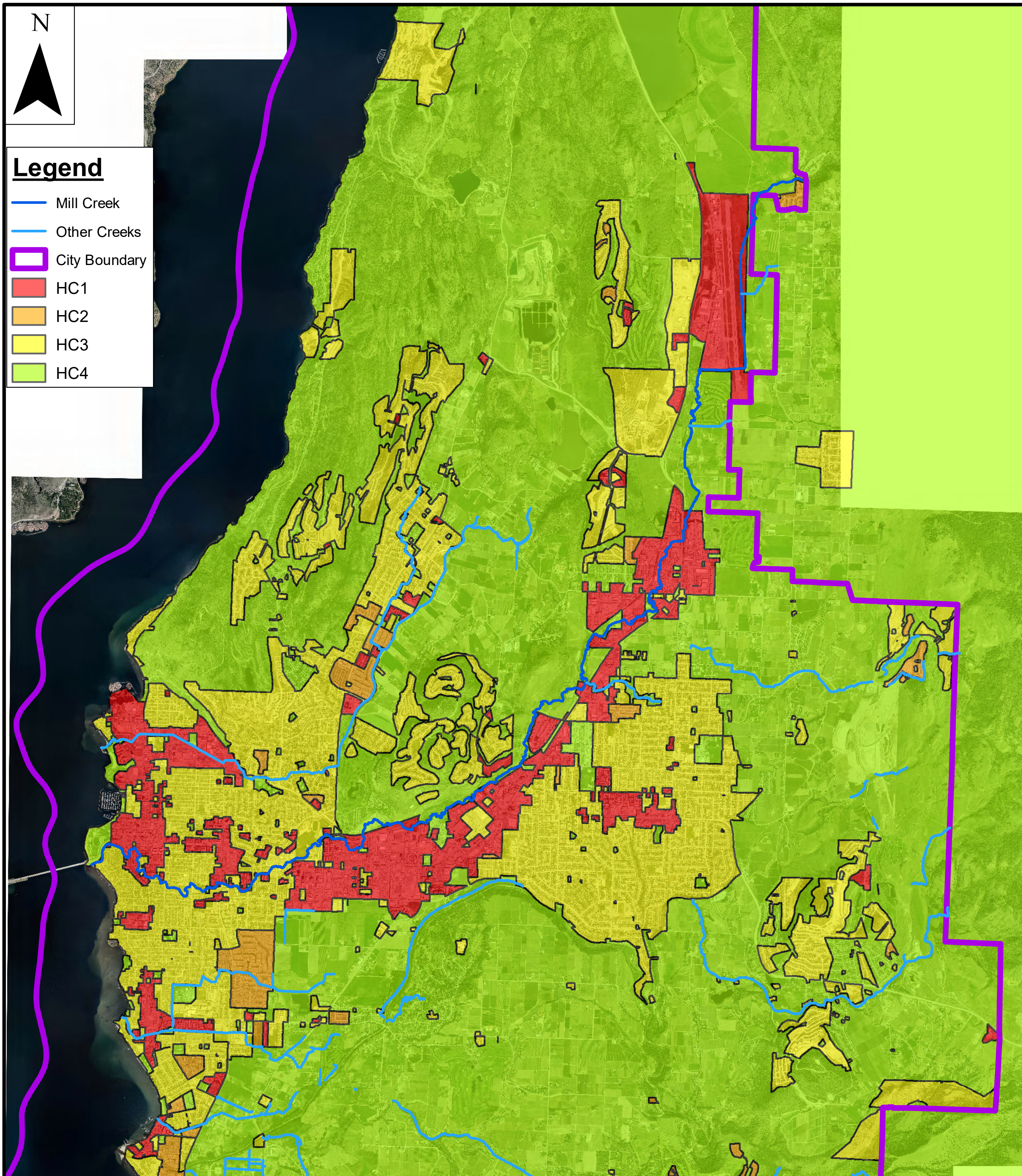

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Figure 5-3

HC Zones

REV NO.	SHEET
0	1/1

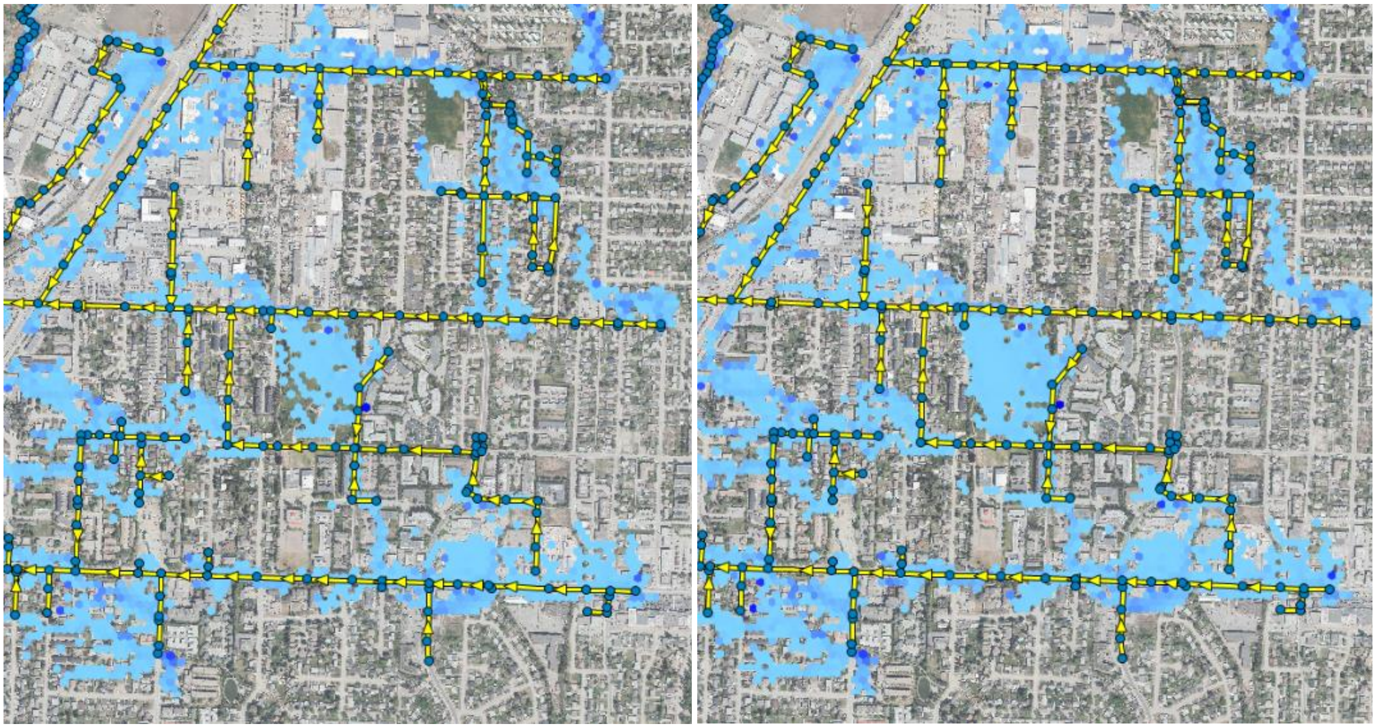


Figure 5-4: 1:10yr, 6-hour Chicago Rainfall without Climate Change Impact Factor (left) and with (right)

5.2.2 Climate Change Impact Factor Evaluation

Following the City's Bylaws, Schedule 4 Section 3.1.3 Climate Change states that an upward adjustment of +15% should be applied to the IDF curves at Station 1123970 (Kelowna A). The previously mentioned AE (2019) report indicated that an upward adjustment of +10% to the peak flow rates which were used to calibrate the design hydrographs for inflows into Mill Creek. It was stated in their report that these follow guidelines according to EGBC (2018); Legislated Flood Assessments in a Changing Climate in BC. The modified IDF curves were included in the PCSWMM model to develop design rainfall scenarios.

5.3 Model Runs and System Assessment

5.3.1 Runtimes

As alluded to above, runtimes were a limiting factor in the model development. The Mill Creek-only flood model developed with a high-resolution 2D mesh and the resulting runtimes were on the order of days, not hours. This was accepted due to the nature of the required flood extent accuracy. It is also not intended for this model to be constantly re-run to test what-if scenarios, that is what the integrated stormwater model is intended for.

The integrated stormwater model takes approximately 5-hours to run on a moderately powerful computer under rainfall simulations only (6-hour rainfall durations and a 10-hour total simulation time). If flooding scenarios are required to be modelled in Mill Creek the runtime increases substantially, to multiple days as a result of the long duration of flood hydrographs (4-day hydrograph simulation time requires >2-days of runtime).

5.3.2 Initial and Boundary Conditions

Three inflow hydrographs were used for each Mill Creek-only model run. These were hydrographs for the upper reaches of Mill Creek (inflow at Old Vernon Road), Whelan Creek, and Scotty Creek. As discussed above, the Gopher Creek hydrograph was omitted due to the presence of the City's stormwater network and subsequent attenuation of flows. These hydrographs were developed for a nine-day flood event, but the scenarios were run only for 96 hours to limit runtimes. This allowed for enough time for the peak of the flood to pass through the study reach and allow the flood extents to reach equilibrium.

For the integrated stormwater model, the same three hydrographs may be used as well. In other scenarios where flood flows of Mill Creek are not of consequence, a baseflow may be specified at the upstream-most junction. The integrated model runs currently have a nominal 1 m^3/s baseflow in Mill Creek. The reported (AE, 2019) mean annual peak flow in Mill Creek is 4.10 m^3/s which was determined too high to be considered for the current model runs given the amount of flooding that tends to occur in the Shadow Ridge Golf Course area at those flowrates. Rainfall timeseries can then be associated with each Subcatchment within the model for any return period (5-, 10-, 25-, 50-, and 100-year).

Boundary conditions are primarily associated with outfalls at Okanagan Lake. The 5-year lake level of 342.91 m was adopted for the present work following AE (2019). This may be updated within the integrated stormwater model as required. Another important boundary condition was the Mill Creek diversion to Mission Creek. The diversion structure itself has been modelled and a 10-year water surface elevation of Mission Creek was determined by running a HEC-RAS model of Mission Creek which was developed concurrently with the Mill Creek model. This was used for the 200-year Mill Creek-Only flood model.

5.3.3 Model Calibration and Verification

5.3.3.1 Roughness Coefficients and Hydraulic Loss Calibration

From the City's OpenData website, hydrometric data was available from two City-owned monitoring stations. However, the lower monitoring station (Mill Creek at Totom) was described by the City to be a poor station for any calibration effort given its type of installation. The upper monitoring station (Mill Creek at Old Vernon Road) is located just upstream of the study area and does not provide for a good calibration point due to its location outside the study reach. Despite the lack of calibration data, the HEC-RAS model of Mill Creek was used to compare the hydraulic results of the model.

The HEC-RAS model results for a very low flowrate event (1 m^3/s) were used to calibrate the PCSWMM model roughness values and structure loss coefficients. Figure 5-5 illustrates the goodness of fit of water surface elevation of both the PCSWMM model and HEC-RAS model at low flowrates. Results from both models are plotted on the same figure and mostly overlap with one-another (the lines are one-on-top of the other). The range of error is -0.390 m to 0.230 m, with a root-mean-square-error (RMSE) of 0.097 m. This is considered to be acceptable.

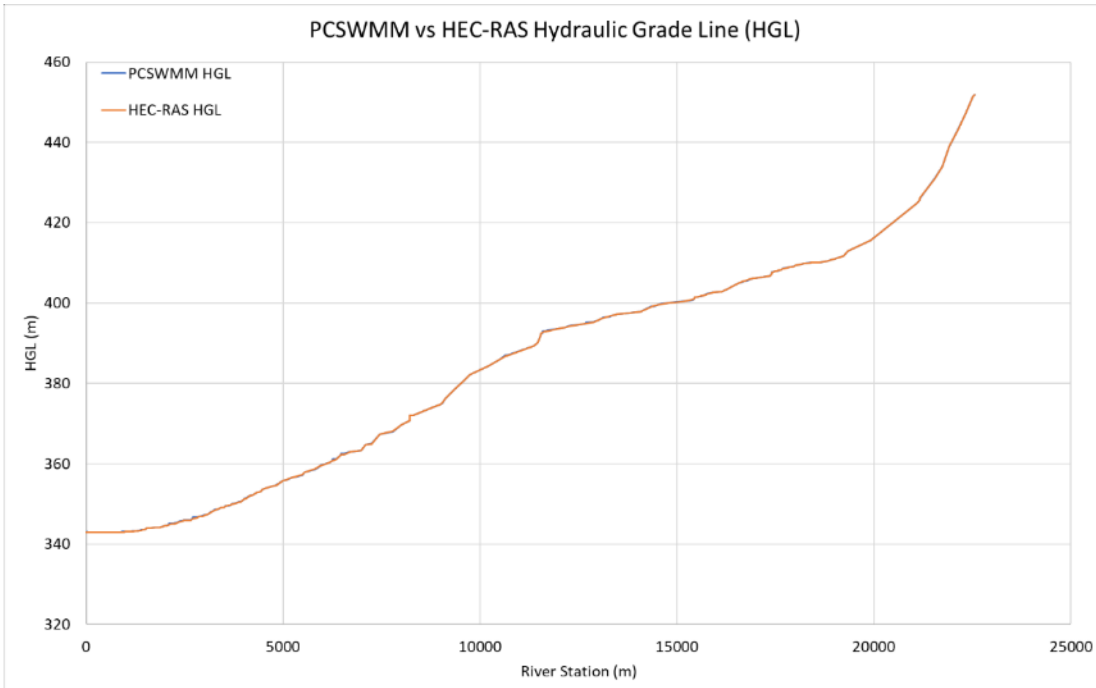


Figure 5-5: PCSWMM vs HEC-RAS Hydraulic Grade Line (HGL)

Large flowrate comparisons were not attempted due to the very different nature of the model computations in overtopping scenarios. Since the HEC-RAS model is 1D, the structure overtopping conditions are modelled very differently from the 2D PCSWMM models and extracting elevation data for a side-by-side comparison proved to be too cumbersome. Instead, a comparison of the flooding extents will be described in Section 6.4.

5.3.3.2 Calibration of Mill Creek Diversion to Mission Creek

The Mill Creek diversion to Mission Creek was a special consideration in the PCSWMM models. The diversion structure consists of two weirs, one is the diversion weir (a side weir) allowing water to spill into the 2.44 m x 2.44 m box culvert that drains into Mission Creek during high-flow events, and an inline weir on Mill Creek just downstream of the diversion weir. The inline weir geometry was explicitly modelled in HEC-RAS and was built into PCSWMM. The diversion weir; however, was handled differently, and it was less trivial to model in PCSWMM. For reasons presently unknown, the HEC-RAS model diversion weir was setup to divert a portion of the upstream inflow into the box culvert based on an inflow-outflow curve. This curve governs outflow independently of water surface elevation and diversion weir geometry. Attempts to reproduce similar curves within PCSWMM were not successful, one potential reason for this is that the HEC-RAS diversion weir geometry does not match the as-built drawings. It would appear that the bottom elevation of the HEC-RAS cross-sections reference the footing elevation in the as-built drawing instead of the creek bottom.

Correcting this bottom elevation in the PCSWMM model also does not appear to fit well with the surrounding creek bottom elevations at cross sections directly downstream as this would create a steep drop in elevation downstream of the weir that does not appear to exist. Only a field survey of the structure and the creek upstream and downstream would resolve the issue; however, from a modelling standpoint it is expected that this can be overcome.

Given that the inline weir was modelled explicitly in HEC-RAS, the same geometry was input into PCSWMM and that allowed for a good calibration between the two models when run under low-flow conditions. For the diversion weir, because attempts to define similar rating curves governing the outflow to Mission Creek were unsuccessful, the weir geometry was explicitly modelled in PCSWMM, holding the existing creek geometry of the HEC-RAS model constant but ensuring that the weir crest elevation was set to the appropriate height. Assuming the inflow-outflow curve defined in the HEC-RAS model is correct, a number of constant flow conditions were run in the PCSWMM model comparing the inflow to the diversion node and the outflow across the weir. These results are plotted in Figure 5-6. Very good agreement exists at low-flow events and the results begin to deviate at higher flow events. This may be expected as the true hydraulic conditions during these events become difficult to model accurately as a result of flooding or near overtopping of the diversion structure itself.

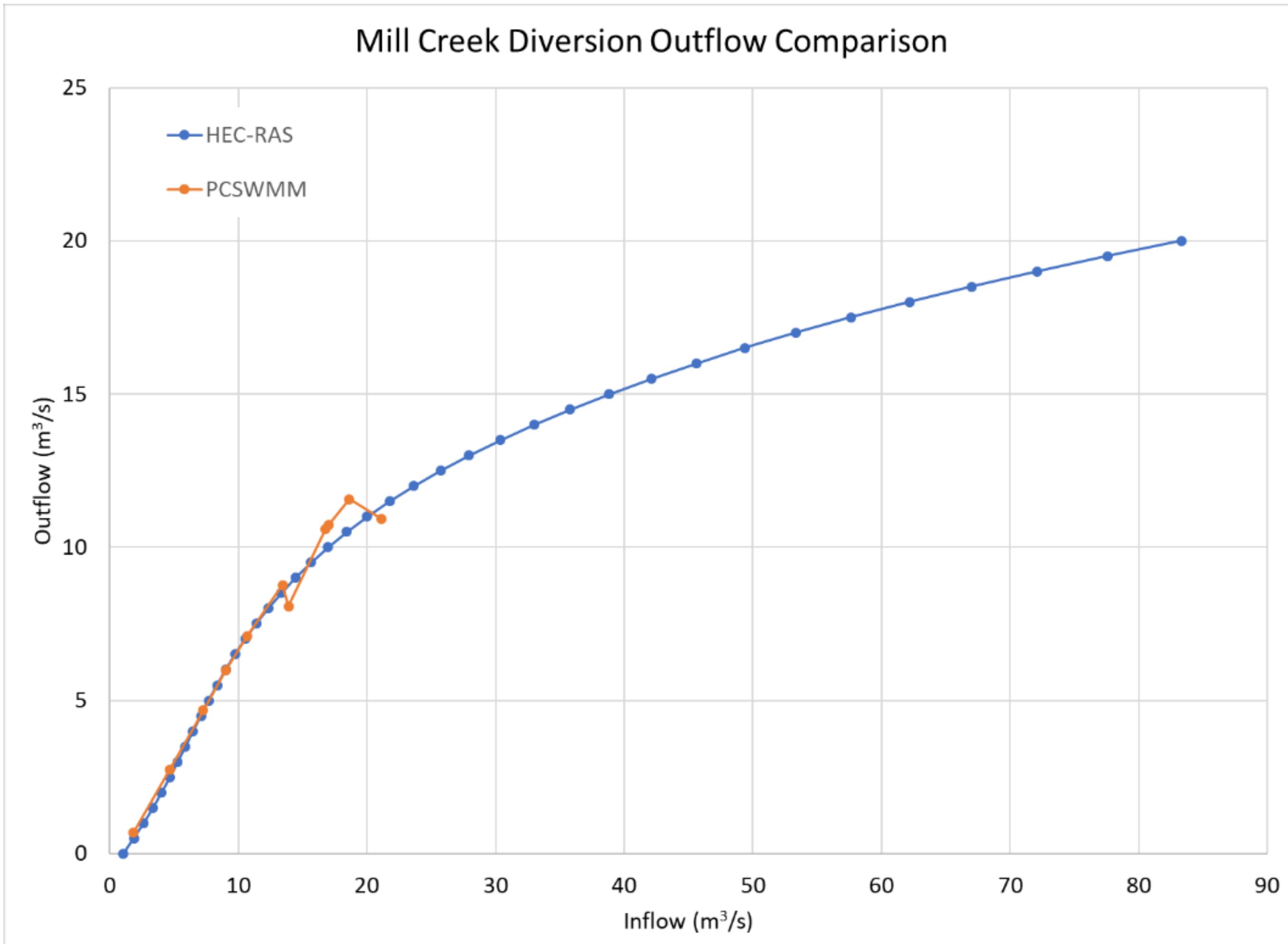


Figure 5-6: Mill Creek Diversion Outflow Comparison

The results indicate a slight underestimation of diversion flows (-0.57 m^3/s) during the 200-year flood event which results in slightly conservative flooding extents downstream. Eleven trial runs were conducted to test the adequacy of the PCSWMM weir geometry against the inflow-outflow curve provided by the HEC-RAS model, a RMSE of 0.56 m^3/s resulted and is considered acceptable.

6. Flood Depth and Hazard Mapping

The following resources have been searched for developing the flood hazard mapping standards and criteria for this study:

- MMM Group Ltd. National Floodplain Mapping Assessment Final Report (2014).
- APEGBC Professional Practice Guidelines for Flood Mapping in BC (V1.0, 2017).
- AECOM National Principles, Best Practices and Guidelines for Flood Mapping (Draft report prepared for Natural Resources Canada, 2017).
- APEGBC Professional Practice Guidelines for Legislated Flood Assessments in a Changing Climate on BC (Version 2.1, 2018).
- Federal Flood Mapping Guidelines Series (Version 2.0, 2018).
- The United States Federal Emergency Management Agency (FEMA) Guidance for Flood Risk Analysis and Mapping – Flood Depth and Analysis Grids (2018).
- FEMA Policy Standards for Flood Risk Analysis and Mapping (FEMA Policy #FP 204-078-1; Rev 9, 2019).

Flood hazard maps usually include more information than merely the flood boundaries that are shown in flood inundation maps. Such extra information includes water depth, velocity and hazard class, which is typically some form of depth and velocity derivative.

6.1 Flood Depth and Hazard Mapping Standards

6.1.1 Topographic Standards

As previously mentioned, LiDAR data collected during 2018 was used as the basis of the flood model. A 1m x 1m DEM surface was used for the purpose of flood mapping. The LiDAR contract specification sheet was provided by the City of Kelowna for AECOM to compare against the Federal Flood Mapping Framework Documents (Federal Airborne LiDAR Data Acquisition Guideline Version 2.0). It was determined that the provided LiDAR data was suitable based on the grounds of point density, and vertical and horizontal accuracy.

6.1.2 Design Flood Standards

Commonly in BC, flood maps have been produced with the larger of the 200-year flood or the flood of record and these floods are used to establish design elevations for flood mitigation works. The 20-year flood levels are also developed and used in compliance with the Health Act Requirements for septic systems.

For the current study, AECOM developed flood depth maps for the 200- and 20-year design flood events, and flood hazard maps for the 200-year flood event.

6.2 Flood Depth and Hazard Mapping Criteria

There are no prescriptive hazard classification schemes laid out by the Federal Flood Mapping Framework or by the Province of BC, however the APEGBC Guidelines for Flood Mapping do illustrate examples of flood hazard classification. One such hazard classification follows the UK formula for flood hazards which follows the Defra and Agency (2005) FD2320 Technical Report 2 methodology. This hazard rating combines effects of water depth, flow velocity, and floating debris potential.

UK Flood Hazard Rating Formula:

Hazard Rating (HR) = flooding depth (d) x [velocity (v) +0.5] + debris factor (DF)

DF = 0, 0.5, or 1 depending on if the debris will lead to significantly greater hazard, as well as the depth and velocity values. The debris factor is dependent on the depth of flow at a particular location, if there is no depth than there is no debris factor, if the depth is <0.25m the debris factor is 0.5, and if the depth is ≥0.25m the debris factor is 1. Table 6-1 describes the different hazard ratings and their classifications.

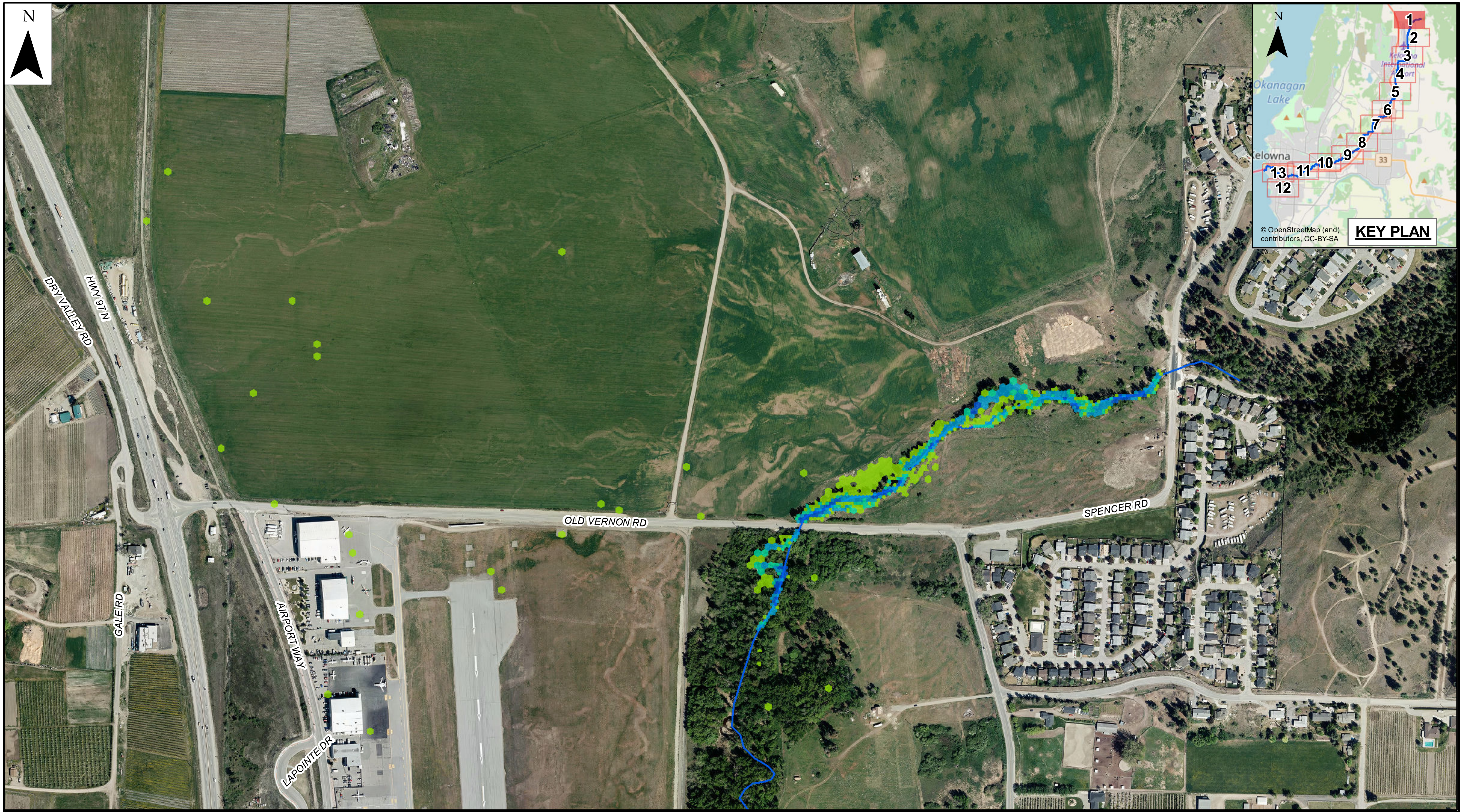
Table 6-1: Hazard to People Classification according to UK Hazard Rating Formula

Hazard Rating (HR)	Hazard Degree	Description
< 0.75	Low	Caution (flood zone with shallow flowing water or deep standing water)
0.75 – 1.25	Moderate	Danger for some; i.e. children, elderly and infirm (flood zone with deep or fast flowing water)
1.25 – 2.00	Significant	Danger for most; includes general public (flood zone with deep fast flowing water)
> 2.00	Extreme	Danger for all; includes emergency services (flood zone with deep fast flowing water)

APEGBC guidelines cite the current coastal flood mapping guidelines recommended by Kerr Wood Leidal Assoc. (KWL) in 2011 to be a minimum of 1:10,000 and preferably 1:5,000. AECOM used a scale of 1:5,000 for flood mapping along Mill Creek, resulting in 13 maps covering the study reach.

6.3 Development of Mapping using PCSWMM

The Mill Creek-only PCSWMM model was used to develop the project's final flood maps. The overland flooding results of the model are displayed with a series of hexagonal cells defined during the creation of the 2D mesh. These cells hold both depth and velocity data after each model run and are exported as a shapefile to be post-processed into final maps using ArcGIS software. The results of the flood mapping can be seen in Figure 6-1 through Figure 6-3.



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
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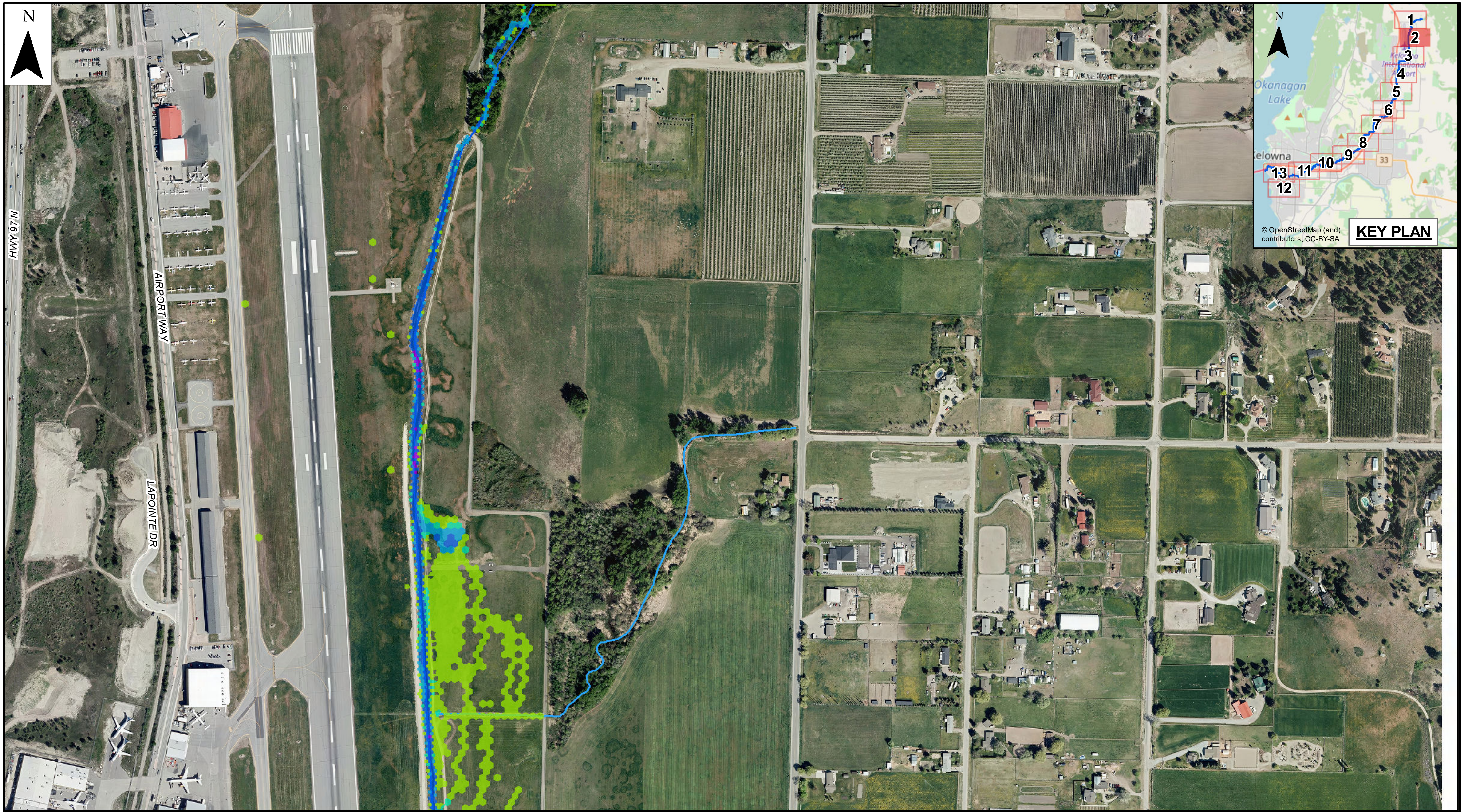
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-1-1
Mill Creek 20 Year
Depth Map

REV NO.	SHEET
0	1 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek
Other Creeks
Max Flooding Depth (m)
0.01 - 0.15
0.16 - 0.25
0.26 - 0.50
0.51 - 1.00
1.01 - 2.00

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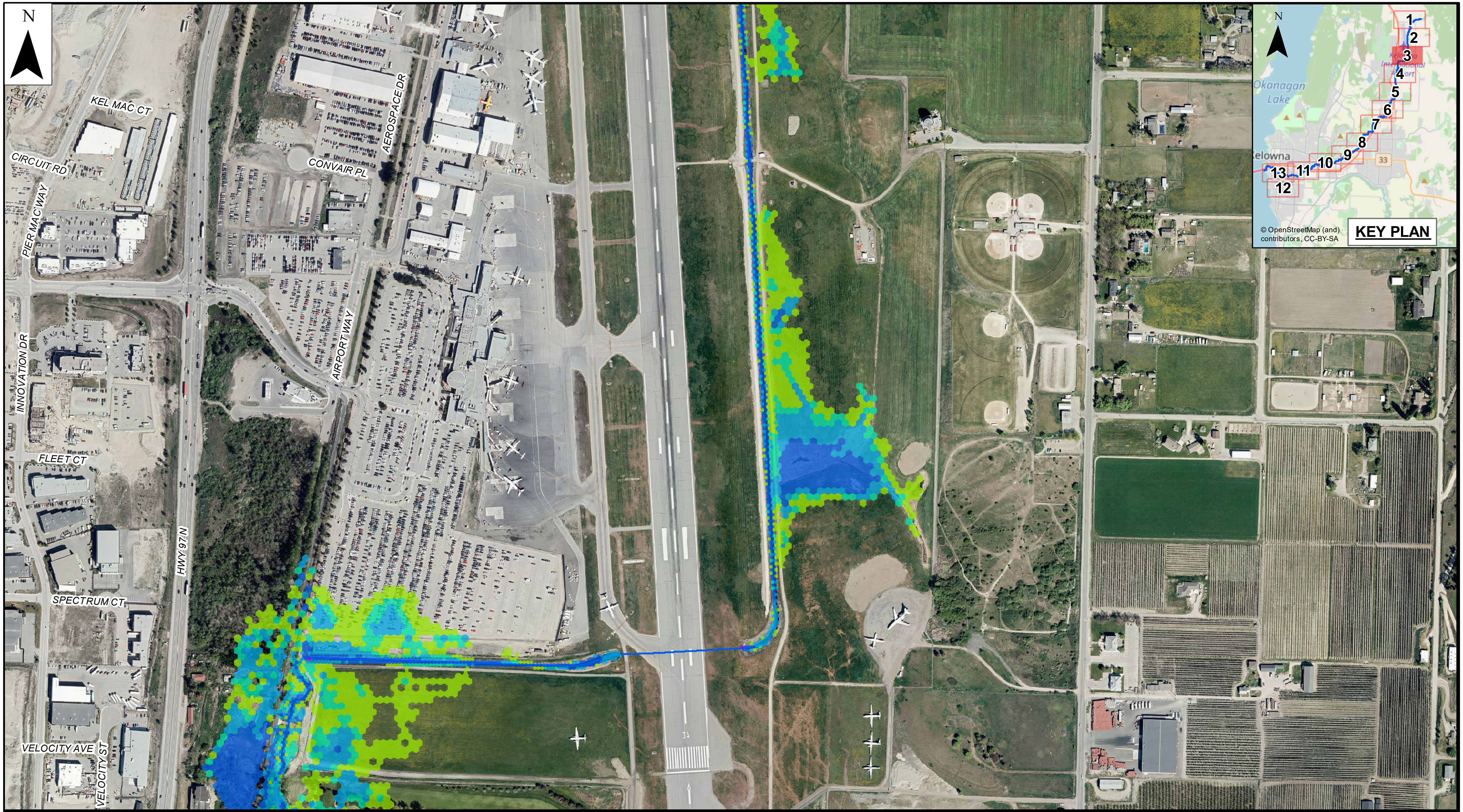
Figure 6-1-2
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	2 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT
REVISIONS				

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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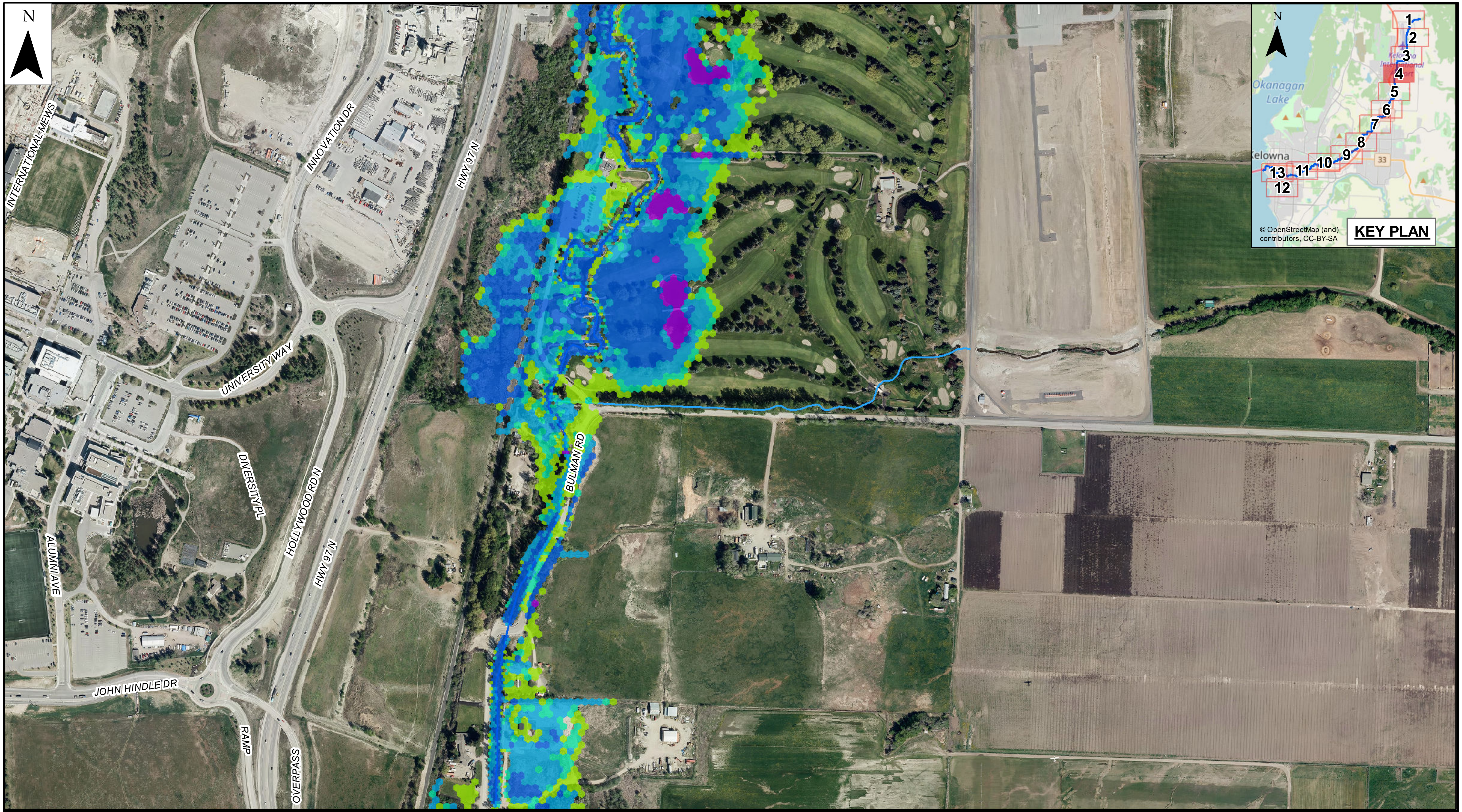
Figure 6-1-3
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	3/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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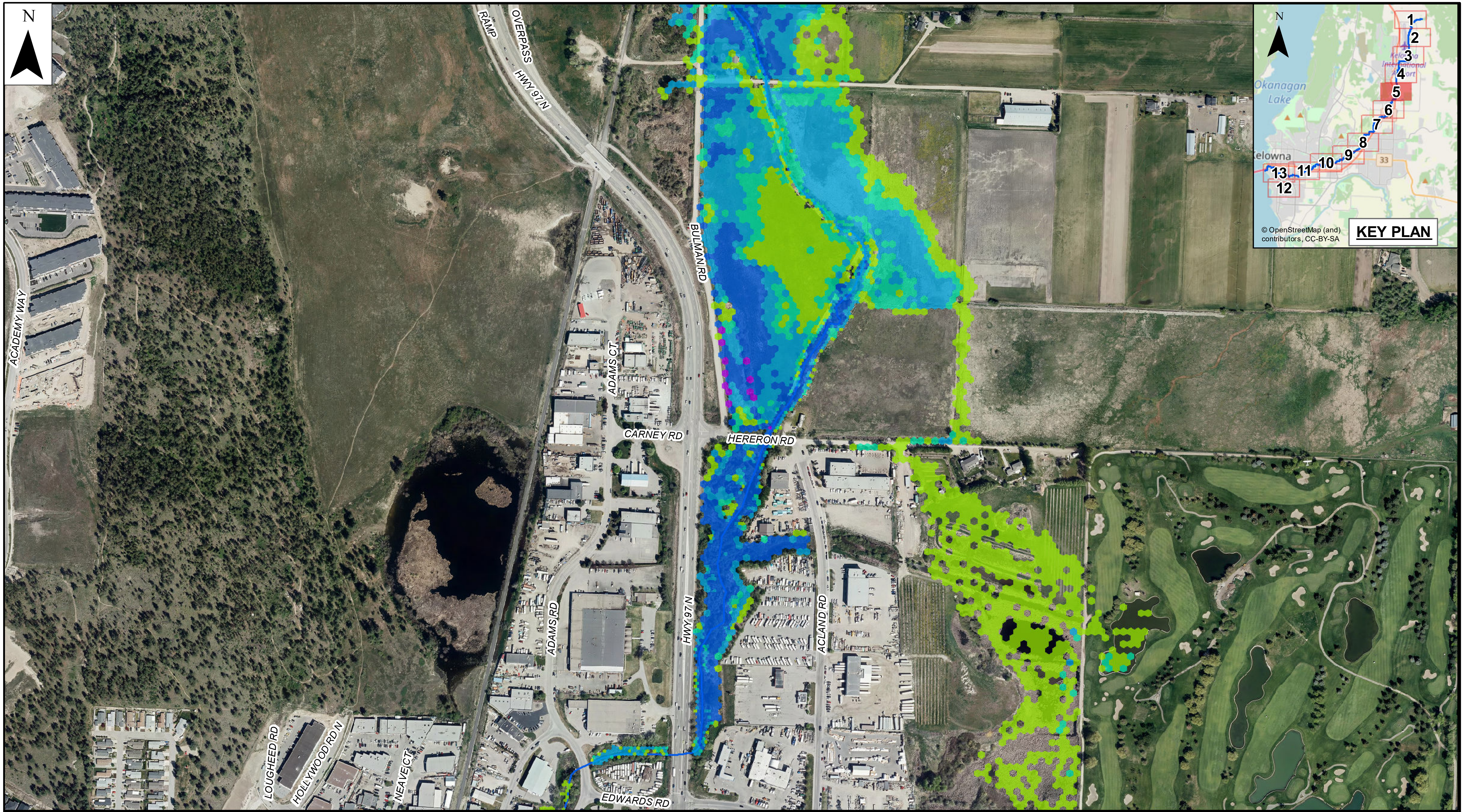
Figure 6-1-4

Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	4 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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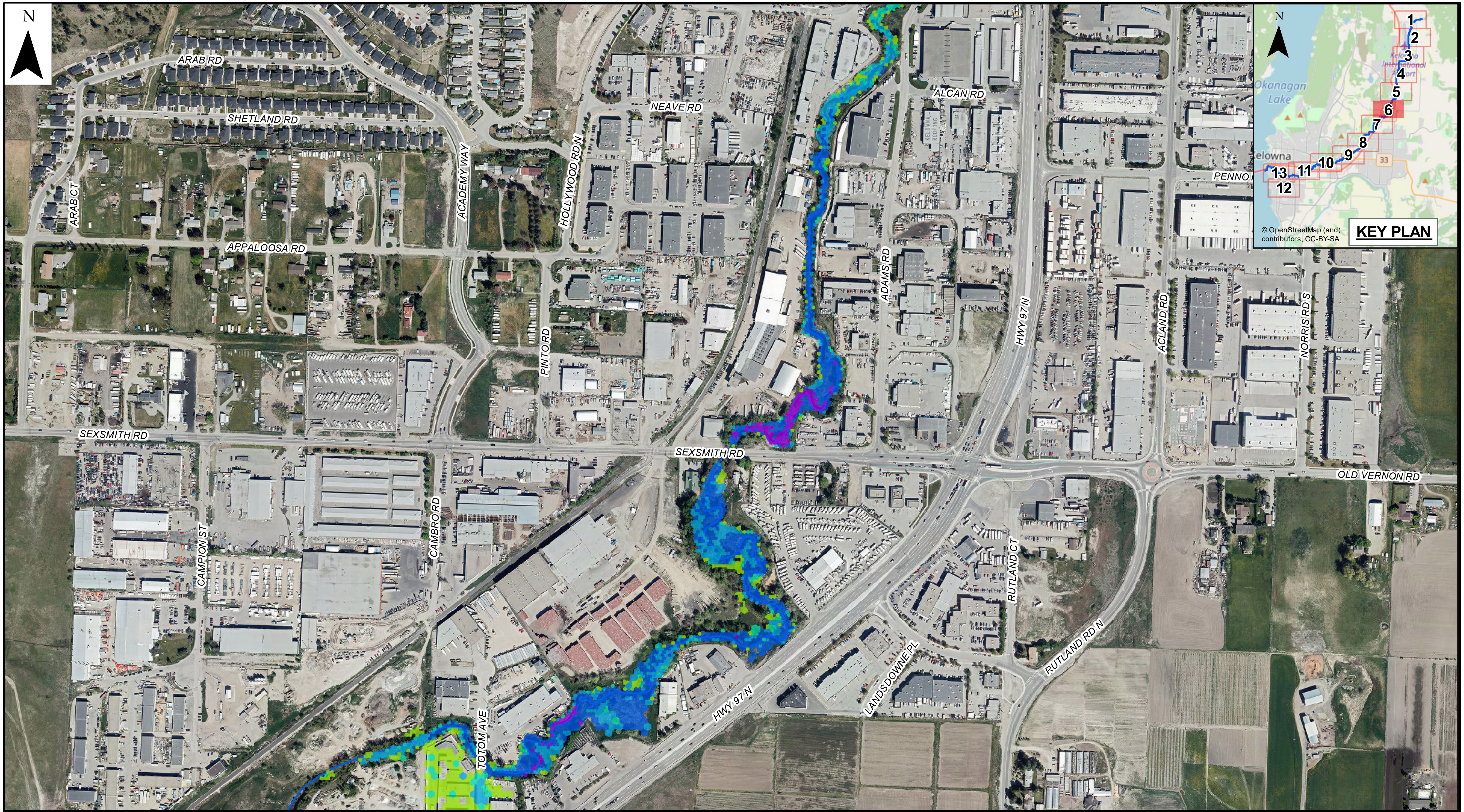
DATE:	2020-04-24

Figure 6-1-5
Mill Creek 20 Year
Depth Map

REV NO.	SHEET
0	5/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek — Other Creeks

Max Flooding Depth (m)

- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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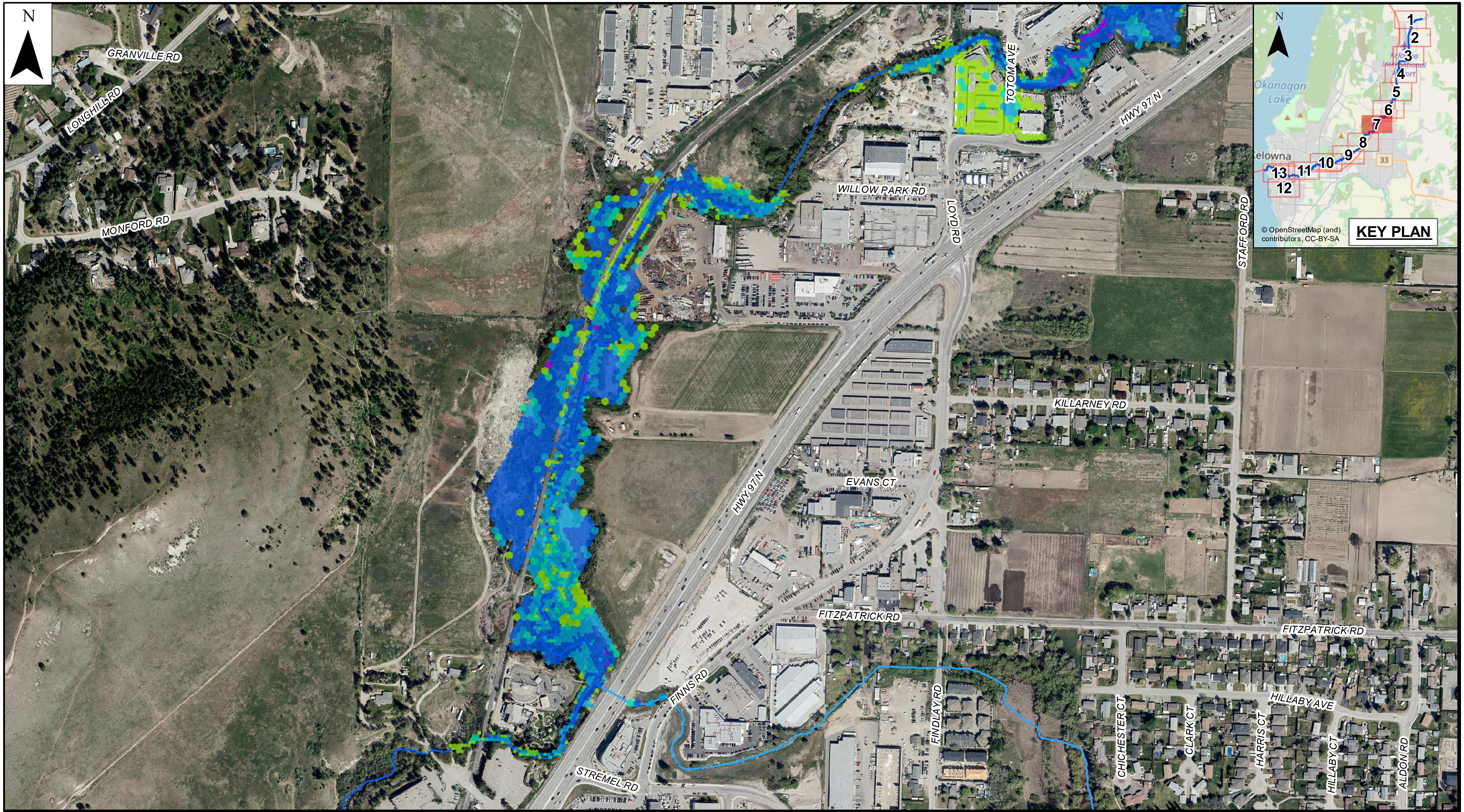
Figure 6-1-6

Mill Creek 20 Year Depth Map

REV NO. 0

SHEET 6/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek — Other Creeks

Max Flooding Depth (m)

- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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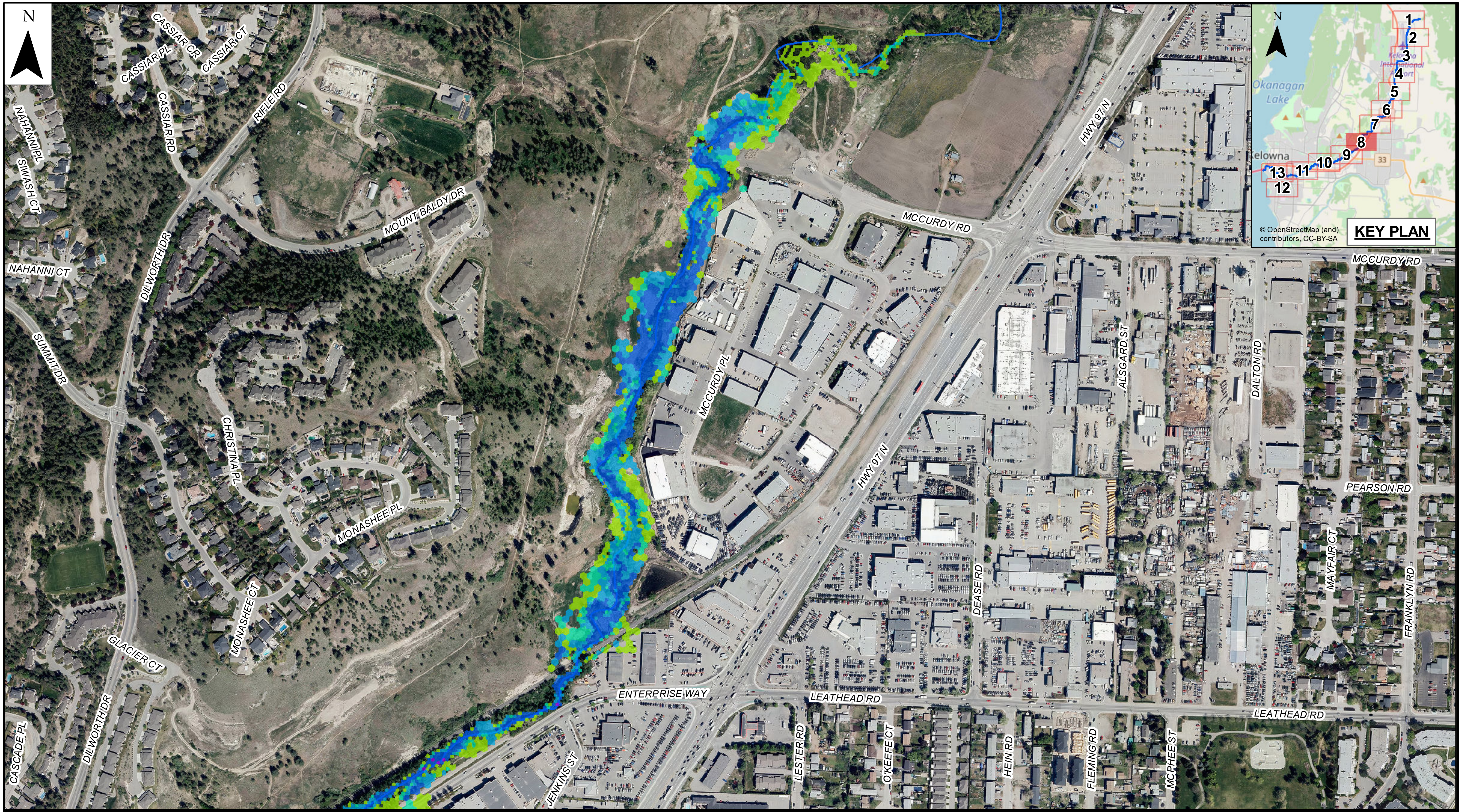
Figure 6-1-7

Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	7 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT
REVISIONS				

Legend:
Mill Creek — Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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Figure 6-1-8
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	8/13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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Figure 6-1-9
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	9 / 13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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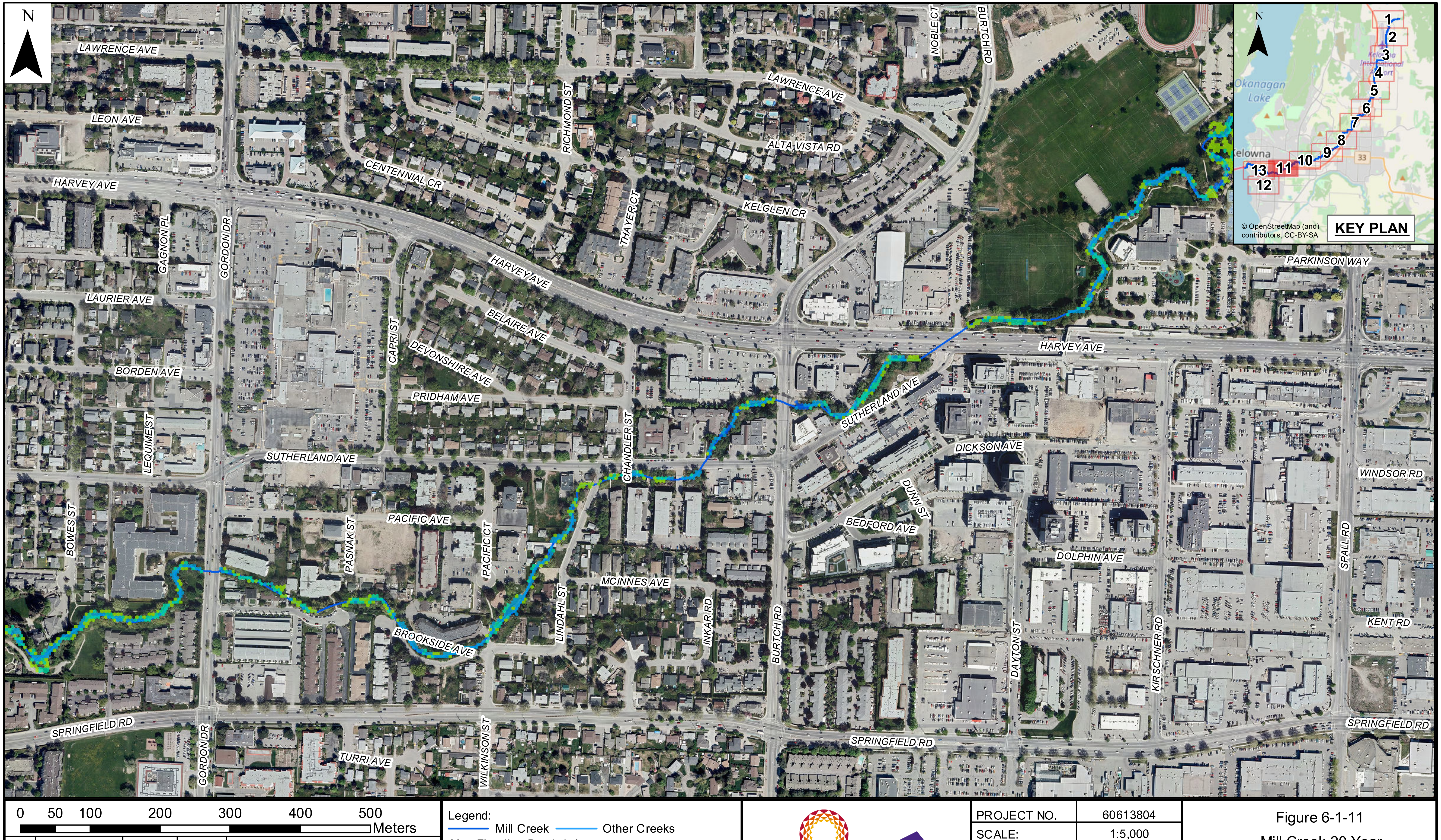
Figure 6-1-10
Mill Creek 20 Year
Depth Map

REV NO.	SHEET
0	10/13



NO.	DATE	ENG.	BY	SUBJECT
REVISIONS				

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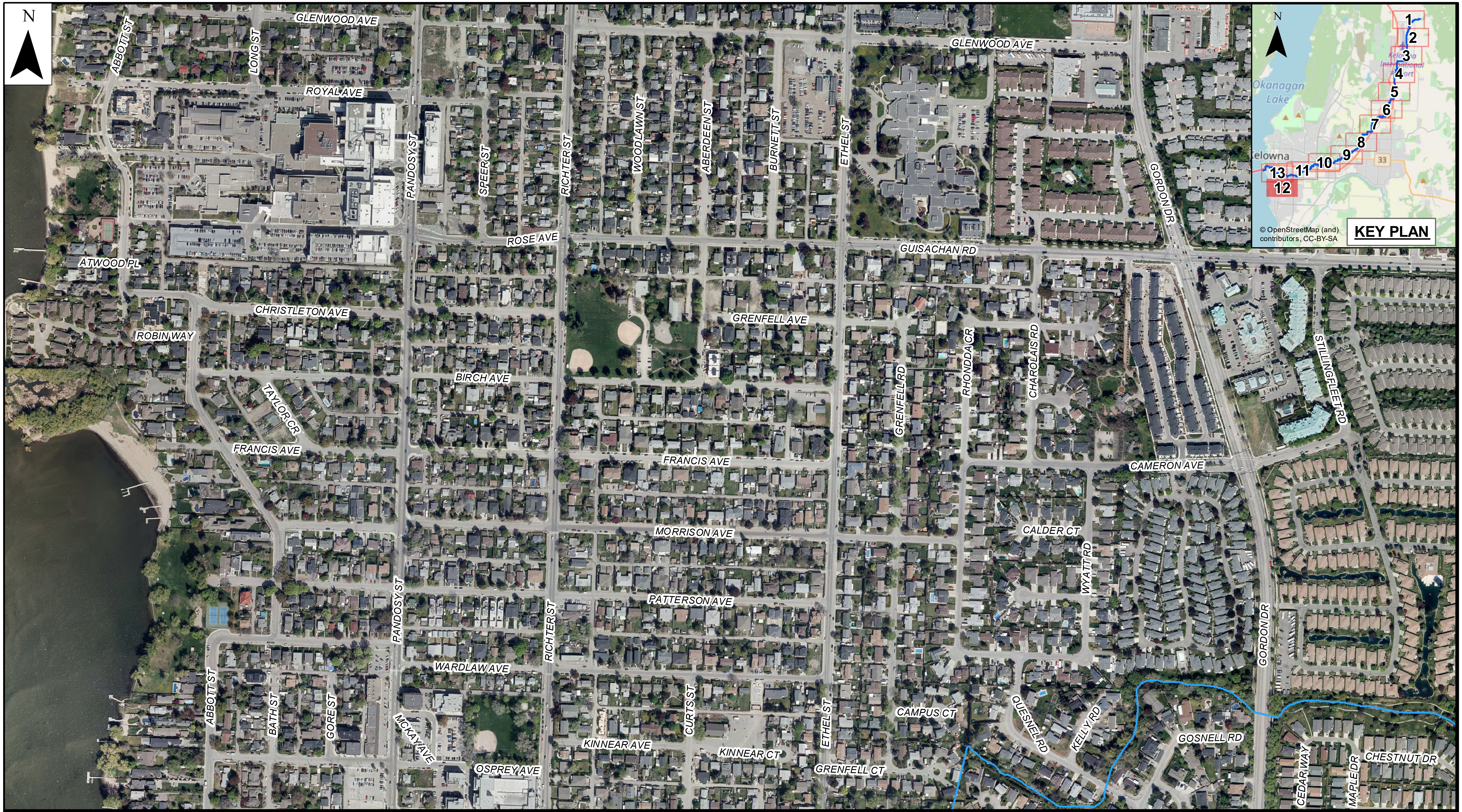
Figure 6-1-11
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	11 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek
Other Creeks
Max Flooding Depth (m)
0.01 - 0.15
0.16 - 0.25
0.26 - 0.50
0.51 - 1.00
1.01 - 2.00

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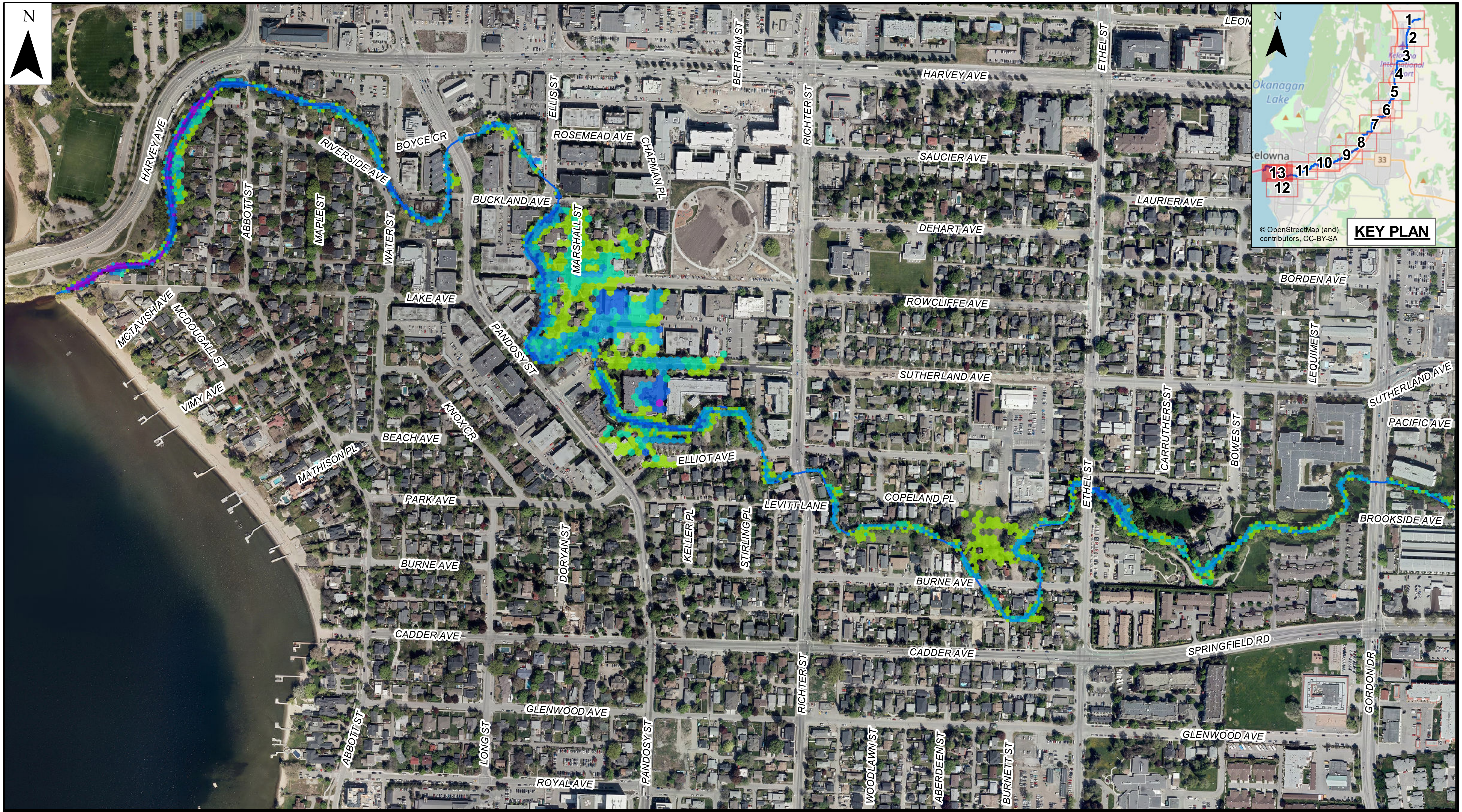
Figure 6-1-12
Mill Creek 20 Year Depth Map

REV NO.	SHEET
0	12/13



NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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Figure 6-1-13
Mill Creek 20 Year
Depth Map

REV NO.	SHEET
0	13/13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek
Other Creeks
Max Flooding Depth (m)
0.01 - 0.15
0.16 - 0.25
0.26 - 0.50
0.51 - 1.00
1.01 - 2.00

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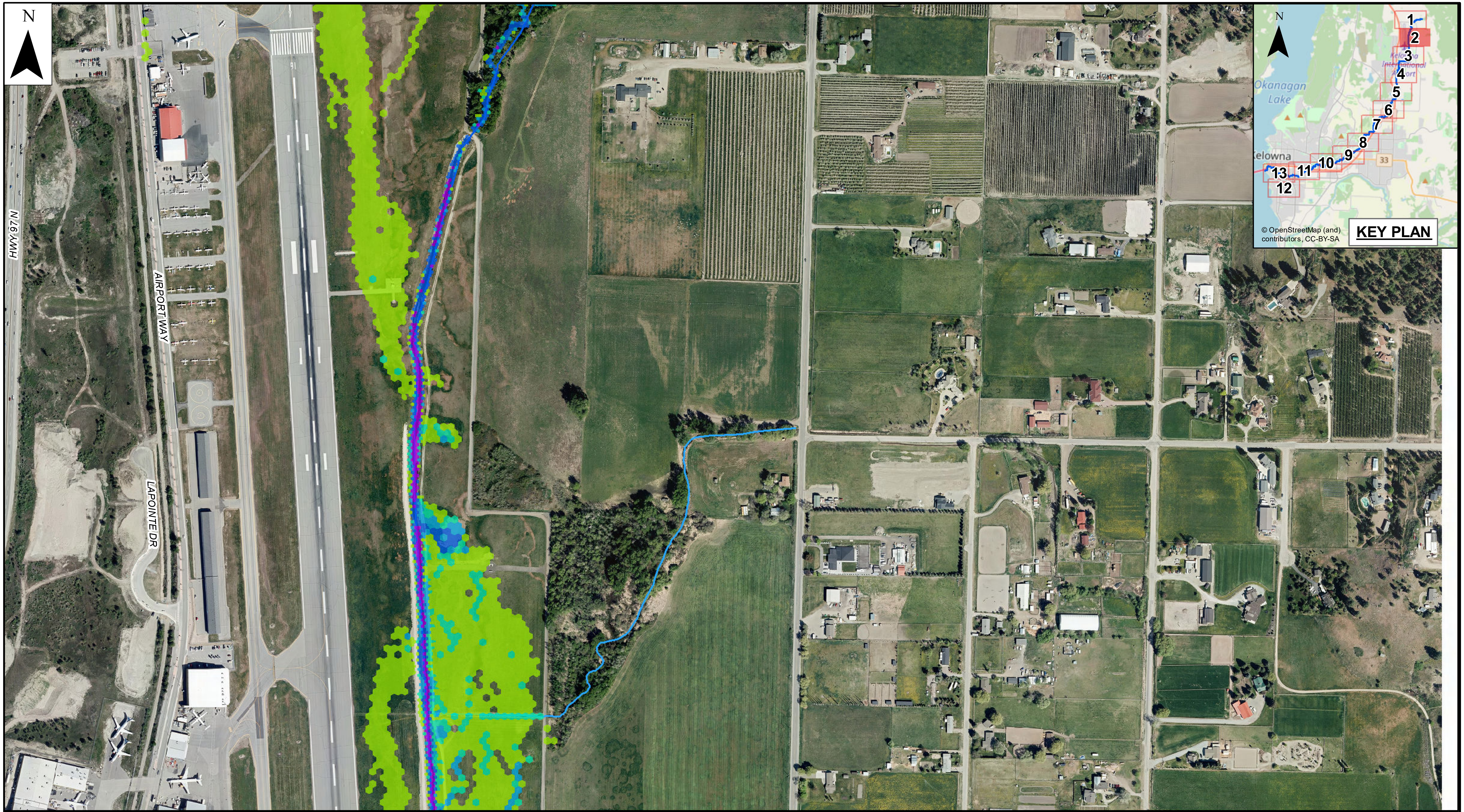
Figure 6-2-1
Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	1 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek
Other Creeks
Max Flooding Depth (m)
0.01 - 0.15
0.16 - 0.25
0.26 - 0.50
0.51 - 1.00
1.01 - 2.00

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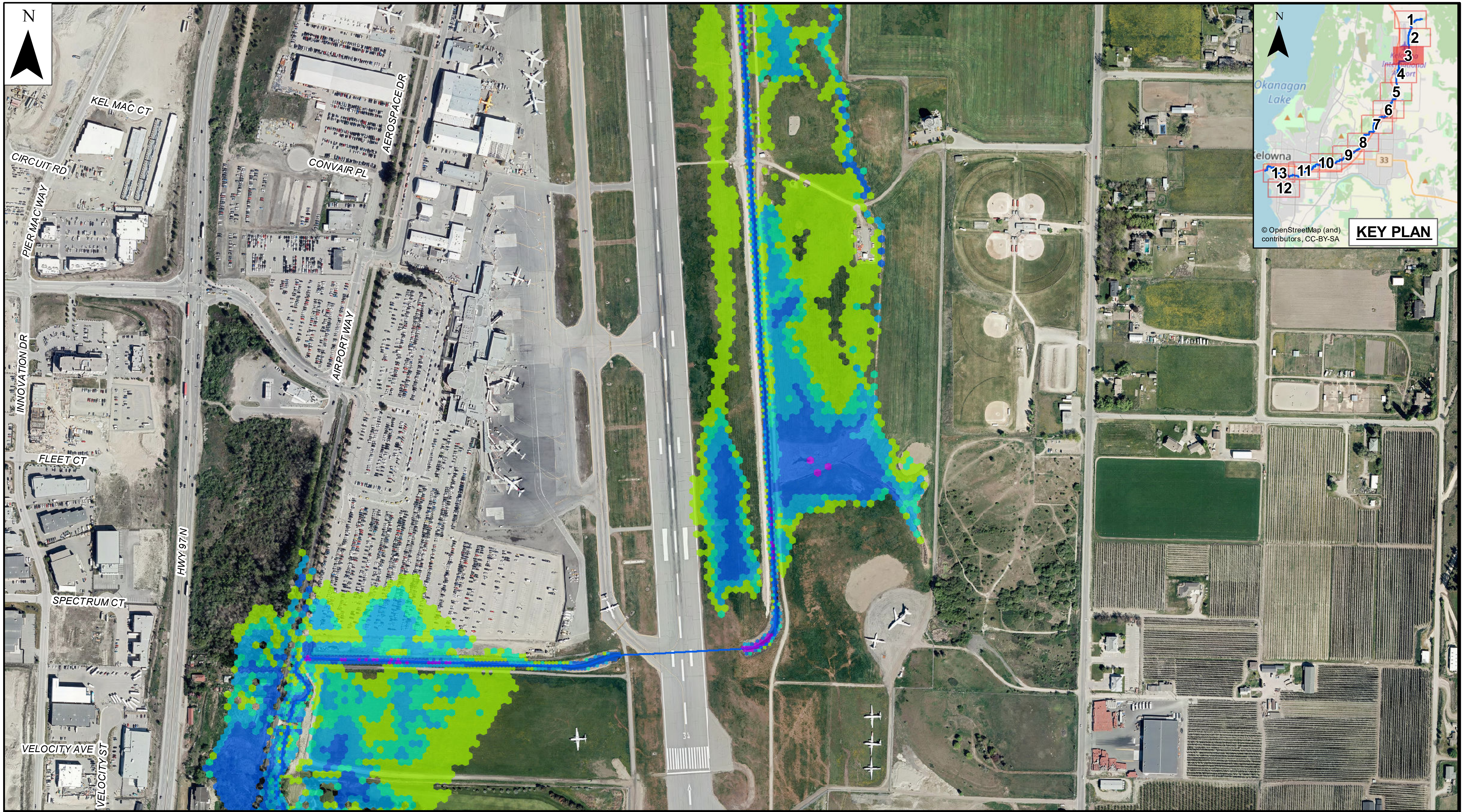
Figure 6-2-2
Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	2 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna

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Regional District of Central Okanagan

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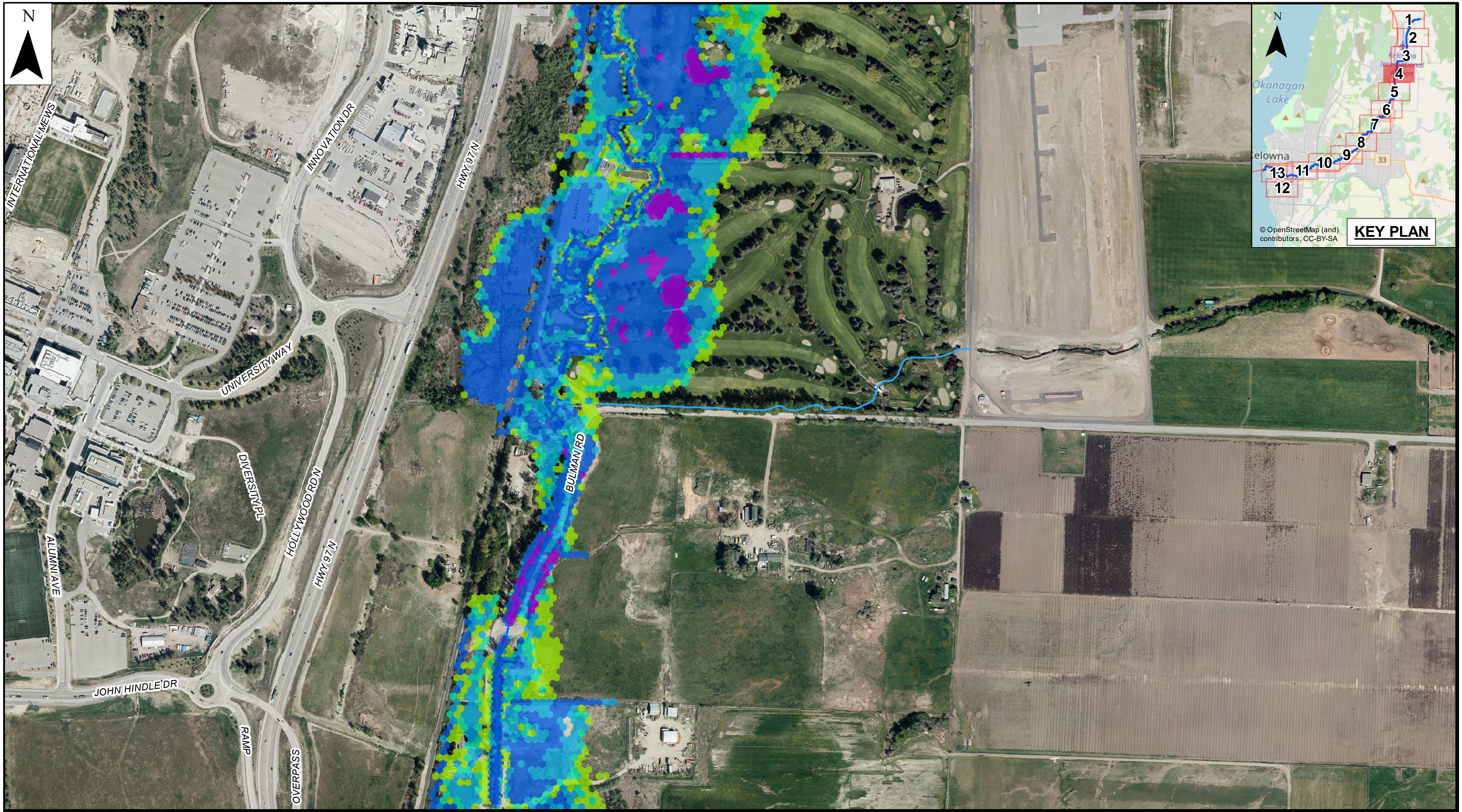
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-3

Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	3/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna
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Regional District of Central Okanagan

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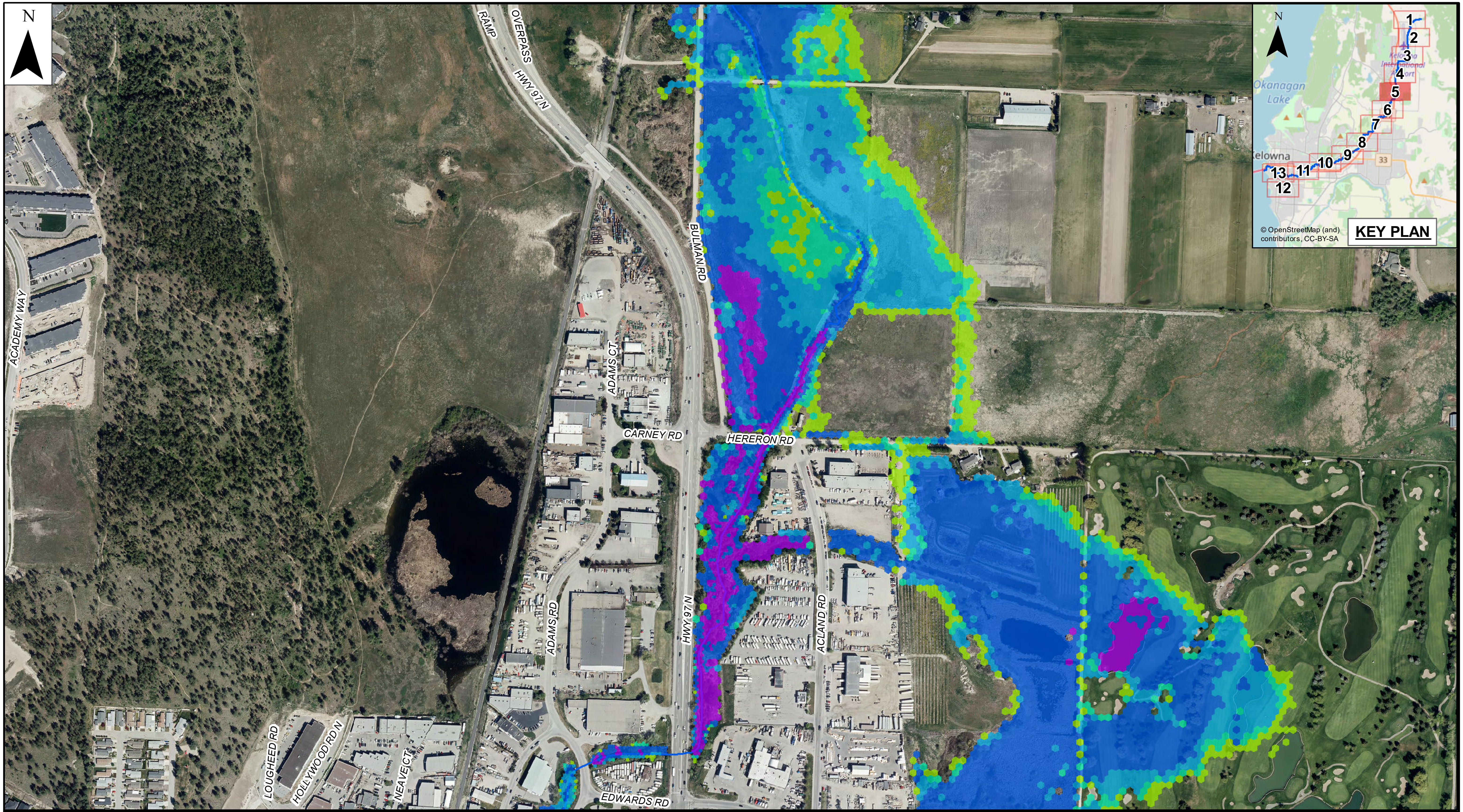
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-4

Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	4 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna

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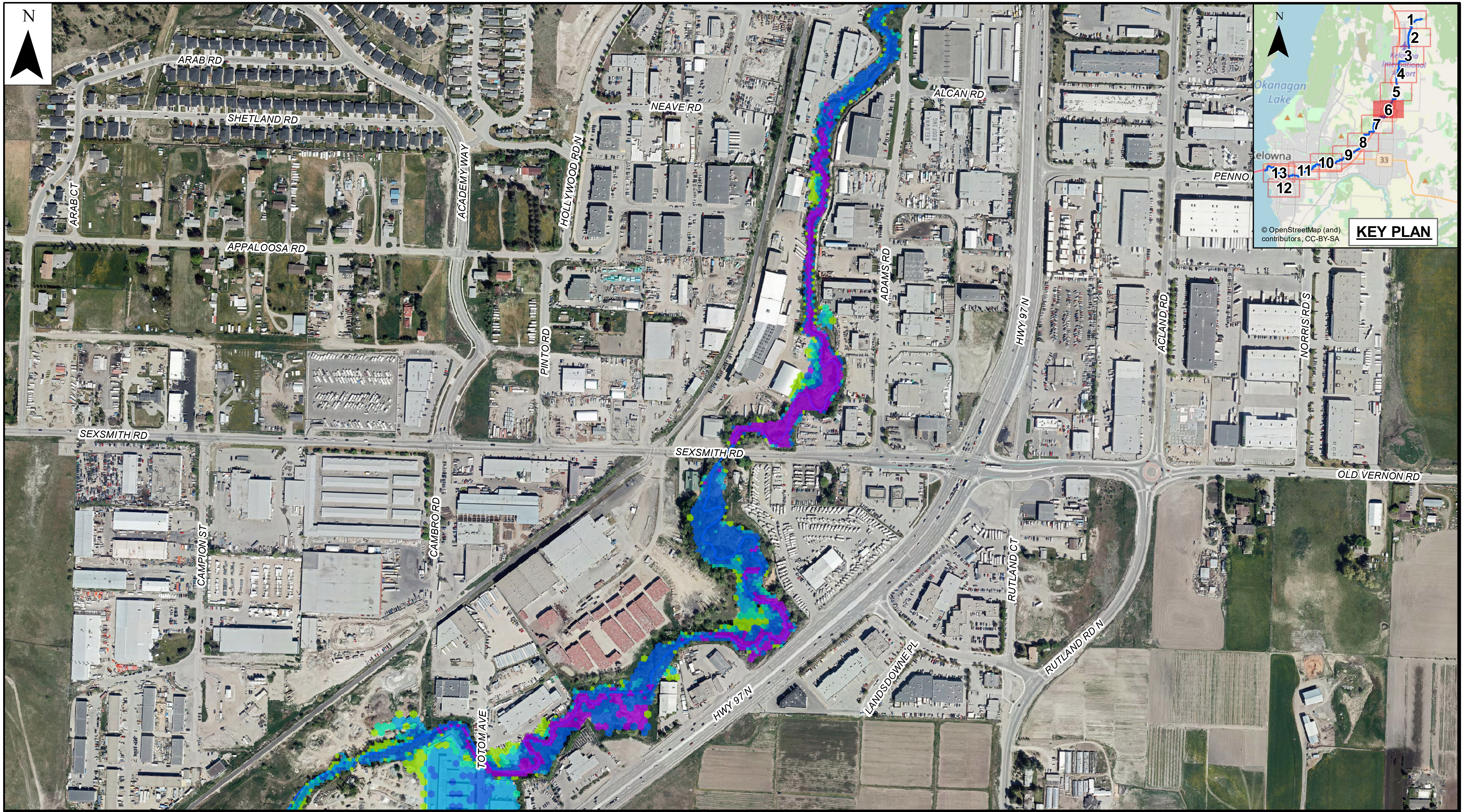
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-5

Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	5 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek — Other Creeks
Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna
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Regional District of Central Okanagan

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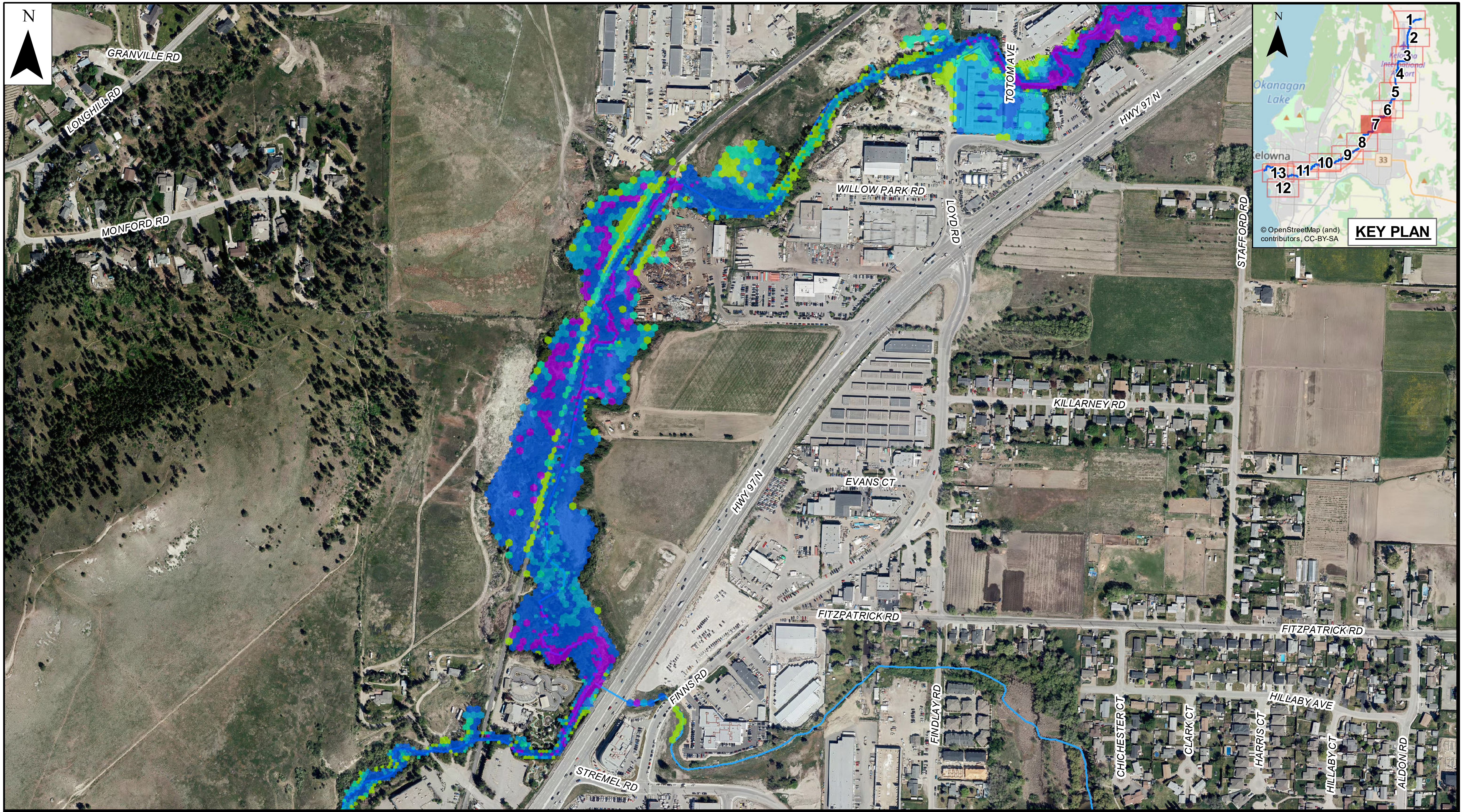
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-6
Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	6 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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PROJECTION:	UTM ZONE 11N
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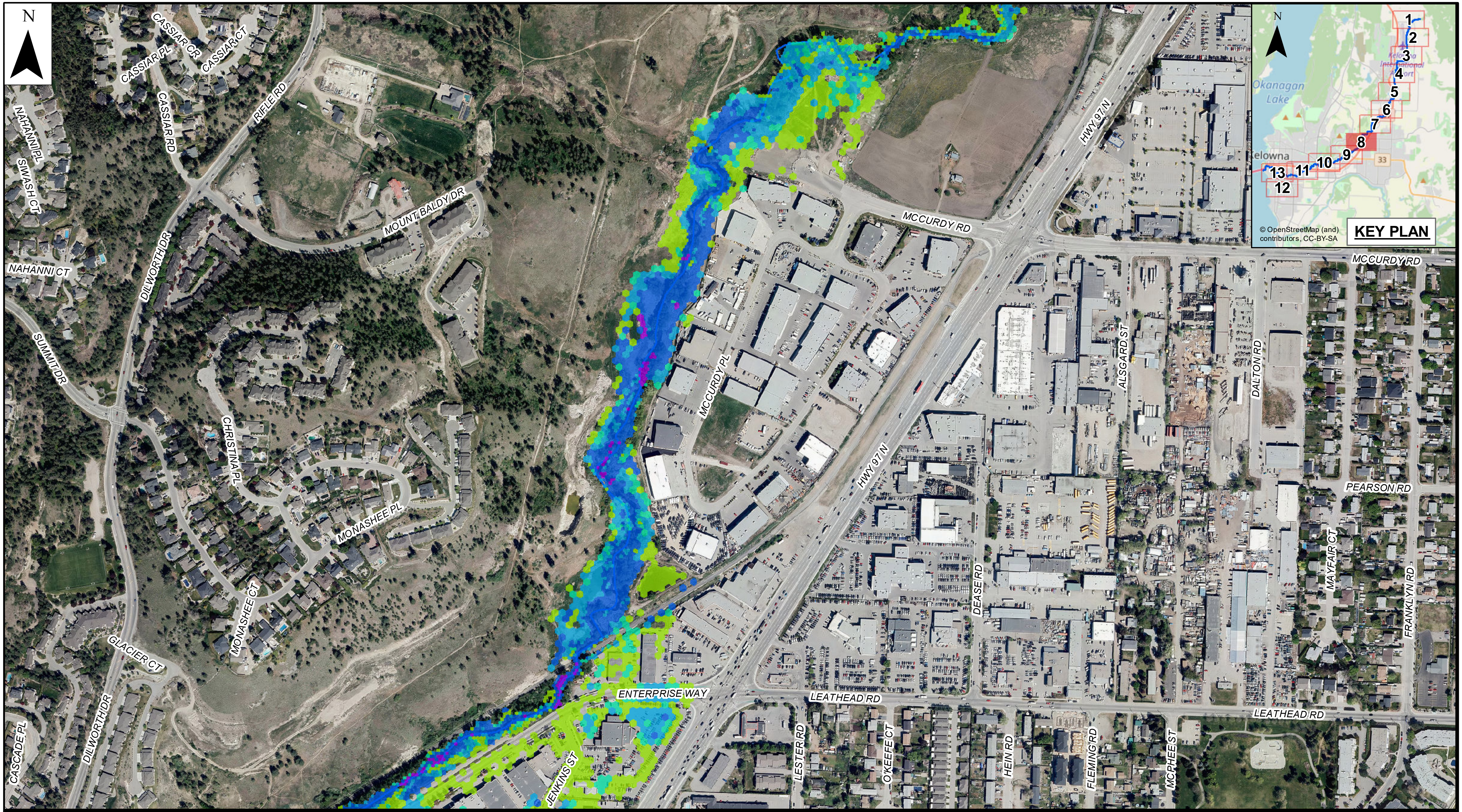
Figure 6-2-7
Mill Creek 200 Year
Depth Map

REV NO.	SHEET
0	7 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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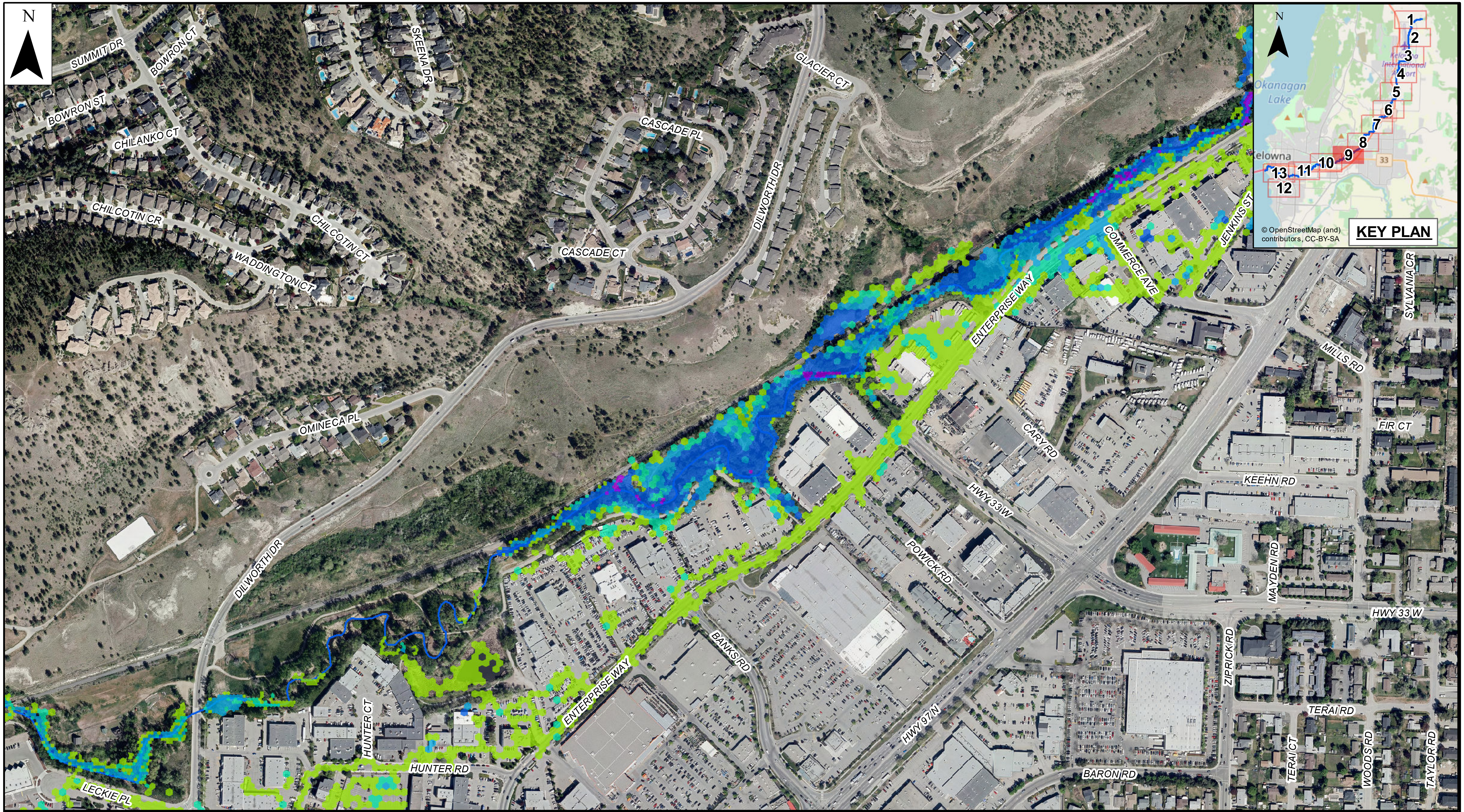
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-8
Mill Creek 200 Year
Depth Map

REV NO.	SHEET
0	8 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

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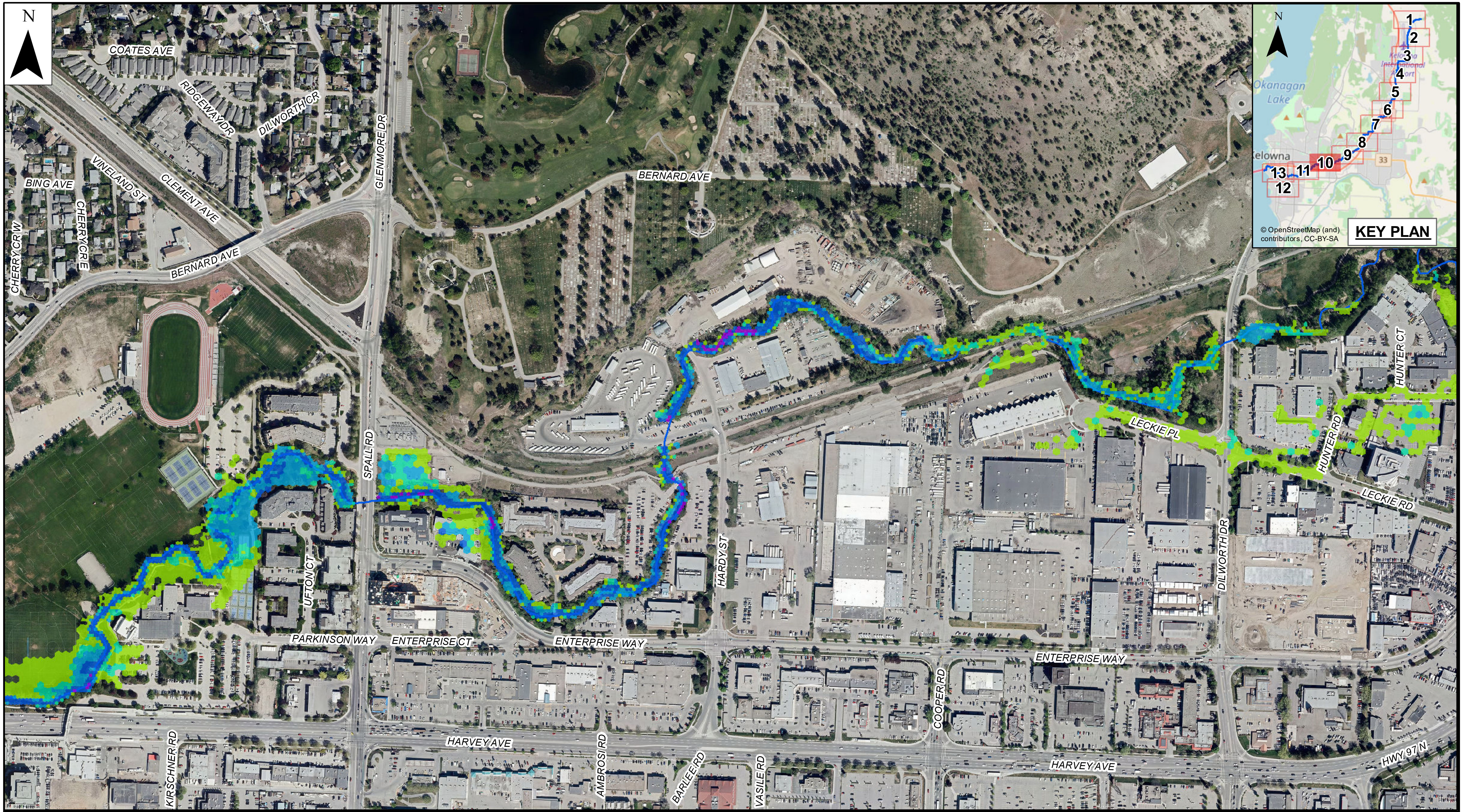
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-9
Mill Creek 200 Year
Depth Map

REV NO.	SHEET
0	9 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna

AECOM

Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-10
Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	10/13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek
- Other Creeks

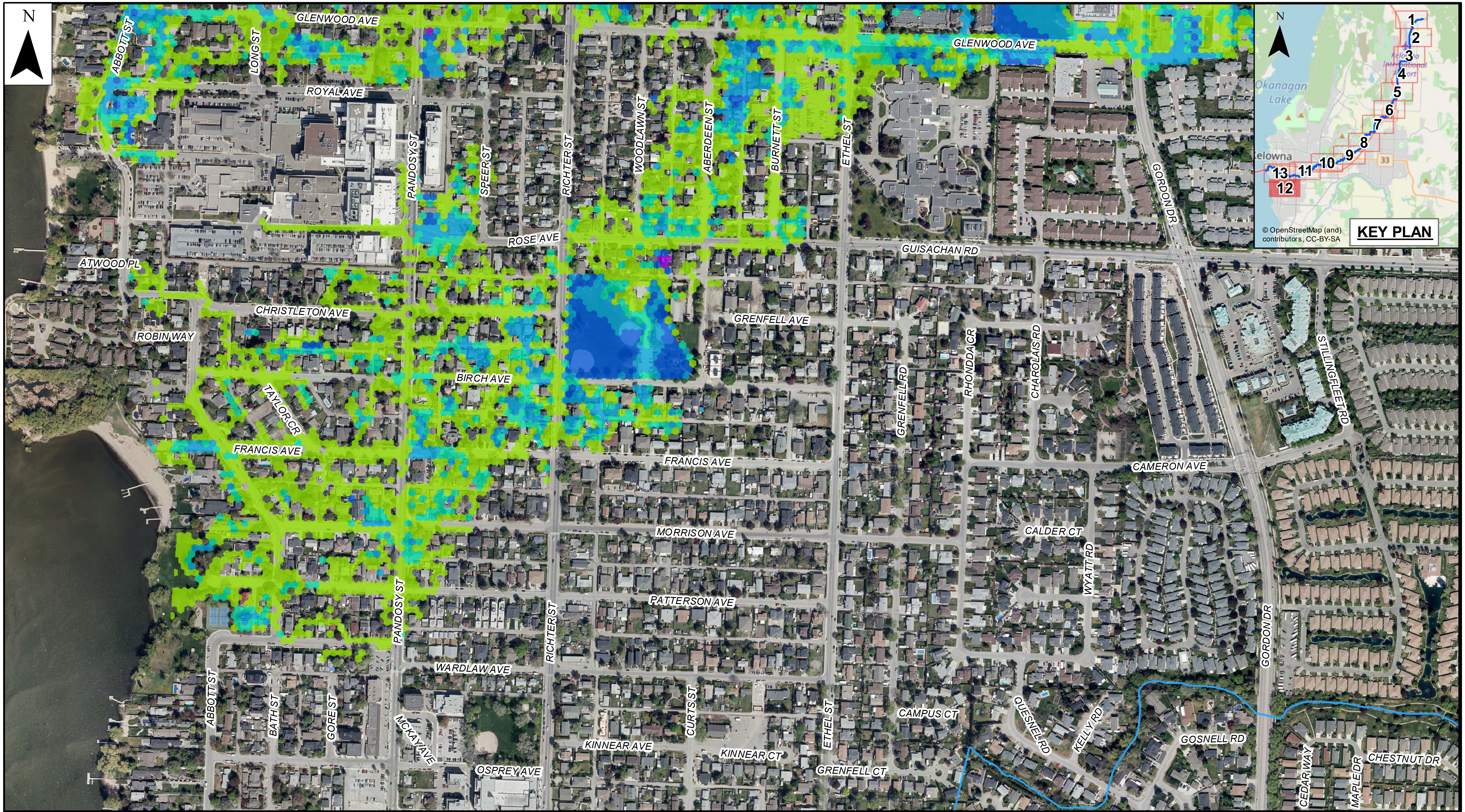
Max Flooding Depth (m)
- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-11
Mill Creek 200 Year
Depth Map

REV NO.	SHEET
0	11 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek — Other Creeks

Max Flooding Depth (m)

- 0.01 - 0.15
- 0.16 - 0.25
- 0.26 - 0.50
- 0.51 - 1.00
- 1.01 - 2.00

City of Kelowna

AECOM

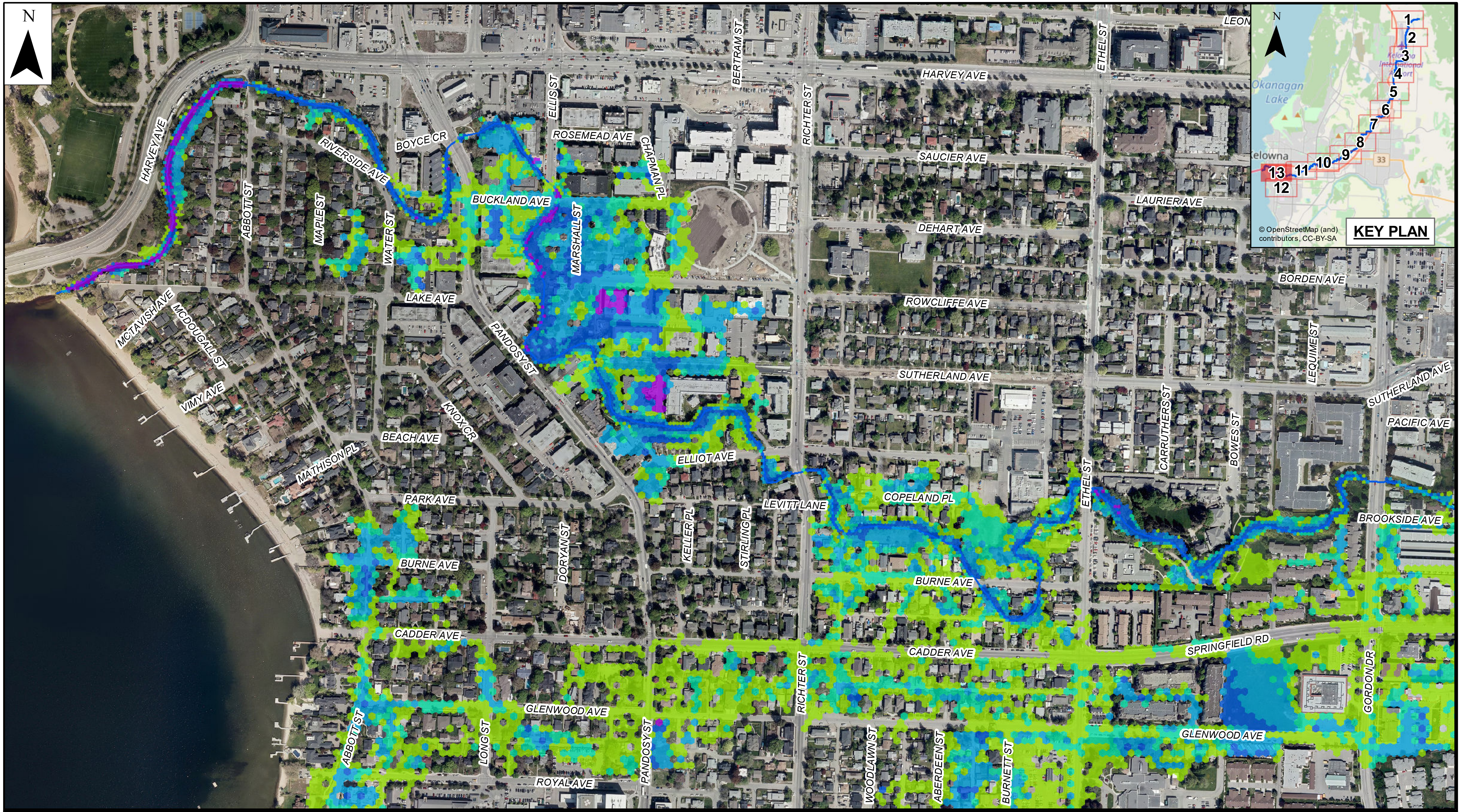
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-12

Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	12/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek
Other Creeks
Max Flooding Depth (m)
0.01 - 0.15
0.16 - 0.25
0.26 - 0.50
0.51 - 1.00
1.01 - 2.00

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-2-13
Mill Creek 200 Year Depth Map

REV NO.	SHEET
0	13/13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

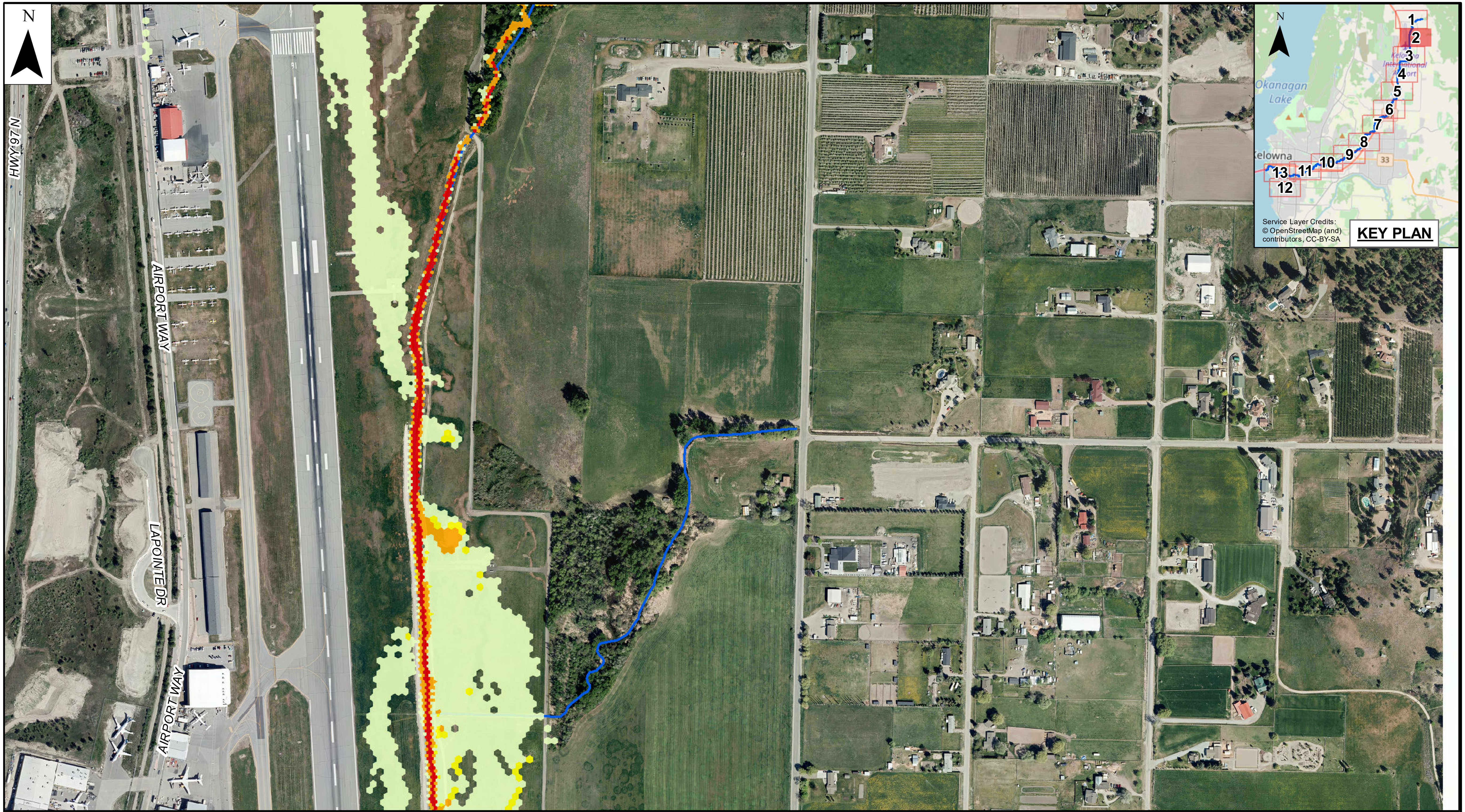
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-1

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	1/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

Regional District of Central Okanagan

PROJECT NO.	60613804
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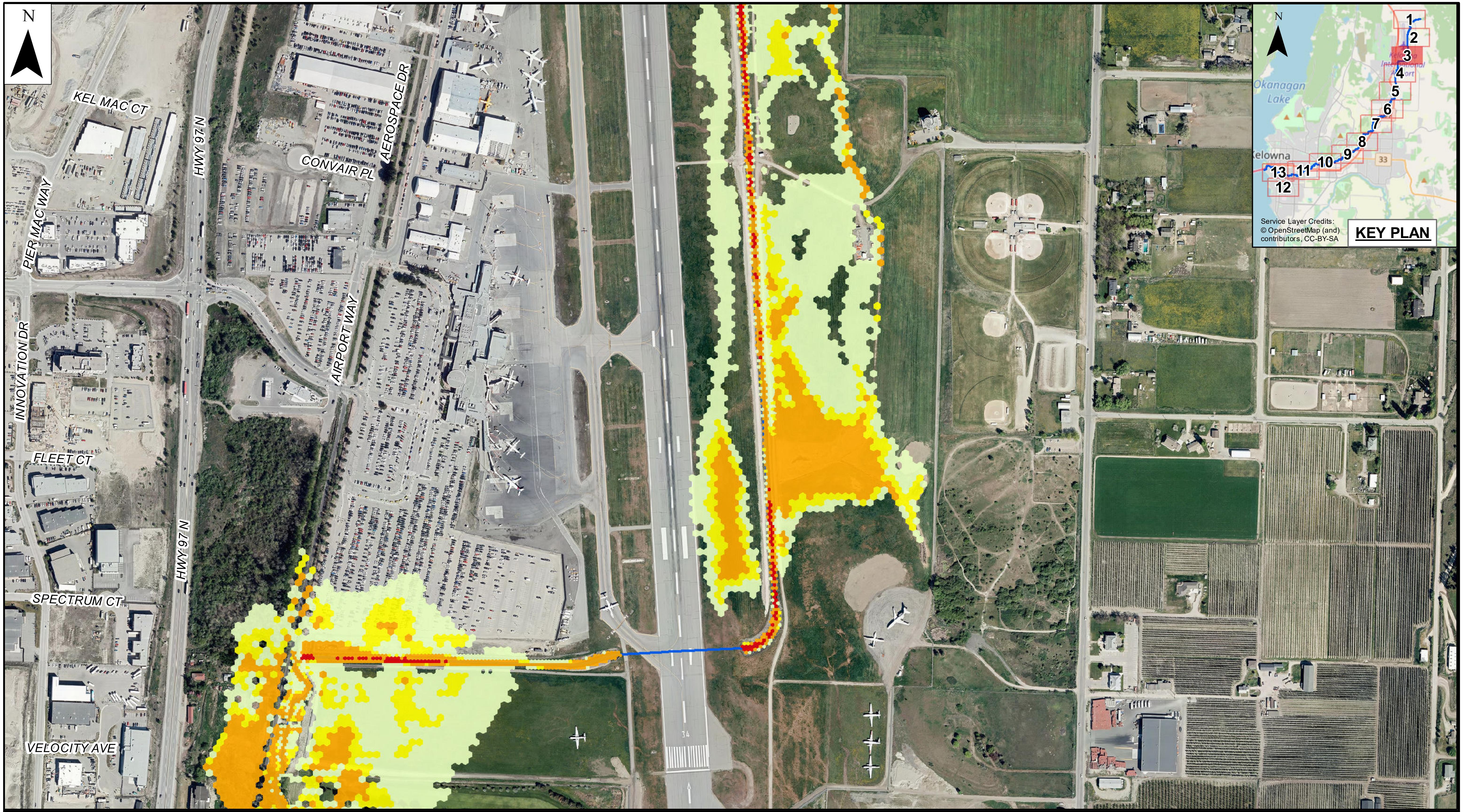
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-2

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	2/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

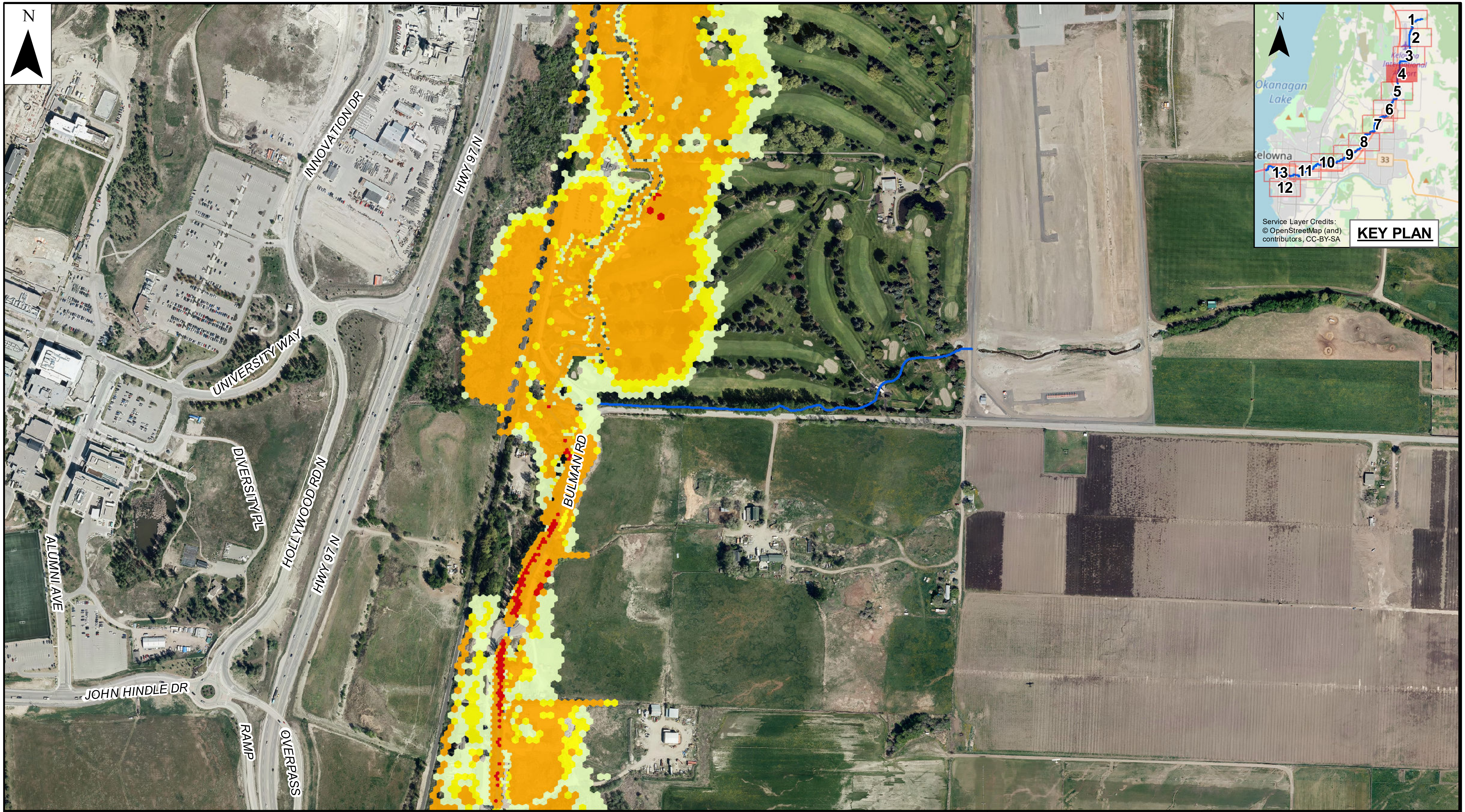
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-3

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	3/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek

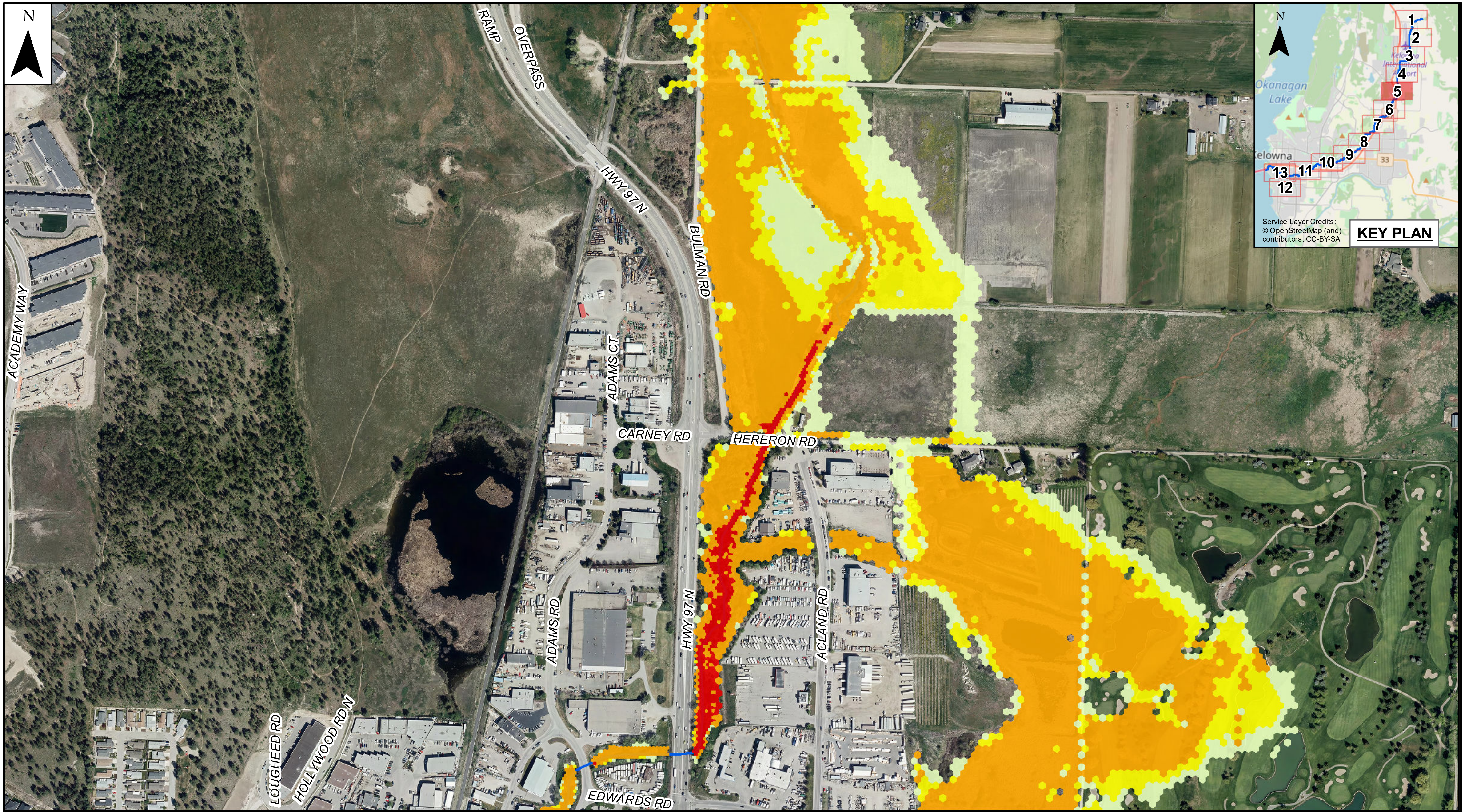
Flood Hazard Classification
- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-4
Mill Creek 200 Year
Flood Hazard Map

REV NO.	SHEET
0	4/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

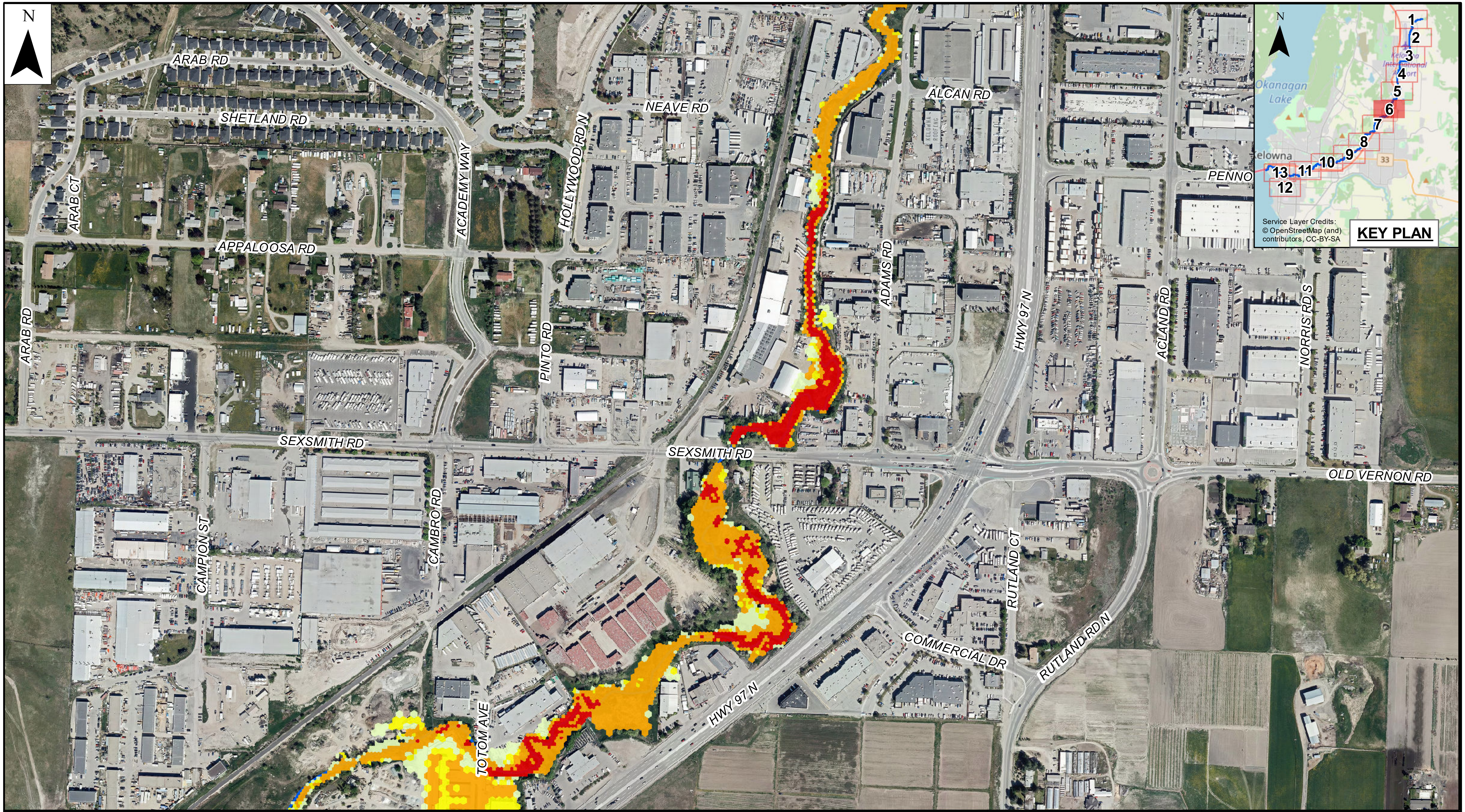
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-5

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	5 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

— Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

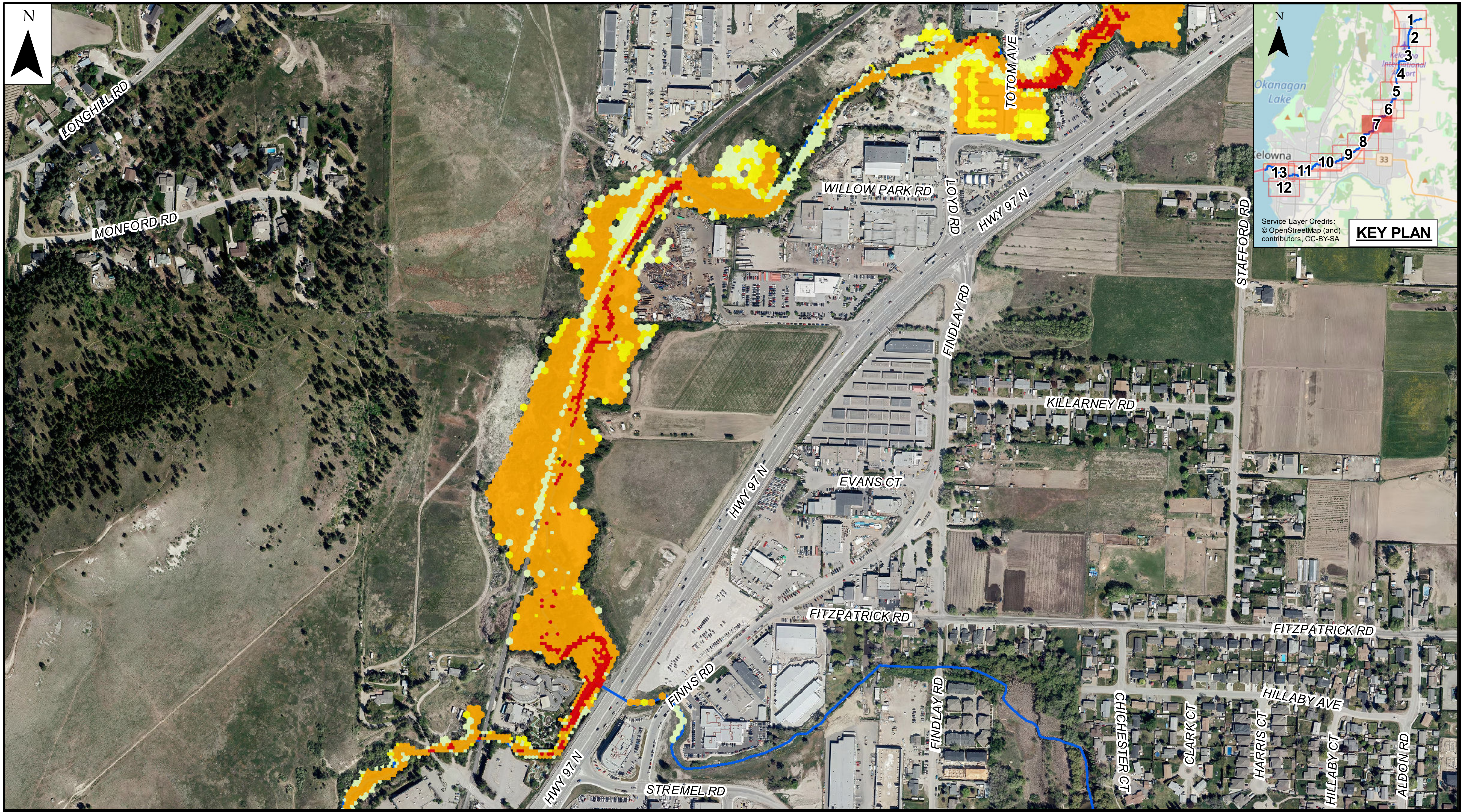
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-6

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	6 / 13



0 50 100 200 300 400 500 Meters

Legend:
Mill Creek
Flood Hazard Classification
Low (<0.75)
Moderate (0.75 - 1.25)
Significant (1.25 - 2.0)
Extreme (2.0+)

NO.	DATE	ENG.	BY	SUBJECT

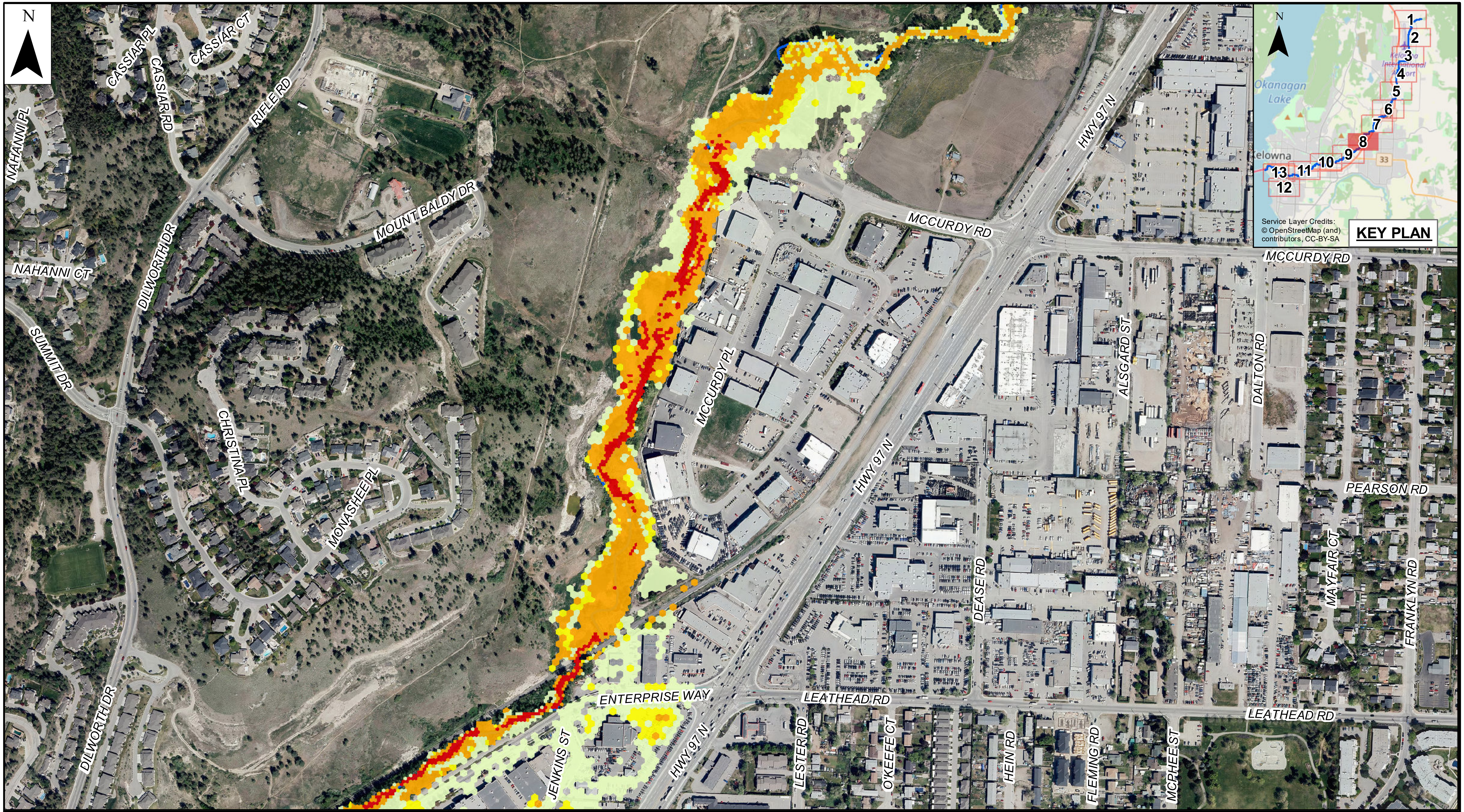
REVISIONS

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-7
Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	7 / 13



NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
- Mill Creek

Flood Hazard Classification
- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
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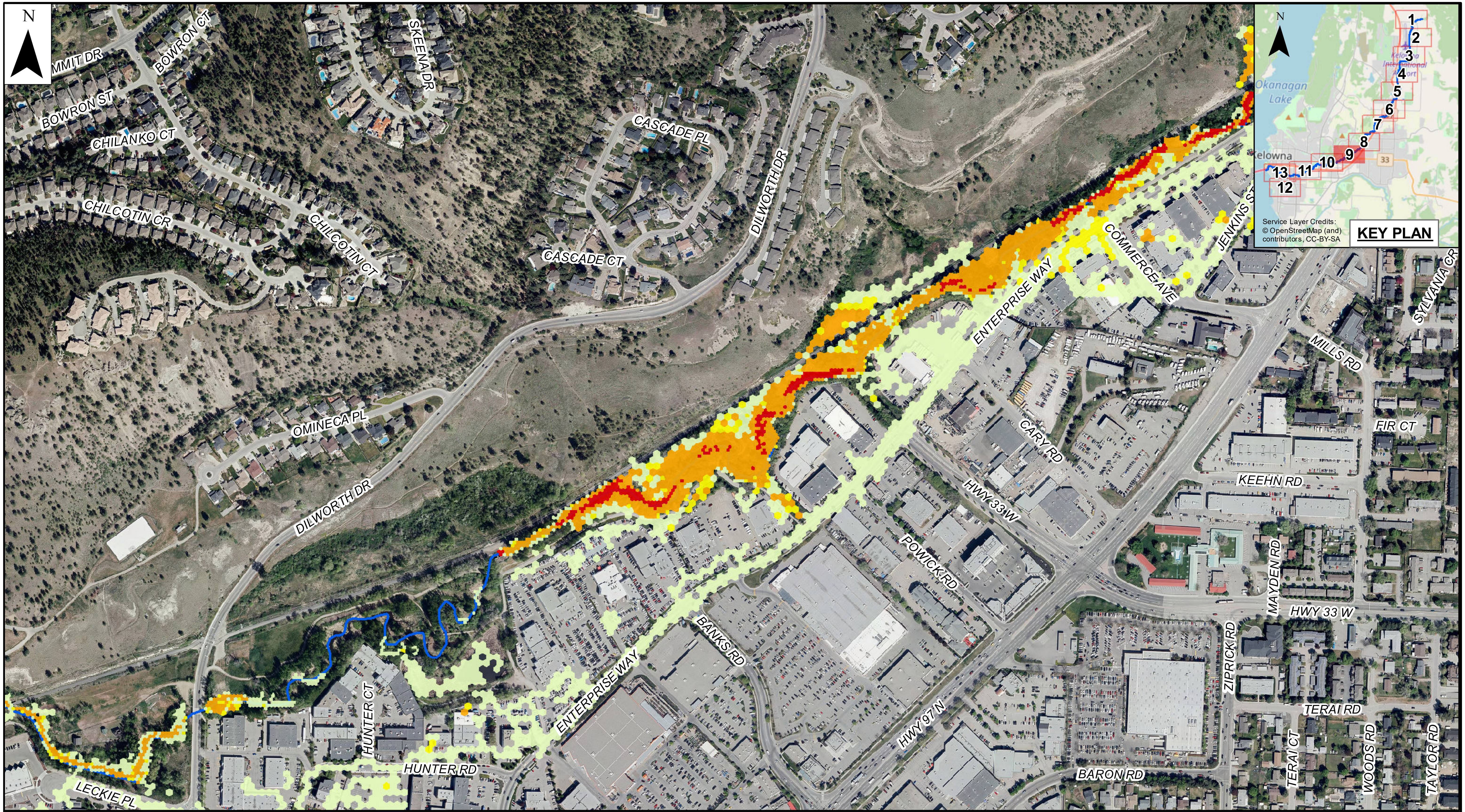
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-8
Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	8 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek

Flood Hazard Classification
- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-9
Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	9 / 13

0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:
Mill Creek

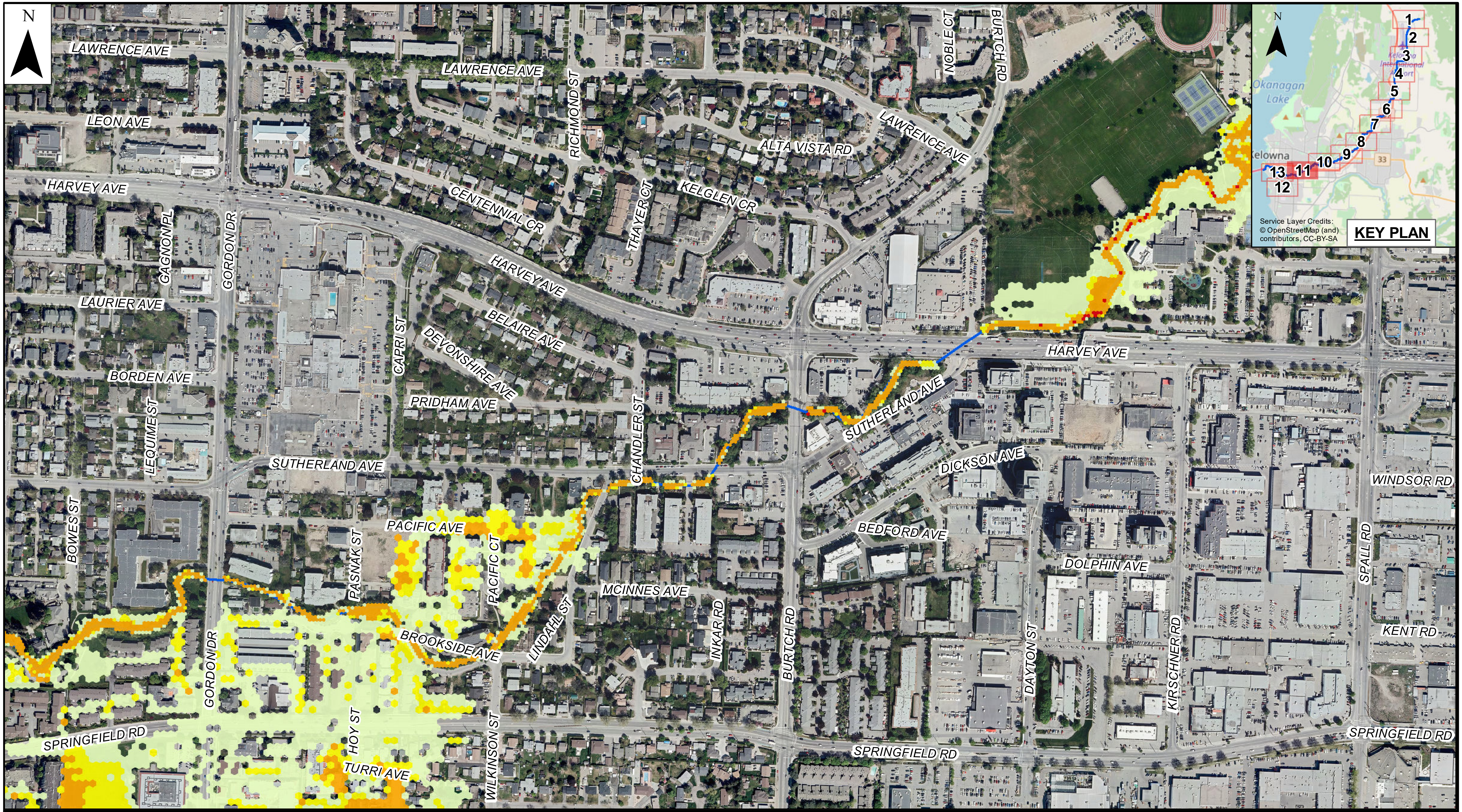
Flood Hazard Classification
- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna
AECOM
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-10
Mill Creek 200 Year
Flood Hazard Map

REV NO.	SHEET
0	10 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

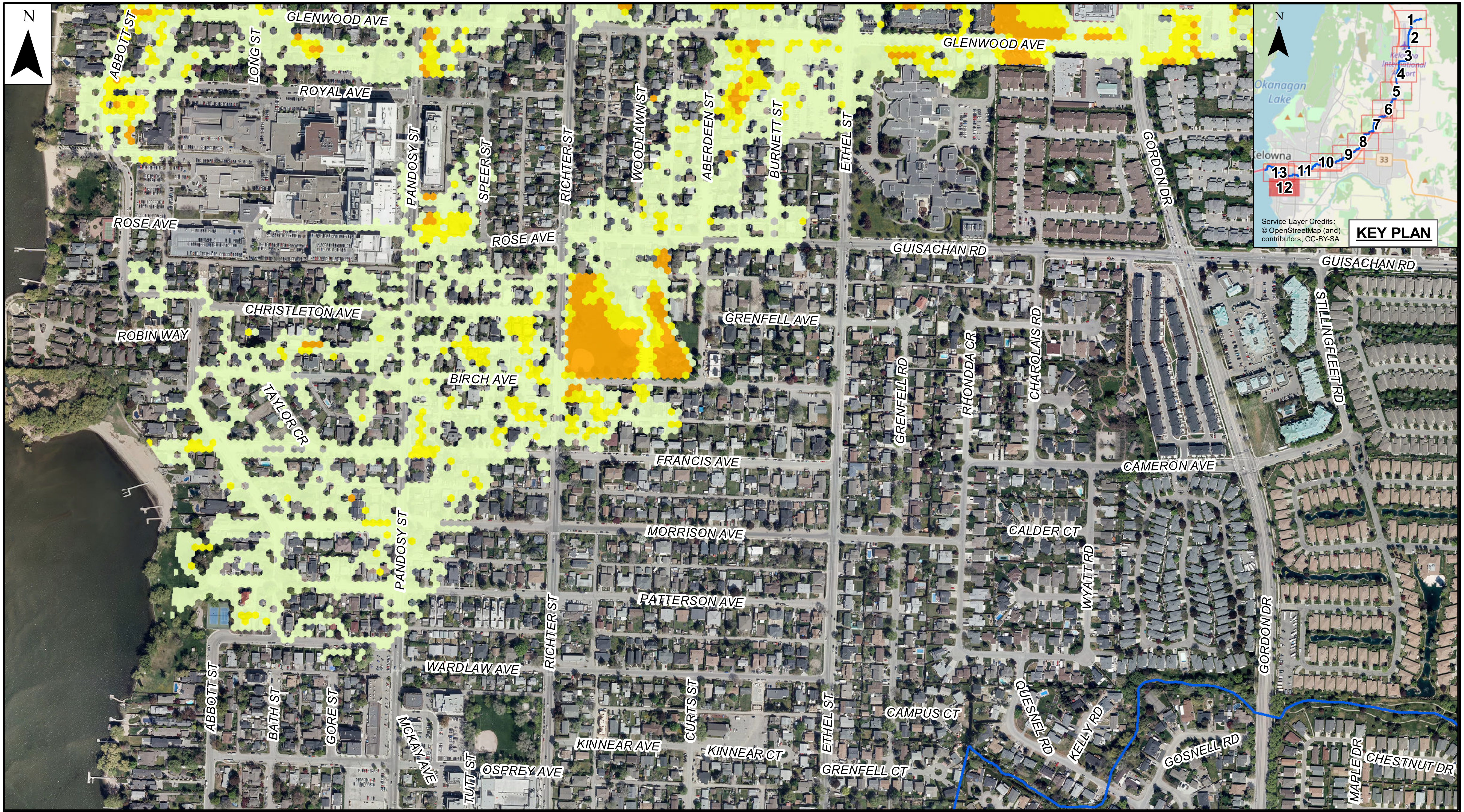
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-11

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	11/13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

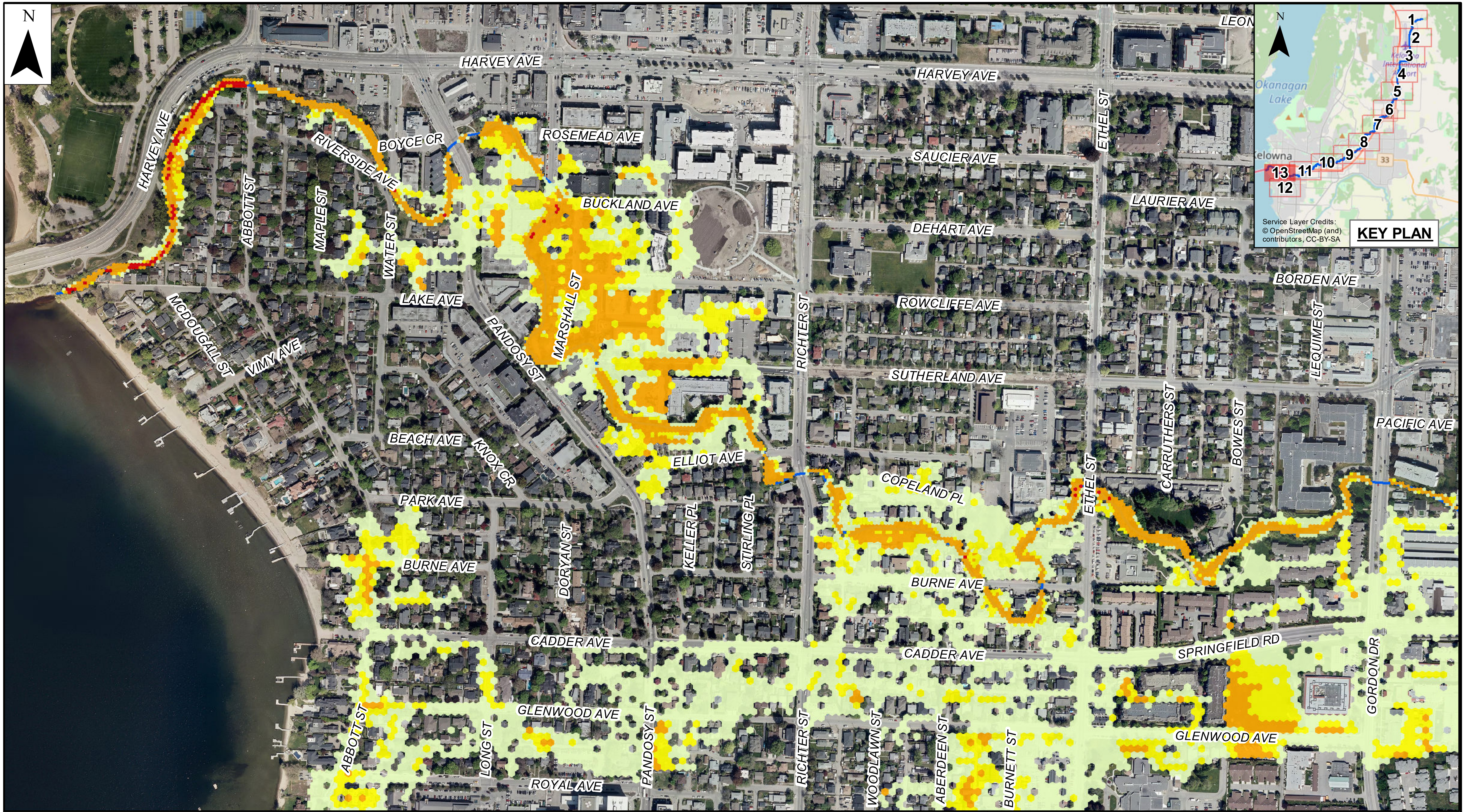
Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-12

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	12 / 13



0 50 100 200 300 400 500 Meters

NO.	DATE	ENG.	BY	SUBJECT

REVISIONS

Legend:

Mill Creek

Flood Hazard Classification

- Low (<0.75)
- Moderate (0.75 - 1.25)
- Significant (1.25 - 2.0)
- Extreme (2.0+)

City of Kelowna

AECOM

Regional District of Central Okanagan

PROJECT NO.	60613804
SCALE:	1:5,000
DRAWN:	B. TROITSKY
APPROVED:	-
PROJECTION:	UTM ZONE 11N
DATE:	2020-04-24

Figure 6-3-13

Mill Creek 200 Year Flood Hazard Map

REV NO.	SHEET
0	13/13

6.4 Final Flood Depth and Hazard Mapping

6.4.1 Comparison of Flood Extents with HEC-RAS Model and 2017 Flood Event

A comparison of flooding extents with the 2017 flood event and the HEC-RAS model (which was also compared against the 2017 flood event in the report AE, 2019) will be discussed below. There is broad agreement between the three pieces of information; however, there are some noticeable differences which will also be discussed. Many of the discrepancies, particularly between the PCSWMM and HEC-RAS models, can be explained by noting the difference between the 1D and 2D methods used.

KelownaNow flew a helicopter over the City during the flood in 2017. Keep in mind that it is unknown at the time of writing this report at what stage the flood would have been at the time the aerial imagery was taken. It is unknown if the flood had yet to progress into other areas of the City or if the flood had peaked. A number of comparisons will be made upstream to downstream with descriptions followed by side-by-side comparisons of model outputs and imagery (Figure 6-4). Explanations are given where applicable to better understand why deviations between model outputs or observed flooding may have occurred.

Kelowna International Airport (YLW)

There was some discrepancy between the HEC-RAS model results and PCSWMM. Particularly at the southern edge of the runway near the Mill Creek culvert crossing. The HEC-RAS model indicates overtopping of the airport runway which spills into the parking lot. The PCSWMM model output shows flooding encroaching on the runway but no overtopping. One potential explanation for this is that overland flooding is observed in the PCSWMM model upstream of Old Vernon Road. This effectively removes a volume of water that no longer travels downstream, it may be this loss of volume that accounts for the difference in flooding extent at the runway location. This loss of volume due to overland flow paths captured in the 2D PCSWMM model may explain further differences between the models.

Flooding has previously occurred at YLW in June 2012. At the time of this writing it is unknown what the magnitude of the flood event was along Mill Creek; however, photos were provided for comparison. In one of these photos, flooding is observed at a low point where two drainage channels meet before entering Mill Creek. This low point is also apparent in the PCSWMM model results as well is the flooding between Mill Creek and the airport runway.

Shadow Ridge Golf Course

The Shadow Ridge Golf Course flooded during the 200-year model run. There is good agreement with the flooding extents when compared to both the 2019 HEC-RAS model and 2017 aerial images. It is suggested that the area around the golf course is particularly constricted or where the channel has a very low capacity given that it is this area along with the area around Mill Creek northwest of Kelowna Springs Golf Club that overtop their banks first in the flooding simulation.

Kelowna Springs Golf Club

Portions of Kelowna Springs Golf Club have also shown to be inundated in both models as well as the aerial imagery. Other images taken by KelownaNow have shown overland flooding northwest of the golf course where the PCSWMM model also exhibits flooding.

Adams Road

There are approximately two industrial lots between Adams Road and Mill Creek which exhibited significant flooding in 2017. The HEC-RAS model provides good agreement between the modelled and observed flood extents. However, the PCSWMM model does not show flooding in this area. By inspection of the LiDAR data (and was confirmed during the field visit), a dike exists along this reach of Mill Creek. There is an important difference between the way the HEC-RAS model of Mill Creek and the PCSWMM model are constructed which may begin to address the difference. The PCSWMM model incorporates 2D elements and can sample the LiDAR data more continuously than the 1D HEC-RAS model. Upon inspection of the HEC-RAS model, it was found that 1D levee elements (HEC-RAS-specific model elements) were used to approximate the dikes along these industrial lots. These levee elements allowed for overtopping to occur where the LiDAR data would not (this being a result of the lower resolution, 1D construction of the model). This could explain the difference between the HEC-RAS and PCSWMM model results. It is also known that debris was a major concern in 2017 and certainly exacerbated the flooding given the nearby crossing approximately 444 m downstream and the relatively well confined channel within the North Industrial Area.

McCurdy Place

The HEC-RAS model indicates McCurdy Place within the floodplain of Mill Creek whereas the PCSWMM model does not. The AE report in 2019 outlined a number of potential reasons for the large discrepancy, namely the challenges associated with 1D modelling. McCurdy Place is largely left out of the Mill Creek floodplain in the PCSWMM model with the exception of some local overland flooding north of McCurdy Road. The 2017 aerial imagery does show some minor flooding as the PCSWMM model in the same area north of McCurdy Road.

Enterprise Way / Mill Creek Diversion

Another location where the HEC-RAS and PCSWMM models differ is along Enterprise Way. Again, this can largely be explained by the difference in the 1D and 2D modelling approaches. The HEC-RAS model would have been limited by the cross-sections that were delineated for the flow paths. Branching flow, like what is observed at the intersection of Enterprise Way and Commerce Avenue would not be picked up in a 1D model. It is noted that there is an embankment along Enterprise Way near the location where Mill Creek overtops at the intersection of Commerce Avenue. The 2D mesh is refined within 10 m of the creek, however it is possible that the mesh does not adequately capture the small embankment along the road and therefore indicates flooding that may not occur. Aerial imagery does show water encroaching on this embankment just south of Commerce Avenue; however, and it is possible that some flooding may have occurred if water levels continued to rise after the photo was taken.

The modelled flooding along Enterprise Way is not substantial however and is confined to the street. The depth is <0.15 m but runs downhill to Hunter Road and terminates at the end of Leckie Place. Further refinements of the mesh were not conducted to maintain reasonable runtimes, but further refinements may be considered in the future.

The Mill Creek diversion to Mission Creek is an area where the HEC-RAS and PCSWMM models agree with one-another more closely than either model does to the observed flooding in the aerial imagery. There is more flooding during the 2017 event than there is in either model, the reason for this is uncertain, but one explanation could be debris. Just downstream of the diversion structure, Mill Creek enters a reach that is more heavily wooded, and it is possible that debris may be backing up water near the diversion causing water levels to rise. It is understood that the City is aware of debris accumulation issues associated with the existing diversion structure and has plans to upgrade the facility in the near future. Although there is slightly more flooding exhibited in the PCSWMM model than in the HEC-RAS model, more of the parking lot adjacent to the diversion structure is flooded than what is shown in the model, again most likely a result of debris.

Springfield Road between Gordon Drive and Wilkinson Street

Perhaps the most notable difference between the PCSWMM model and HEC-RAS model is near the location of Springfield Road between Gordon Drive and Wilkinson Street. There is a similar pattern of overland flow between the two models; however, their extents vary considerably. The HEC-RAS model flood extents intrude on the city no further than the southeastern corner of the field near A.S. Matheson Elementary School, but the PCSWMM model results indicate substantial overland flooding occurring far beyond this location, albeit very shallow, low-volume, overland flow. It is expected that the inclusion of the 2D mesh is what allows for the increase in flood extents. This area is discussed in the AE (2019) report and it indicates potential issues with the 1D approach and the GIS postprocessing that was required to delineate the floodplain. The current PCSWMM model indicates that the nature of the flow path would allow for water to continue flowing in a southwesterly direction towards Cameron Park and Kelowna General Hospital. The flooding around Springfield Road was not observed in the 2017 aerial imagery and it is unknown if there are certain topographical features that were not captured in the LiDAR data.

Kelowna General Hospital and Surrounding Area

The streets north and south of Kelowna General Hospital exhibit shallow flooding in the PCSWMM model. These extents were not observed in the 2017 aerial imagery and the flows in these areas are a result of the overtopping of Mill Creek near Springfield Road and Gordon Drive.

Marshall Street and Rowcliffe Avenue

The area southeast of Rowcliffe Park, including Marshall Street, Rowcliffe Avenue, and Sutherland Avenue show very good agreement with observed flooding in the HEC-RAS model. Whereas the extents in the aerial imagery are somewhat less.

Table 6-2: Model Comparison Summary

Location	PCSWMM vs HEC-RAS	PCSWMM vs Observed (2017)	Comment
Kelowna International Airport	Fair agreement – parking lot floods in both models but PCSWMM does not show overtopping of runway	Good agreement – parking lot has some flooding in the imagery, no runway overtopping	Aerial imagery is unavailable for areas east of runway and north of Old Vernon Road
Shadow Ridge Golf Course	Very good agreement – approximately same extents are exhibited by both models	Very good agreement – similar extents were observed in 2017	Some overtopping was observed along Scotty Creek in 2017, but this is not captured as part of the present study
Kelowna Springs Golf Club	Very good agreement - approximately same extents are exhibited by both models	Very good agreement – similar extents were observed in 2017	None
Adams Road	Poor agreement – two lots which exhibit flooding in the HEC-RAS model do not flood in PCSWMM	Poor agreement – flooding extents are underestimated in PCSWMM compared to observed events	Flooding of this area is suspected to be primarily caused by debris blockage downstream
McCurdy Place	Poor agreement – HEC-RAS indicates the entire area of McCurdy place to be flooded whereas the PCSWMM model confines flooding to the channel and immediate floodplain	Good agreement – some overland flooding was observed in 2017 at the northwest corner of McCurdy Place where the PCSWMM model indicates, no flooding of McCurdy Place is indicated	PCSWMM model results are considered more accurate than HEC-RAS in this instance, reasons for possible HEC-RAS deficiency in this area is given in AE (2019)
Enterprise Way	Poor agreement – PCSWMM model indicates street-level flooding along Enterprise Way and in the general vicinity, HEC-RAS does not	Poor agreement – no flooding was observed to the extents indicated by the PCSWMM model, but water is shown to come up against the embankments along Enterprise Way	The PCSWMM model deficiencies in this area are likely caused by the limitations of the 2D mesh resolution
Mill Creek Diversion	Poor agreement – some flooding in PCSWMM is shown to occur in the parking lot of the industrial area, HEC-RAS does not	Fair agreement – some flooding in PCSWMM is shown to occur in the parking lot of the industrial area but more flooding was observed in 2017	Loss of volume along Enterprise Way may make up for some of the lack of flooding in PCSWMM
Springfield Road	Fair agreement – the same overtopping location is identified by both models, but much greater extents are found in PCSWMM	Poor agreement – no overtopping of Mill Creek was observed in the 2017 imagery	Local topography or obstructions not captured in the LiDAR may explain the discrepancies between observed and modelled conditions
Kelowna General Hospital	Poor agreement – no flooding is indicated in the HEC-RAS model	Poor agreement - no flooding was observed in 2017	The flood extents in this area are attributed to overtopping flow at Springfield Rd, therefore the same comment about LiDAR data applies here
Marshall Street and Rowcliffe Avenue	Very good agreement – both modelled results agree with one anther very well with the exception of slightly more flooding along Pandosy Street in the PCSWMM model	Good agreement – areas flooded in the PCSWMM model were also flooded in 2017 but the modelled results indicated greater extents	None

Figure 6-4: Flood Extent Comparisons

Kelowna International Airport

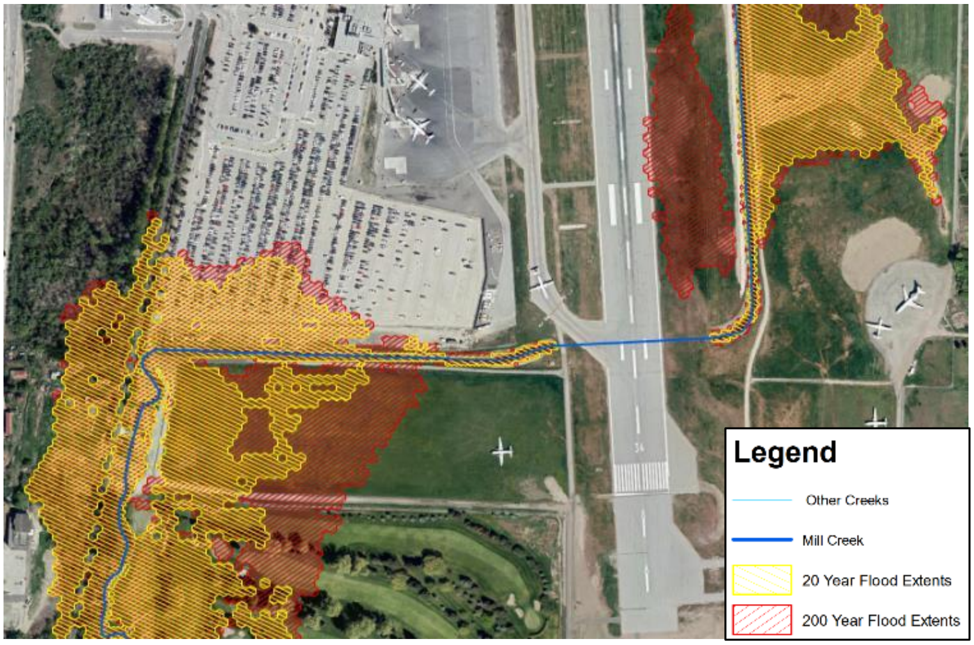


Image from KelownaNow Facebook Page

Image provided by City of Kelowna – flooding during June 2012

Shadow Ridge Golf Course

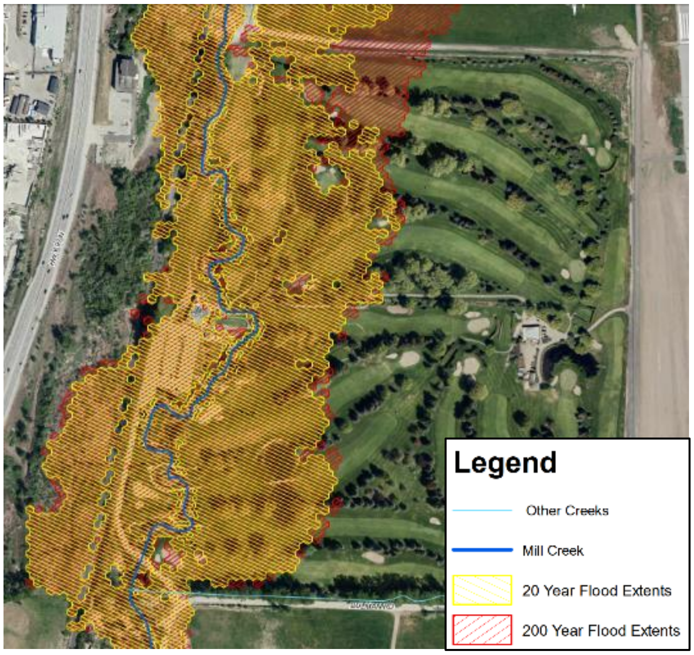


Image from KelownaNow Facebook Page

Kelowna Springs Golf Course

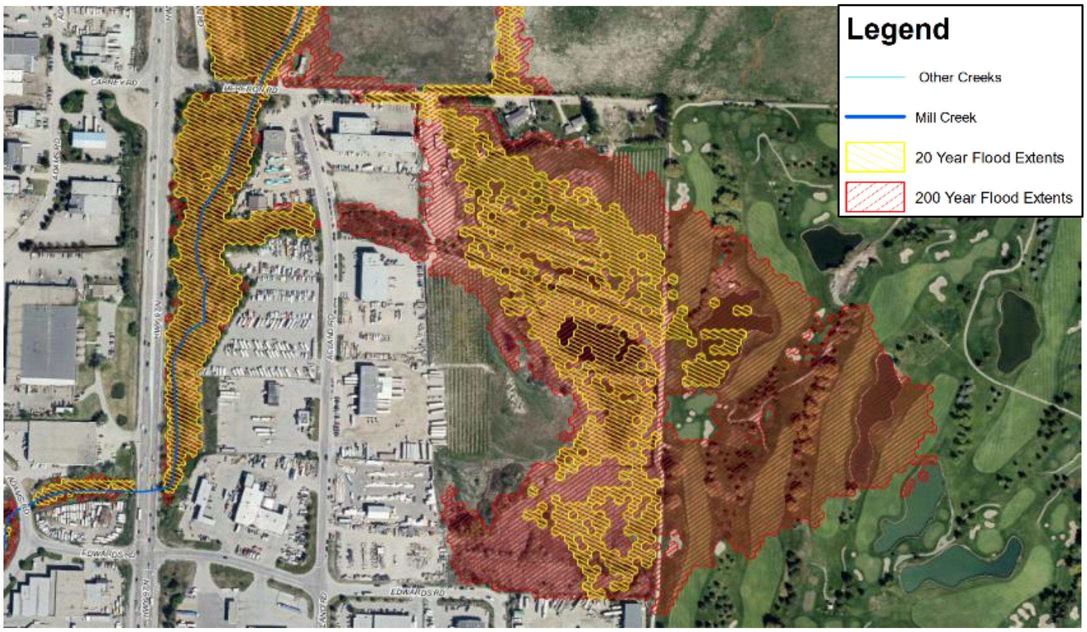


Image from KelownaNow Facebook Page

Adams Road

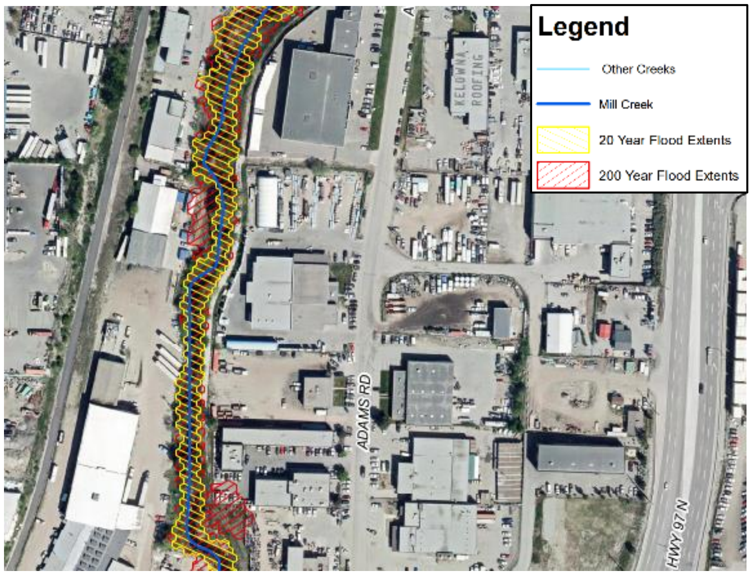


Image from KelownaNow Facebook Page

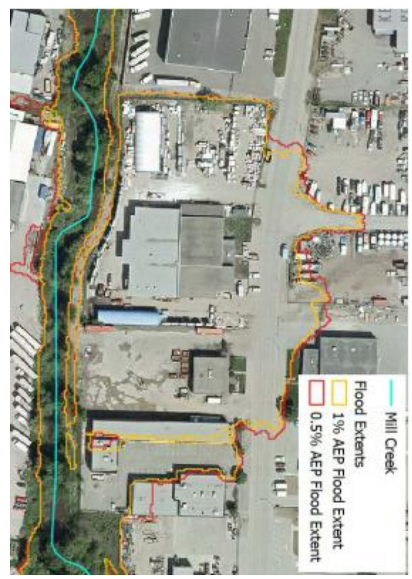


Image from AE (2019)

McCurdy Place

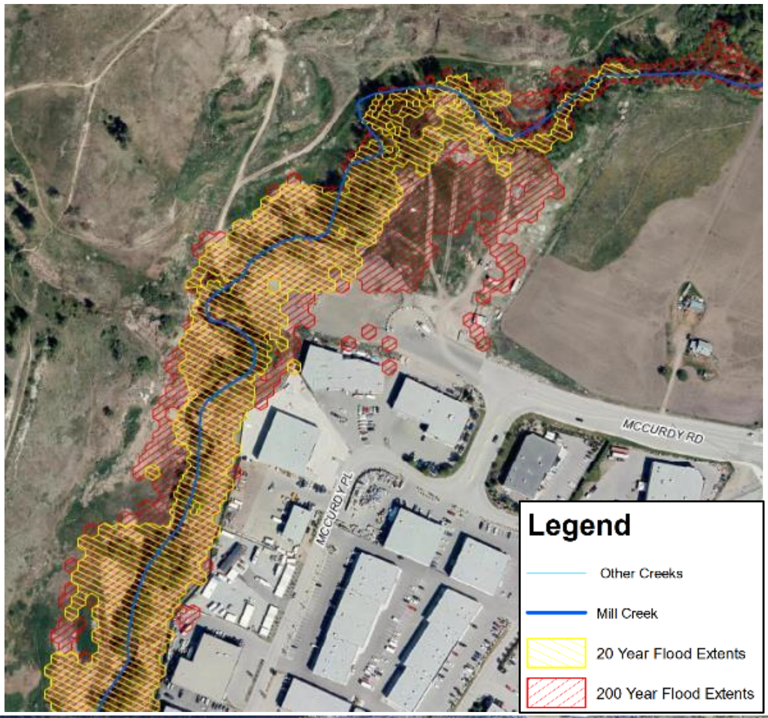


Image from KelownaNow Facebook Page

Enterprise Way and Commerce Avenue

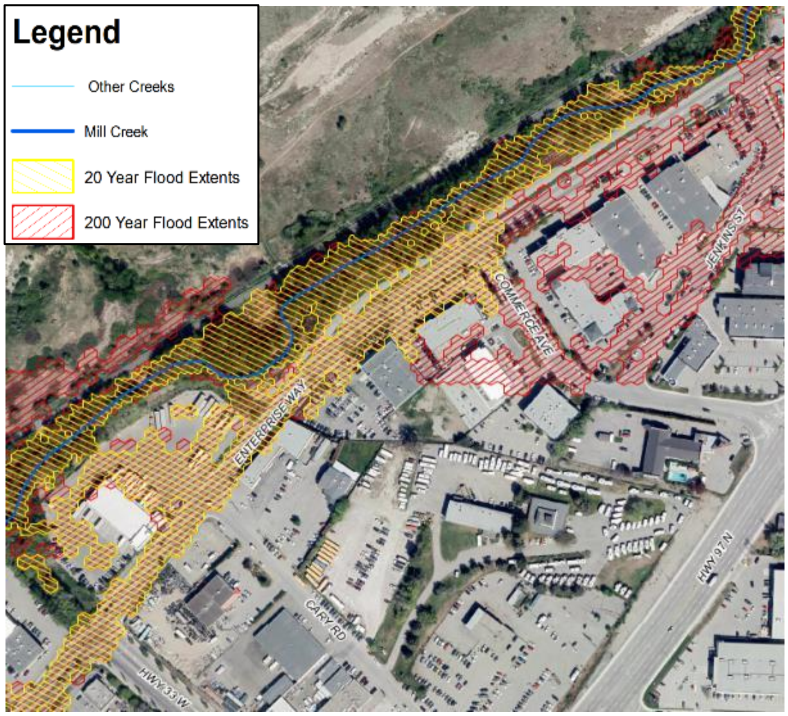


Image from KelownaNow Facebook Page

Mill Creek Diversion to Mission Creek

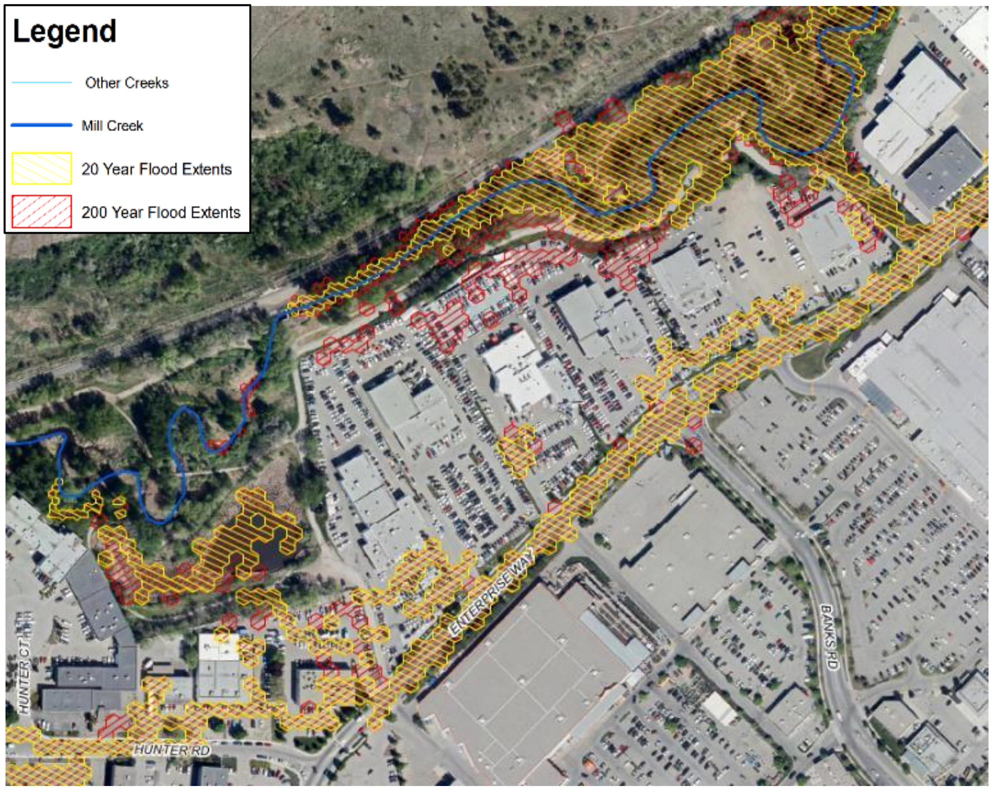


Image from KelownaNow Facebook Page

Springfield Road Between Gordon Drive and Wilkinson Street

Image from AE (2019)

Marshall Street and Rowcliffe Avenue

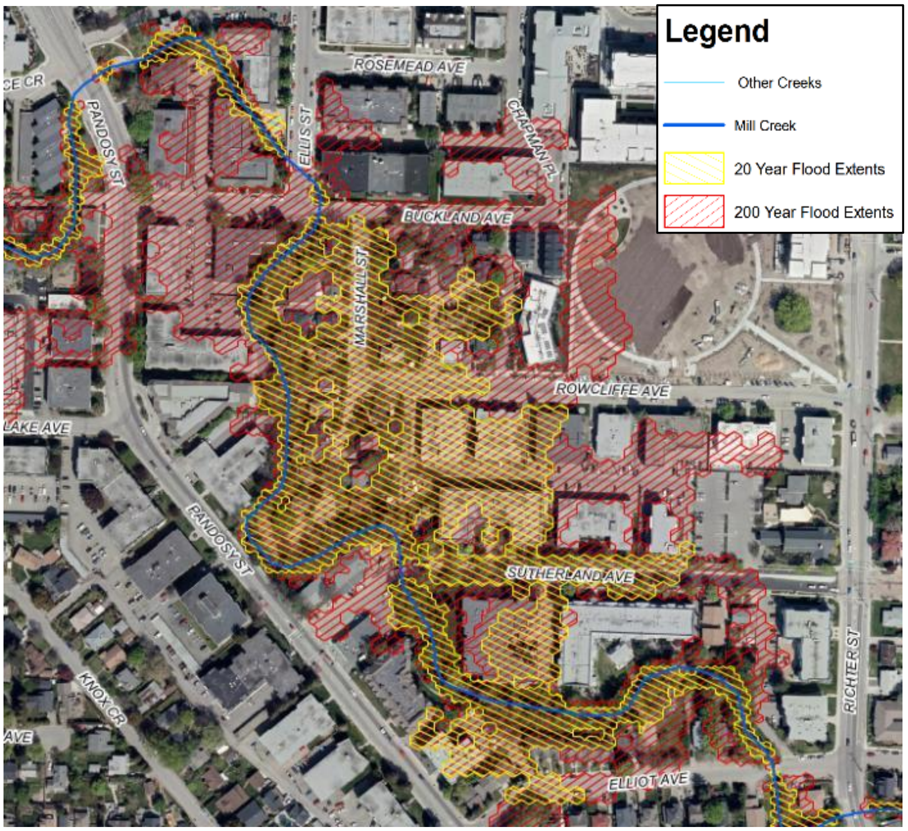


Image from KelownaNow Facebook Page

6.4.2 Identifications of Specific Hazards within the Basin

Figure 6-1 to Figure 6-3 illustrate the hazard levels associated with the floodplain. Generally speaking, the only locations which have the highest hazard rating (extreme) are along the main stream with several locations directly connected to the main stream classified as significant. Most street-bound flooding is classified as low or moderate. Hazards outside of the immediate area of the stream tend to become rated significant when the flows become deep (rather than because of high velocities), such as at low points in roadways or in parks.

Some specific areas which have moderate to extreme hazard classifications include the following:

Kelowna International Airport (YLW)
Significant hazards are identified between the airport runway and Mill Creek just north of the culvert crossing at the south end of the airstrip. There is significant hazard associated with the southern portion of the airport parking lot closest to the creek.

Shadow Ridge Golf Course to Hereron Road
The majority of the hazard is classified as significant in this zone and the flood zone completely envelops the club house. The extents are also quite wide outside of the main channel of the creek due to low-relief topography. This area is also significant since the flooding simulation indicates this as the first area to flood. Few residents are expected to be impacted by flooding in this area due to the majority of the inundated area being agricultural or pastoral land.

North Industrial Area to McCurdy Road
Most of the flooded area in the model that indicates extreme levels of hazard classification exist along the creek in the North Industrial area of the city. These extreme classifications do not extend outside of the main channel, however. As mentioned in the previous section, the industrial lots along Adams Road which exhibited flooding in 2017 did not exhibit flooding during the simulation. This area should be treated as having some flood risk based on historical evidence despite the current modelling results. The two industrial lots near Totom Avenue and Lloyd Road are also at risk to flooding and have a significant risk rating. Significant and extreme hazard areas near McCurdy place are essentially confined to the main channel Mill Creek but does encroach on the back of the west lots.

Enterprise Way
As mentioned above, the flooding along Enterprise Way is street-level flooding with some minor flooding in adjacent parking lots. The hazard classification in this area is primarily low but due to the nature of the flow path afforded by Enterprise Way, people caught between Enterprise Way and Mill Creek will likely have to navigate flood water to escape the affected area. It is expected that such shallow water along Enterprise Way would not impede emergency personnel.

Springfield Road to Kelowna General Hospital
It was identified that Mill Creek spills over Brookside Avenue and flows toward Springfield Road between Gordon Drive and Wilkinson Street. Flood waters then travel in a southwesterly direction towards A.S. Matheson Elementary. The hazard ratings are low-to-moderate around the school, but the flood extents envelop the entire structure. The hazard rating increases to significant within the adjacent park. Flooding is shown to continue to the south west around the north side of Cottonwoods Care Centre along Glenwood Avenue. With the exception of Cameron Park, flood waters are classified as low-to-moderate as it travels further from the Mill Creek.

Mostly low hazards are shown around Kelowna General Hospital. This is mostly indicated by street-flooding and a few areas with moderate flooding.

Marshall Street and Rowcliffe Avenue

Low-to-significant flood hazard exists at the corner of Marshall Street and Rowcliffe Avenue. This area was significantly covered in the KelownaNow aerial imagery.

Okanagan Lake at the Mouth

As mentioned above, the boundary condition for Okanagan Lake was set at the 5-year water level (342.91 m), in keeping with the existing HEC-RAS model conditions. A separate model run was conducted to compare the relative difference in flood extents as a result of the 200-year inflow hydrographs to Mill Creek and the 2017 Okanagan Lake level (343.51 m, from AE, 2019). The AE (2019) report indicates that the 2017 lake level was essentially equivalent to the 200-year lake level, therefore, the likelihood of occurrence of the two simultaneous events is low. The high lake level does create more flooding along Riverside Avenue and McDougall Street once the peak of the flood way makes its way to the lake. See Figure 6-5 below.

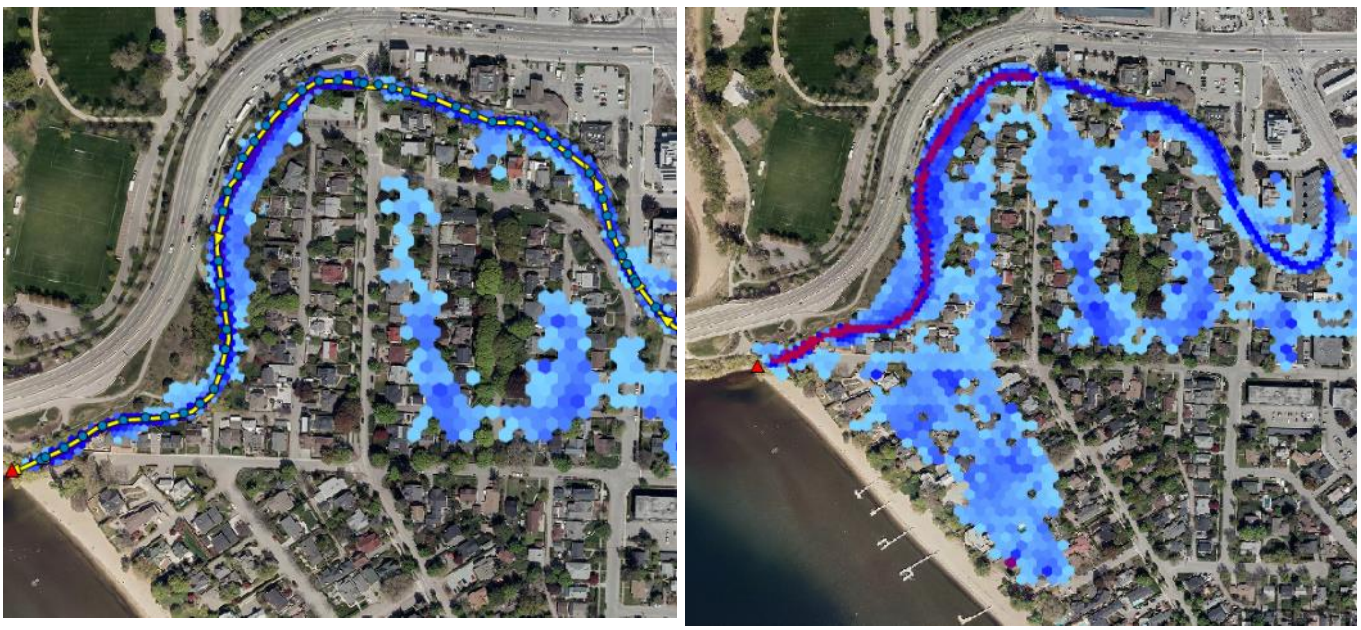


Figure 6-5: 5-year Lake Level (left) with 200-year Mill Creek Flows and 2017 Lake Level (right) with 200-year Flows

Although a couple areas of the city appear to behave differently under flooding conditions than what has been observed in past events, the present model enables future refinement and updates to be made should the need arise. The reported results do support the already understood need by the city to develop further flood mitigation works and the PCSWMM model of Mill Creek is sufficient to support that work.

Table 6-3: Hazard Summary

Location	Most Severe Hazard Rating Outside of Main Channel	Most Affected Areas	Comments
Kelowna International Airport	Significant	Southwest corner of airport parking lot	Significant hazards also lie in the floodplain east of Mill Creek where local roads may be impacted, the area is mostly rural however
Shadow Ridge Golf Course to Heron Road	Significant	Approximately 40-50% of the Golf Course and the area surrounding the Club House, other affected areas are mostly rural	Due to the very small capacity of Mill Creek through the golf course, much of the volume of flood waters exist outside the main channel
North Industrial Area to McCurdy Road	Significant	Totom Avenue industrial lots, which are completely inundated in the model results	There are also significant areas classified as extreme but confined to the creek and its banks
Enterprise Way	Moderate	Enterprise Way, Commerce Avenue, and Jenkins Street	Moderate hazard is indicated at overtopping locations, but the majority of the flooded areas are classified as low due to the very shallow flow of water
Springfield Road to Kelowna General Hospital	Significant	A.S. Matheson Elementary School, Cameron Park	Significant hazard exists in the park locations due to ponding of water; most other locations exhibit low-moderate hazard
Marshall Street and Rowcliffe Avenue	Significant	Corner of Marshall Street and Rowcliffe Avenue and residences in the general area	The degree of hazard in this location is given a high degree of confidence given the extensive KelownaNow coverage of this area

7. Flood Mitigation Measures

7.1 Potential Flood Mitigation Measures

With regard to the main flood event illustrated by the Mill Creek-only model, a number of locations were discussed as being inundated with flood water. Potential flood mitigation measures will be discussed in this section at a conceptual level. No particular flooding scenario was tested with the below mitigation measures, they are described here to facilitate any future work that may be undertaken within the Lower Mill Creek basin.

Although not the first locations to flood throughout the basin, the first areas to flood downstream of Highway 97 are near Marshall Street and Rowcliffe Avenue, and near Springfield Road between Gordon Drive and Wilkinson Street. Given the aerial evidence of flooding around Marshall Street, special attention may be paid to this location especially due to the density of residential lots. The area around Springfield Road where the creek overtops and spills to the southwest did not flood in 2017, its possible that a particular feature of the landscape is not being captured in the LiDAR data which would have inhibited flooding. Despite that, this location should be looked into from a planning point of view as one of importance given the potential area covered by flood water once Mill Creek does overtop, especially since there is important civic infrastructure within the flow path such as the A.S. Matheson Elementary School, a care home, and the hospital. Further discussions with the City have indicated that barriers erected during 2017 would have also limited the observed flooding in this area. The potential mitigation measures for these two areas are likely related to proper emergency planning, including the quick evacuation of residents in the immediate area and the erecting of sandbag dams. There is little-to-no room available in these densely populated areas to construct permanent dikes, leaving emergency response the potential best option. Dynamic models indicating the potential timing of flood waves like this PCSWMM model can help with these planning activities, but it is important to realize that local conditions within the floodplain, such as the presence of debris, can dramatically alter the timing and location of flooded areas.

Some structural mitigation measures include the potential raising of dikes along Adam's Road to prevent flooding of nearby industrial lots as indicated in Section 6.4. Although no significant flooding was found in the PCSWMM model, it is expected that mitigation measures need to be revisited at this location due to the flooding in 2017. Inspecting the creek downstream of this location to ensure no debris or other obstructions are inhibiting the passing of flood flows would also prevent the water from backing up to artificially high levels threatening the dike. It is recognized that the city has already taken steps to remove specific vegetation in areas along the creek since 2017 to prevent this.

It is known at the time of writing this report that the city is pursuing the concept design of a second diversion structure located at some point downstream of the existing diversion to Mission Creek. This proposed second diversion would direct flood flows from Mill Creek to the existing Brandt's Creek along Clement Avenue. This would involve around 3.5 km of earthworks to facilitate a channel that could convey the required flood flows. The PCSWMM model would suggest that the reach of Mill Creek downstream of Highway 97 can handle between 4-5 m^3/s before localized flooding occurs near Marshall Street. With approximately 12.3 m^3/s being discharged downstream of the diversion to Mission Creek, that leaves 7.3 - 8.3 m^3/s of flood flows that may need to be diverted to Brandt's Creek. This number is expected to be confirmed in the forthcoming Mill Creek Diversion Concept project.

Aside from the above-mentioned potential mitigation measures the following projects have been identified by the City of Kelowna as future work, part of the larger Mill Creek Mitigation Project:

- Upper Mill Creek Watershed Storage
- Mill Creek – Airport Section Improvements
- Mill Creek Diversion to Brandt's Creek (discussed above)
- Monashee Court Detention Pond
- Dilworth Drive Detention Pond
- Leckie Place Detention Pond
- Sexsmith Pond 1

Projects likely to have a significant impact on the bulk of flood flows are those upstream of the most populated parts of the City, the Watershed Storage project and the Airport Section Improvements project; however, are identified to be among the most costly and complicated. The Mill Creek Diversion project, currently in the concept design stage, is likely to have the single biggest impact on reducing the volumes of water experienced by downtown Kelowna within a single project. Comparatively, the planned storage ponds upstream of the new diversion would provide for peak flow attenuation but it is likely that all four would need to be constructed within a short period of time of one-another to have immediate positive impacts on downtown flowrates during large flood events. Their benefits would; however, be realised during smaller, more frequent flood events.

8. Conclusions and Recommendations

8.1 Conclusions

Two PCSWMM models were constructed for the purpose of flood mapping and mitigation planning along the Lower Reach of Mill Creek within the City of Kelowna and to provide the City with an integrated major-minor, coupled 1D-2D, stormwater model. Flooding extents for the 20- and 200-year design events were mapped, and hazards were classified for the 200-year event. Comparisons were made between the PCSWMM models, the existing HEC-RAS model, and the available aerial imagery taken by KelownaNow. A few discrepancies were noted with some possible justifications for the differences. Further investigation into these specific instances will be discussed in Section 8.2.

A number of challenges were identified in the modelling exercise, chief among them, PCSWMM's inability to model very large numbers of 2D computational nodes. This limited the scope and refinement of the 2D mesh which may have led to some of the differences between modelled and observed conditions. In order to complete the work in a timely manner and still be able to troubleshoot any errors that may have come up, the refinement of the mesh could only be taken so far. Aside from the images that are available, little calibration data was obtainable. Despite this, there is good general agreement between the PCSWMM model and observed flooding extents in 2017. It is not certain what return period the 2017 flood event was but the AE (2019) reports it as being a higher order event (50-year return period or higher).

The main conclusions drawn from the model results are:

- Marshall Street and Rowcliffe Avenue is the first point of flooding Downstream of Highway 97 during the simulation.
- Overtopping of Mill Creek near Springfield Road may result in widespread, but relatively shallow, flooding towards important civic locations such as A.S. Matheson Elementary School and Kelowna General Hospital.
  - No flooding in these areas occurred in 2017 and it is possible that topographic data available for the study did not capture important features that may have prevented flooding at this location.
- Flooding along Enterprise Way may indicate the need for further refinement of the hydraulic model.
- Very good agreement between the model and observed flooding extents near Kelowna Springs and Shadow Ridge golf courses were found.
- Good agreement between predicted and observed flooding within the Kelowna airport parking lot was found, no validation of predicted flooding was available for the areas east of the airport.

The integrated stormwater model was run with a 5- and 10-year rainfall event. Two different rainfall distributions were tried, the Chicago distribution and the distribution from AE (2019) which was applied to the Brandt's Creek PCSWMM model. The distribution developed by AE (2019) produces what is expected to be more accurate results based on the observed flooding and presumed design capacity of the stormwater network. No calibration data was available at the time of this writing.

Despite the necessary simplifications of the overland flood domain (2D mesh), the integrated PCSWMM model covers a large area of the City of Kelowna and includes a substantial amount of its underground infrastructure. The model will serve adequately as a baseline tool from which further refinements and upgrades can be made in support of future stormwater assessments in the city.

8.2 Recommendations

As described in previous sections, a number of improvements can be made to the models to improve accuracy. One of the challenges associated with developing such comprehensive models within PCSWMM has been balancing the development time with the runtime, there was both a need to develop a model which is precise but that allowed for sufficient iterations during the design process to ensure accuracy. Areas where additional mesh refinement may benefit modelled results are areas around:

- Enterprise Way
- Springfield Road

With regard to the integrated stormwater model; the same type of mesh refinement could be made to improve overland flooding accuracy. Aside from that, further recommendations include:

- Manually delineating subcatchments, which should be done during any future update of the model.
- Addition of stormwater infrastructure under Highway 97 (if any), and other locations as needed.
- Updated survey data around the Mill Creek diversion to Mission Creek to correct inconsistencies between modelled and as-built geometry.

Appendix A

Field Reconnaissance Report

PROJECT NO.	60613804 DATE September 23, 2019		
PROJECT NAME	Flood Mapping and Mitigation Planning	OWNER	City of Kelowna
		REP.	Robinson Puche; Luke Dempsey
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Summary

On September 17, 2019, AECOM visited Mill Creek to assess its main channel, the floodplain areas and key hydraulic structures along the creek within the study limits. The visit started around 8:30 AM at a foot bridge located approximately 250 m upstream of the Spencer Road crossing northeast of Kelowna Airport and ended at the creek's mouth at Okanagan Lake south of WR Bennett Bridge. This report includes photos of the sites that were visited along the creek and summarizes important findings that can be used to evaluate some hydraulic modeling parameters. For direction convention while describing the photos, left and right banks are so termed assuming looking downstream.

GENERAL COMMENTS:

During the flooding in 2017 there was significant sand bagging efforts along Mill Creek in the residential neighborhood along Mill Creek, particularly along Riverside Ave., Maple St. and Abbott St. Beach protection works were in place along beachfront of homes particularly along McDougal Ave. Storm Sewers in the local area were surcharged and sandbagged, as well.

<table>
<tr><td rowspan="2">Site No. 1: Foot Bridge Upstream of Spencer Road Crossing at Mill Creek Regional Park

An automated city-owned gauge with pressure transducer for measuring flow depth was observed on the right bank upstream of the bridge.</td><td>Latitude (N)</td><td>Longitude (W)</td></tr>
<tr><td>49˚ 58’ 20.14”</td><td>119˚ 21’ 45.60”</td></tr>
<tr><td>Photo 1.

Looking downstream at the foot bridge from the right bank
Signs of erosion includes exposed roots of trees on either bank
Existing debris in the form of fallen trunks across the creek was observed</td><td colspan="2">
</td></tr>
<tr><td>Photo 2.

Looking upstream from the right bank
Boulders and gravel characterize the bed material at this location
Surface waves and turbulence were observed further upstream</td><td colspan="2"></td></tr>
</table>

Photo 3.

Looking downstream from the foot bridge at the right bank

- Exposed root ball indicative of bank erosion during high flows

Photo 4.

Looking upstream from the foot bridge at the left bank

- High overbank roughness due to existing shrubs and trees

Site No. 2: CSP Arched Culvert at Spencer Road Crossing	**Latitude (N)**	**Longitude (W)**
	49˚ 58' 21.07"	119˚ 21' 57.33"

Photo 1.

Looking downstream from the left bank at the culvert inlet

- Existing gravel bed has been planned for stream restoration; Mill Creek is a fish-bearing stream
- A long-term agreement is being worked out with the Ministry of Forests, Lands and Natural Resource Operations (MFLNRO) for debris removal and creek maintenance

Photo 2.

Looking upstream from the left bank

- Signs of bank erosion reflected through roots exposure

Site No. 3: Shadow Ridge Golf Club Crossing – Concrete Box Culvert at the Entrance The City indicated that the parking lot of the club gets flooded during extreme events; most recently in 2017 and 2018. During the week of September 9, 2019, they received 18 mm of rainfall within 0.5 hour. A side stream flows from north to south along a local road to the west of the Golf Course.	Latitude (N) 49˚ 56' 25.53"	Longitude (W) 119˚ 23' 7.53"
Photo 1. Looking upstream from the right bank at the culvert outlet		

Photo 2.

Looking downstream from the left bank at the culvert inlet

Photo 3.

Entrance of a local culvert connecting the side stream along a local road between Highway 97 and the golf course.

Photo 4. Looking upstream at Mill Creek from a local concrete bridge approximately 50 m northwest of the golf club entrance.	

Site No. 4: Low floodplain east of Bulman Road by Adams Crescent	Latitude (N)	Longitude (W)
	49˚ 55' 52.88"	119˚ 23' 10.854"

Photo 1.

An aerial view of the floodplain at this location; this property was recently purchased by Westbank First Nations east of Bulman Road off Hereron Road

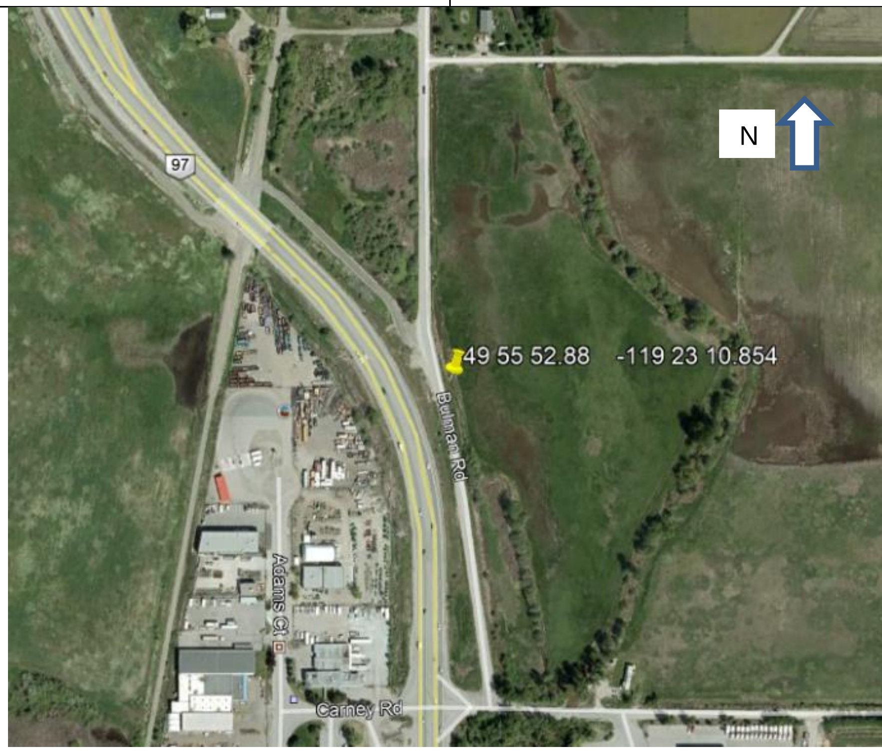

Photo 2.

Looking east at the low floodplain; the right bank of Mill Creek is seen along the tree line.

- The area often gets flooded

Photo 3. Looking southeast at the low floodplain; the right bank of Mill Creek is seen along the tree line.	
Photo 4. Looking southeast at the low floodplain; the right bank of Mill Creek is seen along the tree line.	

Site No. 5: Hwy 97 (Okanagan Hwy) Crossing – twin CSP culvert	Latitude (N)	Longitude (W)
	49˚ 55' 30.39"	119˚ 23' 11.71"
Photo 1. Looking downstream at the culvert inlet • The creek was full of debris and extensive vegetation; the culvert inlet was inaccessible accordingly. The left barrel is not obvious in the photo		
Photo 2. Looking at the culvert outlet from the left bank downstream of the crossing. • Mitered outlet		

Photo 3. A zoomed-in view of the culvert outlet • High water marks indicate the barrel is approximately 60% full	
Photo 4. Looking downstream at the creek from the left bank on the downstream side of the crossing • Extensive trees and vegetation that potentially cause high flow resistance	

Site No. 6: Adams Road Crossing – twin CSP culvert	Latitude (N)	Longitude (W)
	49˚ 55' 29.622"	119˚ 23' 19.26"

Photo 1.

Looking downstream at the culvert inlet from the right bank

- The left barrel invert was observed at lower elevation than that of the right barrel; possibly for fish passage during low flows

Photo 2.

Looking downstream at the culvert outlet while standing on Adams Road

- Minor dents were observed at the upper surface of the left barrel
- The creek has instream shrubs and exhibits meandering further downstream

Site No. 7: Adams Road Industrial Area (diked along the left bank)	Latitude (N)	Longitude (W)
Walking down the earthen dike along the left bank between the indicated co-ordinates, local private outfall pipes, as well as a city-owned outfall were observed. The industrial area appeared generally at lower elevation than the channel bed.	49˚ 55' 22.698" to 49˚ 55' 14.16"	119˚ 23' 22.848" to 119˚ 23' 26.60"
Photo 1. Looking downstream along the dike on the left bank • Excessive vegetation was observed within the channel		
Photo 2. Private sump-pump drainage configuration to remove flood water from one of the low industrial properties along the left floodplain • The City indicated that in the past no approvals that would regulate such practices were required		

Photo 3.

The outlet of the sump-pump drainage configuration in Photo 2 as it drains into the creek

- Two pipes were observed draining into the creek
- Extensive vegetation was observed along the left bank

Photo 4.

A second private sump-pump drainage configuration as that shown in Photo 2 that was observed in another neighboring industrial property along the left floodplain. The shown pipe was observed draining into the creek across the earthen dike.

Photo 5.

A third local private drainage pipe observed on the right bank

- Debris and instream vegetation were observed within the channel

Photo 6.

A city-owned concrete outfall pipe along the left bank

- Excessive vegetation was observed within the channel at the pipe outlet
- During extreme flows, this outfall may not be properly draining the floodplain

Site No. 8: The right floodplain between Cambro Road and Campion Street The City indicated there may be a possibility for constructing a future storm facility at this site. A sanitary sewer and a sanitary manhole were observed near the northeast corner of this floodplain.	**Latitude (N)** 49˚ 54’ 53.81”	**Longitude (W)** 119˚ 23’ 59.44”
Photo 1. An aerial view of the floodplain at this location		
Photo 2. Looking north at the higher developed area from the trail shown in Photo 1 bordering the floodplain along the creek right bank • The City indicated that this area will be further developed, and it is important to control its runoff		

Photo 3.

Looking south from the trail at the low floodplain along the right bank of the creek

- The City indicated it is important to protect this floodplain as it gets flooded frequently
- The tree line in the photo marks the creek path

Photo 4.

Sign indicating existing sanitary sewer line crossing through the floodplain; the location is near that proposed for a future storm facility (see Photo 1)

Photo 5. The sanitary sewer manhole by the sign indicating a sanitary sewer crossing (see Photo 4). The City indicated there is a nearby sanitary lift station.	
Photo 6. Looking north along Cambro Road • The City indicated that the upland areas are transforming from agricultural to industrial practices, and currently there are no stormwater management plans at the neighborhood level in place. Some private owners have their own local mitigation measures to meet predevelopment release rates. • This land use transformation will result in larger imperviousness and increased runoff to the floodplain.	

Site No. 9: Inlet of the Diversion Structure to Mission Creek – One 2.40 m x 2.40 m Concrete Box Tunnel **The inlet is near Enterprise Park adjacent to the Okanagan Rail Trail; a stormwater pond exists south of Mill Creek at this site**	**Latitude (N)** 49˚ 53' 22.25"	**Longitude (W)** 119˚ 25' 54.88"
Photo 1. The creek upstream of the fenced diversion structure • Debris observed on the right bank • Instream vegetation was observed on the side slopes looking upstream		
Photo 2. Looking downstream along the creek • The inlet of the diversion structure is shown on the left with trash rack; its weir has a length of 6.80 m and the weir crest is set at an elevation of 371.30 m • The foot access bridge with handrails also has trash rack • A sluice gate is shown across Mill Creek on the left; it is operated during extreme flows • A side rectangular weir is shown on the right across Mill Creek; the weir crest length and elevation are 1.54 m and 371.30 m, respectively		

Photo 3.

Looking at the inlet of the diversion structure

- A sluice gate is shown across the diversion structure on the right; it is operated during extreme floods
- The City indicated that the structure was built in the 70s and helped mitigate flooding further downstream. The City plans to retrofit the diversion structure
- There is currently a proposed plan to construct a second flood relief diversion structure starting at the crossing with Hardy Street near the Kelowna Regional Transit System Maintenance Facility ultimately entering Brandt's Creek that discharges further west into Okanagan Lake at Rotary Marsh Park

Photo 4.

Looking upstream at the sluice gate and side weir across Mill Creek

- The City indicated that historically Mill Creek's flood on record is approximately 24 m^3/s; of which up to 12 m^3/s may be diverted into Mission Creek through the diversion structure

<table>
<tr><td rowspan="2">Site No. 10: Three Local Road Crossings South of Hardy Street Crossing

South of Hardy Street bridge crossing, two wooden bridges and a third culvert crossing were observed further downstream.</td><td>Latitude (N)</td><td>Longitude (W)</td></tr>
<tr><td>49˚ 53’ 6.90”</td><td>119˚ 26’ 54.64”</td></tr>
<tr><td>Photo 1.

Inlet of the concrete arch culvert
Photo taken from a nearby wooden bridge approximately 10 m upstream of the culvert inlet</td><td colspan="2">
</td></tr>
<tr><td>Photo 2.

Looking upstream from the second wooden bridge crossing at the first wooden bridge crossing approximately 25 m apart</td><td colspan="2">
</td></tr>
</table>

Photo 3. Looking at a naturally depressed area near the crossings adjacent to the maintenance facility • This depressed area is within the City Right-of-Way	
Photo 4. Looking upstream at the sluice gate and side weir across Mill Creek • The City indicated they received a grant for structural flood mitigation measures to be constructed at this site.	

Site No. 11: Parkinson Recreation Center	Latitude (N)	Longitude (W)
	49˚ 52' 58.75"	119˚ 27' 33.65"

Photo 1.

Looking upstream at the creek from the left bank as it flows by the recreation center southeast side.

- The freeboard board seems shallow at the relatively low flow during the visit.
- The City indicated that the grass sports fields usually get flooded during extreme flood events
- There was a significant tree removal adjacent to the Creek at this location in 2018

Photo 2.

The creek downstream of a local foot bridge crossing

- Signs of debris are obvious along the toe of the right bank
- A concrete/rock wall that continues along most of the creek within this reach was observed

Photo 3. The creek upstream of another local foot bridge crossing south of the bridge in Photo 2 • Signs of debris are obvious across the creek	
Photo 4. The creek along the southside of the grass sports fields • Signs of debris are obvious along the creek left bank	

Photo 5.

A pipe outfall along the left bank is observed along the southside of the recreation center grass sports fields

Photo 6.

Looking downstream from the left bank at the inlet of a three-barrel culvert crossing to the south at Sutherland Avenue

- The left barrel seemed blocked at the time of the visit
- The City indicated that these culverts rarely had surcharge problems; they would flow freely even when the grass sports fields are flooded during extreme flood events.

<table>
<tr><td>Site No. 12: Lateral Tributary North of Lindahl Community Garden

This lateral tributary drains urban drainage from the east into Mill Creek.</td><td>Latitude (N)
49˚ 52’ 41.214”</td><td>Longitude (W)
119˚ 28’ 17.442”</td></tr>
<tr><td>Photo 1.

Looking downstream along the tributary from the Lindahl Community Garden</td><td colspan="2"></td></tr>
<tr><td>Photo 2.

Looking downstream along the tributary from a concrete box culvert crossing at Lindahl Street.

• Photo shows the culvert outlet
• The culvert inlet across Lindahl Street seemed dry during the visit; indicative of possible sewer laterals connected to the culvert at an intermediate connection</td><td colspan="2"></td></tr>
</table>

Site No. 13: Bridge Crossing South of the Intersection of Lindahl Street and Sutherland Avenue, and Local Crossings further downstream along Mill Creek	**Latitude (N)**	**Longitude (W)**
	49˚ 52’ 48.35”	119˚ 28’ 9.87”
Photo 1. Looking upstream from the right bank while standing at the top of the bridge near the intersection of Lindahl St. and Sutherland Ave.		
Photo 2. Looking downstream along Mill Creek from the bridge top at the end of Lindahl St.		

Photo 3.

Two local bridges (a foot bridge to the left and a vehicle bridge on the right) crossing Mill Creek; photo taken from the left floodplain on Lindahl St., approximately 120 m south of its intersection with Sutherland Ave.

- The City indicated that this area is often flooded during heavy storm events
- High water reached the soffit of the two bridges

Photo 4.

Photo taken from the left floodplain in the vicinity of the local bridges in Photo 3; the creek is shown with a concrete dike/retaining wall along the right bank.

- The City indicated that this area is often flooded during heavy storm events
- During the 2017 flood, they had to sandbag the banks to protect the properties on the floodplain

Photo 5. Photo taken from the left floodplain in the vicinity of the local bridges in Photo 3 while looking downstream • Failure of one of the dikes/retaining walls along the right bank is observed.	

<table>
<tr><td rowspan="2">Site No. 14: Area Northwest of Sutherland Ave Multiuse Bridge Crossing</td><td>Latitude (N)</td><td>Longitude (W)</td></tr>
<tr><td>49˚ 52’ 47.54”</td><td>119˚ 29’ 35.03”</td></tr>
<tr><td>Photo 1.

Looking at the right floodplain; the creek flows by the tree line along Pandosy Street seen at the far view in the photo

• The City indicated that during the 2017 flood, Okanagan Lake water levels were quite high and backed the flow up in the sewer system. Flooding reached the curb line in the surrounding streets</td><td colspan="2">
</td></tr>
<tr><td>Photo 2.

Looking from the right bank to the creek, an outfall sewer with tide-flex is shown discharging into the creek

• The City indicated that within their system there are currently only four (4) of the outfall sewers having tide-flexes at their ends; these are: pipe ID 151991 (Hwy 33 at Mill Creek), 116139 (Bluebird pump station outfall to Okanagan Lake near creek’s mouth), 181424 (Mission Creek at Gordon Drive), and 167428 (Marshall Street at Mill Creek). The City plans to install more on the remaining outfalls.</td><td colspan="2">
</td></tr>
</table>

<table>
<tr><td rowspan="2">Site No. 15: Two Bridge Crossings at the Intersection of Buckland Avenue and Ellis Street</td><td>Latitude (N)</td><td>Longitude (W)</td></tr>
<tr><td>49˚ 52' 55.04"</td><td>119˚ 29' 36.35"</td></tr>
<tr><td>Photo 1.

Looking at the downstream face of the bridge along Buckland Avenue

• The bridge was flooded during the 2017 and 2018 floods; it was not possible to raise the bridge due to existing utilities</td><td colspan="2"></td></tr>
<tr><td>Photo 2.

Looking at the upstream face of the bridge along Buckland Avenue

• A foot bridge is seen slightly upstream and other utility lines are seen</td><td colspan="2"></td></tr>
</table>

Photo 3. Looking upstream at Mill Creek from the foot bridge	
Photo 4. Looking downstream along Mill Creek from the right bank; the upstream opening of the bridge along Ellis Street is seen	

Site No. 16: Mill Creek Mouth on Okanagan Lake	**Latitude (N)**	**Longitude (W)**
	49˚ 52' 58.75"	119˚ 27' 33.65"
Photo 1. Looking downstream from the right bank near the mouth • An arch foot bridge crosses the creek between the end of Lake Ave. and City Park		
Photo 2. Houses along the left bank near the creek mouth • High water marks on the concrete walls appear to be at the house ground elevations		

Photo 3. Looking along the left bank upstream of the creek mouth; the houses on the floodplain get flooded during extreme flood events	
Photo 4. Looking downstream along the left bank upstream of the creek mouth • Extensive vegetation is observed on the side slopes of the channel	

Photo 5.

Looking along the left bank upstream of the creek mouth

- Shallow freeboard would be available during extreme floods

Photo 6.

Looking along the left bank of the creek approximately 160 m upstream of the mouth

AECOM

Regional District of Central Okanagan

City of Kelowna