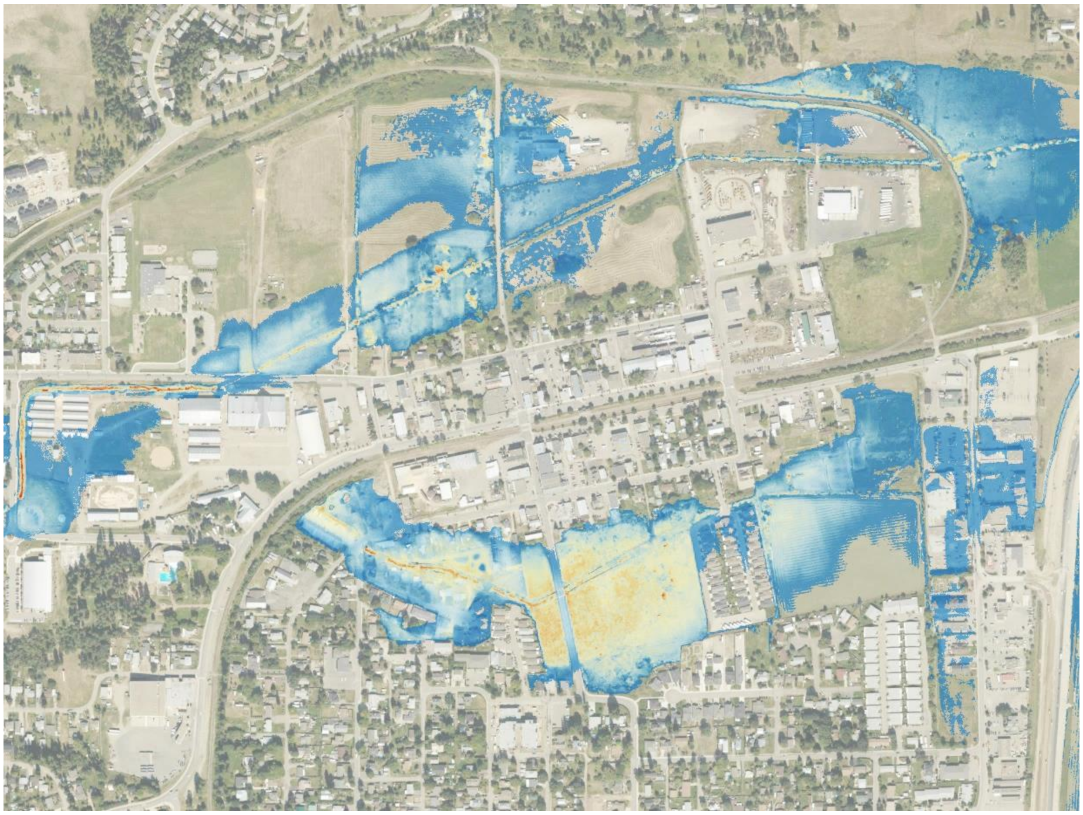
ISSUED FOR USE

City of Armstrong



CITY OF ARMSTRONG
FLOOD MAPPING AND RISK ASSESSMENT REPORT

Issue Date: January 21, 2019
Project No. 2018-001 (0130.05)

Prepared for:
Doug MacKay – Public Works Manager
City of Armstrong
3570 Bridge Street
Armstrong, BC V0E 1B0
Telephone (250) 546-3023

Prepared by:
Interior Dams Incorporated
13890 Forest Hills Drive
Lake Country, BC V4V 1A5
Telephone (778) 480-6063
Fax (778) 508-7716

Revision History

Date	Section/Page	Description
December 15, 2018		Issued for Discussion
January 21, 2019		Issued for Use

ENGINEERS & GEOSCIENTISTS BRITISH COLUMBIA
OQM CERTIFIED

Interior Dams

This page intentionally left blank.

EXECUTIVE SUMMARY

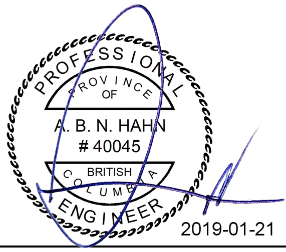
This report intends to support and direct the development and implementation of an integrated flood management plan (IFMP) by providing the City with flood mapping, a risk assessment, and other flood risk mitigation information. This information is to be used by the City to inform decision makers and facilitate stakeholder engagement.

The following points cover the information included in this report:

- City-wide flood inundation maps (floodplain maps);
- City-wide flood hazard maps;
- Flood risk assessment information;
- Summary of flood risk mitigation progress;
- Discussion of future flood risk mitigation strategies; and
- Summary of findings and recommendations.

CERTIFICATION

This report was prepared by:



Aaron Hahn, P.Eng., AScT
Project Engineer

Christian Desjarlais, EIT
GIS and Mapping

This report was reviewed by:

Suzan Lapp, Ph.D., P.Ag., P.Geo.
Technical Reviewer

Acknowledgements

Interior Dams Incorporated (Interior Dams) is grateful for the support from Doug MacKay, Kevin Bertles, Lisa Gyorkos and operational staff of the City of Armstrong (City). We also acknowledge the following consultants and government staff for providing information required for the preparation of this document: Bob Askin, M.Sc., P.Geo., P.Eng. of Integrated Watersheds, Brian Hillson, Eng. L. and Mike Ogloff, P. Eng. of Gentech Engineering Inc., Trina Koch of Western Water Associates Ltd., and supporting staff of the Ministry of Forests Lands and Natural Resource Operations' Regional Water Management Branch (FLNRORD), Emergency Management BC (EMBC) and the National Disaster Mitigation Program (NDMP).

Limitations & Qualifications

This document is for the sole use of the City and contains information licensed under the Open Government Licence – British Columbia, as well as, intellectual property of Interior Dams under Canadian copyright law. No part of this document shall be reproduced or disclosed to any other parties without the written permission of Interior Dams unless it is for the development of the City's IFMP. Neither Interior Dams nor the City accepts liability of any kind that may arise out of the use of this report by any third party. Should any third party rely on the contents of this report, they do so at their own risk.

This report and its contents represent the professional judgement of Interior Dams based on current available information, including, inputs required for the development of the flood hydrology, existing drainage basin conditions, current climate conditions, and existing natural and un-natural hydraulic features in the area and at the time of the study. As information is subject to change, reliance upon this report and its contents, for any purpose, may or may not be valid if one or more inputs are reasonably compromised. No warranty, implied or expressed, is made.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AAR	Automobiles at risk
AEP	Annual exceedance probability
BC	British Columbia
CDA	Canadian Dam Association
CEPF	Community Emergency Preparedness Fund
CFA	Consolidated Frequency Analysis software v3.1
CGVD28	Canadian Geodetic Vertical Datum of 1928
City	City of Armstrong
CSP	Corrugated steel pipe
EMP	Environmental management plan
DEM	Digital elevation model
DV	Product of depth-velocity
DPA	Development permit area
EGBC	Engineers and Geoscientists of British Columbia
FCL	Flood construction level
FERC	Federal Energy Regulatory Commission
FEMA	Federal Emergency Management Agency
FLNRORD	Ministry of Forests Lands and Natural Resource Operations
FSR	Forestry service road
FTD	Functionality threshold depth
GIS	Graphical interface system
GPS	Global positioning system
GSC	Geological Survey of Canada
HR	Hazard rating
HEC-RAS	Hydrologic Engineering Centre’s Hydrologic Modelling System v4.2.1

HY-8	Culvert Hydraulic Analysis Program v7.50
IFMP	Integrated flood management plan
Interior Dams	Interior Dams Incorporated
IPE	Interior Provincial Exhibition
LiDAR	Light imaging detection and ranging
LoL	Loss of life
LoW	Loss of wages
LoBP	Loss of business profit
LoRI	Loss of rental income
NAD83	North American Datum of 1983
OCP	Official community plan
PCIC	Pacific Climate Impacts Consortium
PAR	Population at risk
QGIS	Quantum Geographic Information System Software v3.4.2
RAAD	Remote Access to Archaeological Data
RCEM	Reclamation Consequence Estimating Methodology
RDNO	Regional District of Okanagan
RFP	Request for proposal
SAR	Structures at risk
SDSB	Subdivision and Development Servicing Bylaw No. 1570
TRIM	Terrain Resource Information Management
UBCM	Union of BC Municipalities
USACE	US Army Corps of Engineers
USBR	United States Bureau of Reclamation
UTM	Universal Transverse Mercator
WSA	Water Sustainability Act
WSC	Water Survey Canada
WTP	Water treatment plant
WWTP	Waste water treatment plant

UNITS OF MEASURE

acre	Acre (1 acre = 0.404686 ha)
˚C	Degrees Celsius (0˚C = 32˚F, 21˚C = 70˚F)
cfs	Cubic feet per second (1cfs = 0.0283168 m^3/s)
ha	Hectare (1 ha = 2.47105 acres)
km	Kilometer (1 km = 0.621 miles)
m	Metre (1 m = 3.28084 ft)
mm	Millimetre (1mm = 0.0394 inch)
m^3/s	Cubic metres per second (1 m^3/s = 35.31 cfs)

This page intentionally left blank.

1 INTRODUCTION

Under provincial funding from the Community Emergency Preparedness Fund (CEPF)[1], the City of Armstrong (City) retained Interior Dams Incorporated (Interior Dams) to explore preliminary flood risk mitigation strategies and complete flood mapping[2] for both Meighan Creek and Deep Creek. On October 11, 2018, the City engaged Interior Dams to expand the scope of work to include a flood risk assessment and a public consultation component. Funding provisioned though the Natural Disaster Mitigation Program (NDMP)[3] covered these two components.

1.1 Background and Historical Flooding

On May 5 of 2017, high streamflows were generated by rapidly warming temperatures and intense rainfall[4] following a sustained cold winter with above normal snow accumulation. The high streamflows caused extensive flooding to numerous properties along Meighan Creek and Deep Creek. A community care facility on Willowdale Drive was impacted by Meighan Creek (Figure 1-1) and Deep Creek threatened to breach its banks near the City's Sanitary Sewer Headworks building. As a result, the City declared a local emergency (City of Armstrong, 2018).

Figure 1-1: Willowdale Drive - May 5, 2017 (looking east) (Adapted from Global, 2017)

[1] The CEPF is a provincial suite of funding programs administered by the UBCM that is intended to enhance the resiliency of local governments and their residents in responding to emergencies.
[2] *Flood mapping* refers to both inundation maps (also know as floodplain maps) and hazard maps. For more information see Section 2 of this report.
[3]The NDMP is a federally funded program intended to address the rising national cost of flood impacts by assisting government in making informed risk mitigation investments for the purpose of reducing or negating the impacts of floods.
[4] Rain gauges in Vernon, BC for May 4th and 5th of 2017 measured 19.0 mm and 18.4 mm for Climate Station ID 1128553 (Vernon Bella Vista Gauge) and 18.8 mm and 15.0 mm for Climate Station ID 1128583 (Vernon North Gauge) respectively.

Following the flood of 2017, the City applied for funding to assist in flood risk management. As a result, the City was able to secure funding from the Community Emergency Preparedness Fund (CEPF) to conduct flood mapping and mitigation planning. On March 21, 2018, Interior Dams was contracted to provide these services.

On March 22, 2018, a rain event[5] caused rapid low-elevation snowmelt in the vicinity around the City. As a result of the antecedent saturated and/or frozen ground conditions, runoff from the event caused Meighan Creek to again breach its banks in the Pleasant Valley Road and Meadow Creek Lane areas. Flooding impacted a number of properties and prompted an evacuation of the care facility of Willowdale Drive (VMS, 2018). The City responded and declared a local state of emergency and promptly issued a media release which notified citizens of the threat of flooding posed by a high snowpack[6]. The media release provided links to flood preparation information and notice was given that sandbagging materials were available at the City's public works yard (City of Armstrong, 2018).

On May 9, 2018, the Meighan Creek freshet peaked following a short-duration high-intensity rainfall[7]. Quickly rising water overwhelmed culverts and caused overtopping at Powerhouse Road and flooding throughout Armstrong (Figure 1-2). An Interior Dams stream gauge measured the peak instantaneous streamflow to be 1.32 cubic metres per second (m^3/s) at the Highway 97A crossing immediately downstream of Powerhouse Road.

Figure 1-2: Powerhouse Road following May, 9, 2018 freshet

[5] Rain gauges in Vernon, BC for March 22nd and 23rd of 2018 measured 6.7 mm and 2.2 mm for Climate Station ID 1128553 (Vernon Bella Vista Gauge) and 11.0 mm and 2.4 mm for Climate Station ID 1128583 (Vernon North Gauge) respectively.
[6] The high snowpack was estimated to be 152% of normal for the North Okanagan based on the current BC River Forecast Data at that time.
[7]The hourly Climate Station ID 1128582 (Vernon Auto) in Vernon, BC measured 22.5 mm of rain in the morning of May 9, 2018.

The City responded by installing temporary partial barriers on the culverts located upstream (east side) of Highway 97 between Rosedale Road East and the Highway 97A offramp at Pleasant Valley Road. These efforts effectively diverted a portion of the May 9th storm water to a private field located upstream of the City at the civic address of 1994 Rosedale Avenue East. Figures 1-3 and 1-4 depict the subject field and temporary culvert blockages at that time.

Figure 1-3: Emergency culvert blockage near Pleasant Valley Rd & Hwy 97A - May 9, 2018 (looking south)

Figure 1-4: Emergency culvert blockage north of Rosedale Rd E & Hwy 97A - May 9, 2018 (looking north)

This partial blockage of culverts proved to be effective at attenuating the Meighan Creek streamflow between Highway 97A and the junction of Deep Creek; however, the risk of flooding transferred to business properties along Smith Drive and a storage facility on Wagner Road (refer to Appendix VI for reference to stormwater mapping). Figure 1-5 illustrates some of the transferred flooding along Smith Drive.

Figure 1-5: Flooding at business plaza along Smith Drive (Froats, 2018)

1.2 Purpose and Scope of Work

This report is intended to support and direct the development and implementation of an integrated flood management plan (IFMP) by providing the City with flood mapping, a risk assessment, and other flood risk mitigation information. This information is intended to be used by the City to inform decision makers and facilitate stakeholder engagement.

The following summarizes the objectives and deliverables of this project:

- Prepare city-wide flood inundation maps (floodplain maps);
- Prepare city-wide flood hazard maps;
- Complete a flood risk assessment;
- Review current flood risk mitigation progress and discuss future strategies; and
- Provide and present findings and recommendations.

1.3 Conventional and Non-conventional Flooding

According to the flood assessment professional practice guidelines, a *flood* is a "condition in which a watercourse or body of water overtops its natural or artificial confines and covers land not normally under water." A flood can be both *conventional* and *non-conventional*. A conventional flood is comprised of only water[8] and is generated by rainfall, snowmelt, ice jams or combinations of these causal mechanisms. A non-conventional flood is generated by other causal mechanisms (such as a flood wave generated by a breach of a natural or constructed water impoundment, landslide, etcetera) or is comprised of a significant concentration of sediment load or debris (such as a debris flow, debris flood or hyperconcentrated flow) (EGBC, 2018).

This report does not directly address, assess, or make conclusions based on non-conventional floods or their hazards; however, non-conventional floods were considered, to a reasonable extent required, to support the completion of flood mapping. For clarity, the word *flood* in this report refers only to a conventional flood caused by snowmelt, rainfall or a combination of the two causal mechanisms[9]. As a result, all *hazards* or *risks* discussed in this report refer only to hazards and risks associated with conventional flooding as defined in this section.

2 FLOOD MAPPING

According to the Flood Hazard Area Land Use Management Guidelines, flood mapping is an important first step in developing an IFMP (FLNRORD, 2018). Flood mapping is useful to aid flood mitigation planning as it delineates the potential of flooding and supports estimates of flooding impacts to structures, people and assets, infrastructure, etcetera (Public Safety Canada 2016).

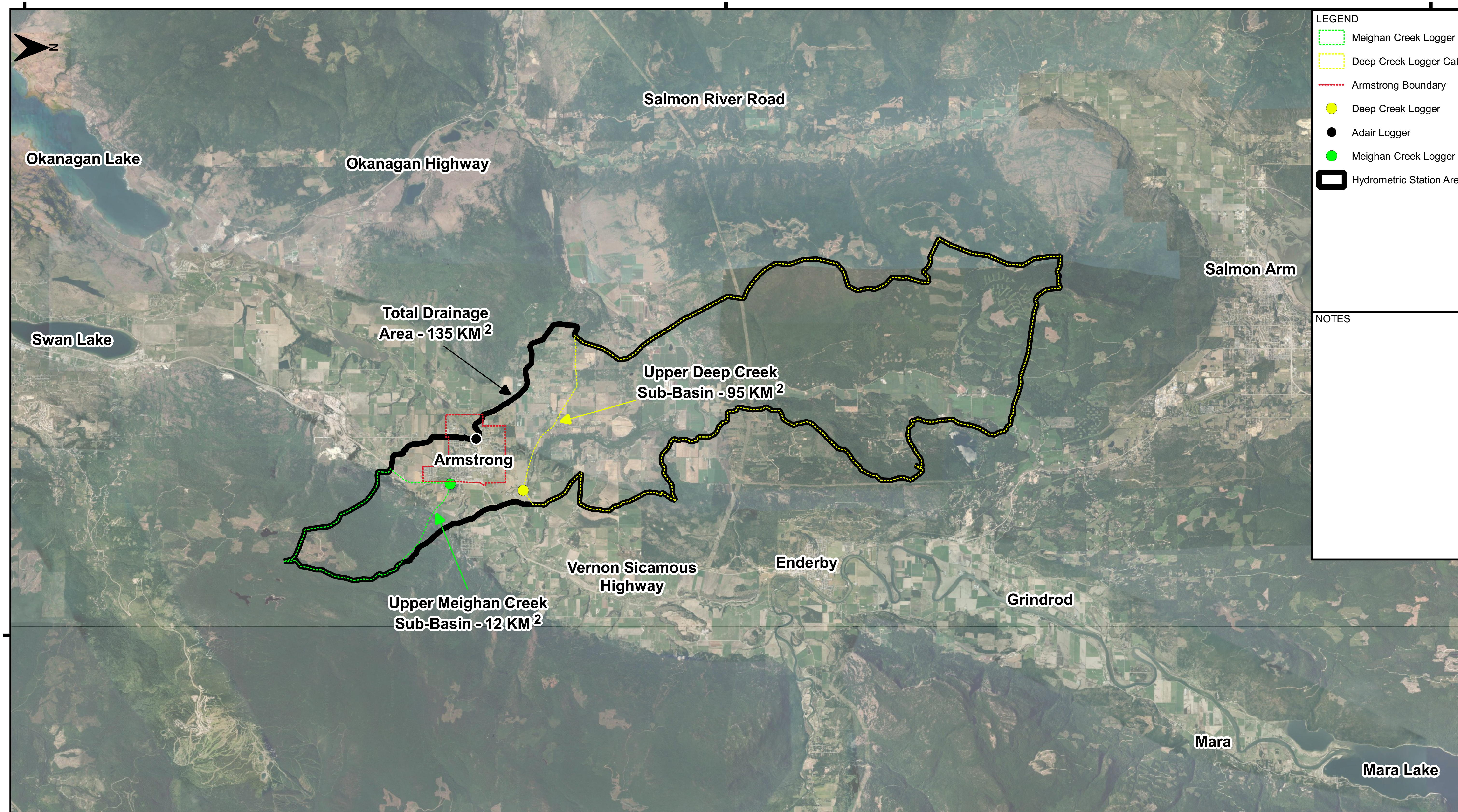
In accordance with provincial legislated guidelines, engineering best practices, and CEPF and NDMP funding requirements, a variety of tasks were completed to support the preparation of flood maps. This section provides a summary of the completed tasks, supporting information, model data input, employed methodologies, and assumptions and decisions used in the preparation of the work.

2.1 Geographic Area and Investigation

In conformance with the City's request for proposal (RFP), the geographic area covered by this investigation includes the Meighan Creek and Deep Creek drainage basins that are within, and upstream of, the City's jurisdictional boundary (City of Armstrong, 2018). A map showing the geographic area of investigation concerning the City boundary and contributing drainage basins are illustrated in Figure 2-1.

[8] Water that does not have a significant sediment load (less than 4% by volume).
[9] Ice jams were omitted from the analysis due to the size of the creeks and absence of any historical issues with ice jams.

This page intentionally left blank.



CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL		MAP NO.
Interior Dams	0	ISSUED FOR USE	2018/12/21	JAN 21,2019	SEE REPORT	FIGURE 2.1: GEOGRAPHIC AREA OF STUDY	N/A
CLIENT				PROJ.NO. 0130.05			
City of Armstrong				GIS CRD / ENG ABH		CATCHMENT MAP	
				0 1 2 3 4 KM			
				SCALE 1:200000 NAD 1983 UTM 11N			

2.2 Supporting Information and Input Data

For portions of the drainage basins within the city boundary, Interior Dams conducted a detailed background investigation of all water conveyance infrastructure, road crossings, and bridges along creek channels. Where possible, the investigation utilized record drawings, infrastructure mapping, and reports collected from City archives, the provincial government, and private data sources.

For portions of the drainage basins that are outside of the City's jurisdictional boundary, the investigation predominantly relied on desktop exercises supported by field verification of critical cross-sections, channel conditions, and other field conditions previously identified. Desktop exercises included the review of available reports, climate station data, hydrometric streamflow data, aerial and satellite photo data, and other supporting environmental and hydroclimatic data.

The following sub-sections provide key supporting data used in the flood mapping analysis. For a list of sources, refer to Section 6 of this report.

2.2.1 LiDAR Elevation Data

LiDAR data was collected by Airborne Imaging between July of 2016 and August of 2017 using a Riegl Q1560 LiDAR system and competitively sourced through Tarin Resources Ltd of Airdrie, Alberta. With a point density of 8.0 points per metre-squared (pts/m^2), processing of data achieved a horizontal and fundamental vertical accuracy[10] of 0.30 and 0.15 metres (m) respectively. The LiDAR effectively covered approximately 85% of the City's jurisdictional boundary, and extends upstream of both Meighan Creek and Deep Creek to Powerhouse Road and Young Road.

Careful inspection of the digital elevation model (DEM) was conducted prior to importation to the flood model. As the data collection did not take place during "leaf-off" conditions, the generated surface contained some cropping of densely vegetated areas. All identified cropping and inaccurate elevations in critical flood areas were corrected using field survey data. See Figure 2.2 for an illustration of the area collected.

[10] Fundamental vertical accuracy refers to the accuracy for smooth or hardened surfaces.

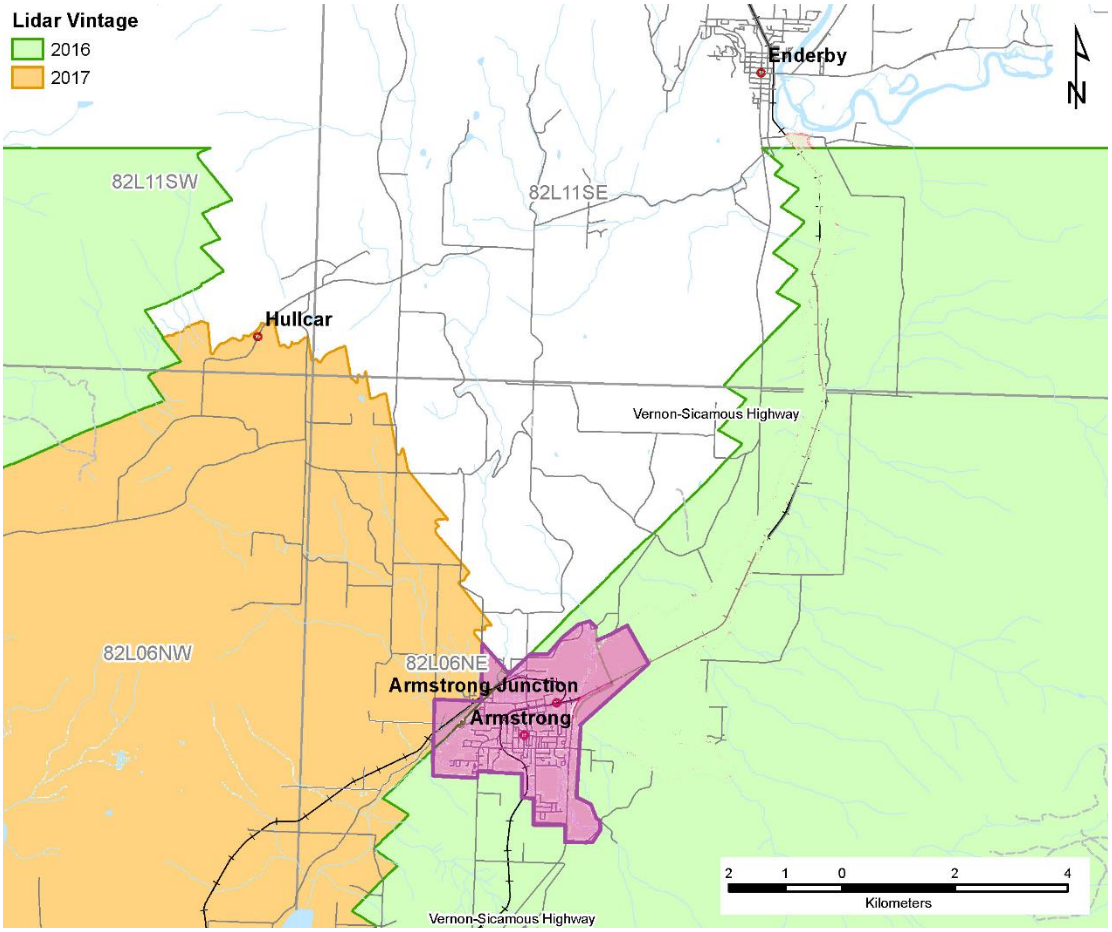


Figure 2-2: LiDAR data (purple area acquired and used in flood model)

Digital copies of the following list of processed data have been included on DVD and included with the hard-copy report:

- 1m grids (ARCINFO binary, bare earth and full feature);
- 1m grids (XYZ ASCII, bare earth and full feature);
- 1m grids (Surfer v7, bare earth and full feature);
- Point cloud (LAS v1.2, ASPRS Classes);
- 1m contours (in .dxf and .shp); and
- Hillshade images (geotiffs, bare earth and full feature).

Appendix VII provides a summary of the LiDAR specifications and terms of use.

2.2.2 Creek Cross-Section Survey

For the areas within the City's boundary, the survey included cross-sections at intervals of 100 m for both the Meighan Creek and Deep Creek reaches. In addition, cross-sections were surveyed immediately upstream and downstream at all critical creek crossings and hydraulic structures. Due to line-of-sight and GPS signal challenges posed by heavy vegetation, temporary geodetic elevation control pins were installed at each cross-section using a Leica Total Station. Cross-sections were then carefully measured using an optical builders' level, 30 m field tape, survey rod and a folding ladder system[11] and then georeferenced to the control pins. Critical hydraulic data was recorded and later inputted into the model. This information included the location and elevation of the thalweg, left and right banks, grade breaks, and levees (where applicable).

2.2.3 Base mapping

Graphical interface system (GIS) base mapping and other publicly available spatial data were collected and used for the flood mapping and background investigation. Data collection included property parcel geometry and parcel information (Ministry of Citizens Services, 2018) (BC Land Title & Survey, 2018), property assessment information (BC Assessment, 2018), Terrain Resource Information Management (TRIM) contour and water line mapping (Province of British Columbia, 2014), ortho and satellite imagery (RDNO, 2012) (Digital Globe), elevation contour data (RDNO, 2018), transportation mapping (GeoBC, 2017), and general location mapping for BC healthcare facility, RCMP detachment, fire department and local authority offices and public works facilities (Ministry of Health, 2018) (GeoBC, 2018) (Digital Globe).

2.2.4 Infrastructure

For both Meighan Creek and Deep Creek, existing hydraulic infrastructure was investigated in areas downstream of Young Road and Powerhouse Road respectively. Where possible, record drawings of road structures, culverts, bridges and other existing infrastructure was collected, reviewed and verified to support flood modelling.

A summary of key record drawings used included the Adair Street & Park Drive Upgrading drawings (Gentech Engineering Inc, 2004), Adair Street to Bridge Street drawings (Gentech Engineering Inc., 2007), Okanagan Highway No. 97A Armstrong Four Laning from Pleasant Valley Cross Road to Lansdowne Road drawings (Ministry of Transportation and Infrastructure, 2012), Sewer Plan drawings (Opus Daytonknight Consultants Ltd, 2014), Wood Avenue Culvert Reconstruction drawings (UMA, 1979), and City storm mapping and record drawings (City of Armstrong, 2016). The investigation verified this data, as well as the compatibility of hydraulic features using field measurements, survey elevation and control, and field measurements. Table 2-1 below summarizes the climate data reviewed. Figure 2-3 illustrates the location of the Climate Stations.

[11] A folding ladder system was used to provide stable foot access where creek flows, sediment deposits, and other natural barriers posed challenges to survey data collection.

Table 2-1: Climate Stations

Station ID	Station Name	Station Period (years)	Record Type	Elevation (m)	Distance to City core (km)
1160450 NOTE	Armstrong	1(1992)	Daily	359	0.9
1160483 NOTE	Armstrong Hullcar	27(1971-1998)	Daily	505	6.0
1160485	Armstrong North	21(1973-1993)	Daily	373	5.0
1120486	Armstrong Otter Lk.	81(1912-1992)	Daily	342	6.5
1162680	Enderby	104(1893-1997)	Daily	354	12.2
1128583	Vernon North	24 (1991-2018)	Hourly	538	12.7
1128584	Silverstar Lodge	47(1970-2018)	Daily	1586	14.0
1128586	Vernon Swan Lk.	13(1994-2006)	Daily	490	16.8
1128553	Vernon Bella Vista	34 (1984-2017)	Daily	427	21.8
Note: Bolded station IDs are within the project's geographic study area and subject drainage basins.					

Figure 2-3: Location of climate stations relative to Armstrong

The location of the Silver Star Mountain snow course station (ID 2F10) is at 1840 m elevation near the Silver Star Lodge. Since 1960, the collection of station data was a manual process. As of 2015, the station became automated and renamed as ID2F10P. Table 2-2 provides the snow course station data reviewed.

Table 2-2: Snow Course Data (MLFNRORD, 2014)

Station ID	Station Name	Station Period (yrs)	Record Type	Mean Snow (mm water eq)	Elevation (m)	Distance to City core (km)
2F10(P)	Silver Star Mountain	56 (1960-2014) 4 (2015-2018)	Manual Continuous	744	1840	14.0

2.2.5 Hydrometric Data

Presently there are no active hydrometric stations located on either Meighan Creek or Deep Creek. There are three identified historical Water Survey Canada (WSC) stations along Deep Creek located at Young Road (ID 08NM177), Adair Street (ID 08NM119), and Highway 97 near Okanagan Lake. A list of the reviewed hydrometric stations is in Table 2-3 (Environment Canada, 2017).

Table 2-3: Hydrometric Stations (Environment Canada, 2017)

Station ID and Name	Drainage Area (km^2)	Period of Record (years)	Data Collection Type	Elevation (m)	Distance to City Core (km)
08NM119 Deep Creek at Armstrong [NOTE]	135	9 (1951-1959) 1 (1960) 3 (1961-1963) 4 (1964-1967) 9 (1974-1982)	Manual, Seasonal Manual, Continuous Manual, Seasonal Miscellaneous Manual, Continuous	~358	0.5 (at site)
08NM177 Deep Creek at Young Road [NOTE]	95	6 (1970-1975)	Manual, Continuous	~369	2.0 (upstream)
08NM075 Deep Creek Near Vernon (Station No. 3)	207	3 (1930-1932) 16 (1935-1950) 3 (1065-1967)	Miscellaneous Manual, Seasonal Miscellaneous	~351	11.2 (down-stream)
08NM153 Deep Creek at the Mouth	306	7(1969-1975)	Manual, continuous	~349	13.2 (down-stream)
08LC035 Fortune Creek Near Armstrong	41.2	2(1911-1912) 2 (1959-1960) 8 (1961-1968) 1 (1969) 2 (1970-1972) 2 (1973-1974) 8 (1977-1987)	Manual, Continuous Manual, Seasonal Manual, Continuous Manual, Seasonal Manual, Continuous Manual, Seasonal Manual, Continuous	~450	3.9
08NM020 B.X Creek Above Vernon Intake	57.5	6(1921-1927) 17(1959-1975) 24 (1976-1999)	Manual, Seasonal Manual, Continuous Recorder, Continuous	~575	16.6
08LC031	132.0	1(1949)	Miscellaneous	~356	8.1

Table 2-3: Hydrometric Stations (Environment Canada, 2017)

Station ID and Name	Drainage Area (km^2)	Period of Record (years)	Data Collection Type	Elevation (m)	Distance to City Core (km)
Fortune Creek at Stepney		10(1950-1959) 1(1960) 1(1961)	Manual, Seasonal Manual, Continuous Miscellaneous		
08NM142 Coldstream Creek Above Intake	60.6	26 (1967-1992) 7 (1993-2010) 2 (2011-2017)	Manual, Continuous Recorder, Continuous Recorder, Continuous	~600	22.4
08NM179 Coldstream Creek Above Kalavista	207	6(1970-1975) 1(1976) 6(1977-1982)	Manual, Continuous Seasonal, Continuous Manual, Continuous	~402	24.8
Note: Bolded station ID/names are within, or contain part of, the project's geographic study area.					

Three (3) temporary hydrometric stations were installed and maintained between April 13, 2018 to May 31, 2018. Onset Hobo Water Level Loggers were installed on Meighan Creek below Powerhouse Road and Deep Creek at Young Road and Adair Street. Hydrometric flow plots have been prepared and included in Appendix I.

Fifteen (15) temporary staff gauges were installed throughout the Meighan Creek and Deep Creek study area. These were installed upstream and downstream of critical cross sections and manually monitored from March 19, 2018 to May 31, 2018. The date, time, and local water depth were recorded and used for model calibration and flow estimation. Figure 2-4 illustrates some of these temporary staff gauges.

Figure 2-4: Typical temporary staff gauges installed

2.2.6 Aerial Photos, Satellite Photos & Land Use Mapping

Aerial and satellite photo input were used to review current and historical land use and cover characteristics. Sources included the Regional District of Okanagan's air photo imagery (RDNO, 2018), Google Earth satellite imagery (Digital Globe), Okanagan Timber supply area mapping and allowable annual cutting data (FLNRORD, 2017), range tenure mapping (MLFNRORD, 2018), and the City zoning and Official Community Plan maps (City of Armstrong, 2014). Tables 2-4 and 2-5 summarize the air and satellite photos reviewed.

Table 2-4: Meighan Creek Watershed Air and Satellite Photos

Year	Air Photo Description	Scale	Notes
1974	bc roll/frame:7675/223	1:16000	
1981	bc roll/frame:81025/45	1:20000	
1981	bc roll/frame:81025/46	1:20000	New roads/trails constructed
1981	bc roll/frame:81024/213	1:20000	
1981	bc roll/frame:81024/220	1:10000	
1981	bc roll/frame:81024/219	1:10000	
1981	bc roll/frame:81024/217	1:10000	
2004	bc roll/frame:04036/145	1:30000	New residential & commercial
2004	bc roll/frame:04036/146	1:30000	
2011	RDNO air photo	n/a	
2012	RDNO air photo	n/a	
2013	DigitalGlobe satellite photo	n/a	Timber harvesting (~140-150ha)
2016	DigitalGlobe satellite photo	n/a	

Table 2-5: Deep Creek Watershed Air and Satellite Photos

Year	Air Photo Description	Scale	Notes
1967	bc roll/frame:8/81	1:16000	
1981	bc roll/frame:81024/220	1:10000	
1981	bc roll/frame:81024/219	1:10000	
1981	bc roll/frame:81024/217	1:10000	
1989	bc roll/frame:965/8	1:15000	New commercial (minor)
1989	bc roll/frame:965/87	1:15000	New commercial (minor)
1989	bc roll/frame:965/115	1:15000	
1989	bc roll/frame:965/114	1:15000	
1989	bc roll/frame:965/113	1:15000	
1989	bc roll/frame:965/124	1:15000	
1989	bc roll/frame:965/125	1:15000	

Table 2-5: Deep Creek Watershed Air and Satellite Photos

Year	Air Photo Description	Scale	Notes
1989	bc roll/frame:965/126	1:15000	
1989	bc roll/frame:963/52	1:15000	
1989	bc roll/frame:963/53	1:15000	
1989	bc roll/frame:963/54	1:15000	
1997	bc roll/frame:97024/247	1:40000	Timber harvesting
1997	bc roll/frame:97024/248	1:40000	Timber harvesting (same)
1997	bc roll/frame:97024/267	1:40000	Timber harvesting (same)
1997	bc roll/frame:97024/267	1:40000	
2000	bc roll/frame:00102/92	1:10000	
2000	bc roll/frame:00102/28	1:10000	
2001	bc roll/frame:01025/11	1:30000	Timber harvesting (~120ha)
2001	bc roll/frame:01025/11	1:30000	Timber harvesting (same)
2004	DigitalGlobe satellite photo	n/a	Timber harvesting (~20-30ha)
2007	DigitalGlobe satellite photo	n/a	Timber harvesting (~60-80ha)
2016	DigitalGlobe satellite photo	n/a	
2018	DigitalGlobe satellite photo	n/a	Timber harvesting (~65-85ha)

In general, land use and cover have been relatively constant over the last 40-50 years. Therefore, the hydrological trend for Deep Creek and Meighan Creek sub-basins are expected to be relatively homogenous in consideration of land use.

Although some temporal variation in timber harvesting was noted, there were no significant long-term changing trends to land use activities related to timber supply and harvesting, impacts of pine-beetle, or residential and commercial development that would suggest a changing trend to watershed hydrology.

2.2.7 Inherent Flood Knowledge

As recommended by the Engineers and Geoscientists of British Columbia's flood mapping guidelines, inherent flood knowledge was collected from the public, City staff, and available historical news articles where possible (APEGBC, 2017). Knowledge collection of note includes a small archive of photographs, media reports, traditional knowledge, and other anecdotal information from the 2017 and 2018 flood events. This information was useful in supplementing other input information by verifying the extent of flooding impacts under known streamflow conditions.

2.3 Basin Drainage Areas

Considering only the geographic area of study above the Adair Street crossing on Deep Creek, the total drainage area was determined to be 135.0 kilometres squared (km^2). The total drainage and sub-basin areas were checked and confirmed by remapping existing watershed boundaries using provincially available 1:20000-scale TRIM contour and water line maps (Province of British Columbia, 2014).

Three characteristically distinct catchments were identified upon review of the subject drainage: 1) upper Meighan Creek sub-basin, 2) upper Deep Creek sub-basin, and 3) low lying farmland and development areas in the immediate vicinity of the City. The following sub-sections describe these catchments.

2.3.1 Upper Meighan Creek Sub-basin

The upper Meighan Creek sub-basin is the smallest contributing catchment of the three. With an area[12] of 12.0 km^2, the sub-basin accounts for approximately 9% of the contributing catchment area of the total subject drainage area. Based on TRIM water line mapping, the total length of the identifiable Meighan Creek measures to approximately 4 km. The location of the catchment is at the boundary between the Northern Columbia Mountains and Okanagan Highland hydrologic zones and has a maximum elevation of approximately 1570 m, a relief of 1025 m, and average streambed slope between 10-15%.

The uppermost headwaters consist of a flatter plateau-like summit that is drained by the steep and relatively incised stream channel below. Annual maximum streamflows typically occur in mid-April to mid-May and gradually reduce in the summer months. In spring, the watershed response time is short and measured to be in the range of 5-6 hours; conversely, in winter, the stream ceases to flow and precipitation accumulates as snow (refer to Appendix I for supporting data).

Based on input data described in previous sections, the watershed is predominantly forested and periodic timber harvesting is common. No clearcutting was observed in historical air photos; however, approximately 30% of the watershed had been selectively harvested in the 1930s and 1940s (Dobson Engineering Ltd., 1998). In 2013, approximately 12% was selectively harvested totalling approximately 140-150 hectares (ha) (Figure 2-5). Based on a watershed assessment conducted in 2015, this harvesting significantly increased the equivalent clearcut area (ECA) above the H40-line[13], and therefore, increased the potential for higher peak flows in the short-

[12] The area of the upper Meighan Creek sub-basin is referenced from the temporary streamflow logger location upstream of Highway 97A (below Powerhouse Road) at an elevation of approximately 545 m.
[13] H40 line refers to the elevation above which 40% of the watershed lies.

term[14] (Tolko Industries Ltd., 2015). Although impacts to peak flows due to increased ECA levels may contribute to short-term elevated peak flows, the current ECA levels identified in the Meighan Creek sub-catchment is consistent with historical norms for the period of record reviewed.

Figure 2-5: Typical timber harvesting in the Meighan Creek Watershed (2018)

2.3.2 Upper Deep Creek Sub-basin

The upper Deep Creek sub-basin is the largest contributing catchment. With an area[15] of 95.0 km^2, the sub-basin accounts for approximately 70% of the contributing catchment area of the total subject drainage area. Compared to the upper Meighan Creek sub-basin, it is eight (8) times larger.

Based on input data described in previous sections, periodic timber harvesting is common throughout the period of data reviewed and has remained relatively constant. Based on TRIM water line mapping, the total length of the identifiable Deep Creek measures to approximately 23 km, where the lower 18 km is relatively flat farmland having less than 200 m of total relief. The headwaters of the catchment originate west of Enderby, BC and east of Mount Ida having a maximum elevation of approximately 1570 m. From there, it flows southward towards Armstrong via the Tohuk valley through Sleepy Hollow and Hullcar farmland. Deep Creek flows year-round with annual maximum streamflows typically occurring in early-April to mid-

[14] Short-term refers to a period of 10-20 years based on the Meighan Creek watershed assessment report and other published data on ECA levels above the H40-line (Schnorbus, M.A., Winkler, R.D. and Y. Alila., 2004) (Austin, S. A., 1999).
[15] The area of the upper Deep Creek sub-basin is referenced from the temporary streamflow logger location upstream of Young Road at an elevation of approximately 369 m.

May due to spring snowmelt and rainfall. The watershed response time is significantly longer than the upper Meighan Creek sub-basin due to attenuation caused by the longer and flatter lower reaches. As a result, time of concentration for the Deep Creek storm hydrograph is estimated to be between 26-30 hours which is roughly five (5) times longer than Meighan Creek (refer to Appendix I for supporting data).

2.3.3 City of Armstrong

The City of Armstrong is located within the catchment area below the upper sub-basins. This area consists of a broad valley bottom with a relatively low gradient. Both the Meighan Creek and Deep Creek reaches through this area have average gradients of less than 1.5% with distinct low-lying wetland areas. Figure 2-6 illustrates a typical Deep Creek riparian and wetland area.

Note variation in vegetation between mid-April to mid-June

Figure 2-6: Typical riparian and wetland area through Armstrong, BC - Deep Creek (2018)

With the exception of riparian and wetland areas, 3.2 km^2 of this catchment consists of urban residential and commercial development. This area calculates to approximately 62% of the developed jurisdictional area of the City. As such, stormwater piping and ditches convey much of the runoff from this area. The creek reaches within this area are un-natural and consist of relatively straight excavated channels and a series of hydraulic structures. At the confluence of Meighan Creek and Deep Creek, both creeks are culverted and merge into a deep straightened earthen channel as illustrated in Figure 2-7. A copy of the City's stormwater map is included in Appendix VI for reference.

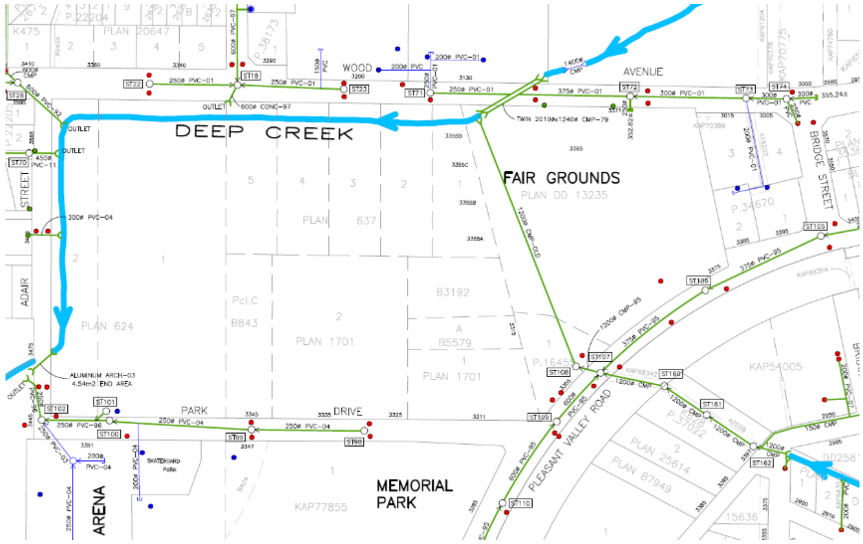


Figure 2-7: Un-natural creek with ditching and hydraulic infrastructure (City of Armstrong, 2016)

2.4 Selection of Flood Return Period and Map Type

In discussion, the City requested that flood mapping be prepared for the 1/200-year and 1/20-year floods to remain consistent with traditional provincial floodplain mapping[16], recent mapping projects conducted in the region, and Health Act requirements for septic systems[17]. In accordance with this request, this report includes both the 1/200-year and 1/20-year flood map sets.

These maps are intended to facilitate comprehension regarding the potential variability of flooding, as well as, provide the City with additional tools[18] to support the development of their IFMP.

2.5 Design Flood Determination

2.5.1 Selection of a Single Station Hydrologic Statistical Frequency Analysis

There are generally two approaches to estimating the magnitude of a design flood, either 1) hydrological statistical frequency analysis (HSFA) of streamflow data or 2) streamflow simulation analysis[19] (SSA) based on consideration of rainfall and snowmelt (NRC, 1989).

---

[16] Provincial floodplain mapping was formerly “designated”.
[17] The 1/20-year flood level is used in applying provincial Health Act requirements for septic tanks.
[18] Section 4 of this report explores non-structural risk mitigation options related to development bylaws. By having both the 1/200-year and 1/20-year flood mapping available, setbacks or flood construction levels for different types of construction can be easily specified by referencing one or the other map set.
[19] SSA is an approach that is independent of statistical analysis of streamflow and water level data. SSA requires input of meteorological data (often having a specified return period) into some form of basin model characterizing the response of the subject catchment upstream of the point of interest.

SSA is extremely sensitive to engineering judgement due to factors such as antecedent rainfall, soil moisture, volume and infiltration rate, and seasonal runoff response (Bedient, P, et al., 2008). Although SSA has its advantages, the available data described in Section 2.2 was not sufficient to adequately characterize the response of the subject drainage basins to support this approach. As such, an HSFA approach was the preferred and selected method due to the availability of useful hydrometric data.

The objective of HSFA is to interpret the past record of hydrologic events in terms of future probabilities of occurrence. The procedure involves selecting an available data series sample of hydrometric data, fitting a theoretical probability distribution to the data, and then making hypothetical inferences about the underlying population based on the fitted distribution (NRC, 1989). According to the National Research Council of Canada, the HSFA approach should consider whether single station and/or regional analysis should be used. Figure 2-8 illustrates a graphical representation of this guidance which suggests that either a single station or a combination of single station and regional analysis be implemented for the 1/20-year and 1/200-year design floods.

As the Deep Creek at Armstrong (ID 08NM119) historical WSC hydrometric station is located within the City and has the longest running period of record available within the geographic study area, the probabilities of the desired design flood outputs are plotted on Figure 2-8 for illustration. Of note, the boundary between Zone B and Zone C – the line between guidance to use either single station or a combination of single station and regional analysis respectively – is bounded by the function $T_d = 4N$, where N is the length of record. According to the Canadian Dam Association, this function can be re-arranged to 1/4N to represent the return period whereby the determination of the design flood can be confidently made based on a single station statistical analysis (CDA, 2007-2016). The application of the available length of record from Deep Creek at Armstrong (N=23) suggests that the design floods can confidently be estimated to a return period of 1/92-years provided the dataset is valid.

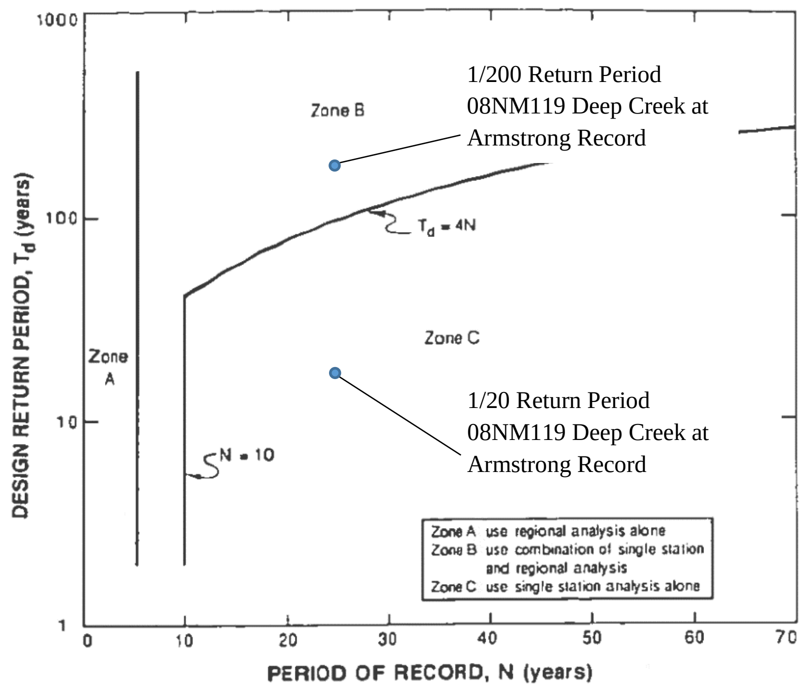
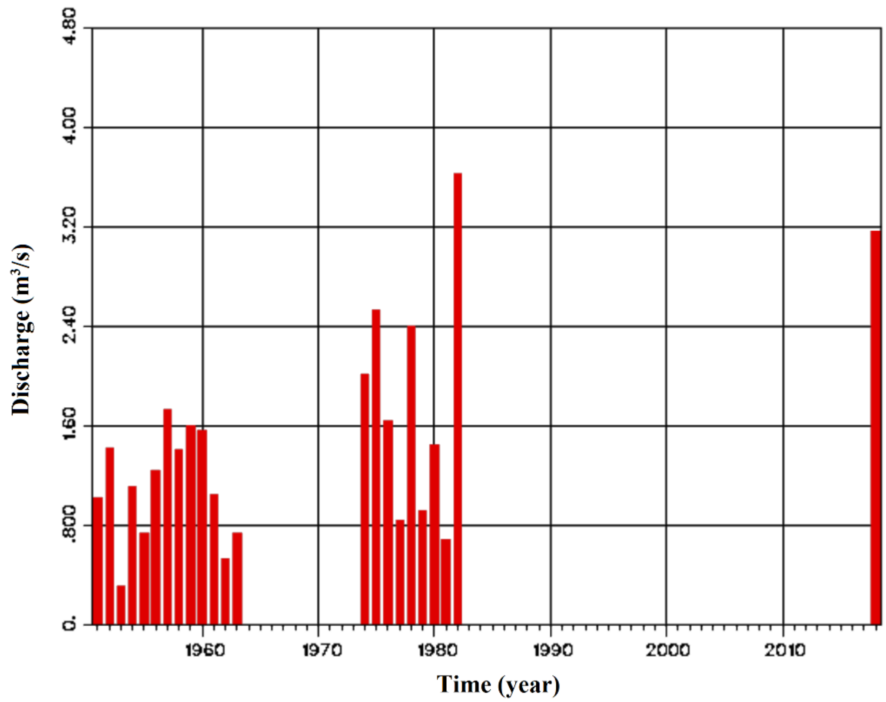


Figure 2-8: Guidance for reliance on single station and/or regional estimates - design return period vs period of record (NRC, 1989)

Although Figure 2-8 suggests that a regional analysis should be used to supplement the determination a single station HSFA for the 1/200-year design flood, it was determined that available data from Section 2.2 would not improve the result. As such, a single station HSFA approach was selected despite some uncertainty that is introduced by extrapolating beyond the 1/92-year return period.

2.5.2 Statistical Criteria and Tests

In order for the statistical frequency analysis to be valid, the hydrometric dataset must meet statistical criteria. The initial review of the identified no errors or outliers. Following this, the Run Test for General Randomness, Spearman Test for Independence, Mann-Whitney Split Sample Test for Homogeneity, and Spearman Test for Trend (stationarity) was used to test the dataset. Based on the results, the dataset was confirmed to be significantly random, independent, homogeneous and stationary and was determined to be valid. Appendix I includes a summary of the CFA-3 statistical test results. Figure 2-9 provides an illustrated summary of the dataset used in the analysis.



*Note: Figure includes a datapoint of 3.18 m^3/s for 2018.

Figure 2-9: Peak Annual Discharge vs. Year – Deep Creek at Armstrong (Station ID 08NM119)

2.5.3 Considerations for Missing Data

In a case where the dataset has missing data, consideration is to be given regarding whether the data is a broken record or incomplete record[20]. The NRC guidelines suggest that, "in the case of a broken record, the different record segments should normally be combined and treated as a continuous record, unless physical changes in the period between segments have produced non-homogeneity in the combined record" (NRC, 1989). As the dataset is a broken homogeneous record, the entire dataset (including the 2018 data point) was adopted and analyzed as a combined record.

2.5.4 Considerations for Historical Flood Records

Adding historical flood records[21] to a HSFA should be considered since it effectively extends the period of record and can increase the confidence of the estimated design flood (NRC, 1989) (USACE, 2016) (Environment Canada, 1993).

[20] A *broken record* is a record that has missing data due to maintenance issues such as financial or staff restraints. An *incomplete record* is a record that has missing data due to damage or data loss due to unusually large flood events.

[21] A *historical flood record* is a large flood that either predates the existing period of record or is a large flood that was not captured in missing data.

Based on inherent flood knowledge and other available data from Section 2.2, the only available information not contained within the record illustrated on Figure 2-9 was related to the flood of 2017. With the absence of this 2017 data point, Figure 2-10 illustrates the known floods by discharge and rank.

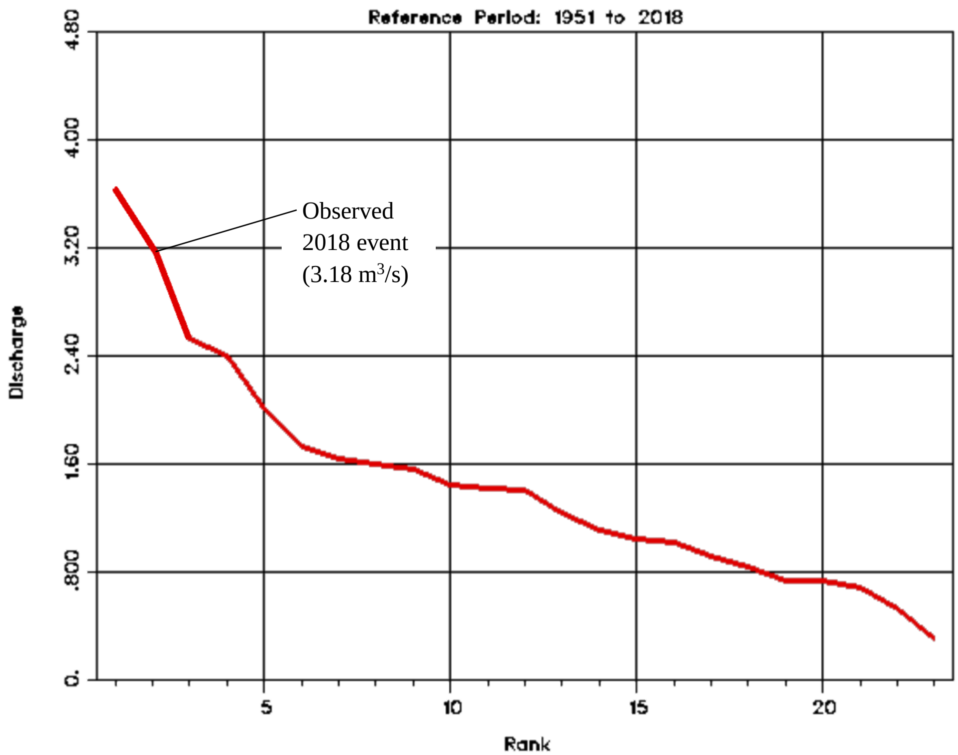


Figure 2-10: Discharge vs. Rank Plot – Deep Creek at Armstrong Station ID 08NM119

Since the absence of other large flood events during the years of missing data could not be definitively ascertained, the inclusion of a 2017 historical flood event estimate could cause the HSFA to underestimate the 1/200-year flood regardless of the selected historical threshold[22]. As such, the inclusion of historical floods of record were not included in the HSFA. For more information refer to Appendix I Table AI-1.

2.5.5 Hydrologic Statistical Frequency Analysis

Using the Environment Canada's Consolidated Frequency Analysis software version 3.1 (CFA-3) (Environment Canada, 1993) and the US Army Corps of Engineer's Hydrologic Engineering Center Statistical Software Package version 2.1.1 (HEC-SSP) (USACE, 2016), a statistical frequency analysis was conducted and verified using the continuous record summarized in Table

[22] The inclusion of historical flood records in an HSFA requires the selection of a threshold. This threshold is a value that assumes all floods exceeding this value to be "large" and assumes that no other large floods occurred within the *extended* period. If this assumption is incorrect, the solution will underestimate the design flood.

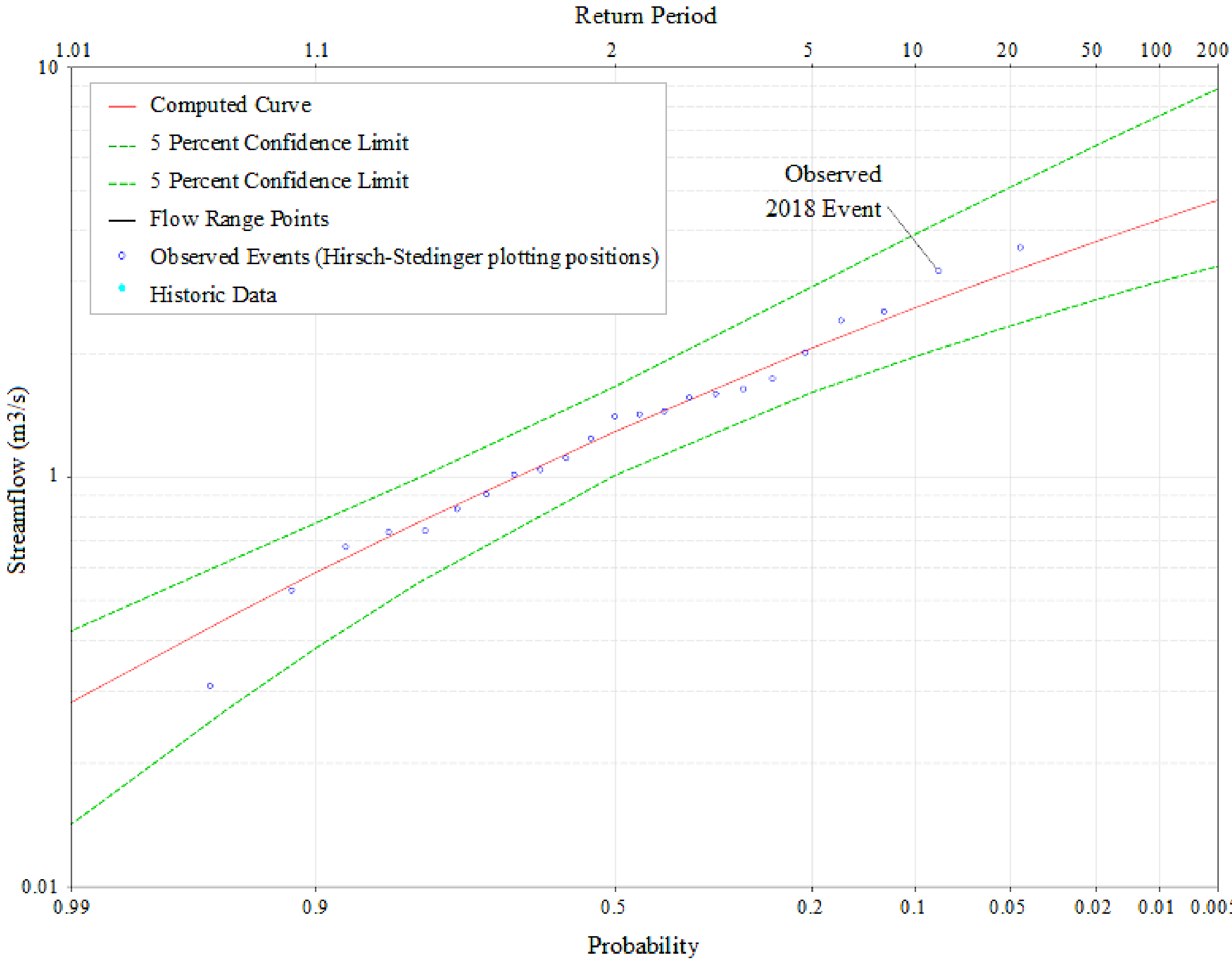
2-6 below. This record represents annual daily maximum streamflows collected at the Deep Creek at Adair Street location.

Table 2-6: Adopted Dataset for Single Station HSFA

Date	Annual Daily Maximum Streamflow (m3/s)
May 13, 1951	1.01
April 20, 1952	1.42
May 9, 1953	0.31
May 13, 1954	1.11
May 20, 1955	0.73
April 23, 1956	1.24
May 2, 1957	1.73
May 4, 1958	1.40
May 21, 1959	1.59
April 6, 1960	1.56
May 5, 1961	1.04
April 7, 1962	0.53
April 14, 1963	0.74
May 2, 1974	2.01
May 13, 1975	2.53
May 7, 1976	1.64
April 27, 1977	0.84
May 1, 1978	2.40
May 6, 1979	0.91
March 1, 1980	1.44
March 5, 1981	0.67
May 18, 1982	3.62
May 10, 2018	3.18 [NOTE]
NOTE: Datapoint was added to historical data from 2018 logger data for Deep Creek at Adair Street. The annual daily maximum was determined by averaging instantaneous streamflow by day and selecting the annual maximum.	

The dataset in Table 2-6 above was analyzed and fitted to the Log-Pearson III (LP3), Lognormal (3P), Gumbel Max (EV1), and the General Extreme Value. Based on a preference for a 3-parameter distribution, general acceptance of the distribution for flood frequency analysis, and goodness of fit tests, the LP3 distribution was selected.

Using HEC-SSP, a general frequency analysis of the continuous dataset was conducted in accordance with the new updated Bulletin 17C (USGS, 2018). Figure 2-11 illustrates the LP3 flood frequency plot solution.



Note: Discharge represents annual daily maximum streamflows not yet factored for climate change.

Figure 2-11: Flood Frequency Plot (LP3) – Deep Creek at Armstrong Station ID 08NM119

The expected value for the 1/20-year and 1/200-year annual daily maximum streamflows at Deep Creek at the Adair Street were determined to be 3.10 m^3/s and 4.75 m^3/s respectively. CFA-3 results verified this solution and are provided in Appendix I.

2.5.6 Consideration of Climate Change

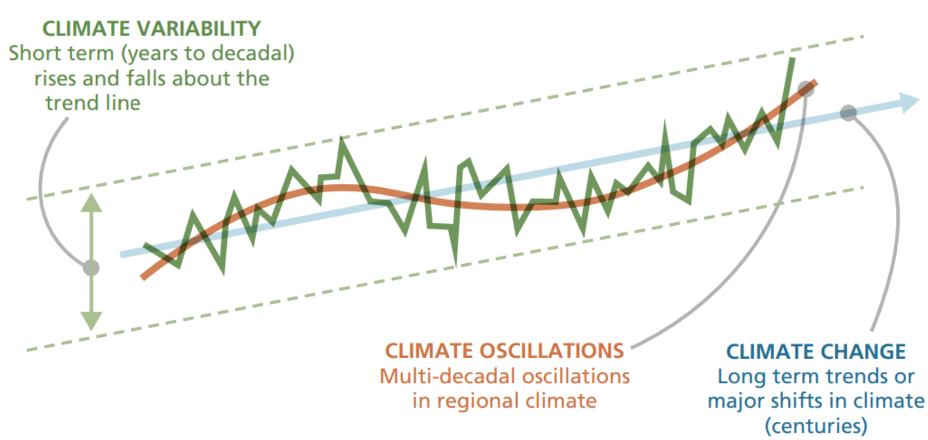
According to the BC flood mapping guidelines, there is a predicted "increase in the frequency and intensity of unusual weather events, including floods and droughts [and] changes in the amount and intensity of rainfall, changes in snowpack and temperature regime, insect infestations, and forest fires" (APEGBC, 2017). Although climate change is difficult to estimate and impossible to accurately predict, BC's Southern Interior has already experienced significant measurable climate change over the recent century with much of the observed change taking place during the period of record used. As such, consideration of the changing climate in the BC's Southern Interior is warranted.

Based on a recent 2016 update of the document entitled "Indicators of Climate Change for British Columbia", the following changing trends[23] have been identified for BC's southern interior and this project's geographic area of study (refer to Appendix I for supporting information) (Province of BC, 2018) (Province of BC, 2016):

- Based on available April 1st snowpack data, there is a trend of -7% snow depth and -11% snow water equivalent per decade for the Southern Interior;
- The springtime average precipitation increase for the Southern Interior is +32% per century; and
- The springtime average temperature increase for the Southern Interior is +1.2˚C per century.

Springtime floods in smaller watersheds, similar to that of Meighan Creek and Deep Creek, may become more rain-dominated and could have potentially higher peak flows due to increased storm precipitation intensity and warmer temperatures (EGBC, 2018). If winters continue to warm and snow-water equivalent continues to decrease, freshet flows would occur earlier, and the total freshet volume would be reduced. As such, any prediction regarding the impact to the potential flood magnitude would be difficult to ascertain based on the combined impact of changing temperature, rainfall and snowpack.

When reflecting on historical climate data, it is important to consider climate variability, climate oscillations, and climate change. Figure 2-12 provides a graphical representation of these below.



Note: Adapted from original.

Figure 2-12: Climate variability, oscillations and change (Province of BC, 2016)

As shown in Figure 2-12, climate data may have considerable climate variability; yet, may not exhibit climate change. For an upward trend to be identified (such as is shown by the blue line in Figure 2-12), a long-running dataset must identify a statistical upward trend.

[23] Only trends associated with the project's geographic study area that are applicable to spring freshet have been listed.

Despite identified trends in temperature, rainfall, and snowpack, the HSFA solution found in Section 2.5.6 did not identify any trend based on annual daily maximum streamflows; however, that is not to say that one does not exist. According to the BC legislated flood assessment guidelines, “if no historical trend is detectable [and] when local or regional streamflow magnitude frequency relations are used, apply a 10% upward adjustment in design discharge to account for likely future change in water input from precipitation” (EGBC, 2018). As no trend was detected in the statistical analysis, a 10% (1.1 times factor) was applied to the 1/20 and 1/200-year maximum daily streamflows to account for this uncertainty.

The resulting climate-factored 1/20-year and 1/200-year annual daily maximum streamflows at Deep Creek at the Adair Street were determined to be 3.41 m^3/s and 5.22 m^3/s respectively.

2.5.7 Hydrograph Development

According to the Canadian Dam Association, the design hydrograph may be chosen using a synthetic hydrograph or a historic hydrograph (CDA, 2007-2016). In the absence of a valid basin model or synthetic hydrographs, the hydrographs captured from the temporary 2018 Meighan Creek and Deep Creek upper sub-basin loggers were used.

As the factored 1/20-year and 1/200-year solution from Section 2.5.6 relies on annual daily maximums, the comparison between 2018 logged streamflow data required conversion to annual daily maximum data. As such, instantaneous streamflow hydrographs from the 2018 Meighan Creek and Deep Creek logger data were averaged for the 24-hour period of the 2018 maximum daily record for the Deep Creek at Adair location. The resulting 2018 annual daily maximum streamflows for Meighan Creek and Deep Creek were calculated to be 0.76 m^3/s and 2.42 m^3/s respectively.

Conservatively assuming[24] that the annual daily maximum streamflow at the Deep Creek at Adair Street location would equal the sum of the daily maximums from both the upper Meighan Creek and upper Deep Creek sub-basins ($Q_{D@A} = Q_1 + Q_2$), a ratio between the 2018 annual daily maximum streamflow at Deep Creek at Adair street to the 2018 daily maximum streamflows for each sub-basin can be calculated. This is given by the following equation:

$$R_{Q_1/Q_{D@A}} = \frac{Q_1}{(Q_1+Q_2)} \qquad \text{[Equation 1]}$$

Where:

[24] This assumption will be used to calculate the input hydrographs to be used in the hydraulic model. By assuming that the upper sub-basins have a flow equal to the flow at Adair Street in Armstrong, runoff contributions from the lower Armstrong catchment are conservatively assumed to be already contained within the streamflow at the upper sub-basin stream logger locations (refer to Figure 2-1 in Section 2.1 for map reference).

$R_{Q_1/Q_{D@A}}$ = Ratio between sub-catchment 1's daily maximum to daily maximum on Deep at Adair (m^3/s),
Q_1 = 2018 daily maximum of sub-catchment 1 (m^3/s); and
Q_2 = 2018 daily maximum of sub-catchment 2 (m^3/s).

Based on Equation 1, the ratio of the Meighan Creek and Deep Creek sub-basin's daily maximum streamflows to the daily maximum streamflows of Deep Creek at Adair Street are calculated to be 0.239 and 0.761 respectively. Table 2-7 summarizes a comparison check between the annual daily maximum streamflow values logged for 2018 to values logged from Station 08NM177 (Deep Creek at Young Road) and Station 08NM191 (Deep Creek at Armstrong) for the flood of 1975.

Table 2-7: Validation of Ratio between Deep Creek Daily Streamflows at Adair Street and Young Street

	Deep Creek daily maximum at Adair Street (m^3/s)	Upper Deep Creek daily maximum at Young Road (m^3/s)	Ratio
1975	2.53	1.93	**0.763**
2018	3.18	2.42	**0.761**

Based on the results from Table 2-7, the assumption of Equation 1 is validated. Therefore, we can assume that the ratio between the 2018 daily maximum streamflow, in either sub-basin, could be increased proportionately to the difference between the 2018 and 1/20 or 1/200-year daily maximum floods on Deep Creek at the Adair Street location. Table 2-8 summarizes the application of this assumption and the calculation of the ratios:

Table 2-8: Ratio between 2018 and the 1/20 and 1/200-year Daily Streamflows at Adair Street

Flood	Streamflow (m^3/s)	Ratio to 2018 Streamflow (unitless)
2018	3.18	**1.000**
1/20-year	3.41	**1.072**
1/200-year	5.22	**1.642**

Based on Table 2-8, the 2018 hourly instantaneous hydrographs were adopted and multiplied by the ratios 1.072 and 1.642 for the 1/20-year and 1/200-year design floods respectively. A total hydrograph length of 72-hours was used spanning from May 9, 2018, to May 11, 2018. A graphical copy of the 72-hour hydrographs are included in Appendix I.

2.6 Model Development

To accurately model flood conditions and generate flood maps, a hydraulic computer model was required. Hydraulic models typically range from simple steady-state one-dimensional (1D) models to dynamic or unsteady-state two-dimensional (2D) models. Available software to construct and simulate these models can vary significantly in cost and capability with licensing that may be proprietary or open-source.

2.6.1 Software Selection

For this project, an open-source based model was preferred to facilitate data sharing and future use by the City. As well, the project required a 2D dynamic hydraulic model because the hydrographs adopted from Section 2.5.7 are relatively short duration with quickly rising flood peaks. Although 2D dynamic models are more complex, a dynamic model is capable of accounting for the attenuation of the flood hydrograph through hydraulic structures, as well as, accurately modelling the flooding in ineffective areas.

To accurately characterize the large number of hydraulic structures in both the Meighan Creek and Deep Creek reaches, the channels and structures had to be constructed in 1D. This approach was ideal as it facilitated the importation of surveyed creek cross-sections and produced a model that is more flexible for future simulation of sediment removal and accumulation in both the channels and culverts.

Due to the requirements above, the Hydrologic Engineering Centers River Analysis System (HEC-RAS) Version 5.0.4 was selected. HEC-RAS is a software package developed by the US Army Corps of Engineers (USACE) and has been developed to manage rivers, harbours, and other public works under their jurisdiction. The HEC-RAS software has found wide acceptance among hydraulic engineers and researchers due to its robust channel flow analysis capabilities and its ability to determine floodplain areas using 1D and 2D state modelling routines – thus making the software ideal for this exercise.

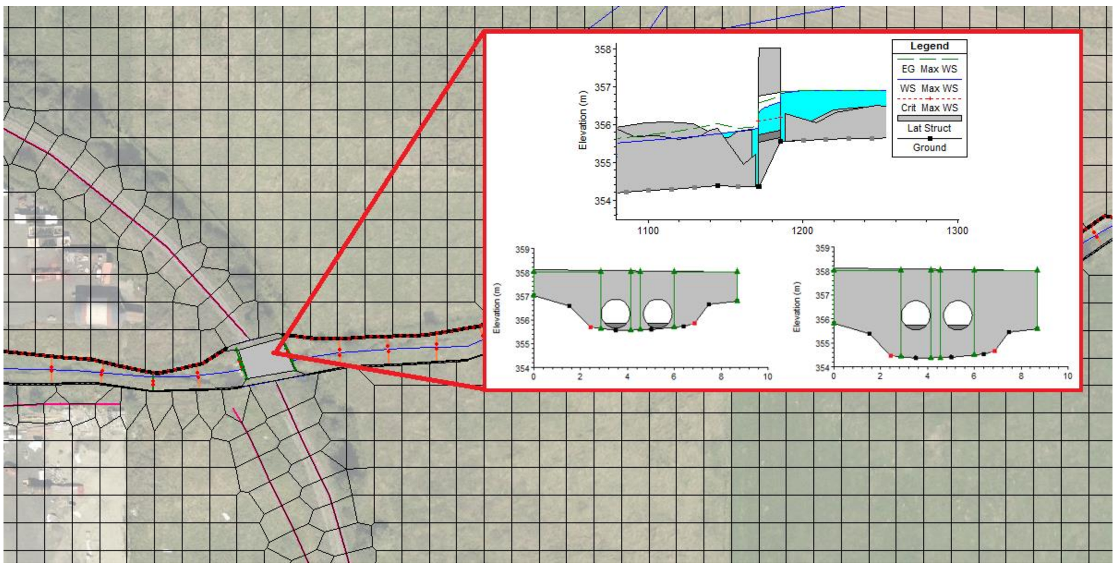
2.7 Model Construction

The information described in Section 2.2 was used to construct the model in accordance with user reference manuals (USACE, 2016) (USACE, 2010) (USACE, 2014).

2.7.1 1D and 2D Geometry

1D channel sections were constructed and connected to 2D floodplains using lateral weir structures characterized by coefficients and geometry parameters consistent with the adjacent 2D floodplain. 2D floodplains were modelled using 2D mesh geometries having between 5 m and 8 m wide grids. These grids directly referenced bare earth LiDAR and friction factors were applied to characterize land cover type (see Appendix I for values used). Where 2D barriers or potential drainage ditches were identified, 2D breaklines were used to ensure natural barriers and flow channels would be registered within the 2D geometries.

Other 1D geometry, such as channels, culverts, and bridges, was constructed using available records and collected field data described in Section 2.2. If sediment deposits were identified, these were also included. All components were constructed as per USACE guidelines and later calibrated. Figures 2-13 graphically illustrates these features as they appear in the hydraulic model (See CN railroad crossing on Deep Creek below).



Note: Figure was modified to show various input components in one image.

Figure 2-13: Typical 1D and 2D geometry component showing culverts, sediment buildup, ineffective flow areas, lateral structures, and breaklines

Friction coefficients for culverts, channels, and 2D overland flow areas were initially selected based on average recommended values from the HEC-RAS user manual (See Appendix I for a summary of friction factor ranges used). Overland flow areas conservatively assumed late-spring vegetated density for channel banks since the risk of flooding is possible as late as early June. Culvert and channel bottom manning coefficients were reserved for adjustment during model calibration.

2.7.2 Boundary Conditions

The model has various boundaries conditions to control the input and output of water. The input is defined by the flood hydrographs (from Section 2.5.7), and the output is defined by the capacity of the downstream channel (1D) and overland flow areas (2D).

The model has two 1D upstream boundaries, one on the Meighan Creek channel below Powerhouse Road and one on the Deep Creek channel above Young Road. Both of these upstream boundaries were selected to coincide with the temporary stream loggers (see Section 2.1 map for reference).

There are three downstream boundaries, one on each of the two overland flow areas (2D) and one on the Deep Creek channel (1D). Both boundaries are located approximately 1320 m downstream of Adair Street on Deep Creek at a private access road southwest of the City. These boundary conditions are both set to normal depth based on average slopes downstream of the geographic investigation area.

2.8 Model Simulation

2.8.1 Sensitivity Analysis

The model iteratively simulated a trial and error approach under Deep Creek and Meighan Creek calibration storms, one parameter adjusted at a time. Parameters were only adjusted within the recommended ranges as per the HEC-RAS manual guidelines (USACE, 2016) (USACE, 2010). As a result, the model was determined to be most sensitive to the variability of partial bury/sediment accumulation in culverts and the downstream boundary conditions. For this reason, careful engineering judgement was given when determining reasonable debris buildup in culverts and the setting of downstream boundary conditions.

The assumed depths of debris buildup in culverts relied on measured field observations and calibration limited to 10% of the total depth. Downstream boundary conditions were carefully adjusted based on field survey and flooding observations under the 2018 flood conditions at 2615 Otter Lake Road residential crossing. Figure 2-14 shows a panoramic photograph of this section.

Figure 2-14: Downstream boundary control section at 2615 Otter Lake Road (April 27, 2018)[25]

[25] A panoramic photograph of the downstream control section taken during the City's local state of emergency 13 days prior to Meighan peak flow of 2018. For reference, the photo is taken looking southeast and Armstrong is upstream is to the left of the photo. The photo depicts the residential access at near-overtopping conditions with deep ponded flooding both upstream and downstream.

Other notable sensitivities in the model, although moderate, included entrance losses (more sensitive under submerged inlet flooding conditions when inlet controlled) and one-dimensional (1D) channel manning coefficients (friction factors). The sensitivity of all other variables was determined to be negligible within the recommended ranges.

2.8.2 Model Calibration

Model calibration simulated the hourly streamflow hydrographs from the Meighan Creek and Deep Creek loggers between April 16, 2018, and April 22, 2018. This period was ideal as it had relatively flat multi-day hydrographs that contained relatively high combined streamflow which was not directly impacted by any significant rainfall. All other periods from 2018 either had lower flow or was affected by emergency activities conducted by the City (refer to Section 1.1 for details on the temporary culvert diversions conducted on Meighan Creek).

With the multi-day hydrograph simulation complete, various reference times and locations along the creek reaches were then compared to field water elevation measurements collected from the fifteen (15) temporary staff gauges (refer to section 2.2.6 for information on temporary staff gauges). Through an iterative process, channel and culvert friction factors were adjusted within the recommended ranges to match field measurements.

As a result, Deep Creek required minor modification and typical channel manning coefficients were in the range of 0.030 and 0.040 as expected; however, Meighan Creek required a substantial increase. Typical channel manning coefficients were in the range of 0.080 to 0.140 with a short portion between downstream of Meadow Creek Lane to just beyond Okanagan Road requiring coefficients even higher as this portion was heavily impacted by sediment deposition and vegetation growth. This portion used the maximum recommended value of 0.200 representing dense willows. Figure 2-15 and 2-16 depicts a section of this reach under flood and low flow conditions.

Figure 2-15: Just upstream of Okanagan Road on Meighan Creek – flood flow conditions (March 23, 2018)

Figure 2-16: Sediment deposition and heavy vegetation growth in thalweg just upstream of Okanagan Road on Meighan – low flow conditions (April 7, 2018)

Culvert crossings required little adjustment to the friction and entrance loss coefficients. Some required minor modification to the depth of sediment deposition at most crossings but these were considered minimal and similar to field observations. All modifications to sediment deposition were limited to 10% of the total depth measured in the field. Figure 2-17 illustrates some typical sediment deposition identified in the field.

Figure 2-17: Sediment deposition in culvert – Wood Avenue right culvert shown

2.8.3 Consideration of Future Floodplain and Stream Channel Adaptation

Future adaptation to the floodplain and stream channels may include sediment deposition, vegetation encroachment, lack of maintenance to culvert and bridge, and the development of roads, structures, or temporary emergency flood protection works. These adaptations may have the potential to increase the extent of flooding or may transfer it to a less flood-prone area.

For this project, short-term development of new roads and structures was determined to be minimal based on historical rates of change and available development area within the floodplain. As such, flood modelling analysis included no modifications to the number of structures or the location or elevation of roads. In comparison, adaptation to the stream channel due to vegetation encroachment, sediment deposition, and maintenance of culvert and bridge crossings was assumed to have a large impact[26] based on current conditions.

Although plans to implement vegetation management, dredging, maintenance to culvert and bridge crossings, and construction of minor structural modifications to culverts are likely to occur in the near future, it was assumed that current conditions[27] are representative of a somewhat conservative and reasonable future adapted states. As it is likely that past emergency responses can be successfully applied in future flood events, the simulation of multiple flood scenarios with current conditions has various partially blocked[28] and or partially filled culverts

[26] Section 2.8.1 identified the model to be sensitive to depths of debris buildup in culverts.
[27] For a description of current conditions of the watershed and stream channels, see Section 2.
[28] The Meighan Creek and Highway 97 culvert crossings between Rosedale Road East and Pleasant Valley Road were modelled with 90% flow blockage and 90% partially buried culvert conditions respectively to mimic successful emergency flood mitigation activities conducted by City of Armstrong crews. Maximum water depths

and bridge crossings. Outputs from all modelled simulations were then combined using graphical interface software (GIS) to generate a combined representation of potential flooding. These combined output layers were then used to generate the flood maps and GIS files as described later in this section.

2.9 Flood Mapping Output

In accordance with the scope of work and requested deliverables, the report includes both inundation and hazards maps for the 1/20-year and 1/200-year floods. All model output files and plots where prepared using the open source Quantum Geographic Information System Software Version 3.4.2 (QGIS) and horizontal and vertical control datums used were the North American Datum of 1983 (NAD83) and Canadian Geodetic Vertical Datum of 1928 (CGVD28) respectively. In conformance with BC mapping guidelines, the Universal Transverse Mercator (UTM) projection for topographic mapping was selected and coordinate grids expressed in metres as northings and eastings are shown on all flood plots (APEGBC, 2017).

2.9.1 Inundation Maps

Topographic maps have been prepared to show the extent of floodwater under the two defined 1/20-year and 1/200-year design floods. These maps illustrate the delineated floods and show the maximum geodetic water elevation and total depth. The following list provides a summary of the inundation plots prepared and included in Appendix II:

- Water Surface Elevation – 20 Year Inundation Mapping
    - Key Map – Water Surface Elevation (Scale 1:20000)
    - Map No. 1D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 2D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 3D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 1M – Meighan Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 2M – Meighan Creek – Water Surface Elevation (Scale 1:5000)

- Water Surface Elevation – 200 Year Inundation Mapping
    - Key Map – Water Surface Elevation (Scale 1:20000)
    - Map No. 1D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 2D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 3D – Deep Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 1M – Meighan Creek – Water Surface Elevation (Scale 1:5000)
    - Map No. 2M – Meighan Creek – Water Surface Elevation (Scale 1:5000)

- Flood Depth – 20 Year Inundation Mapping
    - Key Map – Flood Depth (Scale 1:20000)

and velocities were combined to other flood simulations to include this transitioned flood potential from these adaptations.

   - Map No. 1D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 2D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 3D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 1M – Meighan Creek – Flood Depth (Scale 1:5000)
   - Map No. 2M – Meighan Creek – Flood Depth (Scale 1:5000)

- Flood Depth – 200 Year Inundation Mapping
   - Key Map – Flood Depth (Scale 1:20000)
   - Map No. 1D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 2D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 3D – Deep Creek – Flood Depth (Scale 1:5000)
   - Map No. 1M – Meighan Creek – Flood Depth (Scale 1:5000)
   - Map No. 2M – Meighan Creek – Flood Depth (Scale 1:5000)

Digital copies of the plots have been included on DVD and included with the hard-copy report.

2.9.2 Hazard Maps

Hazard maps are maps that go beyond inundation maps by providing information on the hazards associated with defined flood events, such as water depth and velocity. For this project, maps have been prepared to illustrate the depth, velocity, and hazard rating (HR) of floodwater in the plan under the two described 1/20-year and 1/200-year defined flood events.

HR is illustrated only for the for the hazard plots. HR is a numerical value that is calculated based on the depth and velocity. This value is intended to convey an understanding of the potential of a flood to inflict a negative impact. HR is defined by the following equation:

$$HR = d \times (v + 0.5) + DF \qquad \text{[Equation 2]}$$

Where:
HR = flood hazard rating,
d = depth of flooding (m),
v = velocity of flood waters (m/s), and
DF = debris factor (0 in this case)

The following list provides a summary of the depth, velocity and HR plots prepared and included in Appendix II:

- Hazard Index – 20 Year Hazard Mapping
    - Key Map – Hazard Index (Scale 1:20000)
    - Map No. 1D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 2D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 3D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 1M – Meighan Creek – Hazard Index (Scale 1:5000)
    - Map No. 2M – Meighan Creek – Hazard Index (Scale 1:5000)

- Hazard Index – 200 Year Hazard Mapping
    - Key Map – Hazard Index (Scale 1:20000)
    - Map No. 1D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 2D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 3D – Deep Creek – Hazard Index (Scale 1:5000)
    - Map No. 1M – Meighan Creek – Hazard Index (Scale 1:5000)
    - Map No. 2M – Meighan Creek – Hazard Index (Scale 1:5000)

Digital copies of the plots have been included on DVD and included with the hard-copy report.

2.9.3 GIS Mapping Files

The following GIS data was digitally prepared and exported as follows:

- Water Surface Elevation File
    - Filename: Armstrong-20YearWSE – Geotiff Raster Format (NAD83 UTM 11N)
    - Filename: Armstrong-200YearWSE – Geotiff Raster Format (NAD83 UTM 11N)
- Flood Depth File
    - Filename: Armstrong-20YearFD – Geotiff Raster Format (NAD83 UTM 11N)
    - Filename: Armstrong-200YearFD – Geotiff Raster Format (NAD83 UTM 11N)
- Hazard Index File
    - Filename: Armstrong-20YearHI – Geotiff Raster Format (NAD83 UTM 11N)
    - Filename: Armstrong-200YearHI – Geotiff Raster Format (NAD83 UTM 11N)

GIS mapping files have been included on DVD and included with the hard-copy report.

3 FLOOD RISK ASSESSMENT

According to the Engineers and Geoscientists of British Columbia's flood assessment professional practice guidelines, *risk* is defined as "a measure of the probability and severity of an adverse effect to health, property, or the environment [and] is often estimated by the product of probability and consequence" (EGBC, 2018).

In alignment with this project's purpose and scope, a risk assessment has been conducted using the probability of occurrence of the 1/200-year flood hazard (0.05) and the estimated consequence of that event. The risk assessment is in alignment with NDMP funding guidelines and other industry best practices. As such, this risk assessment contains the following components (Government of Canada, 2018) (EGBC, 2018):

1) identification of the potential hazard (*risk identification*);
2) determination of the probability of the flood occurring (*risk analysis*);
3) estimation of potential flood impact from the flood hazard (*risk evaluation*);
4) determination of the flood risk (*risk evaluation*); and
5) review of the community's vulnerabilities (*risk evaluation*).

By using the 1/200-year flood depth and hazard maps (covered in Section 2 of this report), the *risk identification* and *risk analysis* portions of the assessment are complete as 1) the potential hazard is defined by the depth and hazard maps, and 2) the probability of the flood occurring is 0.05 (or 1/200). The remainder of this section forms the *risk evaluation* components of the risk assessment.

The following sub-sections provide high-level estimations of potential flood impact for various loss categories. The loss categories included in this assessment are as follows:

- Impact on Local Infrastructure;
- Impact on Environment and Cultural Values;
- Impact on People and Society; and
- Impact on Local Economy.

The information contained in this section is to implement an IFMP and direct flood mitigation planning and decision making only. This information is based on high-level estimates, therefore general information and discussion regarding existing infrastructure components are not to be considered design review of those components; rather, it is intended to provide a general understanding of potential risk associated with the conventional flood hazard from Meighan Creek and Deep Creek.

3.1 Impact to Local Infrastructure

Some local infrastructure is fundamental to the viability and sustainability of the City's community. Based on NDMP guidelines, the infrastructure reviewed includes local electrical power, transportation, wastewater, potable water, natural gas and telecommunication systems.

3.1.1 Electric Power System

A high-level impact estimate considering local power infrastructure used the Department of Homeland Security's Federal Emergency Management Agency's (FEMA) Multi-hazard Loss Estimation Methodology data. Table 3-1 provides functionality thresholds and damage functions from that document.

Table 3-1: Electrical Power Components - Functionality Thresholds and Damage Function

System Component	FTA[1] (m)	Percent Damage by depth of flooding[2] (m)										
		0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Substation (low / medium / high voltage)	0.2	0	2	4	6	7	8	9	10	12	14	15
Distribution Circuits Elevated Crossings	n/a	0	0	0	1	1	1	1	2	2	2	2
Distribution Circuits Buried Crossings	n/a	0	0	0	0	0	0	0	0	0	0	0
Distribution Circuits (non-crossings)	n/a	0	0	0	0	0	0	0	0	0	0	0
Power Plants (small / medium / large)	1.2	0	2.5	5	7.5	10	12.5	15	17.5	20	25	30

NOTE1 Functionality Threshold Depth (FTA) refers to the depth of water where the water system component ceases to function. Table has been adapted to assume 0.2 m FTA for substation due to the length of warning and the likelihood of a proactive shut-down.
NOTE2 Assumes electrical switch gear is located 1.2m above grade.

The 1/200-year flood hazard maps were compared to known locations of key electrical power infrastructure. Overlap was identified at the Armstrong Substation as well as at various points of the distribution system. As the depth of flood water in all overlap areas was below 0.6 m, it is estimated that only the substation might be impacted. Based on Table 3-1, the substation was assumed to be temporarily shut-down, and a 2% percent damage was selected. Table 3-2 below provides an estimate of the total losses.

Table 3-2: Electrical Power Loss Estimation

Loss Component	Capital Cost[1]	Loss Percent	Loss Estimate[2]
Substation	$10,000,000	2%	$200,000
		TOTAL	**$200,000**

NOTE1 Capital costs are based on recommended FEMA Hazus Valuation for a low-voltage sub-station (FEMA, 2001).
NOTE2 Loss estimate is calculated in 2018 dollars.

Although FEMA's capital cost estimate may overestimate the cost of the Armstrong Substation, it does not include lost revenue or other indirect impacts caused by a prolonged electrical power shutdown. As this station powers approximately 8000 homes and many businesses in the vicinity of Armstrong, a prolonged shut-down would slow flood response and impede vital activities that are essential for the community's sustainability. As well, smaller residential and industrial sub-systems that rely on its electrical power, such as septic, storm, industrial or municipal wastewater treatment, fuel delivery, or any other electrical systems, may cause other indirect impacts.

3.1.2 Transportation System

The flood hazard overlaps a network of transportation infrastructure including City roads, a provincial highway and a CN railroad. According to the BC consequence guideline for dams, roads and railroads are classified differently to facilitate consequence estimation. Roads are broken up into five classes: 1) primary highways, 2) secondary highways, 3) major roads, 4) minor roads, and 5) local roads. Railroads are classified as either major or minor. Of note, the portion of CN railroad in Armstrong is considered a minor railroad and Highway 97A is considered a Secondary Highway.

To estimate the impact of the flood hazard to roads and railroads, the assessment assumes that any transportation crossing overtopped by the flood hazard is at risk of washout. As such, Table 3-3 summarizes the Meighan Creek and Deep Creek crossings and identifies whether or not they at risk of washout.

Table 3-3: Transportation Crossings – Washout Risk Identification

Infrastructure Crossing Name	Road Class	Washout Risk?
MEIGHAN CREEK		
Powerhouse Road	Local Road	**Yes**
Highway 97A	Secondary Highway	No
Highway 97A	Secondary Highway	No
Rosedale Road East	Local Road	No
Highway 97A/Smith Drive	Secondary Highway/Local Road	No
Meadow Creek Lane	Local Road	No*

Table 3-3: Transportation Crossings – Washout Risk Identification

Infrastructure Crossing Name	Road Class	Washout Risk?
Okanagan Street	Local Road	**Yes**
Patterson Road / CN Rail / Pleasant Valley Road	Local Road / Minor / Local Road	No
DEEP CREEK		
Young Road	Local Road	No
CN Rail	Minor	No
Okanagan Street	Local Road	**Yes**
Wood Avenue	Local Road	**Yes**
Adair Street	Local Road	**Yes**
*Crossing gets overtopped in a round-about way that would not likely cause wash-out. NOTE Only crossings within the study area are listed.		

It was assumed that all crossings at risk would have a 50% chance of washout. For simplicity, washout loss estimates were assumed to be in line with bridge crossings replacement costs for low volume local creek bridges as described by the BC Construction and Rehabilitation Cost Guide. Using a replacement value of $2,950/m^2 per deck surface area[29] and an average deck area of 80 m^2, the loss estimate for a washed-out road was determined to be $236,000 (MOTI, 2013). Table 3-4 below summarizes the calculation of total losses.

Table 3-4: Transportation Infrastructure Loss Estimation

Loss Component	Capital Cost[1]	Loss Probability	Loss Estimate[2]
Powerhouse Road	$236,000	50%	$118,000
Okanagan Street (Meighan)	$236,000	50%	$118,000
Okanagan Street (Deep)	$236,000	50%	$118,000
Wood Avenue	$236,000	50%	$118,000
Adair Street	$236,000	50%	$118,000
		TOTAL	**$590,000**
NOTE1 Capital costs are based on the BC Construction and Rehabilitation Cost Guide for low volume creek bridges (MOTI, 2013). NOTE2 Loss estimate is calculated in 2018 dollars.			

Since all impacts to transportation infrastructure are to local roads, the impact would be limited to the City and would not have provincial or national impacts (FLNRORD, 2016). Although the loss of function to one or more roads is possible, there are alternate routes available for all road crossings at risk. As such, the indirect impact to the community due to loss of transportation infrastructure was assumed to be limited to the direct cost of replacement.

[29] Value includes mobilization, traffic management and quality management and is adjusted for inflation.

3.1.3 Wastewater System

The City has approximately 29 km of wastewater distribution piping. This piping conveys raw sewage and industrial wastewater to a Wastewater Treatment Plant (WWTP) located on Adair Street directly adjacent to Deep Creek. The WWTP services a population of approximately 5,000 and handles an average daily wastewater flow rate of 2,200 m^3/day (Opus Daytonknight Consultants Ltd, 2014).

By comparing the 1/200-year delineated flood hazard to the location of existing wastewater infrastructure, a high-level impact estimate was conducted using the FEMA Multi-hazard Loss Estimation Methodology data. According to this guideline, the impact to functionality and damage to wastewater infrastructure components can be estimated based on flood water depth. Functionality thresholds and damage functions used in the analysis are provided below in Table 3-5.

Table 3-5: Wastewater Components - Functionality Thresholds and Damage Function (FEMA, 2001)

System Component	FTA[1] (m)	Percent Damage by depth of flooding[2] (m)										
		0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Collector at River Crossings (exposed / buried)	n/a	0	0	0	0	0	0	0	0	0	0	0
Pipes at River Crossings	n/a	0	0	0	0	0	0	0	0	0	0	0
Pipes (non-crossings)	n/a	0	0	0	0	0	0	0	0	0	0	0
Wastewater Treatment Plants (small / medium / large)	0	0	5	8	10	17	24	30	30	30	30	40
Control Vaults and Control Stations (all)	0	0	40	40	40	40	40	40	40	40	40	40
Wet well / Dry Well Lift Station (all)	1.2	0	0	0	0	40	40	40	40	40	40	40
Submersible Lift station (all)	n/a	0	0	0	0	10	10	10	10	10	10	10

NOTE1 Functionality Threshold Depth (FTA) refers to the depth of water where the water system component ceases to function.
NOTE2 Assumes electrical switch gear is located 1.2 m above grade.

Based on the above, components of the piped wastewater distribution network and WWTP were identified within the extents of the flood hazard. Applying Table 3-1 functionality thresholds and damage functions for buried pipes, exposed river crossings, and small WWTPs, no impact to the piped distribution network or creek crossings is expected; however, there is potential for loss of functionality and damage to the WWTP. Using a 10% loss and an estimated capital cost for the entire WWTP of $6,500,000 [30], Table 3-6 calculates a loss estimate of $650,000 (Province of Ontario, 2005).

Table 3-6: Wastewater Infrastructure Loss Estimation

Loss Component	Capital Cost	Loss Percent	Loss Estimate
WWTP including all lagoons and equipment	$6,500,000	10%	$650,000
Pipes (non-crossings)	n/a	0%	$0
Pipes at River Crossings	n/a	0%	$0
		TOTAL	**$650,000**
NOTE Loss estimate is calculated in 2018 dollars.			

Anecdotally, loss of WWTP functionality could result from loss of electrical power due to failure of the Armstrong Substation (identified in Section 3.1.1) and failure of backup power systems due to flood water damage (150 kW standby genset and transfer switch). Failure of one or more of the aerated lagoons embankments is also plausible due to the souring of embankments or from overtopping as a result of direct infiltration (from overland flooding) or from excessive inflows (perhaps from failed pumping systems or infiltration of flood waters to any part of the piped wastewater distribution network). If reduced functionality or failure of any of these components were to occur, the uncontrolled release of raw sewage and industrial waste from the WWTP or the piped wastewater network could occur.

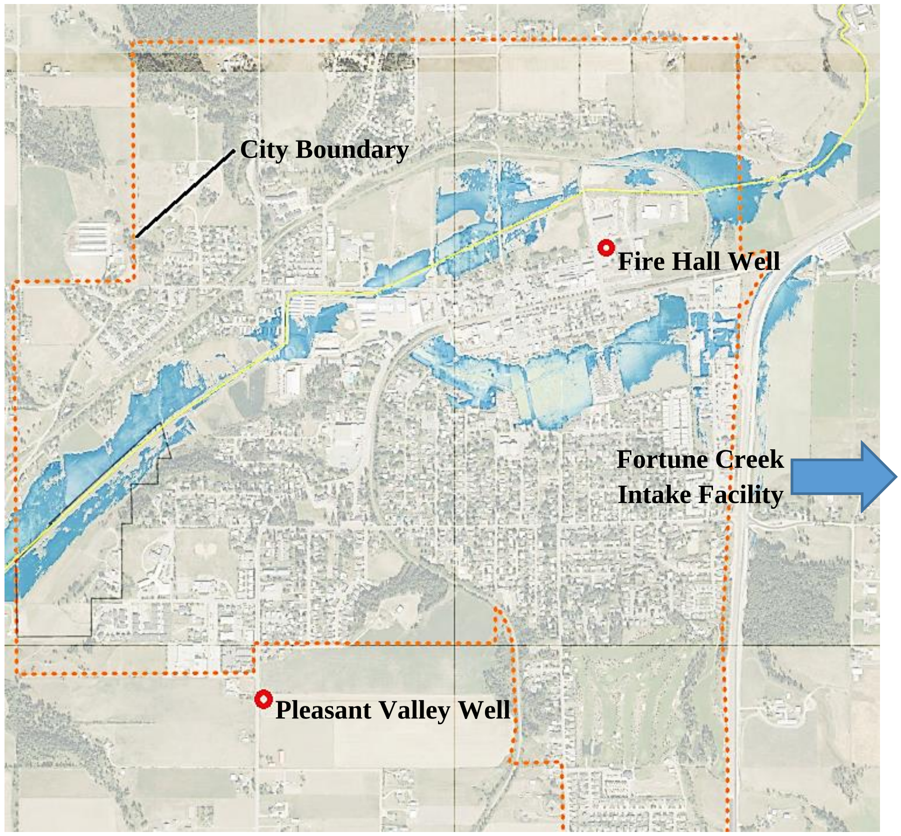
3.1.4 Potable Water System

Utilizing the City's Master Water Plan and available Water Composite Map (City of Armstrong, 2017) (City of Armstrong, April), a review of the potable water system was reviewed to identify potential flood impacts.

The City's potable water system has a maximum daily demand (MDD) of approximately 6700 m^3/day and delivers water to six water districts located in the Township of Spallumcheen. The entire system operates on a single pressure zone and services roughly 5,000 residents. The system has two sources, surface water from Fortune Creek and groundwater from two wells within the City's service area.

As source water intakes are susceptible to damage from flooding, the location of these were compared to the extents of the flood. Figure 3-1 illustrates the City limit and the location of the three water sources in relation to the flood hazard. As none of the three sources are within the flood hazard, impact to the sources is not expected.

[30] The capital cost of the WWTP was determined based on the capacity and treatment type of an entire wastewater plan in accordance with Ontario Ministry of Public Infrastructure Renewal data.



Note: Fortune Creek Intake Facility is approximately 330 m above and 2700 m east of the flood.

Figure 3-1: Potable water source locations relative to flood (City of Armstrong, 2016)

For other potable water infrastructure, the FEMA Multi-hazard Loss Estimation Methodology guidelines were used (FEMA, 2001). According to this guideline, the impact to functionality and damage to potable water components can be estimated based on flood water depth. Table 3-7 below provides functionality thresholds and damage functions based by flood water depth.

Table 3-7: Potable Water Components - Functionality Thresholds and Damage Function (FEMA, 2001)

System Component	FTA[1] (m)	Percent Damage by depth of flooding[2] (m)										
		0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Exposed Transmission Pipeline Crossing	n/a	0	0	0	0	0	0	0	0	0	0	0
Buried Transmission Pipeline Crossing	n/a	0	0	0	0	0	0	0	0	0	0	0
Buried Pipelines (non-crossing)	n/a	0	0	0	0	0	0	0	0	0	0	0
Small WTP (open / gravity)	0	0	5	8	10	17	24	30	30	30	30	40
Medium WTP (open / gravity)	0	0	5	8	10	17	24	30	30	30	30	40

Table 3-7: Potable Water Components - Functionality Thresholds and Damage Function (FEMA, 2001)

System Component	FTA[1] (m)	Percent Damage by depth of flooding[2] (m)										
		0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Large Water Treatment Plants (open / gravity)	0	0	5	8	10	17	24	30	30	30	30	40
Small Water Treatment Plants (closed / pressure)	1.2	0	1	2	5	15	30	40	40	40	40	40
Medium Water Treatment Plants (closed / pressure)	1.2	0	1	2	5	15	30	40	40	40	40	40
Large Water Treatment Plants (closed / pressure)	1.2	0	1	2	5	15	30	40	40	40	40	40
Pumping Plants (all / below grade)	1.2	0	0	0	0	40	40	40	40	40	40	40
Pump Plants (all / above grade)	1.2	0	1	2	5	15	30	40	40	40	40	40
Control Vaults and Stations (all)	0.3	0	40	40	40	40	40	40	40	40	40	40
Water Storage Tanks (at grade conc/steel/wood)	7.3	0	0	0	0	0	0	0	0	0	0	0
Water Storage Tanks (all / below grade)	1.2	0	0	0	0	5	5	5	5	5	5	5
Wells (all)	1.2	0	1	2	5	20	25	30	30	30	30	30

NOTE1 Functionality Threshold Depth (FTA) refers to the depth of water where the water system component ceases to function.
NOTE2 Assumes electrical switch gear is located 1.2 m above grade.

The location of the City's potable water system components was compared to the depth of the flood hazard. As a result, only the water transmission pipeline and related features such as blow-off valves, control valves, fire hydrants, and water services were identified in the flood hazard area (City of Armstrong, 2017). No air valve, metering chambers, wells, or any other system components were identified. Using Table 3-7, it was estimated that no damage or loss of functionality to the water system would occur; though, this does not consider the potential for contamination or impact from road washouts.

Comparing estimates of road washouts covered in Section 3.1.2, it was assumed that transmission mains existing within any expected washout location would be damaged and functionality would be compromised. As such, the location of washout roads was compared to the City's Water Composite Maps and two vulnerable transmission mains were identified: 1) Meighan Creek Crossing at Okanagan Street, and 2) Deep Creek crossing at Okanagan Street. Since a 50% probability of failure was assumed, only one (1) washout having a watermain pipeline was assumed to be impacted. Figure 3-2 illustrates one of these crossings.

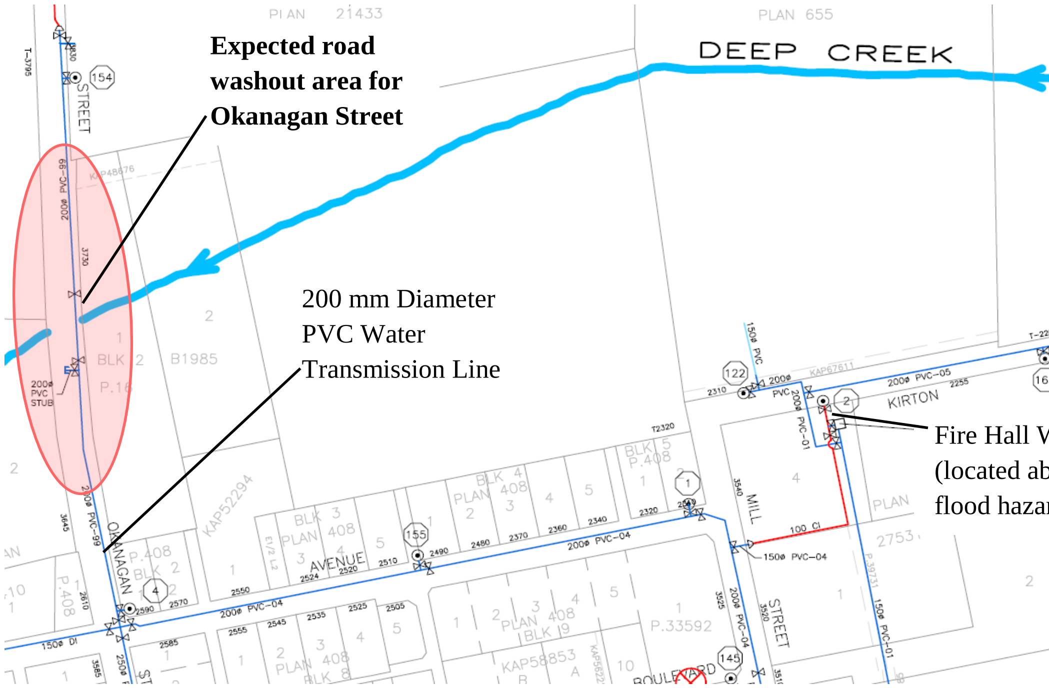


Figure 3-2: Water Composite Map compared to an expected Okanagan Street washout location

Since the water system network is looped and operates on a single pressure zone, a damaged transmission main from a washout at either location can reasonably be isolated. As such, it is expected that essential water services could continue to function with no extended loss of service. Therefore, the total direct flood impacts to the City's potable water system was assumed to be limited to the cost of repairs of the water transmission main on Okanagan Street. Assuming a 20 m length of 200 mm diameter PVC costs[31] $250/m, the estimated direct loss including only the watermain calculates to roughly $5,000. Losses related to damaged transmission mains at washouts are estimated in Table 3-8.

[31] Cost includes supply and install of watermain but does not include road construction. For road washout costs, refer to Section 3.1.2.

Table 3-8: Potable Water Infrastructure Loss Estimation

Loss Component	Capital Cost	Loss Probability	Loss Percent	Loss Estimate[1]
Buried Transmission Pipeline Crossing (Okanagan Street – Deep Creek)	5000	50%	100%	$2,500
Buried Transmission Pipeline Crossing (Okanagan Street – Meighan Creek)	5000	50%	100%	$2,500
			TOTAL	**$5,000**

NOTE1 Loss estimate is calculated in 2018 dollars.

Overland flooding of urbanized areas has the potential to carry pollutants into waterways leading to source water contamination. As Section 3.1.3 identified a potential release of raw sewage and industrial waste to Deep Creek, increased risk of source water contamination and environmental pollution is expected.

As pollution can be carried long distances, the contamination of source water along Deep Creek downstream of the WWTP may extend as far as Okanagan Lake. A search of the BC Water Atlas identified a total of 25 water licences between the location of the City's WWTP and the mouth of Deep Creek at Okanagan Lake (BC Water Resources Atlas, 2018). Table 3-9 lists the water licences identified.

Table 3-9: Water licences on Deep Creek from Armstrong to Okanagan Lake

Licence	Source	Purpose	Distance Downstream of WWTP (km)
C126134	Otter Spring	01A - Domestic	4.8
C110664	Otter Lake	03B – Irrigation Private	4.9
C045166	Otter Lake	03B – Irrigation Private	5.0
C110664	Otter Lake	03B – Irrigation Private	5.4
F019515	Deep Creek	03B – Irrigation Private	6.9
C062832	Deep Creek	03B – Irrigation Private	7.8
C062833	Deep Creek	03B – Irrigation Private	7.8
F021312	Deep Creek	03B – Irrigation Private	7.8
C069205	Deep Creek	03B – Irrigation Private	7.8
C069206	Deep Creek	03B – Irrigation Private	8.3
F021503	Deep Creek	03B – Irrigation Private	8.3
500183	Deep Creek	00A – Waterworks Local Provider	9.4
F021505	Deep Creek	03B – Irrigation Private	9.5
F015901	Deep Creek	03B – Irrigation Private	9.9

Table 3-9: Water licences on Deep Creek from Armstrong to Okanagan Lake

Licence	Source	Purpose	Distance Downstream of WWTP (km)
F021502	Deep Creek	03B – Irrigation Private	10.8
F052952	Deep Creek	03B – Irrigation Private	10.8
F052953	Deep Creek	03B – Irrigation Private	10.8
C052893	Deep Creek	03B – Irrigation Private	11.1
C052891	Deep Creek	03B – Irrigation Private	11.1
C064257	Deep Creek	02F – Fairway Watering	11.1
C052892	Deep Creek	03B – Irrigation Private	11.1
F052953	Deep Creek	03B – Irrigation Private	11.1
C064226	Deep Creek	02F – Fairway Watering	11.1
F013130	Deep Creek	03B – Irrigation Private	12.1
C018611	Okanagan Lake	03B – Irrigation Private	14.1

Only one water licence was identified to be domestic and it sources a spring near the alignment of Deep Creek. Although no potable water licences directly source water from Deep Creek downstream of Armstrong, the indirect risk of potable water contamination in all flood areas is still possible. No monetary estimate of this impact was calculated.

3.1.5 Natural Gas System

For natural gas infrastructure, the report relies on FEMA Multi-hazard Loss Estimation Methodology guidelines. According to this guideline, the impact to functionality and damage to natural gas system components can be estimated based on flood water depth. Figure 3-10 below provides functionality thresholds and damage functions based by flood water depth.

Table 3-10: Natural Gas Components - Functionality Thresholds and Damage Function (FEMA, 2001)

System Component	FTA[1] (m)	Percent Damage by depth of flooding[2] (m)										
		0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Exposed Transmission Pipeline Crossing	n/a	0	0	0	0	0	0	0	0	0	0	0
Buried Transmission Pipeline Crossing	n/a	0	0	0	0	0	0	0	0	0	0	0
Pipelines (non-crossing)	n/a	0	0	0	0	0	0	0	0	0	0	0
Control Valves and Control Stations	0.3	0	40	40	40	40	40	40	40	40	40	40
Compressor Stations	1.2	0	1	2	5	15	30	40	40	40	40	40

NOTE1 Functionality Threshold Depth (FTA) refers to the depth of water where the system component ceases to function (FEMA, 2001).
NOTE2 Assumes electrical switch gear is located 1.2 m above grade.

Since there are no identified natural gas infrastructure within the delineated flood hazard, no loss of functionality or damage is expected based on the thresholds and functions of Table 3-10.

3.1.6 Telecommunication System

For telecommunication systems, no FEMA functionality thresholds or damage functions were available to estimate flood impacts. Since there are no key telecommunication infrastructure identified within the delineated flood hazard, it is likely that only communication lines may be exposed. As such, impact to telecommunication systems is expected to be negligible in comparison to other local infrastructure.

3.2 Impact to Environment

A priority for municipal, provincial, and federal governments is to protect Canada's natural environment for current and future generations (Government of Canada, 2018). Although the City cannot be held responsible for protecting the environment from natural conventional flooding[32], developed areas within the City's jurisdiction are expected to negatively impact the environment when subjected to flood conditions. As identified above, the release of pollutants due to overland flooding, erosion, and failure of urban systems is expected.

Reduced water quality can affect fish habitat, vegetation, and wildlife. Although no indications of the presence of red-listed[33] or blue-listed[34] species within these areas were identified by the BC Conservation Data Centre (BC CDC) mapping system (Figure 3-3), a recent report identified the potential inhabitancy of species at risk including "one plant, four avian, three mammal, one reptile, two gastropod and five insect[s]" which are all provincially blue-listed (Western Water, 2018).

[32] Flooding often plays and integral role in ensuring biological productivity and diversity in the flood plain.
[33] *Red-listed* species or ecosystems are at risk of being lost (extirpated, endangered or threatened).
[34] *Blue-listed* is any species or ecosystem this is of special concern.

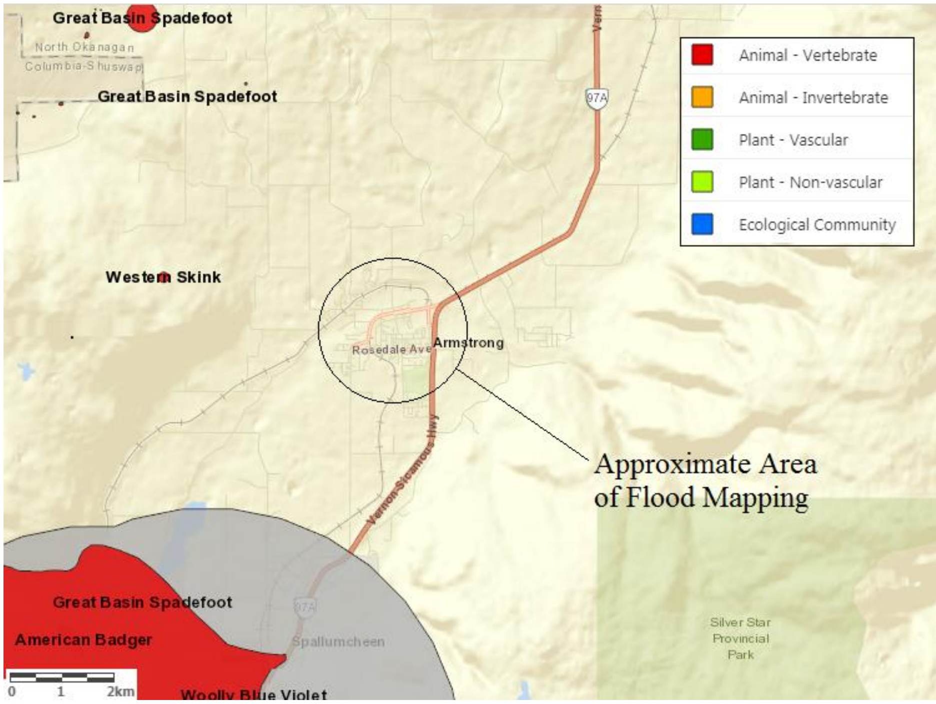


Figure 3-3: BC CDC map of red- and blue-listed species and ecosystems (BC CDC, 2018)

According to the BC guidelines for assessing environmental flood consequence in relation to dam breaches, if red- or blue-listed species are impacted, the consequence is considered *high*[35] (FLNRORD, 2016). The Dam Safety Regulation defines a high environmental consequence as a "significant loss or deterioration of important fisheries habitat or important wildlife habitat, rare or endangered species, or unique landscapes" where "restoration or compensation in kind is highly possible" (BC, 2016). Although a monetary value is not attributed to the environmental losses described above, significant pollution of water quality and potential impact to species at risk are identified; however, there are no expectations of permanent environmental loss

3.3 Impact to Cultural Values

Review of impact to sites of cultural significance is an important component of consequence assessment (FLNRORD, 2016).

As the City was once a "sprawling western town" with history dating back to 1892, there are many historic sites and heritage buildings throughout the municipality (City of Armstrong, 2018). As such, there is a large inventory of heritage buildings, many of which are from the 1930s. A review of all properties listed in the heritage inventory for the City was conducted and overlap with the mapped flood hazard. Table 3-11 summarizes this overlap and includes a list of properties at risk.

[35] *High* is a defined regulated rating which describes the consequence classification of dams in BC.

Table 3-11: Heritage Sites Impact Summary

IMPACT EXPECTED
2885 Patterson Avenue
AT RISK - WITHIN METRES
3395 Patterson Avenue
2315 Patterson Avenue
2335 Patterson Avenue
2485 Patterson Avenue
2495 Patterson Avenue
3120 Pleasant Valley Road
AT RISK - SETBACK SOMEWHAT
2495 Patterson Avenue
2360 Patterson Avenue
2370 Patterson Avenue
2590 Wood Avenue
2750 Wood Avenue
2850 Wood Avenue

In addition to the above heritage sites, there are other sites impacted that have cultural value. These sites include community assets or recreation areas such as the Okanagan Regional Library, Highland Park Elementary School yard, or the Interior Provincial Exhibition (IPE) fairgrounds. Of these, the library will be most impacted and it is expected to be fully recovered in a period of weeks to months resulting in little impact to cultural values (refer to Section 3.5.3 for more details).

A review of the flood hazard area did not identify any archaeology sites within the inundation zone[36]. Although the absence of archaeological sites could not be definitively confirmed, if one does exist, the likelihood of impact from flood was not considered significant due to the nature of the depth and velocity of the flooding. As such, no impact to culturally significant archaeological sites is expected.

3.4 Impact to People and Society

According to NDMP, impact to people and society should be included in the risk assessment (Government of Canada, 2018). In alignment with the National Resource Canada's (NRC) guidelines for estimating flood vulnerabilities, the scope of the impacts to people and society was limited to the individuals of the community of Armstrong who are directly impacted by the flood hazard. As such, this section provides hypothetical direct cost estimates to individuals in the

[36] Absence of archaeological or valuable cultural sites was not confirmed due to access limitations to the Remote Access to Archaeological Data (RAAD) mapping program (FLNRORD, 2018).

following categories: loss of wages, loss of life, loss to residential property (automobiles, residential structural and content), and loss due to displacement.

3.4.1 Loss of Wages

According to NDMP guidelines, losses to people and society should include estimates for loss of wages (LoW). A comparison between the flood hazard and the location of all business structures in the City was conducted by overlaying the flood hazard GIS files to a spatial point file database (SPFD)[37] of all known structures in the City. Where overlap to business structures was identified, flood depth data was populated to the SPFD resulting in a list of all flood-impacted businesses which included business type, total structure area and flood depth hazard.

According to FEMA, approximate estimates of flood restoration time by building type rely on the simple linear function between the depth of flooding to the number of days displaced. By applying the recommended 45 days per 0.30 m of flood water depth, the duration of business shut-down is estimated in weeks.

Supported by a limited telephone survey, anecdotal information and other various sources, the approximate number of employees at each business was based on the building area and business type. Average weekly employment income was assumed to be on par with the average annual compensation for all Canadians since the sample population of businesses represents a non-bias selection of employment types. As such, calculation of LoW assumes an average weekly compensation of \$892.90[38] for all employees. Table 3-12 summarizes the results of this calculation.

Table 3-12: Estimated Loss of Wages (LoW) – Impacted Businesses and their Employees by Industry

Business Type	Area/Creek	Flood Impact	E[1]	W[2]	EW[3]	LoW[4]
HEALTHCARE*						
Medical Clinic*	Smith Dr/Meighan	Bldg, parking lot	12	1.7	20.1	17,909
Dental Clinic*	Smith Dr/Meighan	Bldg, parking lot	8	2.1	16.8	15,001
Physiotherapy Clinic*	Smith Dr/Meighan	Bldg, parking lot	8	1.9	15.4	13,776
Pharmacy*	Smith Dr/Meighan	Bldg, parking lot	15	2.1	31.5	28,126
Optometry Clinic*	Smith Dr/Meighan	Bldg, parking lot	8	1.7	13.4	11,939
PROFESSIONAL SERVICES						
Accounting Office	Smith Dr/Meighan	Bldg, parking lot	8	1.7	13.4	11,939
Notary Public	Smith Dr/Meighan	Bldg, parking lot	8	1.7	13.4	11,939
Investment Office	Smith Dr/Meighan	Bldg, parking lot	8	1.7	13.4	11,939
Insurance Broker	Smith Dr/Meighan	Bldg, parking lot	10	1.7	16.7	14,924

[37] This database was manually created using recent satellite imagery supplemented by field investigation and Google Streetview data.
[38] Based on 2016 StatCan data, the annual average income of \$46,431 was used. This value has been adjusted for inflation.

Table 3-12: Estimated Loss of Wages (LoW) – Impacted Businesses and their Employees by Industry

Business Type	Area/Creek	Flood Impact	E[1]	W[2]	EW[3]	LoW[4]
Real Estate Broker	Smith Dr/Meighan	Bldg, parking lot	6	2.1	12.6	11,251
Veterinary Clinic	Smith Dr/Meighan	Parking lot	8	0.0	0.0	-
Autobody Garage	Patterson/Meighan	Bldg, parking lot	2	16.3	32.6	29,083
PARKS AND PUBLIC SERVICES						
Public Works Facility	Patterson/Meighan	Bldg, parking lot	5	3.0	15.0	13,394
Elementary School	Wood Ave/Deep	Parking lot	40	0.0	0.0	-
Fairgrounds	Wood Ave/Deep	Bldg, Parking lot	10	2.6	25.7	22,960
Postal Office*	Smith Dr/Meighan	Bldg, parking lot	6	6.6	39.9	35,589
Library	Smith Dr/Meighan	Bldg, parking lot	5	7.1	35.4	31,571
TRANSPORTATION						
Transportation Services	Kirton Ave/Deep	Yard	5	0.2	1.1	957
Trucking Facility	Kirton Ave/Deep	Yard	30	0.2	6.4	5,740
CONSTRUCTION						
Contractor Bldg	Kirton Ave/Deep	Yard	20	0.2	4.3	3,827
RETAIL						
Grocery Store*	Smith Dr/Meighan	Bldg, parking lot	30	7.1	212.1	189,423
Pet Retail	Smith Dr/Meighan	Bldg, parking lot	8	2.1	16.8	15,001
Pet Retail	Smith Dr/Meighan	Bldg, parking lot	8	7.1	56.6	50,513
Electronics Retail	Smith Dr/Meighan	Bldg, parking lot	5	1.7	8.4	7,462
Automotive Retailer	Smith Dr/Meighan	Bldg, parking lot	6	1.1	6.4	5,740
Health Food Retailer	Smith Dr/Meighan	Bldg, parking lot	8	6.9	54.9	48,982
General Merchandise	Smith Dr/Meighan	Bldg, parking lot	20	7.1	141.4	126,282
Flower Shop	Smith Dr/Meighan	Bldg, parking lot	4	0.9	3.4	3,061
Thrift Store	Patterson/Meighan	Bldg, parking lot	4	2.1	8.6	7,653
RESTAURANT						
Pizza Eatery	Smith Dr/Meighan	Bldg, parking lot	6	2.1	12.6	11,251
Sandwich Eatery	Smith Dr/Meighan	Bldg, parking lot	6	2.1	12.6	11,251
Sushi Restaurant	Smith Dr/Meighan	Bldg, parking lot	8	7.1	56.6	50,513
Bakery	Smith Dr/Meighan	Bldg, parking lot	10	6.4	64.3	57,401
Coffee Shop	Smith Dr/Meighan	Bldg, parking lot	6	8.6	51.4	45,921
OTHER						
Financial Institution*	Smith Dr/Meighan	Bldg, parking lot	12	0.0	0.0	-
Fitness Centre	Smith Dr/Meighan	Bldg, parking lot	4	2.1	8.4	7,500
Barber	Smith Dr/Meighan	Bldg, parking lot	5	6.4	32.1	28,700
Car Wash Facility	Smith Dr/Meighan	Bldg, parking lot	1	0.9	0.9	765
Storage Facility	Hwy 97A	Parking lot	2	0.0	0.0	-
Food Processing Facility	Okanagan St/Deep	Bldgs, yard	80	10.7	856.0	764,326
Hotel/Inn	Smith Dr/Meighan	Parking lot	5	0.6	3.2	2,870

Table 3-12: Estimated Loss of Wages (LoW) – Impacted Businesses and their Employees by Industry

Business Type	Area/Creek	Flood Impact	E[1]	W[2]	EW[3]	LoW[4]
Assisted Living Facility	Willowdale/Meighan	Bldg, parking lot	15	12.6	189.6	169,333
				TOTAL		**$ 1,895,813**

*These are considered vital to sustaining a community according to NDMP guidelines: communications technology, finance, healthcare, food, water, transportation, safety, government and manufacturing (Government of Canada, 2018)
NOTE1 The number of working employees represents the number of full 8-hour working days of labour that are required for a typical business day. These numbers are approximate estimates based on building area and industry type.
NOTE2 Weeks represent the approximate time the place of business is disrupted based on the severity of flooding (depth) at that particular business.
NOTE3 EW is the product of the number of working employees to the number of weeks displaced.
NOTE4 LoW is calculated in 2018 dollars.

Based on the above, the total LoW for all displaced employees was calculated to be $1,895,813.

3.4.2 Loss of Life

The estimation of loss of life (LoL) used the Reclamation Consequence Estimating Methodology (RCEM) published by the United States Bureau of Reclamation (USBR). Using the RCEM graphical approach, fatality rates (FR) were selected based on the upper limit of the RCEM's suggested range for cases with adequate warning[39]. Figure 3-4 illustrates the selected FR curve used. As this method is most often applied to dam breaches and floods with quickly rising floodwaters, this selection may be conservative.

[39] *Adequate warning* is an undefined amount of time that would allow most of the PAR to understand the threat posed by dam failure, to take reasonable actions to leave the inundation plain and to successfully move to a safe location (USBR, 2015).

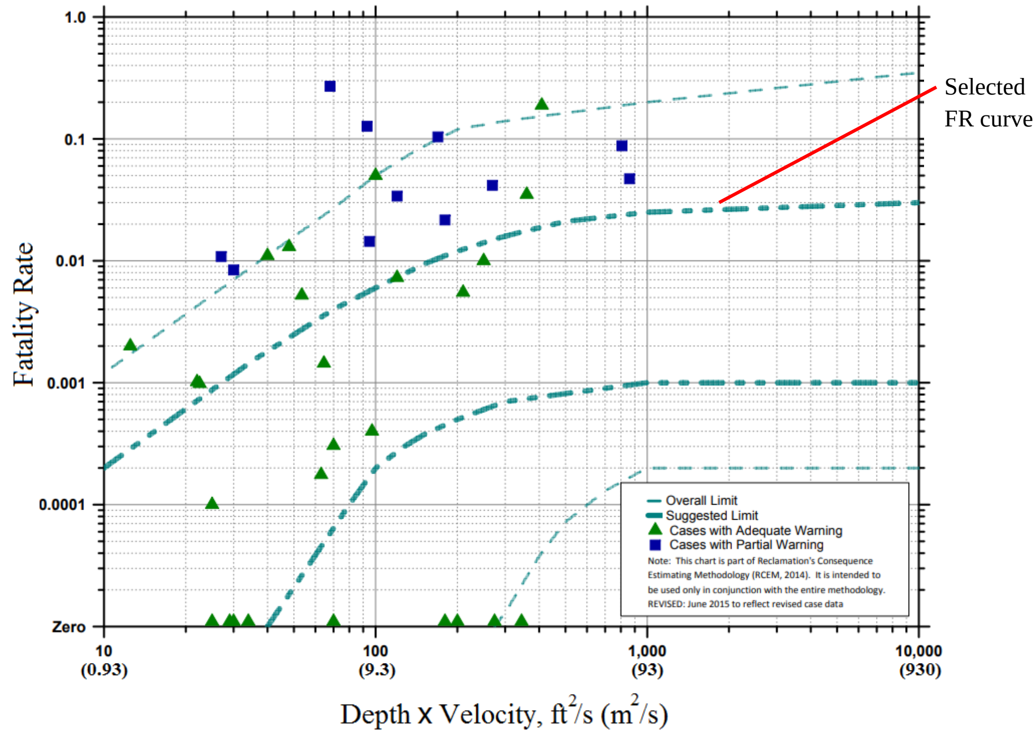


Figure 3-4: Loss of Life Fatality Rates for No Warning (USBR, 2015)

Analysis compared the the delineated flood hazard and the location of all structures in the City. Using the flood hazard GIS output files described in Section 2.9, the SPFD of structures (used in the LoW estimate) was compared to the flood hazard using QGIS. Where overlap existed, QGIS was used to apply flood hazard attributes for water depth (D) and velocity (V) at the particular location of that structure. This information was then used to estimate the LoL for the population that would be located at or within that structure.

Based on the BC dam break inundation guidelines, all residential structure types assume 3 people per residence. For businesses, the number of employees from the LoW estimate was used, and where appropriate, the number of customers was added. For all businesses that have customers, a ratio of 1:1 of customers to employees was assumed. Table 3-13 provides a summary of the LoL estimate and includes the population at risk (PAR), the value of the product of depth times velocity (DV), and the selected fatality rate (FR). The LoL estimate is the product of PAR and FR and represents a numerical value of the expected number of lives lost.

Table 3-13: Loss of Life (LoL) Estimation

Building Type	Area/Creek	PAR[1]	DV[2]	FR[3]	LoL[4]
RESIDENTIAL					
Single Family Dwelling	Otter Lake Rd/Deep	3	0.002	0.0002	0.0006
Single Family Dwelling	Wood Ave/Deep	3	0.165	0.0002	0.0006
Single Family Dwelling	Wood Ave/Deep	3	0.013	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.142	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.188	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.209	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.458	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.148	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.197	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.170	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.184	0.0002	0.0006
Single Family Dwelling	Willowdale Dr/Meighan	3	0.024	0.0002	0.0006
Single Family Dwelling	Patterson Ave/Meighan	3	0.037	0.0002	0.0006
Single Family Dwelling	Patterson Ave/Meighan	3	0.072	0.0002	0.0006
Single Family Dwelling	Patterson Ave/Meighan	3	0.046	0.0002	0.0006
Single Family Dwelling	Patterson Ave/Meighan	3	0.033	0.0002	0.0006
Single Family Dwelling	Patterson Ave/Meighan	3	0.012	0.0002	0.0006
Single Family Dwelling	Wolfden Terrace/ Meighan	3	0.004	0.0002	0.0006
Single Family Dwelling	Wolfden Terrace/ Meighan	3	0.002	0.0002	0.0006
Single Family Dwelling	Wolfden Terrace/ Meighan	3	0.000	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.016	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.049	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.007	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.002	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.000	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.001	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.000	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.000	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.001	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.003	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.001	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.015	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.007	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.007	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.001	0.0002	0.0006
Single Family Dwelling	Meadow Creek Ln/ Meighan	3	0.000	0.0002	0.0006
Single Family Dwelling	Okanagan St/Meighan	3	0.021	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.000	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.001	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.003	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.003	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.039	0.0002	0.0006

Table 3-13: Loss of Life (LoL) Estimation

Building Type	Area/Creek	PAR[1]	DV[2]	FR[3]	LoL[4]
Mobile Home	Adair Rd/ Deep	3	0.062	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.022	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.039	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.011	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.002	0.0002	0.0006
Mobile Home	Adair Rd/ Deep	3	0.003	0.0002	0.0006
Duplex	Willowdale Dr/Meighan	6	0.014	0.0002	0.0012
Duplex	Willowdale Dr/Meighan	6	0.007	0.0002	0.0012
Duplex	Willowdale Dr/Meighan	6	0.021	0.0002	0.0012
Duplex	Willowdale Dr/Meighan	6	0.026	0.0002	0.0012
Apartment Complex	Willowdale Dr/Meighan	60	0.149	0.0002	0.0120
Apartment Complex	Patterson Ave/Meighan	45	0.006	0.0002	0.0090
Apartment Complex	Patterson Ave/Meighan	21	0.034	0.0002	0.0042
HEALTHCARE*					
Medical Clinic*	Smith Dr/Meighan	24	0.003	0.0002	0.0048
Dental Clinic*	Smith Dr/Meighan	16	0.005	0.0002	0.0032
Physiotherapy Clinic*	Smith Dr/Meighan	16	0.005	0.0002	0.0032
Pharmacy*	Smith Dr/Meighan	30	0.005	0.0002	0.0060
Optometry Clinic*	Smith Dr/Meighan	16	0.003	0.0002	0.0032
PROFESSIONAL SERVICES					
Accounting Office	Smith Dr/Meighan	16	0.003	0.0002	0.0032
Notary Public	Smith Dr/Meighan	16	0.003	0.0002	0.0032
Investment Office	Smith Dr/Meighan	16	0.003	0.0002	0.0032
Insurance Broker	Smith Dr/Meighan	20	0.003	0.0002	0.0040
Real Estate Broker	Smith Dr/Meighan	12	0.014	0.0002	0.0024
Autobody Garage	Patterson/Meighan	4	0.285	0.0002	0.0008
PARKS AND PUBLIC SERVICES					
Public Works Facility	Patterson Ave/Meighan	10	0.012	0.0002	0.0020
Postal Office*	Smith Dr/Meighan	12	0.005	0.0002	0.0024
Library	Smith Dr/Meighan	10	0.014	0.0002	0.0020
RETAIL					
Grocery Store*	Smith Dr/Meighan	60	0.014	0.0002	0.0120
Pet Retail	Smith Dr/Meighan	16	0.005	0.0002	0.0032
Pet Retail	Smith Dr/Meighan	16	0.014	0.0002	0.0032
Electronics Retail	Smith Dr/Meighan	10	0.003	0.0002	0.0020
Automotive Retailer	Smith Dr/Meighan	12	0.002	0.0002	0.0024
Health Food Retailer	Smith Dr/Meighan	16	0.014	0.0002	0.0032
General Merchandise	Smith Dr/Meighan	40	0.014	0.0002	0.0080
Flower Shop	Smith Dr/Meighan	8	0.001	0.0002	0.0016
Thrift Store	Patterson/Meighan	8	0.014	0.0002	0.0016
RESTAURANT					
Pizza Eatery	Smith Dr/Meighan	12	0.005	0.0002	0.0024

Table 3-13: Loss of Life (LoL) Estimation

Building Type	Area/Creek	PAR[1]	DV[2]	FR[3]	LoL[4]
Sandwich Eatery	Smith Dr/Meighan	12	0.005	0.0002	0.0024
Sushi Restaurant	Smith Dr/Meighan	16	0.014	0.0002	0.0032
Bakery	Smith Dr/Meighan	20	0.014	0.0002	0.0040
Coffee Shop	Smith Dr/Meighan	12	0.014	0.0002	0.0024
OTHER					
Financial Institution*	Smith Dr/Meighan	24	0.005	0.0002	0.0048
Fitness Centre	Smith Dr/Meighan	8	0.005	0.0002	0.0016
Barber	Smith Dr/Meighan	10	0.014	0.0002	0.0020
Car Wash Facility	Smith Dr/Meighan	2	0.002	0.0002	0.0004
Food Processing Facility	Okanagan St/Deep	80	0.006	0.0002	0.0160
				Calculated Value	0.1788
				LoL ESTIMATE	**0**

*These are considered vital to sustaining a community according to NDMP guidelines: communications technology, finance, healthcare, food, water, transportation, safety, government and manufacturing (Government of Canada, 2018)

NOTE1 The population at risk (PAR) was assumed based on 3 people per home as per BC dam break inundation guidelines. PAR at places of businesses was assumed to be equal to the number of employees (from Section 3.3.4). The PAR at places of businesses with customers was assumed to be 2 times the number of employees.

NOTE2 DV is the product of depth (D) and velocity (V).

NOTE3 FR is the fatality rate as per the RCEM graphical method.

NOTE4 Loss of life (LoL) is the product of PAR and DV.

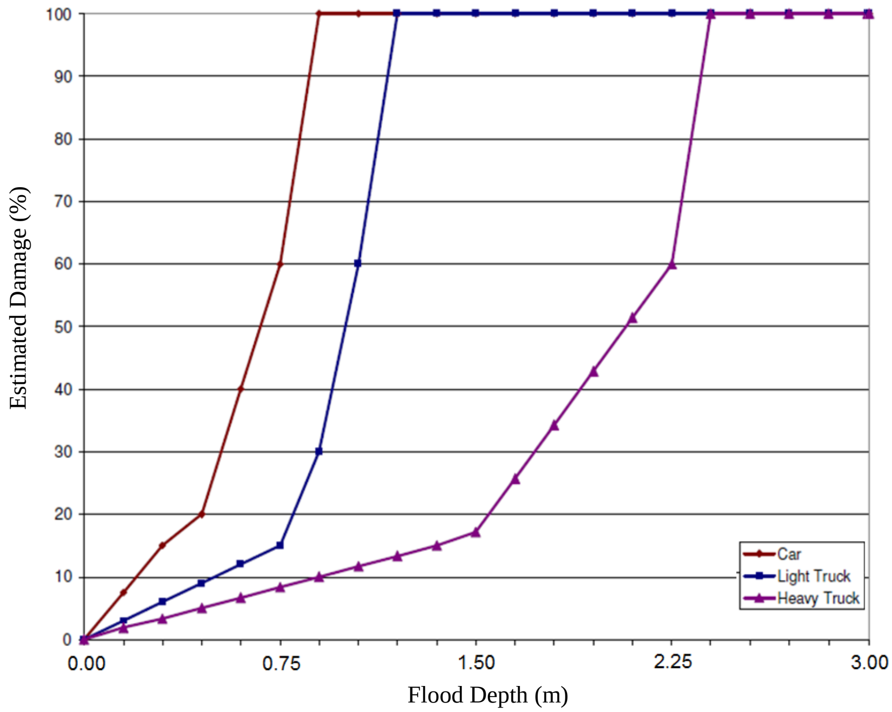
Based on calculations from Table 3-13, the direct LoL estimate is 0 for the 1/200-year flood hazard. Although the flood hazard is not expected to cause loss of life, the risk to human life does exist for the 1/200-year flood.

3.4.3 Loss to Property

The following sub-categories provide estimates for loss to automobiles and residential structural and content damage.

3.4.3.1 Loss to Automobiles

According to NRC guidelines, loss to automobiles can be estimated based on the depth of flooding. Figure 3-5 illustrates some typical loss functions illustrating the potential damage expected to various vehicle types.



Note: Adapted to metric units.

Figure 3-5: Vehicle Depth vs. Damage Curves

If the location of a vehicle is known relative to the flood hazard, the flood depth can be estimated and the loss can be calculated. Using the spatial SPFD of all structures (refer to Section 3.4.1), the Canadian average of 1.43 vehicles per residence[40] was applied to all nodes representing residential residences (Statistics Canada, 2018). The probability of damage from Table 3-14 was spatially attributed to each node based on the depth of flooding (D) from the GIS mapping output files using QGIS.

Table 3-14: Adopted Loss Function for Automobile Loss Estimation

Flood Level (m)	Description	% of Damage
0 – 0.149	Below carpet	0 %
0.150 – 0.456	Between carpet & dashboard	15 %
0.457 – 0.732	At dashboard	60 %
> 0.732	Above dashboard	100 %

The application of the FEMA guideline accounted for automobiles not located at residences. Assuming a density of 3 automobiles per 1000 ft^2 (93 m^2), the total number of automobiles at all public lots was estimated and the loss function from Table 3-14 was applied.

[40] The average number of vehicles owned per residence is based on 2018 StatsCan data.

The weighted average value of vehicles was calculated to be $19,487.50 based on the age and type of all vehicles owned in Canada (Statistics Canada, 2018). By multiplying this value by the number of vehicles, all individual nodes representing number of vehicles at each node (NV) and the depth of flooding at that location (DF), the total loss was calculated in 2018 dollars. Table 3-15 provides a summary of this calculation.

Table 3-15: Impact to Automobiles Loss Estimation

Automobile Location	Area/Creek	D[1] (m)	NV[2]	DF[3] (%)	Total Loss[4] ($)
AUTOMOBILES AT RESIDENCES					
Single Family	Wood Ave/Deep	0.487	1.43	60%	16,720
Single Family	Wood Ave/Deep	0.251	1.43	15%	4,180
Single Family	Willowdale Dr/Meighan	0.579	1.43	60%	16,720
Single Family	Willowdale Dr/Meighan	0.718	1.43	60%	16,720
Single Family	Willowdale Dr/Meighan	0.800	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	0.970	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	0.959	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	1.118	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	0.896	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	1.125	1.43	100%	27,867
Single Family	Willowdale Dr/Meighan	0.338	1.43	15%	4,180
Single Family	Patterson Ave/Meighan	0.421	1.43	15%	4,180
Single Family	Patterson Ave/Meighan	0.882	1.43	100%	27,867
Single Family	Patterson Ave/Meighan	0.871	1.43	100%	27,867
Single Family	Patterson Ave/Meighan	0.471	1.43	60%	16,720
Single Family	Patterson Ave/Meighan	0.369	1.43	15%	4,180
Single Family	Meadow Ck Ln/ Meighan	0.153	1.43	15%	4,180
Single Family	Meadow Ck Ln/ Meighan	0.376	1.43	15%	4,180
Single Family	Meadow Ck Ln/ Meighan	0.186	1.43	15%	4,180
Single Family	Meadow C Ln/ Meighan	0.624	1.43	60%	16,720
Mobile Home	Adair Rd/ Deep	0.308	1.43	15%	4,180
Mobile Home	Adair Rd/ Deep	0.378	1.43	15%	4,180
Mobile Home	Adair Rd/ Deep	0.169	1.43	15%	4,180
Mobile Home	Adair Rd/ Deep	0.227	1.43	15%	4,180
Duplex	Willowdale Dr/Meighan	0.175	2.86	15%	8,360
Duplex	Willowdale Dr/Meighan	0.280	2.86	15%	8,360
Apartment	Willowdale Dr/Meighan	0.600	28.6	60%	334,406
Apartment	Patterson Ave/Meighan	0.823	21.45	100%	418,008
Apartment	Patterson Ave/Meighan	0.423	10.01	15%	29,261
AUTOMOBILES IN PUBLIC AREAS					
Commercial	Smith Dr/Meighan	0.180	99.0	15%	289,390
Commercial	Smith Dr/Meighan	0.332	90.0	15%	263,082
Commercial	Smith Dr/Meighan	0.203	78.0	15%	228,004

Table 3-15: Impact to Automobiles Loss Estimation

Automobile Location	Area/Creek	D[1] (m)	NV[2]	DF[3] (%)	Total Loss[4] ($)
AUTOMOBILES AT RESIDENCES					
Commercial	Smith Dr/Meighan	0.193	30.0	15%	87,694
School	Wood Ave/ Deep	0.671	78.0	60%	912,017
Commercial	Okanagan St/Deep	0.583	69.0	60%	806,785
				TOTAL	**$3,737,887**

NOTE1 D represents the depth of flood at a particular GIS node location.
NOTE2 NV represents the number of vehicles at that GIS node.
NOTE3 DF is the damage function in percent.
NOTE4 Values are in 2018 dollars.

Based on the results of the above, a total loss to automobiles was estimated to be $3,737,887.

3.4.3.2 Impact on Residential Property

Impact to residential structures and content was estimated using available NRC damage functions. An example damage function used in this analysis is illustrated by Figure 3-6. For all other damage functions used, refer to Appendix IV.

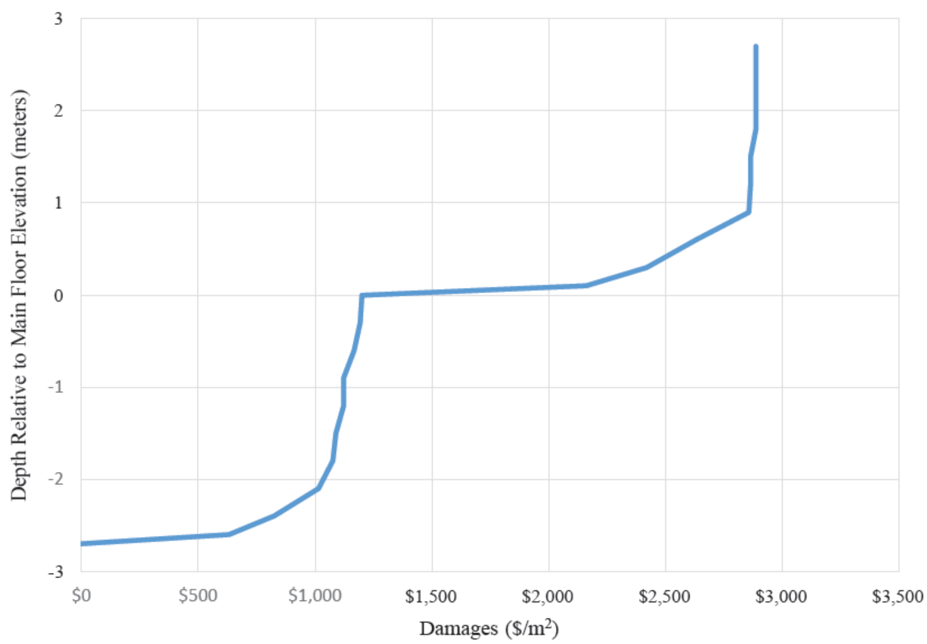


Figure 3-6: Residential One-Storey Class A – Damage Function

Since both structural and content damage varies significantly depending on the class of the structure, type of structure, and whether or not the structure has a basement, population of this data to the SPFD was required.

With the assistance of City, staff collected the BC Assessment information for all Armstrong property parcels. The information included information about the type of structures on each property and information regarding the presence of a basement, finished area, number of stories, and other assessment information required to determine structure class (BC Assessment, 2018). Using property parcel and geometry data collected from the Ministry of Citizens Services, BC Assessment data was populated to the parcel geometry attributes and spatially joined to the SPFD using QGIS (Ministry of Citizens Services, 2018).

Structure-specific information for each SPFD node was then exported to Microsoft Excel where loss calculations were conducted using the damage functions for residential one- and two-storey homes (Class A, B, and C), one-storey mobile homes, and apartment buildings. Table 3-16 and Table 3-17 provides a summary of the calculation results for residential structural, content, and property damage.

Table 3-16: Residential Structural and Content Damage Loss Estimation

Building Classification	Area/Creek	Flood Depth (m)	Structural Damage ($/m^2)	Content Damage ($/m^2)	Total Residential Loss ($)
Single Family Dwelling	Otter Lake Rd/Deep	0.070	614	637	62,308
Single Family Dwelling	Wood Ave/Deep	0.487	965	907	43,782
Single Family Dwelling	Wood Ave/Deep	0.251	914	835	94,922
Single Family Dwelling	Willowdale Dr/Meighan	0.579	986	923	113,825
Single Family Dwelling	Willowdale Dr/Meighan	0.718	1,034	947	101,644
Single Family Dwelling	Willowdale Dr/Meighan	0.800	1,073	963	128,913
Single Family Dwelling	Willowdale Dr/Meighan	0.970	1,111	981	211,577
Single Family Dwelling	Willowdale Dr/Meighan	0.959	1,111	980	209,634
Single Family Dwelling	Willowdale Dr/Meighan	1.118	1,111	986	165,072
Single Family Dwelling	Willowdale Dr/Meighan	0.896	1,103	976	191,162
Single Family Dwelling	Willowdale Dr/Meighan	1.125	1,111	987	149,841
Single Family Dwelling	Willowdale Dr/Meighan	0.338	923	875	155,776
Single Family Dwelling	Patterson Ave/Meighan	0.421	949	895	64,769
Single Family Dwelling	Patterson Ave/Meighan	0.882	1,103	976	152,845
Single Family Dwelling	Patterson Ave/Meighan	0.871	1,096	973	83,986
Single Family Dwelling	Patterson Ave/Meighan	0.471	960	903	165,153
Single Family Dwelling	Patterson Ave/Meighan	0.369	934	883	141,034
Single Family Dwelling	Wolfden Terrace/ Meighan	0.129	907	763	74,115
Single Family Dwelling	Wolfden Terrace/ Meighan	0.081	813	703	58,206
Single Family Dwelling	Wolfden Terrace/ Meighan	0.061	719	655	56,751
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.153	908	775	34,834
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.376	934	883	96,727
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.136	907	763	92,002
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.063	719	655	51,126
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.024	532	559	12,634

Table 3-16: Residential Structural and Content Damage Loss Estimation

Building Classification	Area/Creek	Flood Depth (m)	Structural Damage ($/m^2)	Content Damage ($/m^2)	Total Residential Loss ($)
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.043	626	607	31,313
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.057	626	607	29,438
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.117	906	751	71,287
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.076	719	655	38,701
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.026	532	559	17,322
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.186	911	799	94,580
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.065	719	655	42,731
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.032	532	559	17,378
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.026	532	559	16,469
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.624	1,004	934	108,210
Single Family Dwelling	Meadow Cr Ln/ Meighan	0.129	907	763	74,115
Single Family Dwelling	Okanagan St/Meighan	0.081	813	703	58,206
Mobile Home	Adair Rd/ Deep	0.077	217	146	19,828
Mobile Home	Adair Rd/ Deep	0.137	366	257	34,024
Mobile Home	Adair Rd/ Deep	0.108	362	243	33,046
Mobile Home	Adair Rd/ Deep	0.308	405	379	42,822
Mobile Home	Adair Rd/ Deep	0.378	405	388	43,337
Mobile Home	Adair Rd/ Deep	0.169	375	284	35,979
Mobile Home	Adair Rd/ Deep	0.227	388	325	81,207
Mobile Home	Adair Rd/ Deep	0.109	362	243	68,965
Mobile Home	Adair Rd/ Deep	0.037	72	49	13,793
Mobile Home	Adair Rd/ Deep	0.120	362	243	68,965
Mobile Home	Adair Rd/ Deep	0.077	217	146	19,828
Duplex	Willowdale Dr/Meighan	0.133	907	763	135,687
Duplex	Willowdale Dr/Meighan	0.083	813	703	77,010
Duplex	Willowdale Dr/Meighan	0.175	910	787	104,314
Duplex	Willowdale Dr/Meighan	0.280	917	859	186,552
Apartment Complex	Willowdale Dr/Meighan	0.600	1,105	494	1,260,243
Apartment Complex	Patterson Ave/Meighan	0.823	1,177	546	1,725,318
Apartment Complex	Patterson Ave/Meighan	0.423	990	434	438,905
				TOTAL	**$7,702,213**

NOTE Values are calculated in 2018 dollars.

Table 3-17: Residential Property Cleanup Damages

Building Classification	NRC Classification	Area/Creek	Flood Depth (m)	Damage ($)
Single Family Dwelling	B	Otter Lake Rd/Deep	0.07	5,326
Single Family Dwelling	C	Wood Ave/Deep	0.487	2,663
Single Family Dwelling	C	Wood Ave/Deep	0.251	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.579	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.718	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.8	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.97	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.959	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	1.118	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.896	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	1.125	2,663
Single Family Dwelling	C	Willowdale Dr/Meighan	0.338	2,663
Single Family Dwelling	C	Patterson Ave/Meighan	0.421	2,663
Single Family Dwelling	C	Patterson Ave/Meighan	0.882	2,663
Single Family Dwelling	C	Patterson Ave/Meighan	0.871	2,663
Single Family Dwelling	C	Patterson Ave/Meighan	0.471	2,663
Single Family Dwelling	C	Patterson Ave/Meighan	0.369	2,663
Single Family Dwelling	C	Wolfden Terrace/ Meighan	0.129	2,663
Single Family Dwelling	C	Wolfden Terrace/ Meighan	0.081	2,663
Single Family Dwelling	C	Wolfden Terrace/ Meighan	0.061	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.153	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.376	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.136	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.063	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.024	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.043	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.057	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.117	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.076	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.026	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.186	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.065	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.032	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.026	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.624	2,663
Single Family Dwelling	C	Meadow Creek Ln/ Meighan	0.129	2,663
Single Family Dwelling	C	Okanagan St/Meighan	0.081	2,663
Duplex	C	Willowdale Dr/Meighan	0.133	2,663
Duplex	C	Willowdale Dr/Meighan	0.083	2,663
Duplex	C	Willowdale Dr/Meighan	0.175	2,663

Table 3-17: Residential Property Cleanup Damages

Building Classification	NRC Classification	Area/Creek	Flood Depth (m)	Damage ($)
Duplex	C	Willowdale Dr/Meighan	0.28	2,663
Apartment Complex	MW	Willowdale Dr/Meighan	0.6	15,977
Apartment Complex	MW	Patterson Ave/Meighan	0.823	15,977
Apartment Complex	MW	Patterson Ave/Meighan	0.423	15,977
			TOTAL	**$159,765**
NOTE Values are calculated in 2018 dollars.				

Based on Table 3-16 and 3-17, the total impact on residential structural, content, and property damage was estimated to be $7,861,978.

3.4.4 Loss due to Displacement

The FEMA Multi-hazard Loss Estimation Methodology document guides the estimation of flood restoration time by building type. This restoration time was assumed to be equal and representative of displacement time for this analysis.

For typical structures located in the study area, depths up to 1.2 m of floodwater can indicate a large range of restoration times. In some cases, between seven to 13 months. In comparison, a floodwater depth of several centimetres could be recovered from in months. For flood depths higher than 1.2 m, it is reasonable to assume that the length of disruption time would be reduced since re-construction (a 100% loss) can often be achieved in less than 2 years (FEMA, 2001).

By applying a linear function fitted to the above information, the time that inhabitants would be displaced was calculated for all structures by the depth of floodwater. It was assumed that for every 0.30 m of floodwater there would be 45 days of displacement to a maximum displacement time of 24 months. Using QGIS, the displacement time was calculated for all residential structures in the SPFD using this linear relationship and mapping output from Section 2.9.

According to the Canadian Floodplain Mapping Guidelines, the loss due to displacement is estimated based on the displacement time and typical behavior of displaced individuals. Assuming three people per household (as per LoL estimate), loss calculations relied on the following typical behaviours:

- Displaced households will spend up to 14 days in a hotel ($150/day per household for the first 14 days);
- In the first 14 days, each individual spends an extra amount per day on personal goods or meals that they otherwise wouldn't have purchased (an additional $100/day per household for first 14 days);

- People requiring alternate accommodation beyond 14 days will rent ($33.20/day[41] per household for each day in excess of 14 days); and
- Many displaced households will find accommodation with friends or family resulting in a negligible displacement cost for those households (40% assumed to be accommodated, a 0.6 factor to the losses was assumed) (NRC, 2017).

Applying the assumptions above, the total loss due to displacement was calculated. Table 3-18 provides a summary of the loss estimation.

Table 3-18: Loss Due to Displacement of Residents Loss Estimation

Building Classification	Area/Creek	D[1] (m)	DT[2] (days)	Loss ($)		
				1-14 days	14+ days	Sum losses x 0.6
Single Family Dwelling	Otter Lake Rd/Deep	0.070	11	2,950	0	1,770
Single Family Dwelling	Wood Ave/Deep	0.487	73	2,300	1,959	2,555
Single Family Dwelling	Wood Ave/Deep	0.251	38	2,300	797	1,858
Single Family Dwelling	Willowdale Dr/Meighan	0.579	87	2,300	2,424	2,834
Single Family Dwelling	Willowdale Dr/Meighan	0.718	108	2,300	3,121	3,252
Single Family Dwelling	Willowdale Dr/Meighan	0.800	120	2,300	3,519	3,492
Single Family Dwelling	Willowdale Dr/Meighan	0.970	146	2,300	4,382	4,009
Single Family Dwelling	Willowdale Dr/Meighan	0.959	144	2,300	4,316	3,970
Single Family Dwelling	Willowdale Dr/Meighan	1.118	168	2,300	5,113	4,448
Single Family Dwelling	Willowdale Dr/Meighan	0.896	134	2,300	3,984	3,770
Single Family Dwelling	Willowdale Dr/Meighan	1.125	169	2,300	5,146	4,468
Single Family Dwelling	Willowdale Dr/Meighan	0.338	51	2,300	1,228	2,117
Single Family Dwelling	Patterson Ave/Meighan	0.421	63	2,300	1,627	2,356
Single Family Dwelling	Patterson Ave/Meighan	0.882	132	2,300	3,918	3,731
Single Family Dwelling	Patterson Ave/Meighan	0.871	131	2,300	3,884	3,711
Single Family Dwelling	Patterson Ave/Meighan	0.471	71	2,300	1,892	2,515
Single Family Dwelling	Patterson Ave/Meighan	0.369	55	2,300	1,361	2,197
Single Family Dwelling	Wolfden Terrace/ Meighan	0.129	19	2,300	166	1,480
Single Family Dwelling	Wolfden Terrace/ Meighan	0.081	12	3,200	0	1,920
Single Family Dwelling	Wolfden Terrace/ Meighan	0.061	9	2,450	0	1,470
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.153	23	2,300	299	1,559
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.376	56	2,300	1,394	2,217
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.136	20	2,300	199	1,500
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.063	10	2,700	0	1,620
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.024	4	1,200	0	720
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.043	7	1,950	0	1,170
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.057	9	2,450	0	1,470
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.117	18	2,300	133	1,460
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.076	11	2,950	0	1,770
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.026	4	1,200	0	720

[41] $33.20 is the daily rental cost of a typical rental unit assuming a 30-day month. See Section 3.5.1 for average rental costs per month.

Table 3-18: Loss Due to Displacement of Residents Loss Estimation

Building Classification	Area/Creek	D[1] (m)	DT[2] (days)	Loss ($)		
				1-14 days	14+ days	Sum losses x 0.6
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.186	28	2,300	465	1,659
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.065	10	2,700	0	1,620
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.032	5	1,450	0	870
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.026	4	1,200	0	720
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.624	94	2,300	2,656	2,974
Single Family Dwelling	Meadow Creek Ln/ Meighan	0.129	19	2,300	166	1,480
Single Family Dwelling	Okanagan St/Meighan	0.081	12	3,200	0	1,920
Mobile Home	Adair Rd/ Deep	0.077	12	3,200	0	1,920
Mobile Home	Adair Rd/ Deep	0.137	21	2,300	232	1,519
Mobile Home	Adair Rd/ Deep	0.108	16	2,300	66	1,420
Mobile Home	Adair Rd/ Deep	0.308	46	2,300	1,062	2,017
Mobile Home	Adair Rd/ Deep	0.378	57	2,300	1,428	2,237
Mobile Home	Adair Rd/ Deep	0.169	25	2,300	365	1,599
Mobile Home	Adair Rd/ Deep	0.227	34	2,300	664	1,778
Mobile Home	Adair Rd/ Deep	0.109	16	2,300	66	1,420
Mobile Home	Adair Rd/ Deep	0.037	6	1,700	0	1,020
Mobile Home	Adair Rd/ Deep	0.120	18	2,300	133	1,460
Mobile Home	Adair Rd/ Deep	0.077	12	3,200	0	1,920
Duplex	Willowdale Dr/Meighan	0.133	20	2,300	199	1,500
Duplex	Willowdale Dr/Meighan	0.083	13	3,450	0	2,070
Duplex	Willowdale Dr/Meighan	0.175	26	2,300	398	1,619
Duplex	Willowdale Dr/Meighan	0.280	42	2,300	930	1,938
Apartment Complex	Willowdale Dr/Meighan	0.600	90	2,300	2,523	2,894
Apartment Complex	Patterson Ave/Meighan	0.823	124	2,300	3,652	3,571
Apartment Complex	Patterson Ave/Meighan	0.423	64	2,300	1,660	2,376
					TOTAL	**$117,647**

NOTE1 D represents the depth of flood at a particular GIS node location.
NOTE2 DT represents the calculated displacement time in days.

Based on Table 3-18, the total loss due to displacement was calculated to be $117,647.

3.5 Impact to Local Economy

According to NDMP guidelines, it is necessary to consider the impact to the local economy. The risk assessment should include estimation of “losses to local economically productive assets, as well as, disruptions to the normal functioning of the community/region's local economic system” (Government of Canada, 2018).

The following statement from NRC's Canadian Guidelines and Database of Flood Vulnerability Functions document provides an important perspective on the estimation of impacts to local economy:

> "Due to limited budgets, time, and a lack of reliable data, no flood damage estimate can ever be considered complete. Damage estimates are generally utilized to inform decisions that reduce risks, not to reach a conclusion on the economic impact of flooding. As such, the assessment of damages takes a financial impact approach, rather than an economy-wide perspective. Financial impact refers to the sum of losses experienced by individuals or organisations as a result of a flood. The assumed scale of a damage study is the flood-affected area and the goal is to reduce the damages upon impacted properties and individuals" (NRC, 2017).

The scale of impact estimation to the local economy was limited to the loss of rental income (LoRI), the loss of business profit (LoBP), and the impacts to non-residential property (structural and content damage) since these were identified to be the most significant direct economic impacts to individuals and organizations within the City's community.

3.5.1 Loss of Rental Income to Landlords

The Tenancy Act in BC requires that landlords maintain their rental properties in a state that is suitable for occupancy (Province of BC, 2018). When a renter's home is no longer habitable and neither the landlord or tenant is responsible, the tenancy is deemed to be frustrated, and neither party has to give notice to end the tenancy and landlords are exposed to loss of rental income.

According to StatCan, the 2016 homeownership rate was 68% (StatsCan, 2017). Assuming 32% of structures in the Armstrong flood area are renting and paying an average monthly rate of $996 per month[42], an estimated total potential loss of rental income can be calculated. Using the duration of displacement from Section 3.5.1 for all residential structures and the average monthly rental rate, the total LoRI was calculated. Table 3-19 provides the results of this calculation.

Table 3-19: Loss of Rental Income (LoRI) Estimation

Building Classification	Area/Creek	Displacement Time (Months)	Rental Value ($/month)	LoRI ($)
RESIDENTIAL				
Single Family Dwelling	Otter Lake Rd/Deep	0.37	996	117
Single Family Dwelling	Wood Ave/Deep	2.43	996	776
Single Family Dwelling	Wood Ave/Deep	1.27	996	404
Single Family Dwelling	Willowdale Dr/Meighan	2.90	996	924
Single Family Dwelling	Willowdale Dr/Meighan	3.60	996	1,147

[42] The City of Vernon average rental rate used in the calculation of the Canadian Rental Housing Index's Okanagan-Similkameen average of $996/month.

Table 3-19: Loss of Rental Income (LoRI) Estimation

Building Classification	Area/Creek	Displacement Time (Months)	Rental Value ($/month)	LoRI ($)
Single Family Dwelling	Willowdale Dr/Meighan	4.00	996	1,275
Single Family Dwelling	Willowdale Dr/Meighan	4.87	996	1,551
Single Family Dwelling	Willowdale Dr/Meighan	4.80	996	1,530
Single Family Dwelling	Willowdale Dr/Meighan	5.60	996	1,785
Single Family Dwelling	Willowdale Dr/Meighan	4.47	996	1,424
Single Family Dwelling	Willowdale Dr/Meighan	5.63	996	1,795
Single Family Dwelling	Willowdale Dr/Meighan	1.70	996	542
Single Family Dwelling	Patterson Ave/Meighan	2.10	996	669
Single Family Dwelling	Patterson Ave/Meighan	4.40	996	1,402
Single Family Dwelling	Patterson Ave/Meighan	4.37	996	1,392
Single Family Dwelling	Patterson Ave/Meighan	2.37	996	754
Single Family Dwelling	Patterson Ave/Meighan	1.83	996	584
Single Family Dwelling	Wolfden Terrace/ Meighan	0.63	996	202
Single Family Dwelling	Wolfden Terrace/ Meighan	0.40	996	127
Single Family Dwelling	Wolfden Terrace/ Meighan	0.30	996	96
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.77	996	244
Single Family Dwelling	Meadow Crk Ln/ Meighan	1.87	996	595
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.67	996	212
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.33	996	106
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.13	996	42
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.23	996	74
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.30	996	96
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.60	996	191
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.37	996	117
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.13	996	42
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.93	996	297
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.33	996	106
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.17	996	53
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.13	996	42
Single Family Dwelling	Meadow Crk Ln/ Meighan	3.13	996	999
Single Family Dwelling	Meadow Crk Ln/ Meighan	0.63	996	202
Single Family Dwelling	Okanagan St/Meighan	0.40	996	127
Mobile Home	Adair Rd/ Deep	0.40	996	127
Mobile Home	Adair Rd/ Deep	0.70	996	223
Mobile Home	Adair Rd/ Deep	0.53	996	170
Mobile Home	Adair Rd/ Deep	1.53	996	489
Mobile Home	Adair Rd/ Deep	1.90	996	606
Mobile Home	Adair Rd/ Deep	0.83	996	266
Mobile Home	Adair Rd/ Deep	1.13	996	361

Table 3-19: Loss of Rental Income (LoRI) Estimation

Building Classification	Area/Creek	Displacement Time (Months)	Rental Value ($/month)	LoRI ($)
Mobile Home	Adair Rd/ Deep	0.53	996	170
Mobile Home	Adair Rd/ Deep	0.20	996	64
Mobile Home	Adair Rd/ Deep	0.60	996	191
Mobile Home	Adair Rd/ Deep	0.40	996	127
Duplex	Willowdale Dr/Meighan	0.67	1,992	425
Duplex	Willowdale Dr/Meighan	0.43	1,992	276
Duplex	Willowdale Dr/Meighan	0.87	1,992	552
Duplex	Willowdale Dr/Meighan	1.40	1,992	892
Apartment Complex	Willowdale Dr/Meighan	3.00	19,920	19,123
Apartment Complex	Patterson Ave/Meighan	4.13	14,940	19,761
Apartment Complex	Patterson Ave/Meighan	2.13	6,972	4,760
			TOTAL	**$70,628**

Based on Table 3-19, the total LoRI to landlords was estimated to be $70,628.

3.5.2 Loss of Profits to Local Businesses

LoBP was selected to represent impacts to business activity and lost opportunity costs since other indicators, such as total revenue, do not account for the reduced overhead of inactive businesses (such as frustrated rent/leaseholds, reduced payroll obligations and limited operating expenditures).

Due to the time-sensitive nature and limited scope of this project, calculation of LoPB was simplified since an in-depth survey of businesses in Armstrong was not feasible. As such, a simple approach to estimating an approximate LoBI based on the total LoW estimate from Section 3.4.1 was used.

Primarily, it was assumed that all businesses in Armstrong of a particular industry category will have the same ratio of net profit to total employee and labour compensation (NP/C) as the average of all Canadian businesses in the same industry category. Using 2016 StatCan data, the net profit to compensation ratio (NP/C) was calculated for each industry category. Table 3-20 summarizes these calculations.

Table 3-20: Ratio of Net Profit to Employee and Labour Compensation (Statistics Canada, 2016)

Industry Category	TR ($)	C ($)	NP ($)	NP/C ($)
Construction (23)	427.3	108.8	11.5	0.106
Food Services (722)	642.6	193.0	24.4	0.126
Grocery Stores (4451)	782.0	80.7	22.6	0.280

Table 3-20: Ratio of Net Profit to Employee and Labour Compensation (Statistics Canada, 2016)

Industry Category	TR ($)	C ($)	NP ($)	NP/C ($)
Hotels and Motels (72111)	764.3	210.6	52.0	0.247
Professional & Technical Services (54)	259.3	79.5	77.6	0.976
Retail Trade (44-45)	667.0	99.1	36.7	0.370
Offices of Physician (6211)	411.1	89.7	235.3	2.623
Offices of Other Health Practitioners (6213)	211.6	47.7	84.4	1.769
Offices of Dentists (6212)	647.0	200.6	213.0	0.941
Slaughtering and Processing (31161)	962.1	205.6	46.0	0.224
Transportation and Warehousing (48-49)	272.6	58.9	38.1	0.647
Nursing & Residential Care (623)	757.7	378.8	39.5	0.104
Calculated Average for All Categories				0.701
All values represent national averages and in thousands of dollars for that category. All data used had quality indicators of *Very Good* or *Excellent* based on StatsCan financial performance data statistics. TR – whole industry average total revenue. C – average total wages including benefits and commission expenses. NP – average total net profit. NP/C – ratio of net profit to compensation				

Assuming LoW from Section 3.4.1 is equal to C, the LoBP was calculated by multiplying LoW by NP/C. Table 3-21 summarizes the results of this calculation.

Table 3-21: Loss of Business Profit (LoBP) Estimation

Business Type	LoW	NP/C	LoBP
HEALTHCARE*			
Medical Clinic*	17,909	2.623	46,976
Dental Clinic*	15001	0.941	14,116
Physiotherapy Clinic*	13776	1.769	24,370
Pharmacy*	28126	1.769	49,756
Optometry Clinic*	11939	1.769	21,121
PROFESSIONAL SERVICES			
Accounting Office	11939	0.976	11,653
Notary Public	11939	0.976	11,653
Investment Office	11939	0.976	11,653
Insurance Broker	14924	0.976	14,566
Real Estate Broker	11251	0.976	10,981
Veterinary Clinic	-	0.976	n/a
Autobody Garage	29083	0.976	28,385
TRANSPORTATION			
Transportation Services	957	0.647	619
Trucking Facility	5740	0.647	3,714
CONSTRUCTION			
Contractor Bldg	3827	0.106	406
RETAIL			
Grocery Store*	189423	0.280	53,038

Table 3-21: Loss of Business Profit (LoBP) Estimation

Business Type	LoW	NP/C	LoBP
Pet Retail	15001	0.370	5,550
Pet Retail	50513	0.370	18,690
Electronics Retail	7462	0.370	2,761
Automotive Retailer	5740	0.370	2,124
Health Food Retailer	48982	0.370	18,123
General Merchandise	126282	0.370	46,724
Flower Shop	3061	0.370	1,133
Thrift Store	7653	0.370	2,832
RESTAURANT			
Pizza Eatery	11251	0.126	1,418
Sandwich Eatery	11251	0.126	1,418
Sushi Restaurant	50513	0.126	6,365
Bakery	57401	0.126	7,233
Coffee Shop	45921	0.126	5,786
OTHER			
Financial Institution*	0	n/a	n/a
Fitness Centre	7500	0.701**	5,258
Barber	28700	0.701**	20,119
Car Wash Facility	765	0.701**	537
Storage Facility	0	0.647	n/a
Food Processing Facility	764326	0.224	171,209
Hotel/Inn	2870	0.247	709
Assisted Living Facility	169333	0.104	17,611
		TOTAL	**$638,603**

*These sectors are considered critical according to NDMP guidelines: communications technology, finance, healthcare, food, water, transportation, safety, government and manufacturing (Government of Canada, 2018).
**The average NP/NC for all categories was used.
NOTE1 Values are calculated in 2018 dollars.

Based on Table 3-21, the total LoBP was estimated to be $638,603.

3.5.3 Impact to Non-Residential Properties

To account for economic losses related to non-residential structural and content damage, the impact was estimated using available NRC damage functions. Damage functions used in this analysis for structural and content damage for all industry categories are illustrated in Figure 3-7 and Figure 3-8.

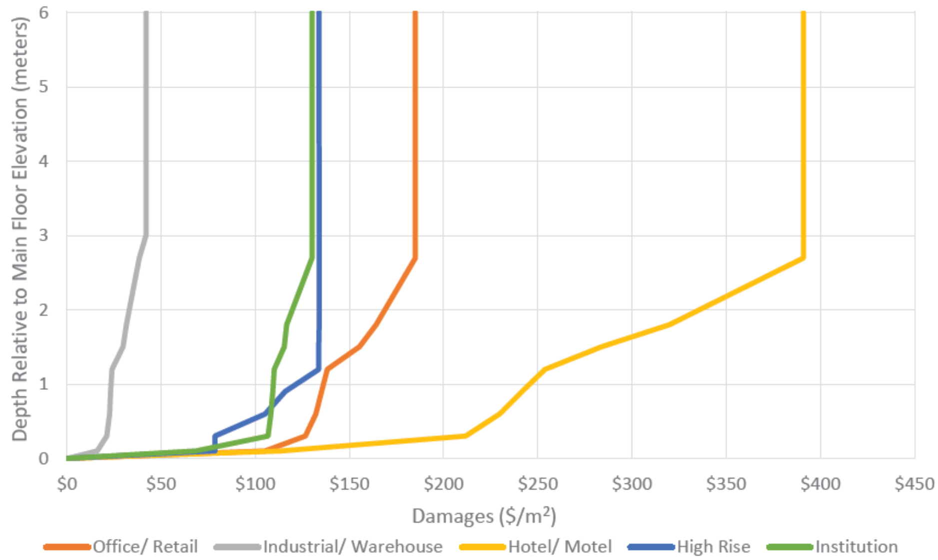


Figure 3-7: Non-Residential Structural Damage Function

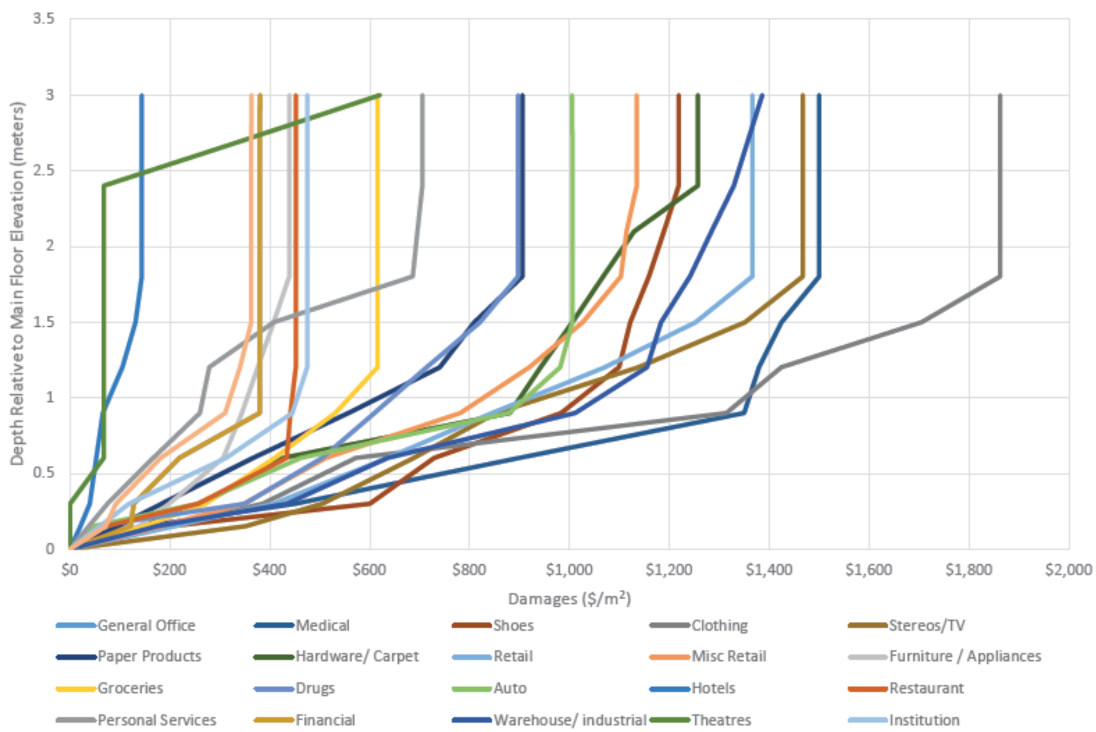


Figure 3-8: Non-Residential Content Damage Function

Since both structural and content damage varies significantly depending on the industry category of the structure and the depth of floodwaters, the SPFD was used in the same manner as with residential loss calculations conducted in Section 3.4. Results of the calculations are summarized in Table 3-22.

Table 3-22: Impact to Non-Residential Properties Loss Estimation

Building Classification	Area/Creek	Flood Depth (m)	Structural Damage ($/m²)	Total Damage
Office/Retail	Patterson/Meighan	0.60	135	9,948
Office/Retail	Patterson/Meighan	0.46	134	36,782
Office/Retail	Smith Dr/Meighan	0.08	82	12,952
Office/Retail	Smith Dr/Meighan	0.08	82	12,952
Office/Retail	Smith Dr/Meighan	0.08	82	12,952
Office/Retail	Smith Dr/Meighan	0.08	82	12,952
Office/Retail	Smith Dr/Meighan	0.08	82	12,952
Office/Retail	Smith Dr/Meighan	0.08	82	36,962
Office/Retail	Smith Dr/Meighan	0.10	104	48,816
Office/Retail	Smith Dr/Meighan	0.10	104	77,642
Office/Retail	Smith Dr/Meighan	0.10	104	15,407
Office/Retail	Smith Dr/Meighan	0.10	104	15,407
Office/Retail	Smith Dr/Meighan	0.10	104	15,407
Office/Retail	Smith Dr/Meighan	0.10	104	69,358
Office/Retail	Smith Dr/Meighan	0.10	104	15,407
Office/Retail	Smith Dr/Meighan	0.10	104	26,175
Office/Retail	Smith Dr/Meighan	0.33	132	84,981
Office/Retail	Smith Dr/Meighan	0.33	132	87,518
Office/Retail	Smith Dr/Meighan	0.33	132	38,192
Office/Retail	Smith Dr/Meighan	0.33	132	315,261
Office/Retail	Smith Dr/Meighan	0.33	132	41,856
Office/Retail	Smith Dr/Meighan	0.33	132	20,928
Office/Retail	Smith Dr/Meighan	0.33	132	20,928
Office/Retail	Smith Dr/Meighan	0.33	132	113,872
Office/Retail	Smith Dr/Meighan	0.06	60	26,297
Office/Retail	Smith Dr/Meighan	0.04	45	13,061
Industrial/Warehouse	Patterson/Meighan	0.74	23	5,808
Industrial/Warehouse	Patterson Ave/Meighan	0.53	23	4,319
Industrial/Warehouse	Patterson Ave/Meighan	0.40	22	6,312
Industrial/Warehouse	Smith Dr/Meighan	0.05	8	5,083
Industrial/Warehouse	Okanagan St/Deep	0.50	22	68,342
			TOTAL STRUCTURAL	$1,284,827
Building Classification	Area/Creek	Flood Depth (m)	Content Damage ($/m²)	Total Damage
General Office	Patterson/Meighan	0.60	177	48,596

Table 3-22: Impact to Non-Residential Properties Loss Estimation

General Office	Patterson/Meighan	0.46	218	16,038
General Office	Smith Dr/Meighan	0.099	80	11,836
Financial	Smith Dr/Meighan	0.079	63	9,950
Financial	Smith Dr/Meighan	0.079	63	9,950
Financial	Smith Dr/Meighan	0.079	63	9,950
Financial	Smith Dr/Meighan	0.099	80	37,503
Medical	Smith Dr/Meighan	0.079	79	12,335
Medical	Smith Dr/Meighan	0.079	79	35,203
Drugs	Smith Dr/Meighan	0.099	33	24,649
Restaurant	Smith Dr/Meighan	0.099	27	4,048
Restaurant	Smith Dr/Meighan	0.099	27	4,048
Restaurant	Smith Dr/Meighan	0.332	276	79,574
Restaurant	Smith Dr/Meighan	0.332	276	43,604
Stereos/TV	Smith Dr/Meighan	0.079	276	43,420
Institution	Smith Dr/Meighan	0.099	39	26,004
Personal Services	Smith Dr/Meighan	0.099	24	6,149
Personal Services	Smith Dr/Meighan	0.332	84	13,257
Paper Products	Smith Dr/Meighan	0.332	202	129,938
Clothing	Smith Dr/Meighan	0.332	405	267,704
Groceries	Smith Dr/Meighan	0.332	285	678,518
Retail	Smith Dr/Meighan	0.332	432	371,836
Misc Retail	Smith Dr/Meighan	0.099	120	17,803
Misc Retail	Smith Dr/Meighan	0.332	366	115,843
Misc Retail	Smith Dr/Meighan	0.043	52	15,092
Auto	Smith Dr/Meighan	0.057	17	7,680
Auto	Patterson/Meighan	0.741	657	166,016
Warehouse/Industrial	Patterson Ave/Meighan	0.530	588	112,763
Warehouse/Industrial	Patterson Ave/Meighan	0.401	502	146,122
Warehouse/Industrial	Smith Dr/Meighan	0.049	57	36,639
Warehouse/Industrial	Okanagan St/Deep	0.503	570	1,742,335
			TOTAL CONTENT	$4,195,807
			TOTAL STRUCTURAL & CONTENT	**$5,480,634**

Based on Table 3-22, the total impact to non-residential property, including structural and content damage, was estimated to be $5,480,634.

3.6 Summary of Flood Risk

In accordance with best practices, NDMP guidelines and requests from the City, impacts to all individuals and organizations within Armstrong were estimated based on the 1/200-year flood hazard. As a result, the total monetary losses were estimated to be $21,248,190. Table 3-23 provides a summary of this estimate and includes descriptions of other non-monetary impacts for each category.

Table 3-23: Summary of 1/200-year Flood Impact

<table>
<tr><th>Category</th><th>Sub-category</th><th>Section</th><th>Sub-Category Loss ($)</th><th>Total Loss ($)</th></tr>
<tr><td rowspan="7">Local Infrastructure</td><td>Electrical Power System</td><td>3.1.1</td><td>$200,000</td><td rowspan="6">$1,445,000</td></tr>
<tr><td>Transportation System</td><td>3.1.2</td><td>$590,000</td></tr>
<tr><td>Wastewater System</td><td>3.1.3</td><td>$650,000</td></tr>
<tr><td>Potable Water System</td><td>3.1.4</td><td>$5,000</td></tr>
<tr><td>Natural Gas System</td><td>3.1.5</td><td>-</td></tr>
<tr><td>Telecommunication System</td><td>3.1.6</td><td>-</td></tr>
<tr><td colspan="4">Other non-monetary impacts:
• Electrical power outage
• Local road washout(s) (non-isolating)
• Failure of WWTP functionality
• Impact to watermain (not causing extended shut-down)
• Increased risk of potable water contamination</td></tr>
<tr><td rowspan="2">Impact to Environment</td><td>n/a</td><td>3.2</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Other non-monetary impacts:
• Risk of impact to red- and blue-listed species
• Contamination of water and pollution of wetlands</td></tr>
<tr><td rowspan="2">Impact to Cultural Values</td><td>n/a</td><td>3.3</td><td>-</td><td>-</td></tr>
<tr><td colspan="4">Other non-monetary impacts:
• One (1) heritage site was impacted by flood
• 12 other heritage sites were considered to be at risk but outside of the mapped 1/200-year inundation
• Impact to the Okanagan Regional Library, Highland Park Elementary School yard, and the IPE fairgrounds</td></tr>
<tr><td rowspan="6">Impact to People and Society</td><td>Loss of Wages</td><td>3.4.1</td><td>$1,895,813</td><td rowspan="5">$13,613,325</td></tr>
<tr><td>Loss of Life</td><td>3.4.2</td><td>-</td></tr>
<tr><td>Loss of Automobiles</td><td>3.4.3.1</td><td>$3,737,887</td></tr>
<tr><td>Loss of Residential Property (includes structural, content & property)</td><td>3.4.3.2</td><td>$7,861,978</td></tr>
<tr><td>Loss due to Displacement</td><td>3.4.4</td><td>$117,647</td></tr>
<tr><td colspan="4">Other non-monetary impacts:
• Stress and other non-monetary hardships related to displacement, property loss and loss of wages
• Shut-down of vital service providers including a financial institution, a grocery store, postal office, and five medical service providers (medical clinic, dental office, physiotherapy clinic, pharmacy, and optometry clinic)
• Incremental increase of risk to health and safety due to increased potential of water contamination and drowning</td></tr>
</table>

Table 3-23: Summary of 1/200-year Flood Impact

Impact to Local Economy	Loss of Rental Income	3.5.1	$70,628	$6,189,865
	Loss of Business Profits	3.5.2	$638,603	
	Impact to Non-Residential Properties	3.5.3	$5,480,634	
	Other non-monetary impacts: • Stress and other non-monetary hardships related to business displacement, property loss, and loss of profits			
			TOTAL	**$21,248,190**

According to the Engineers and Geoscientists of British Columbia's flood assessment professional practice guidelines, *risk* is defined as "a measure of the probability and severity of an adverse effect to health, property, or the environment" and "is often estimated by the product of probability and consequence" (EGBC, 2018).

In consideration of the above quote, it is important to recognize that loss estimates provided in Table 3-22 are based on the occurrence of a single event having a probability[43] of 1/200. As such, the risk of this event (the 1/200-year) can be represented as the product of the probability (1/200 or 0.005) and the impact (value from Table 3-23). The result of the product calculates to an annual risk to all individuals and organizations in Armstrong for this event (the 1/200-year) to be $106,240/year.

Since smaller floods that are more likely to occur have significant negative consequences (for example, the 1/100-year flood may have roughly half the impact), it is important to consider the *total risk* of all combinations of flood probabilities and impacts. To illustrate this, if it is assumed that there are no negative impacts (impact of $0) from a flood having a severity equivalent to the 1/20-year flood event, a straight-line[44] relationship may be drawn to the total impact and severity of the 1/200-year flood event. Figure 3-9 below graphically represents the assumed *impact function* by flood severity between the 1/20-year and 1/200-year floods.

[43] The probability of 0.005 represents the likelihood of a particular event occurring in any one-year period (or a 0.5% chance per year).
[44] The relationship will not be linear. In the absence of data, this is a rough approximation to calculate *total risk* for illustration purposes.

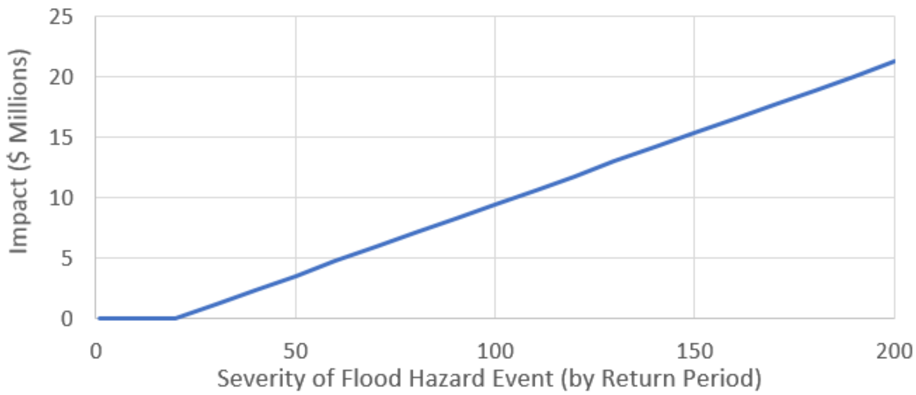


Figure 3-9: Example Impact Function by Flood Severity (Assumed Linear)

To obtain a *risk curve*, the probability for all flood severities (*probability curve*) must be multiplied by the *impact function* shown in Figure 3-9. Figure 3-10 and Figure 3-11 graphically illustrate the *probability curve* and resulting *risk curve* respectively. Tabulated data used to generate these graphs has been included in Appendix IV.

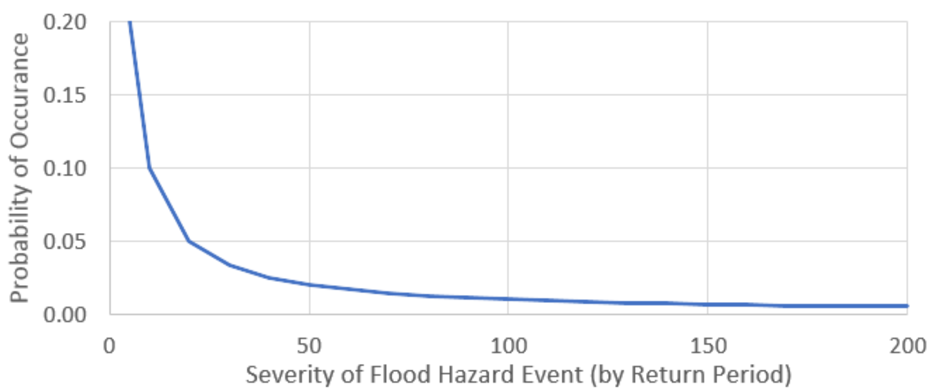


Figure 3-10: Example Probability Curve by Flood Severity

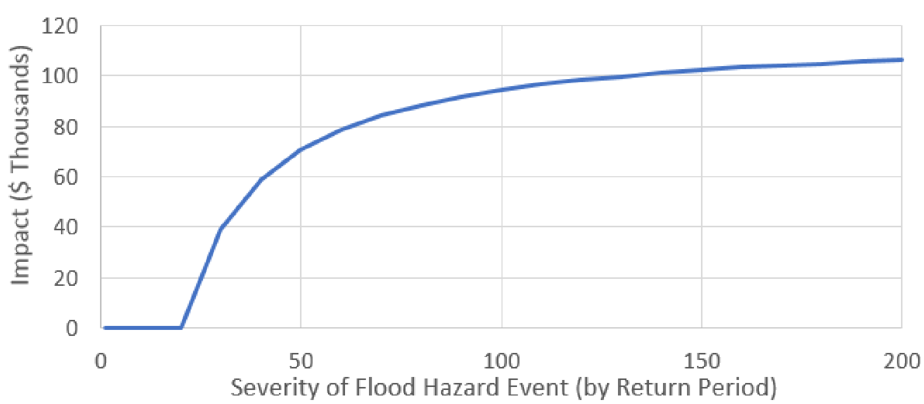


Figure 3-11: Example Risk Curve by Flood Severity

By summing the risk for all combinations of flood probabilities and impacts, the total annual impact of flooding to all individuals and organizations roughly calculates to $1.6 million/year. By applying the ratio of impacts from Table 3-23 for People and Society to total impacts, the example suggests that the individuals of Armstrong may bear roughly $1.3 million/year due to flooding.

4 FLOOD RISK MITIGATION

In alignment with the purpose of this project, this section is intended to support and direct the development and implementation of an IFMP. It contains contextual information regarding flood management roles and responsibilities, general mitigation strategies, and an overview of the current flood mitigation efforts that are already in place or are currently being implemented. Where any opportunity to improve flood mitigation efforts was identified, findings are provided at the end of each their appropriate sub-section sections.

4.1 Flood Management Roles and Responsibilities

Everyone is affected by flooding. As such, everyone has a role in flood mitigation planning and implementation. For this reason, it is important that all stakeholders work together to develop and implement a balanced and effective IFMP (Province of British Columbia, 1999).
A brief summary of the roles and responsibilities for individuals, local authorities, and provincial agencies and federal government agencies has been provided.

4.1.1 Individuals

According to the Flood Planning and Response Guide for BC, “regardless of governmental involvement, the first line of defense against floods always rests with the individual. All homeowners, landlords and individuals, although not mandated by legislation, have a responsibility to protect their homes and families to the greatest extent possible. It is up to each individual to know what to do in an emergency. Individuals living in flood-prone areas should be aware or made aware, of that fact so they can take appropriate precautions in regard to their living arrangements and their planned response to a flood event” (Province of British Columbia, 1999). In addition to this, individuals play an important role in supporting their community and local authorities in the effort to implement an IFMP.

4.1.2 Local Authorities

According to the Flood Hazard Area Land Use Management guidelines, local authorities have the responsibility to act on behalf of individuals to coordinate and direct flood management. Local authorities are the conduit in which flood mitigation activities are directed and implemented. For this reason, local governments have been given the authority to:

- Develop flood hazard area bylaws without provincial government approval, but with consideration for their policies and guidelines;

- Grant flood hazard area land development exemptions, provided that the exemptions are consistent with provincial government guidelines, or certified by a suitably qualified professional engineer or geoscientist; and
- Establish the requirements for subdivision in flood-prone areas, which includes engineering reports assessing flood hazards and restrictive covenants (FLNRORD, 2018)

In consideration of the above role and granted authority, local governments must consider the Flood Hazard Area Land Use Management Guidelines if designating floodplains (Local Government Act). The designation of floodplains, as well as management of approvals for residential, commercial, and industrial development, must protect riparian areas as per requirements under the Riparian Areas Protection Act (APEGBC, 2017).

4.1.3 Provincial and Federal Agencies

Relative to the scale of emergencies and the impact of flooding, both provincial and federal government provide emergency response and disaster assistance to both individuals and local governments. In addition, both provincial and federal governments are committed in providing support, education, and tools necessary for local authorities to direct and implement flood risk management. As an example of this commitment, this project was funded under the NDMP and CEMP programs which are both federal and provincial programs respectfully.

Although the provincial government still provides a role in development approvals in certain cases, according to the Legislated Flood Assessment guidelines for BC, "the role of the provincial government has lessened in the area of development approvals in Flood Hazard areas, with an increasing role for local governments and consultants." As such, it is expected that the provincial government will continue to shift towards a supportive role whereby the local government will be responsible for tailoring and implementing local flood risk management.

4.2 Introduction to Flood Risk Mitigation Strategies for Local Authorities

Flood risk mitigation planning "is the process by which a community reflects on its identified risks, and uses this information to make informed planning decisions" (Government of Canada, 2018). According to NDMP guidelines, this process should be led by the local authority and should include the following steps:

1. Identification of broad mitigation goals;
2. Identification of feasible strategies which can achieve those goals; and
3. Develop a plan for execution that will clearly state the identified goals and strategies which identifies key activities to be completed (IFMP).

In alignment with the above process, these flood mitigation steps align with the *risk reduction* components of a risk-based approach according to the Engineers and Geoscientists guidelines (EGBC, 2018). Figure 4-1 below illustrates this risk-based approach.

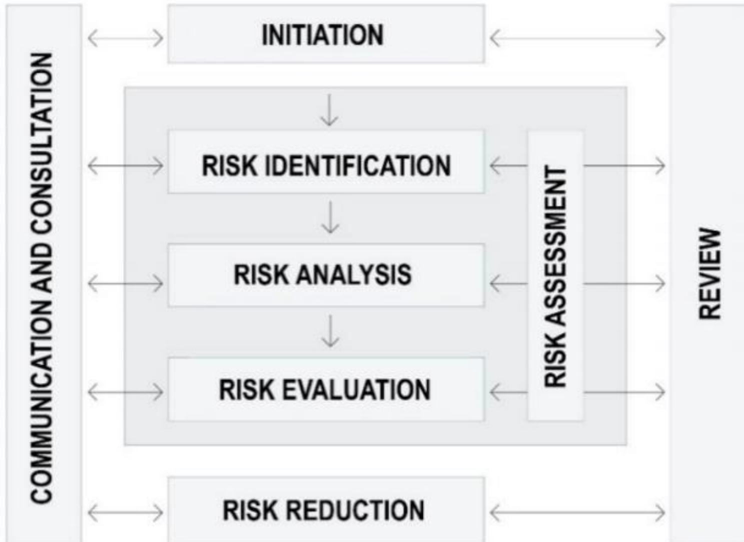


Figure 4-1: Flood Risk Assessment - Risk-based approach (Adapted from EGBC, 2018)

The components bound by the shaded box in Figure 4-1 have been covered in the flood mapping and flood risk assessment portions of this report (Section 2, 3, and 4) of this report. The remainder of this report is intended to focus on *risk reduction.* As such, the following sections provide potential flood risk mitigation strategies that are intended to be reviewed, and if appropriate, implemented through communication and consultation.

At the present time, since no design-based or risk-based goals[45] have been defined at this time, the mitigation strategies presented are broadly aimed at reduction of flooding risk and have not been guided by any prescribed targets.

4.3 Non-Structural Mitigation

This section covers non-structural flood risk mitigation (also known as passive mitigation). Non-structural mitigation is defined as “non-physical measures that incorporate the measurement and assessment of the risk environment and contribute to risk reduction” (Government of Canada, 2018). Upon completing a review of the referenced flood-related information, including, the results of the flood mapping and flood risk assessments, a discussion is provided for the following non-structural mitigation categories:

- Flood Mapping;
- Risk Assessment;

[45] Goals for risk reduction may be design-based or risk-based. Design-based goals typically involve descriptive targets such as water elevations or flow capacities, whereas risk-based goals typically involve more general thresholds for acceptable impacts.

- Official community planning;
- Subdivision and development servicing bylaws
- Emergency Response; and
- Integrated Flood Management Planning.

4.3.1 Flood Mapping

In recent years, the City has been actively seeking opportunities to develop flood mapping. Upon acceptance of a 2017 application for funding, the City initiated the mapping portion of this project. As of the date of this report, flood mapping is available to the City to guide and support other flood mitigation strategies (Section 2 of this report).

This information is valuable in that it supports risk assessment and guides the implementation of other non-structural mitigation activities. These are discussed in the following sections.

4.3.1.1 Flood Mapping – Future Strategies

Flood mapping should be reviewed, and if necessary, updated once every 10 years. This ensures that flood mapping is useful and continues to represent current conditions since changes to design criteria, land use, or climate change is expected to occur. Other changes requiring updates may include: significant hydrologic or hydraulic change in the upstream watershed, changes to the channel geometry (such as a flood, landslide or other event), identification of new flood hazards (may include collection and analysis of more recent data), construction of structural mitigation works, land use changes and urbanization, or other significant impacts (APEGBC, 2017).

4.3.2 Risk Assessment

Similar to flood mapping, the City has been seeking opportunities to conduct a flood risk assessment. As of the date of this report, a completed risk assessment is available to the City to guide and support other flood mitigation strategies (Section 3 of this report).

4.3.2.1 Risk Assessment – Future Strategies

Risk assessment information provides valuable information about the frequency of negative impacts from floods. As this is required to fully understand the ongoing cost to individuals and organizations in the community, risk assessment provides the necessary information to determine the feasibility of flood mitigation options, as well as, set balanced and attainable goals.

Although BC has not developed formal flood risk tolerance criteria, it is important that the City consider and identify a risk tolerance that reflects the community’s level of acceptable risk. This level of risk should be balanced and determined in consultation with stakeholders.

Once an acceptable level of risk is determined, this will guide the development and implementation of other feasible mitigation strategies, of which, some may include design standards. As Figure 4-2 illustrates, a simple adoption of common design standards from another jurisdiction may not necessarily provide the optimum mitigation plan for the City (often referred to as a design-standard approach). However, careful selection and implementation of design standards have significant benefits if implemented with consideration of total risk.

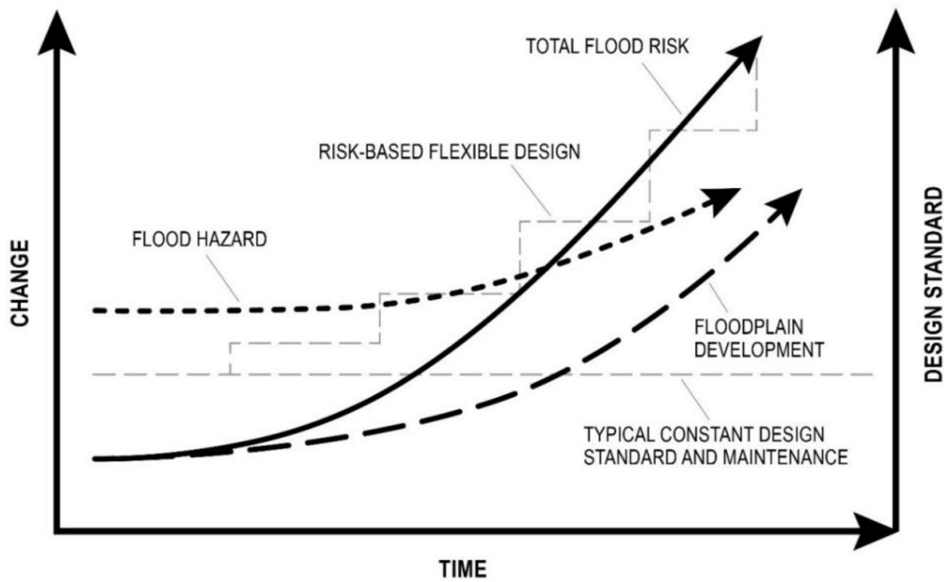


Figure 4-2: Flood Risk and Design Standards vs. Time (EGBC, 2018)

In addition to providing informed design standard implementation, risk assessment provides the necessary information needed to perform loss estimation analysis[46]. According to NDMP guidelines, all structural mitigation options should be assessed for feasibility and effectiveness prior to implementation, therefore, ensuring the maximum benefit and prioritization of all flood management activities (Government of Canada, 2018).

4.3.3 Official Community Planning

Over considerable time and investment, the City has developed a robust Official Community Plan (OCP). In that OCP, there are identified development permit areas, as well as, a clear framework for implementing specific development permit requirements for "hazardous condition and natural environment areas" which are mapped and designated on a Development Permit Areas (DPA) map. In relation to flooding, the DPA map generally identifies: 1) riparian wetland, the Meighan Creek watercourse, and the Deep Creek watercourse, referred to as *natural*

[46] Loss estimation analysis compares the loss differences between implementing and not implementing any particular mitigation option. The feasibility and effectiveness of implementing that option is then determined by comparing the net loss avoidance gained to the costs of implementation or construction.

environment, and 2) the City's floodplain, referred to as a *hazardous condition* area. For reference, the City's DPA map has been included in Appendix VI (City of Armstrong, 2014).

4.3.3.1 Official Community Planning – Future Strategies

Although the OCP has some effective components that support integrated flood management, the document's DPA map requires review and revision as its pre-dates the 2016 Riparian Areas Regulation revisions as well as the flood mapping and risk assessment work contained within this report.

4.3.4 Subdivision and Development Servicing Bylaws

The City's Subdivision and Development Servicing Bylaw No. 1570 (SDSB) contains information to address site drainage design requirements[47] and provides some general considerations for riparian areas and flooding. In the event that a proposed subdivision is traversed by a watercourse, Bylaw No. 1570 requires that the subdivisions provide the City with an SRW along the watercourse (or its planned realignment) to facilitate "construction, maintenance, conservation and/or beautification purposes" (City of Armstrong, 2007). This effectively assists the City's ability to implement future flood management strategies by providing necessary access to newly developed areas.

The SDSB references the requirements of the Provincial Riparian Areas Regulation and encourages all applicants to contact the Province to obtain prior confirmation that proposed subdivisions, strata or developments will not likely adversely affect the environment. The bylaw also prescribes that "discharges to natural drainage courses shall not adversely affect downstream properties"; however, no specific outflow requirement is defined[48] (City of Armstrong, 2007). For reference, a copy of the City Composite Map illustrating the existing stormwater infrastructure is included in Appendix V (City of Armstrong, 2014).

4.3.4.1 Subdivision and Development Servicing Bylaws – Future Strategies

According to the Flood Hazard Area Land Use Management guidelines, "local governments are responsible for understanding the risks of flooding in their areas and make appropriate land use decisions so that developments are built in a manner that limits flood damage and ensures public safety." The document goes on affirming that the incorporation of flood risk management principals and standards into development bylaws may be "the key requirement of land use planning" (FLNRORD, 2018).

As new flood mapping information is available, the SDSB should be reviewed and implementation of appropriate flood construction levels (FCL) and/or setbacks should be

[47] The bylaw includes prescriptive site drainage design requirements for the 1/25-year and 1/100-year rainfall events.
[48] In some cases, site specific drainage systems are required to have a maximum outflow that is less than or equal to pre-development conditions at a prescribed return period.

considered. The Flood Hazard Area Land Use Management Guidelines provides useful recommendations for FCL and setbacks which could be easily referenced to flood mapping. These setback recommendations must also consider riparian requirements which may be greater; however, they are useful in guiding the design standard setback and FCL assuming that the 1/200-year flood map is the "natural boundary". The following bullets summarize applicable quotations from these guidelines:

- Small lakes, ponds, swamps and marsh areas[49] – Buildings should be set back at least 7.5 metres from the natural boundary of the lake, pond, swamp or marsh. The elevation requirement may be reduced to 1.5 metres above the natural boundary of the lake, pond or adjacent swamp or marsh area (MWLAP, 2004)
- Standard requirements for ordinary watercourse set backs – Buildings should be setback at least 30 metres from the natural boundary of any watercourse[50] (MWLAP, 2004); and
- Where a designated flood level has been determined – Areas used for habitation, business, or storage of goods damageable by floodwaters should be constructed within any building at an elevation such that the underside of the floor system thereof is no less than the FCL (MWLAP, 2004).

As discussed earlier, the Riparian Areas Protection Act requires that consideration is given to riparian protection during residential, commercial and industrial development. As such, setbacks established under this Act may be greater or less than flood hazard listed above and therefore should be given due consideration (APEGBC, 2017).

4.3.5 Emergency Response

The City's Emergency Program is established through the Armstrong's Emergency Program Bylaw No. 1794, 2016. This bylaw provides a framework for City Council to select and appoint persons to fill the roles of the Emergency Management Executive Committee, Emergency Program Management Committee, and Emergency Program Coordinator, as well as, establish the council's responsibility to:

- Declare a State of Local Emergency,
- Appoint the Emergency Management Executive Committee,
- Adopt an Emergency Plan,
- Delegate powers available under the Emergency Program Act,
- Establish emergency policies, resolutions, or bylaws necessary to facilitate the response to an emergency or disaster,

[49] Small lakes where a lake is less than 15 kilometres in length and where there is no history of severe flooding or concern for shoreline erosion, and for ponds, swamps or marsh areas:
[50] Some exceptions are recommended in the guideline (MWLAP, 2004).

- Ensure that sufficient budget and staff are provided to maintain an essential level of emergency program preparedness, and
- Enter into agreements with other local authorities for the purpose of emergency assistance or the formulation of coordinated emergency preparedness, response or recovery (City of Armstrong, 2016).

Based on the information reviewed regarding the City's response to 2018 flooding, a variety of successes were noted. Section 1 of this report identified the following successful activities that were conducted as a result of emergency response planning and the existing Emergency Program:

- A local state of emergency was declared promptly facilitating emergency activities;
- Media releases were promptly and routinely made which kept the public informed regarding flood hazard potential, availability of flood protection supplies and notification of post-disaster assistance availability; and
- The City demonstrated effectiveness by forecasting weather and adjusting emergency response activities which proved successful in mitigating some of the impacts of flooding.

4.3.5.1 Emergency Response – Future Strategies

Based on the above, the 2018 flood response demonstrated that emergency preparedness does reduce risk. As such, it is important to reflect on the recent incidents of 2017 and 2018, and where appropriate, improve the emergency response plans.

With flood mapping now available, emergency plans should also be updated to consider the potential impacts to infrastructure (Section 3.1) and vital structures (Section 3.5.3). Of note, infrastructure impacts to electrical power, potable water, wastewater, and certain road crossings, as well as, impacts to the public works yard on Patterson Avenue will impact operations staff and ability to respond.

Newly delineated areas for potential flood hazard should also be considered when designating suitable sites for distribution of flood supplies. Of note, sand and sandbags were provided to residents free of charge in support of the 2017 flood mitigation effort; however, if the flood had been more severe, this location would have been underwater and would have hindered the ability of individuals to take advantage of these vital resources in their time of need.

4.3.6 Integrated Flood Management Planning

Over the past year, the City has engaged Western Water Associates Ltd, Gentech Engineering Inc, and Integrated Watersheds to support a variety of activities related to flood mitigation. These activities have included the repair of culverts, preparation of creek sediment removal plans, maintenance of culverts, and preparation of required environmental management plans to facilitate the work. These consultants have also provided an in-kind contribution of their time in providing information in the support of the preparation of this report.

At this time, it is understood that the City has engaged Integrated Watersheds to prepare a scope of work to prepare an IFMP for both Deep and Meighan Creeks.

4.3.6.1 Integrated Flood Management Planning – Future Strategies

As stated above, flood risk mitigation planning "is the process by which a community reflects on its identified risks, and uses this information to make informed planning decisions." As such, it is recommended that the IFMP development is conducted through public consultation in the context of the risk assessment findings, such that it achieves a balanced, feasible, and cost-effective approach to flood risk mitigation in accordance with the recommended NDMP steps summarized in Section 4.2.

4.4 Structural Mitigation

This section covers structural flood risk mitigation (also known as active mitigation). Structural mitigation is defined as "physical measures designed to mitigate the impact of hazards (e.g., channel improvement [construction of floodways and dykes], flow regulation [diversions, creating upstream storage], flood-proofing measures [reinforcing or raising homes to minimize vulnerability to floods])" (Government of Canada, 2018). Upon completing a review of the referenced flood-related information, including, the results of the flood mapping and flood risk assessments, a discussion is provided for the following structural mitigation categories:

- Hydraulic capacity of creek crossings;
- Headwall upgrade at Patterson Ave;
- Channel and culvert maintenance; and
- Meighan Creek bypass (concept).

According to the BC Flood Hazard Land Use Management branch, "well-designed structural measures can be highly effective in reducing flood damage when used appropriately; however, they can inherently reduce the risk of flood in one location while increasing it in another". As such, <u>feasibility analysis should be conducted and consideration for *transferred* flood risk should be given prior to implementing any structural mitigation option</u> (FLNRORD, 2018). In addition, <u>all mitigation options should be assessed using loss estimation analysis (as described in Section 4.3.2) and modelled to ensure that downstream obstructions do not limit the effectiveness of risk reduction.</u>

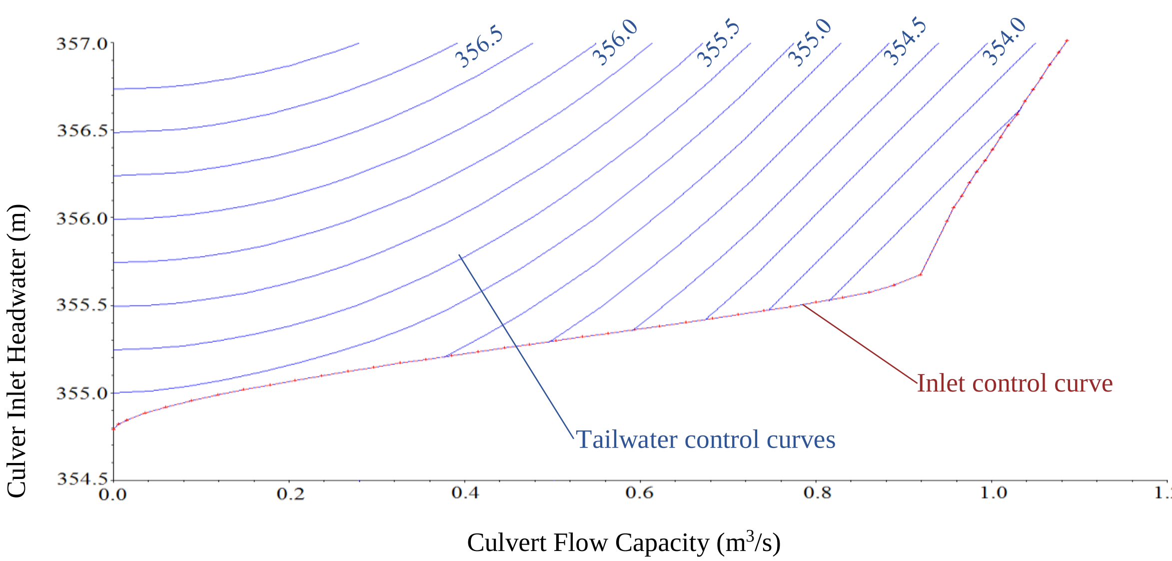
4.4.1 Hydraulic Capacity of Creek Crossings

According to the findings from Section 3.1.2, there are four (4) road crossings that get overtopped under the 1/200-year flood (Okanagan Street at two locations, Wood Avenue, and Adair Street). The Patterson Avenue (culverted hydraulic works through IPE to Deep Creek) and Meadow Creek Lane crossings were also identified as flow restriction points[51].

A brief discussion of these flow restriction points is included below. These discussions are intended to guide and prioritize structural mitigation options only.

4.4.1.1 Patterson Avenue to Deep Creek Crossing

This crossing was identified as the largest contributor to flood impact. The crossing consists of a long 1200 mm diameter corrugated steel pipe (CSP) with an approximate length of 365 m. Under most flow conditions in Deep Creek and Meighan Creek, this pipe capacity is dictated by the geometry of the culvert's inlet (referred to as inlet controlled). However, under high flow conditions in Deep Creek – such as from obstructions in Deep Creek in the vicinity of Adair Street, or a combination of both – the water elevations at the downstream end of the pipe limit the flow capacity (referred to as tailwater controlled). Streamflow in Meighan Creek that cannot be managed by this simply backs up causing significant impacts to upstream flood risk. Figure 4-3 illustrates the estimated rating curves showing flow capacity under inlet control and tailwater control conditions.



*Note: Tailwater could not be calibrated as all field data collected was under headwater control[52]

Figure 4-3: Meighan Creek with and without sediment management and new headwall

[51] Based on current conditions and results from the flood model.
[52] Headwater control is when a culvert's capacity is dictated by the inlet losses of a culvert. Since the culvert is only tailwater controlled under severe flood conditions, collection of data for calibration could not be conducted and therefore making calibration of the tailwater curves unfeasible

Structural mitigation of this culvert has the potential to significantly mitigate flood risk. Mitigation strategies may include implementation of any of the following strategies:

- Shortening the overall length of the culvert (such as reverting to a smoothed ditch where possible – improves tailwater control);
- Reducing the wall friction coefficients in the pipe (such as slip-lining or application of other trenchless rehabilitation options that do not significantly reduce the diameter but provide much lower manning coefficients – improves tailwater control),
- Increasing the diameter of the pipe where possible (such as replacing accessible upstream and downstream portions of the culvert with a larger diameter – improves tailwater control);
- Reducing inlet restrictions at the headwall (such as with the installation of a new headwall and bar rack that reduce head losses [discussed further in Section 4.4.3] – improves headwater control);
- Reducing tailwater at the downstream of the culvert by making changes downstream of the culvert (such as improving the capacity downstream of the Meighan Creek and Deep Creek junction at Adair Street [discussed further in Section 4.4.1.2] or in the channel section below); and
- Reducing streamflows in Meighan Creek by making changes upstream of the culvert (such as with a Meighan Creek bypass [discussed further in Section 4.4.4]).

4.4.1.2 Adair Street on Deep

Under the 1/200-year flood, the Adair Street crossing on Deep Creek was identified as a causal mechanism to the overtopping of the Deep Creek channel banks between Adair Street and Wood Avenue. Figure 4-3 depicts a portion of this channel under moderately high flows.

Figure 4-4: Deep Creek Channel Along Adair Street (2018)

Based on results from Section 3, overtopping of the Deep Creek banks at this location causes impact to the City's WWTP. As such, improvement of this crossing's capacity may significantly reduce the flood risk to the WWTP and other indirect loss categories as described in the risk assessment. In addition, backup of this channel was identified as being a direct contributor to the reduced capacity of the Meighan Creek Patterson Avenue culvert. According to Figure 4-3, if the Adair Street crossing were to be the direct cause of a tailwater increase of 0.5 m at the Patterson Avenue culvert (say between 354.0 to 354.5 m), the flow capacity through that culvert could be reduced by roughly 35%. As such, optimization of this crossing may have significant benefits to the Patterson Avenue culvert on Meighan Creek.

4.4.1.3 Okanagan Street on Deep

The Deep Creek crossing at Okanagan Street was identified in Section 3.1.2 as being undersized and at risk of washout. In addition to the possible impact on local transportation and potable water systems, the crossing also increases the floodwater upstream of Okanagan Street. Figure 4-5 illustrates this crossing under moderately high flood flows.

Figure 4-5: Okanagan Street Crossing on Deep Creek (2018)

The structures shown in Figure 4-5 were identified as being large contributors to the local economy, and indirectly, to individuals who are employed by this business. As such, improvement of this crossing may significantly reduce the total risk to the individuals and organizations within the community of Armstrong[53].

4.4.2 Channel and Culvert Maintenance

This sub-section discusses channel and culvert maintenance and includes components of non-structural and structural mitigation. Although physical maintenance of hydraulic structures is considered structural, there are non-structural strategies that can greatly benefit the City regarding water licensing and associated future approvals for in-stream routine maintenance of drainage works.

[53] Note: risk reduction may be limited by Wood Avenue / IPE private crossing.

Currently, the City has a conditional water licence for the purpose of land improvement and drainage control. Authorized works associated with the licence are described to be consisting of pipe and open ditch, and as a condition of this licence, the City is obligated to maintain the works in accordance with the Water Sustainability Act (WSA) (Ministry of Environment, 1989) (Ministry of Environment, 1957). The licence is registered to both the Deep Creek and Meighan Creek sources and therefore has two separate reference locations. These reference locations were identified in the BC Water Resources Atlas mapping system and are summarized in Table 4-1 below. A copy of the water licence and map has been included in Appendix VI.

Table 4-1: Point of Diversions (BC Water Resources Atlas, 2018)

License	Date	Source	Licensee	Purpose	Map Location
C066582 (substitutes C023643)	1956	Deep Creek	City of Armstrong	04A - Land Improve: General	Lat 50.4486, Long -119.2007 (Wood Ave & Deep Creek)
C066582 (substitutes C023643)	1956	Meighan Creek	City of Armstrong	04A - Land Improve: General	Lat 50.447, Long -119.1989 (Pleasant Valley Rd & Meighan Creek)

As the reaches of lower Meighan Creek and Deep Creek through Armstrong are subject to continual aggradation and sediment deposition, the City routinely conducts maintenance and repairs of the licensed works when required.

Earlier this year, the City submitted a Change Approval[54] application to upgrade the existing works on Meighan Creek by replacing a portion of Patterson Avenue culvert and install a new headwall assembly (Change Approval Application File no. R8003862 and Tracking no. 100206821). This application has been approved and work is planned to be completed by March 30, 2019 (Western Water, 2018).

In a parallel project, Integrated Watersheds assessed the feasibility of conducting sediment removal[55] along the Meighan Creek from behind the Shopping Plaza on Smith Drive to the Pleasant Valley Road culvert (Station 1+600 to Station 2+910 as referenced in the Appendix II maps). The report concluded that "improvements to the in-channel storage and conveyance of streamflows along [Meighan Creek] can be achieved through the implementation of a channel [sediment management] program" (Integrated Watersheds, 2018). The City subsequently submitted a second Change Approval application to conduct sediment removal and culvert maintenance along Meighan Creek (Change Approval Tracking no. 100243511). On October 25, 2018, Western Water Associates assisted the City in obtaining approvals by preparing an updated environmental management plan (EMP) (Western Water, 2018). Currently this

[54] A *Change Approval* is a type of application made under Section 11 of the Water Sustainability Act.
[55] Sediment removal is often referred to as dredging when the sediment is removed by a dredge. This is the process of cleaning out the bed of a creek harbour, river, or other area of water, by mechanically removing mud, weeds, and rubbish.

application has not yet been approved; however, work is planned to be completed by March 30, 2019.

As requested by the City, an assessment of the effectiveness of the above structural mitigation modifications was conducted using the new model. By inputting the proposed channel sections from the Integrated Watersheds report (to characterize the removal of sediment and vegetation with an assumed channel bottom manning coefficient of 0.035) and modifying the inlet of the Patterson Avenue culvert (to characterize the installation of the new headwall), the 1/20-year and 1/200-year floods were simulated. As a result, the flood inundation area was reduced for both floods; however, the reduction was not as significant as expected. This is due to tailwater restrictions from an elevated head in Deep Creek (refer to Section 4.4.1.1 for details).

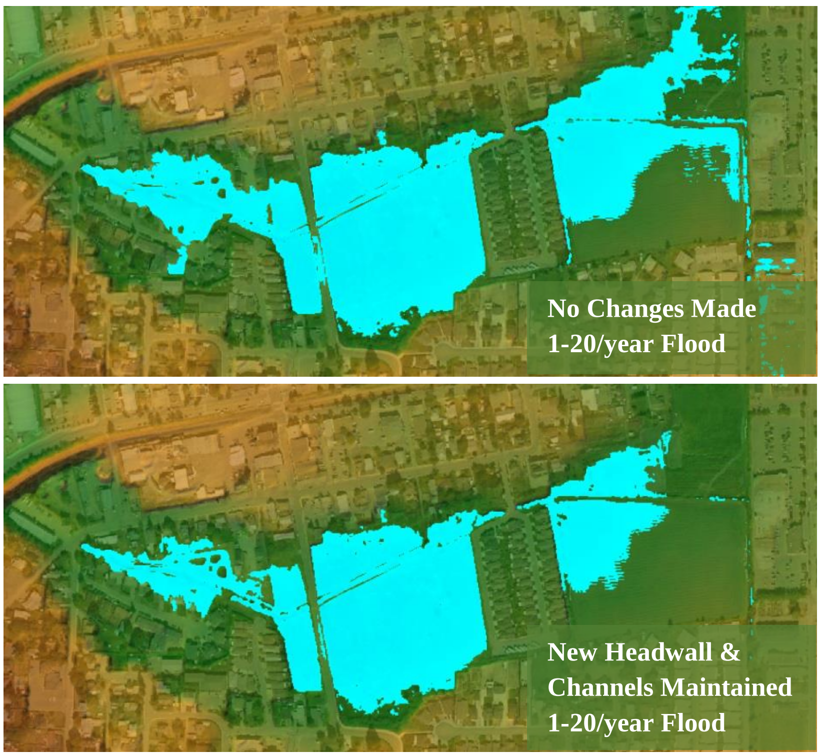


Figure 4-6: Meighan Creek with and without sediment management and new headwall – 1/20-Year

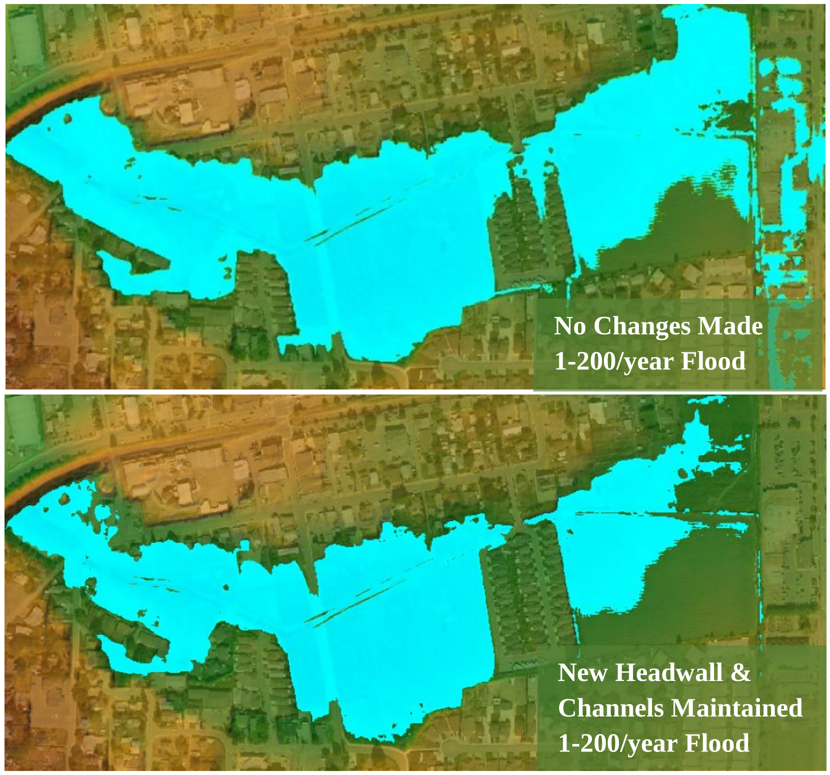


Figure 4-7: Meighan Creek with and without sediment management and new headwall – 1/200-Year

4.4.2.1 Channel and Culvert Maintenance – Future Strategies

Through stakeholder engagement and consideration of all applicable best practices, exploration of the opportunity to licence and maintain all critical ditched and culverted portions of the Meighan Creek and Deep Creek should take place. If the works[56] and associated required plans[57] are detailed within a licence which has been granted approval, future maintenance and operations may be conducted under *notification* through the Water Sustainability Act (WSA), and more specifically, the Water Sustainability Regulation. Text from this regulation has been included in Appendix V for convenience and clarification.

In consideration of hydraulics, banks stability, and future vegetation encroachment, it is recommended that the Environmental Guidelines for Vegetation Management on Flood Protection Works to Protect Public Safety and the Environment be followed (MOE & DFO, 1999). If required, modify these guidelines to suit more recent environmental regulatory updates by following recommended best practices provided in the Western Water report (Western Water, 2018).

[56] *Works* refer to either future or existing drainage works such as ditches, culverts, access roads, water diversions pipes, etcetera
[57] *Plans* refer to all environmental and work-specific maintenance and operational procedures to isolate work areas, divert streamflows and remove sediment/vegetation in accordance with best practices and applicable regulations.

Regarding current plans to dredge Meighan Creek, the Wester Water report identified challenging access conditions to certain reaches of Meighan Creek along private land. The existing Bylaw 1570 is effective in acquiring SRWs to simplify access challenges in newly developed property; however, there is no provision for facilitating City access on existing private property. Strategic acquisition of SRWs on existing private land along the creek alignments could secure access to support various flood management activities such as vegetation maintenance and dredging operations.

4.4.3 Meighan Bypass - Concept

Based on the risk assessment results of Section 3, the majority of flood risk was identified along Meighan Creek. Of this risk, the Patterson Avenue culvert was determined to be the largest causal mechanism. After considering various mitigation strategies (some of these included in Section 4.4.1.1), merit in the exploration of a Meighan Creek bypass concept was identified. Figure 4.8 and Figure 4.9 illustrate the alignment of the conceptual bypass in plan and profile.

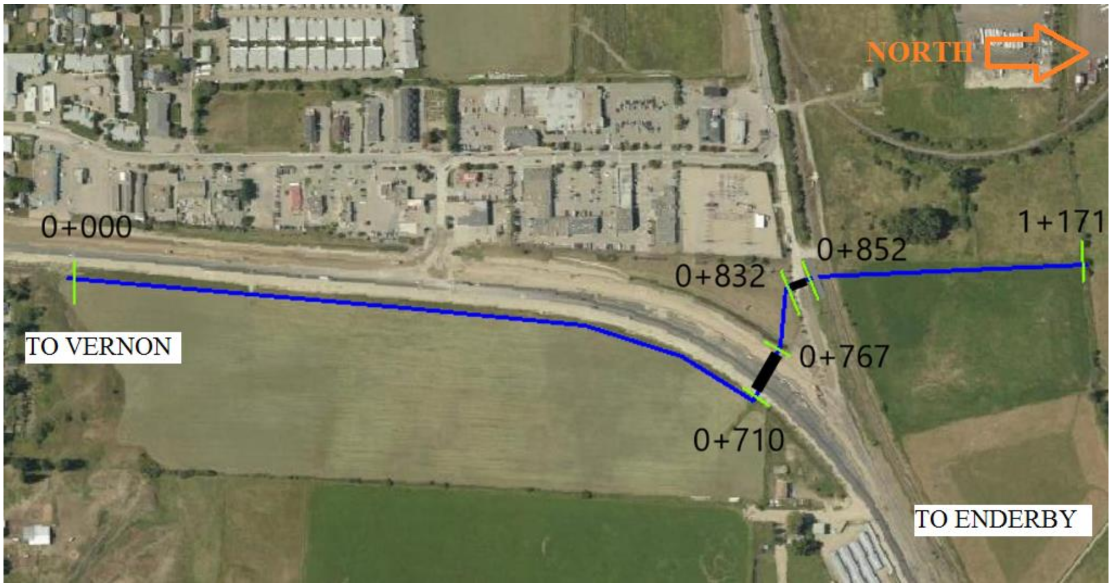


Figure 4-8: Meighan Creek Bypass Concept – Plan View

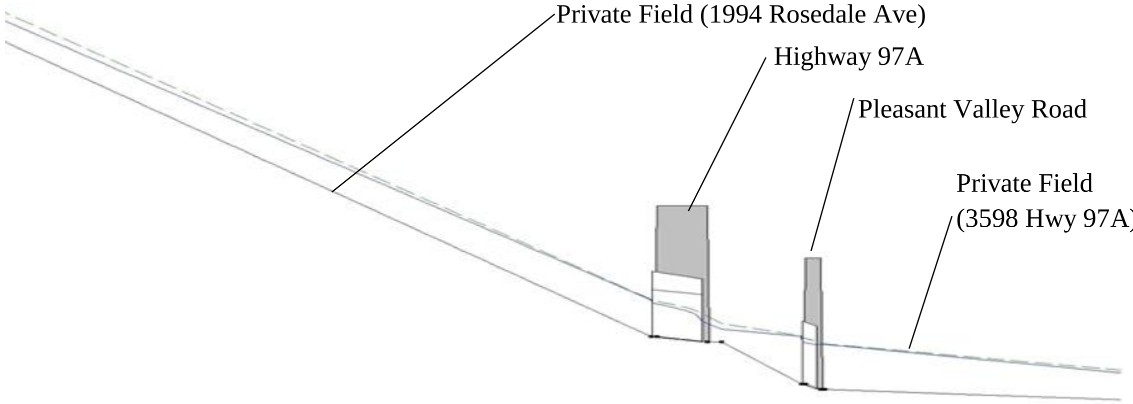


Figure 4-9: Meighan Creek Bypass Concept – Profile View

Figure 4-9 illustrates the profile of the Meighan Creek bypass alignment in HEC-RAS under a selected design flow of 1.0 m^3/s. The conceptual bypass consists of vegetated earthen channel ditches, existing culvert infrastructure, and one (1) new 1200 mm culvert. Based on the results of a 1D steady-state HEC-RAS analysis, the available head and existing alignment are adequate to convey the flow by gravity to Deep Creek. Table 4-2, summarizes the modelled input components of the Meighan Bypass as per Figure 4-7 and 4-8.

Table 4-2: Meighan Bypass – HEC-RAS Inputs

Description	Station	Invert (m)	Length (m)
Earthen Channel – vegetated 2:1 side slopes Bottom width 1m Side Slope 1:1	0+000	363.15	710
Earthen Channel – vegetated 2:1 side slopes Bottom width 2m Side Slope 1:1	0+710	357.50	1
Existing Culvert Inlet 1200mm Diameter	0+711	357.50	55
Existing Culvert Outlet 1200mm Diameter	0+766	357.40	
Existing Culvert Invert 900mm Diameter	0+711	357.55	55
Existing Culvert Outlet 900mm Diameter	0+766	357.40	-
Earthen Channel – vegetated 2:1 side slopes Bottom Width 2m Side Slope 1:1	0+767	357.40	65
Earthen Channel – vegetated 2:1 side slopes Bottom Width 1.2m Side Slope 1:1	0+832	356.90	1
Culvert Inlet 1200 mm Diameter 0.5 Metres of Bury	0+833	356.90	16

Table 4-2: Meighan Bypass – HEC-RAS Inputs

Description	Station	Invert (m)	Length (m)
Culvert Outlet 1200 mm Diameter 0.5 Metres of Bury	0+851	356.8	-
Earthen Channel – vegetated 2:1 side slopes Bottom Width 1.2m Side Slope 1:1	0+852	356.8	319
Earthen Channel – vegetated 2:1 side slopes Bottom Width 1.2m Side Slope 1:1	1+171	356.6	End

The construction of the ditches and culvert crossing would not be considered work in and about a stream, and therefore, would not require approval under the WSA. However, parts of the alignment would be on private land and would require a statutory right-of-way (SRW).

The new 1200 mm CSP culvert crossing at Pleasant Valley Road (on City property) would also need to cross the railroad. Although this railroad is not part of the CN mainline, it was identified as being owned by the Kelowna Pacific Railway and is referred to as the Okanagan Subdivision (CN, 2018) (CP, 2018). At this time, the requirements to expedite the approval and construction of this culvert crossing is unknown. Alternatively, if an existing crossing of the railway exists nearby, the bypass may be altered to utilize an existing crossing (similar to the Hwy 97A culvert). As there is available head in the energy grade line shown in Figure 4-9, this may be a feasible alternative.

The following two properties would require SRWs to achieve this. They are as follows:

Civic: 1994 Rosedale Ave E
Plan: KAP998B
Legal property: SECTION 5, KAMLOOPS DIV OF YALE, PLAN KAP998B, TOWNSHIP 35 EXCEPT PLAN B5180, 16621, H732, KAP89122 &KAP90326.

Civic: 3598 Highway 97A
Plan KAP807B
Legal Property: SECTION 5, KAMLOOPS DIV OF YALE, PLAN KAP807B, TOWNSHIP 35

5 FINDINGS AND RECOMMENDATIONS

5.1 Key Findings

Based on the information reviewed and analysis conducted, the following information summarizes key findings that are intended to aid in the direction and development of the City's IFMP:

1. The resulting climate-factored 1/20-year and 1/200-year annual daily maximum streamflows at Deep Creek at the Adair Street were determined to be 3.41 m^3/s and 5.22 m^3/s respectively.
2. The 2018 storm of May 9, 2018, was estimated to be of a severity similar to that of a 1/15-year flood event.
3. The estimated impact from the 1/200-year flood to individuals and organizations of the community of Armstrong included:
   - Total monetary losses of $21,248,190 (Local Infrastructure - $1,445,000, People and Society - $13,613,325, and Local Economy - $6,189,865)
   - Loss of functionality (full or partial) to the following infrastructure systems: electrical power, local roads, WWTP, and potable water;
   - The contamination of water and wetland and possible impact to red-listed and blue-listed species;
   - Direct impact to one (1) heritage site and risk of impact to various others;
   - Impact on vital services including a financial institution, a grocery store, postal office, and five medical service providers; and
   - An incremental increase of risk to human health and safety due to increased potential for water contamination and drowning.
4. The total cost of flooding based on total risk was estimated to be roughly $1.6 million/year where $1.3 million/year is borne by the category of People and Society;
5. The City's OCP pre-dates the 2016 Riparian Areas Regulation revisions as well as the flood mapping and risk assessment work contained within this report and is therefore considered out-of-date;
6. The City's SDSB pre-dates the flood mapping and risk assessment work contained within this report and is therefore considered out-of-date;
7. The City has a robust and effective emergency plan, however, there are no flood-specific emergency plans currently in place;
8. A risk tolerance[58] or acceptable level of flood hazard for the City not been defined;
9. There are no streamflow measurement programs in place;
10. Based on the 1/200-year flood mapping, at least 5 hydraulic structures do not meet the 1/200-year design flow requirements; and
11. The Patterson Avenue culvert on Meighan Creek was identified as the largest contributor to flood risk.

[58] Risk tolerance is referred to as risk threshold in the NDMP guidelines.

5.2 Recommendations

In support of the development and implementation of the City's IFMP, it is recommended that the City do the following:

1. Through stakeholder consultation, determine an acceptable risk tolerance;
2. Develop the IFMP in the context of determined risk tolerance, such that it achieves a balanced, feasible, and cost-effective approach to flood risk mitigation in accordance with the recommended NDMP steps summarized in Section 4.2;
3. Within the IFMP, include a prioritized plan for execution that considers the following discussed structural and non-structural mitigation strategies based on loss estimation analysis:
    - Review and revise, if necessary, the OCP, DPA map, and SDSB as may be required to improve future development planning per IFMP risk tolerance;
    - Develop a flood-specific emergency plan with consideration of the flood mapping and risk assessment information to facilitate emergency responses;
    - Upgrade hydraulic structures identified in Section 4.4.1;
    - Explore water licensing opportunities and conducted culvert and ditch maintenance on a regular basis (sediment removal and vegetation management);
    - Proceed with preliminary design on the Meighan Creek bypass strategy outlined in Section 4.4.3 and elsewhere in this report;
4. Install streamflow measurement stations on Deep Creek and Meighan Creek to support future updates to the design flood and flood mapping; and
5. Review, and if necessary, update the flood mapping and risk assessment every 10 years.

6 REFERENCES

AECOM. (2017). *National Principals, Best Practices and Guidelines - Flood Mapping (Draft).* Natural Resources Canada.

APEGBC. (2017). *Flood Mapping in BC-APEGBC Profesional Practice Guidelines.* Vancouver: Association of Professional Engineers and Geoscientists of BC.

Austin, S. A. (1999). *Streamflow response to forest management: a meta-analysis using published data and flow duration curves.* Fort Collins, CO.: Colorado State University.

BC. (2016). *British Columbia Dam Safety Regulation - B.C. Reg 40/2016 as amended.* Victoria, British Columbia, Canada: Queens Printer.

BC Assessment. (2018). Retrieved from Property Assessment Data: https://www.bcassessment.ca/Property/AssessmentSearch

BC CDC. (2018, 11 28). *Conservation Data Centre (CDC) iMap Web Application*. Retrieved May 17, 2017, from http://maps.gov.bc.ca/ess/hm/cdc/

BC Land Title & Survey. (2018). *Parcel Map BC.* Retrieved from myLTSA: https://ltsa.ca/online-services/parcelmap-bc

BC Maps Online. (n.d.). *Orthophoto (various) - Compilation Scale 1:20000.* Victoria, BC: British Columbia Air Photos.

BC Water Resources Atlas. (2018, 10 22). Retrieved from http://maps.gov.bc.ca/ess/hm/wrbc/

Bedient, P, et al. (2008). *Hydrology and Floodplain Analysis - Fourth Edition.* Upper Saddle River, NJ: Prentice Hall.

CDA. (2007-2016). *Dam Safety Guidelines - Technical Bulletins.* Canadian Dam Association.

City of Armstrong. (2007). Subdivision and Development Servicing Bylaw No. 1570, 2007. Armstrong, BC, Canada.

City of Armstrong. (2010). *Fortune Creek Source Water Assessment and Protection Report, 2030 and Beyond.* Vernon, BC: Summit Environmental Consultants Inc.

City of Armstrong. (2014, June). Official Community Plan - 9.4 Development Permit Areas. Armstrong, BC, Canada.

City of Armstrong. (2014, June 14). Official Community Plan - Bylaw 1750, 2014 - As adopted on June 24, 2017. Armstrong, BC, Canada.

City of Armstrong. (2016). *Armstrong Master Water Plan Water Source Report.* Vernon, BC: Western Water.

City of Armstrong. (2016). *Storm Composite Map.* Salmon Arm, BC: Gentech Engineering Inc.

City of Armstrong. (2016). *The City of Armstrong Bylaw No. 1794, 2016 - Emergency Program Bylaw.* Salmon Arm, BC: City of Armstrong.

City of Armstrong. (2017). *Master Water Plan - Final Report.* Kelowna, BC: AECOM.

City of Armstrong. (2018, April 6). *City of Armstrong: Civic Web.* Retrieved from Media Release: The City of Armstrong Encourages Businesses and Residents to Educate and Prepare Themselves on Flood Prevention Strategies: https://armstrong.civicweb.net/document/108952/Media%20Release%20Flooding%20Prepardness%2004-06-2018.pdf?handle=CF98E96A349940519EAE745B056A2BE9

City of Armstrong. (2018, Nov 25). *Did you know? Around Armstrong - A Brief History*. Retrieved from City of Armstrong Website: http://www.cityofarmstrong.bc.ca/content/history

City of Armstrong. (2018). *Request for Proposal 2018001: Flood Mapping and Mitigation.* Armstrong, BC: Public Works Department.

City of Armstrong. (2018). *Surveillance Records - Creek Crossing Checks and Measurements.* Armstrong, BC: Department of Public Works.

City of Armstrong. (2018). *Surveillance Records - Culvert Measurements and Checks.* Armstrong, BC: Department of Public Works.

City of Armstrong. (April). *Water Composite Map - Amstrong.* Salmon Arm, BC: Gentech Engineering.

CN. (2018, 12 7). *CN - Network Map*. Retrieved from http://cnebusiness.geomapguide.ca/

CP. (2018, 12 7). *CP Network Map*. Retrieved from https://www.cpr.ca/en/choose-rail-site/Documents/cp-network-map-2018.pdf

Digital Globe. (n.d.). *Orthophoto (various).* Google Earth Pro v7.3.2.5495.

Digital Globe. (n.d.). *Street Mapping.* Google Earth Pro v7.3.2.5495.

Dobson Engineering Ltd. (1998). *Interior Watershed Assessment for the Meighan Creek Watershed.* Kelowna, BC: Riverside Forest Products Limited.

EGBC. (2018). *Legislated Flood Assessments In a Changing Climate In BC.* Vancouver: Engineers and Geoscientists British Columbia.

Environment Canada. (1993). *Consolidated Frequency Analysis (CFA) Version 3.1 - Reference Manual.* Ottawa, ON: Conservation & Protection - Surveys and Information Systems Branch.

Environment Canada. (1993). *Consolidated Frequency Analysis Software Version 3.1 - Reference Manual.* Ottawa, Ontario: Surveys and Information Systems Branch.

Environment Canada. (2017). *Environment Canada Data Explorer Version 2.1.8.* Water Survey Canada.

FEMA. (2001). *Multi-hazard Loss Estimation Methodology: Hazus-MH Technical Manual.* Washington, DC: Department of Homeland Security - Mitigation Division.

FLNRORD. (2016). *Downstream Consequence of Failure Classification Interpretation Guideline for Dam Safety Officers.* Dam Safety Program.

FLNRORD. (2017, March). *Forest Tenure Administration.* Retrieved from Farming, Natural Resources & Industry: https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/timber-tenures/tfl_tsa_district_map.pdf

FLNRORD. (2017, December). *Okanagan Timber Supply Area - Timber Supply Review Data Package.* Retrieved from https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stewardship/forest-analysis-inventory/tsr-annual-allowable-cut/okanagan_tsa_datapackage_2017.pdf

FLNRORD. (2018, September 12). *Flood Hazard Area Land Use Management*. Retrieved from https://www2.gov.bc.ca/gov/content/environment/air-land-water/water/drought-flooding-dikes-dams/integrated-flood-hazard-management/flood-hazard-land-use-management

FLNRORD. (2018, 11 25). *Obtaining Access to RAAD*. Retrieved from Remote Access to Archaeological Data Application: https://www.for.gov.bc.ca/archaeology/accessing_archaeological_data/obtaining_access.htm

Froats, G. (Director). (2018). *Photographs of May 2018 Flooding* [Motion Picture].

Gentech Engineering Inc. (2004). *Adair Street & Park Drive Upgrading - Record Drawings.* Salmon Arm, BC.

Gentech Engineering Inc. (2007). *Adair Street to Bridge Street - Record Drawings.* Salmon Arm, BC.

GeoBC. (2017, 11). *Trim Transportation Lines.* Retrieved from BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset/trim-transportation-lines

GeoBC. (2018, May). *Emergency Social Service Facilities*. Retrieved from BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset/8473689f-2d06-4e84-ac8b-e91033fd0f0b

Global. (2018, May 9). *Armstrong cleaning up after 'pretty devastating' flood.* Retrieved from https://globalnews.ca/news/3439648/armstrong-cleaning-up-after-pretty-devastating-flood/

Government of Canada. (2018, October 20). *Public Safety Canada.* Retrieved from National Disaster Mitigation Program (NDMP) Guidelines: https://www.publicsafety.gc.ca/cnt/mrgnc-mngmnt/dsstr-prvntn-mtgtn/ndmp/prgrm-gdlns-en.aspx#a34

Integrated Watersheds. (2018). *City of Armstrong, BC - Lower Meighan Creek Dredging Assessment.* Vancouver, BC.

Interior Dams Inc. (2016). *NSSL & SSSL Dam Safety Reviews - Hydrotechnical Appendices.* Lake Country, BC.

Ministry of Citizens Services. (2018). *ParcelMap BC Parcel Fabric.* Retrieved from BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset/4cf233c2-f020-4f7a-9b87-1923252fbc24

Ministry of Environment. (1957). *Conditional Water Licence 23643 (superseded by C066582).* Kamloops, BC: Department of Lands and Forests.

Ministry of Environment. (1989). *Conditional Water Licence 66582 - File No. 0213837.* Kamloops, BC: Water Management Branch.

Ministry of Health. (2018, May). *BC Health Care Facilities*. Retrieved from BC Data Catalogue: https://catalogue.data.gov.bc.ca/dataset/8912ec4f-b87f-4056-a2d0-e019e045b53a

Ministry of Transportation and Infrastructure. (2012). *Okanagan Highway No. 97A Armstrong - Four Laning Pleasant Valley Cross Road to Lansdowne Road - Record Drawings.* Southern Interior Region.

MLFNRORD. (2014). *Manual Snow Survey Data - 2F10 Silver Star Mountain.*

MLFNRORD. (2018, June). *Strategic Land Policy and Legislation.* Retrieved from Range Tenure: https://catalogue.data.gov.bc.ca/dataset/range-tenure

MOE & DFO. (1999). *Environmental Guidelines for Vegatation Management on Flood Protection Works to Protect Public Safety and the Environment.* BC Ministry of Environment, Lands and Parks & Department of Fisheries and Oceans Canada.

MOTI. (2013). *Construction and Rehabilitation Cost Guide.* Ministry of Transportation.

MWLAP. (2004). *Flood Hazard Area Land Use Management Guidelines.* Province of British Columbia: Ministry of Water, Land and Air Protection (2018 Amendment).

NRC. (1989). *Hydrology of Floods in Canada - A Guide to Planning and Design.* Ottawa, ON: Associate Committee on Hydrology.

NRC. (2017). *Canadian Guidelines and Database of Flood Vulnerability Functions (Draft).* Government of Canada: Public Safety Canada.

OBWB. (2012). *Phase 3 Projected Water Supply and Use in the Okanagan Basin (2011-2040) - Okanagan Basin Water Accounting Models.* Victoria, BC: Natural Resources Canada. Retrieved from https://www.obwb.ca/fileadmin/docs/okanagan_instream_flow_needs_analysis_essa.pdf

Opus Daytonknight Consultants Ltd. (2014). *City of Armstrong - Master Sewer Plan Update.* North Vancouver, BC.

Province of BC. (2016). *Indicators of Climate Change for British Columbia - 2016 Update.* Ministry of Environment.

Province of BC. (2018, October 21). *Climate Change - Change in Snowpack BC*. Retrieved from British Columbia - Environmental Reporting BC: http://www.env.gov.bc.ca/soe/indicators/climate-change/snow.html

Province of BC. (2018, November 14). *Residential Tenancy Act [SBC 2002] Chapter 78*. Retrieved from http://www.bclaws.ca/civix/document/id/complete/statreg/02078_01

Province of BC. (2018). *Water Sustainability Regulation.* Victoria: Queen's Printer.

Province of British Columbia. (1999). *Flood Planning and Response Guide for British Columbia.* Water Management Branch - Provincial Emergency Program.

Province of British Columbia. (2014). *Terrain Resource Information Management (TRIM) - Contour Mapping (1:20,000 Scale).* Victoria, BC: BC Data Catalogue.

Province of British Columbia. (2014). *Terrain Resource Information Management (TRIM) - Water Lines (1:20,000 Scale).* Victoria, BC: BC Data Catalogue.

Province of British Columbia. (2015). *Local Government Act [RSBC 2015] Chapter 1.* Victoria, British Columbia: Queen's Printer.

Province of Ontario. (2005). *Water and Wastewater Asset Cost Study.* Orangeville, ON: Ministry of Public Infrastructure Renewal.

RDNO. (2012, July). *Digital Data.* Retrieved from Orthophoto: http://www.rdno.ca/index.php/maps/digital-data/orthos

RDNO. (2018). *Digital Data.* Retrieved from Contours: http://www.rdno.ca/index.php/maps/digital-data/contours

Schnorbus, M., Bennett, K., Werner, A. (2010). *Quantifying the Water Resource Impacts of Mountain Pine Beetle and Associated Salvage Harvest Operations across a Range of Watershed Scales: Hydrologic Modelling of the Fraser River basin. Information Report: BC-X-423.* Victoria, BC: Natural Resources Canada, Canadian Forestry Service, Pacific Forestry Centre.

Schnorbus, M.A., Winkler, R.D. and Y. Alila. (2004). *Modeling Forest Harvesting Effects on Maximum Daily Peak Flow at Upper Penticton Creek. Extension Note No. 67.* Ministry of Forests - Forest Science Program.

Statistics Canada. (2016). *Canadian Industry Statistics.* Ottawa, ON: Government of Canada.

Statistics Canada. (2018, December 4). *Road Motor Vehicle Registrations by Type of Vehicle*. Retrieved from https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=2310006701

StatsCan. (2017, October 25). Housing in Canada: Key results from the 2016 Census. Ottawa, Canada.

Summit Environmental. (2010). *Fortune Creek Source Water Assessment and Protection Report, 2030 and Beyond.* City of Armstrong.

Tolko Industries Ltd. (2015). *Meighan Creek Community Watershed Assessment.* Kelowna, BC: Urban Systems.

U.S. Department of the Interior Bureau of Reclamation. (2015). *Reclamation - Managing Water in the West: Reclamation Consequence Estimating Methodology (RCEM): Guidelines for Estimating Life Loss for Dam Safety Risk Analysis (Interim).*

UACE. (1992). *Hydrologic Engineering Centre - Flood Frequency Analysis (HEC-FFA) User's Manual.* Davis, CA: US Army Corps of Engineers - Institute for Water Resources Hydrologic Engineering Centre.

UMA. (1979). *Wood Avenue Culvert Reconstruction at Wood Avenue - Record Drawings.* Armstong, BC: Underwood McLellan & Associates Limited.

USACE. (2010, January). HEC-RAS River Analysis System - Hydraulic Reference Manual V4.1. Davis, California, United States.

USACE. (2014). *Using HEC-RAS for Dam Break Studies.* Davis, CA: US Army Corps of Engineers, Institute of Water Resources, Hydrologic Engineering Centre.

USACE. (2016). *HEC-RAS River Analysis System - 2D Modeling User's Manual Version 5.0.* US Army Corps of Engineers.

USACE. (2016). *HEC-SSP Statistical Software Package - User Manual.* Davis, CA: Institute for Water Resources.

USBR. (1988). *Acer Technical Memorandum No. 11 - Downstream Hazard Classification Guidelines.* Denver, CO: Assistant Commissioner - Engineering and Research.

USBR. (2015). *Reclamation - Managing Water in the West: Reclamation Consequence Estimating Methodology (RCEM): Guidelines for Estimating Life Loss for Dam Safety Risk Analysis (Interim).* U.S. Department of the Interior Bureau of Reclamation.

USGS. (2018). *Guidelines for Determining Flood Flow Frequency Bulletin 17C - Techniques and Methods 4-B5.* Reston, VA: US Department of the Interior & US Geological Survey.

VMS. (2018, March 23). *Vernon Morning Star.* Retrieved from Flooding leads to Pioneer Square evacuation in Armstrong: https://www.vernonmorningstar.com/news/flooding-leads-to-pioneer-square-evacuation/

Water Survey Canada. (2017, April). *Hydrometric records for Coldstream Creek Above Municipal Intake (08NM142).* Retrieved 2017, from https://wateroffice.ec.gc.ca/report/real_time_e.html?stn=08NM142

Western Water. (2018, October 25). Re: Updated Environmental Management Plan for Meighan Creek Sediment Removal and Culvert Maintenance (Letter). Vernon, BC.

Western Water Associates. (2016). *Technical Memo: Aquatic Management Plan for Meighan Creek Culvert Replacement.* Vernon, BC.

Western Water Associates Ltd. (2016). *City of Armstrong Master Water Plan - Groundwater and Surface Water Supply Assessment.* Vernon, BC: AECOM.

APPENDIX I: SUPPORTING FLOOD MAPPING DATA

This page intentionally left blank.

Field photos of Meighan Creek crossings:

Figure AI-6-1: Meighan Creek – Powerhouse Road crossing (2018)

Figure AI-6-2: Meighan Creek – Hwy 97A crossing near Game Court – Station 0+000 (2018)

Figure AI-6-3: Meighan Creek – Royal York Golf Course – Station 0+600 (2018)

Figure AI-6-4: Meighan Creek – Hwy 97A crossing near Catherine Crescent – Station 1+040 (2018)

Note: Parallel 600 mm diameter CSP culvert partially blocked and submerged (not shown)

Figure AI-6-5: Meighan Creek – Rosedale Road East near Hwy 97A – Station 1+258 (2018)

Figure AI-6-6: Meighan Creek – Hwy 97A north of Rosedale Road East – Station 1+375 (2018)

Figure AI-6-7: Meighan Creek – Meadow Creek Lane crossing – Station 2+320 (2018)

Figure AI-6-8: Meighan Creek – Okanagan Street crossing – Station 2+610 (2018)

Figure AI-6-9: Meighan Creek – Patterson Street & Becker Street crossing – Station 2+910 (2018)

Field photos of Deep Creek crossings - Young Rd to Adair St (clear span bridges omitted):

Figure AI-6-10: Deep Creek – Young Road crossing – Station 0+000 (2018)

Figure AI-6-11: Deep Creek – CN Rail crossing – Station 1+660 (2018)

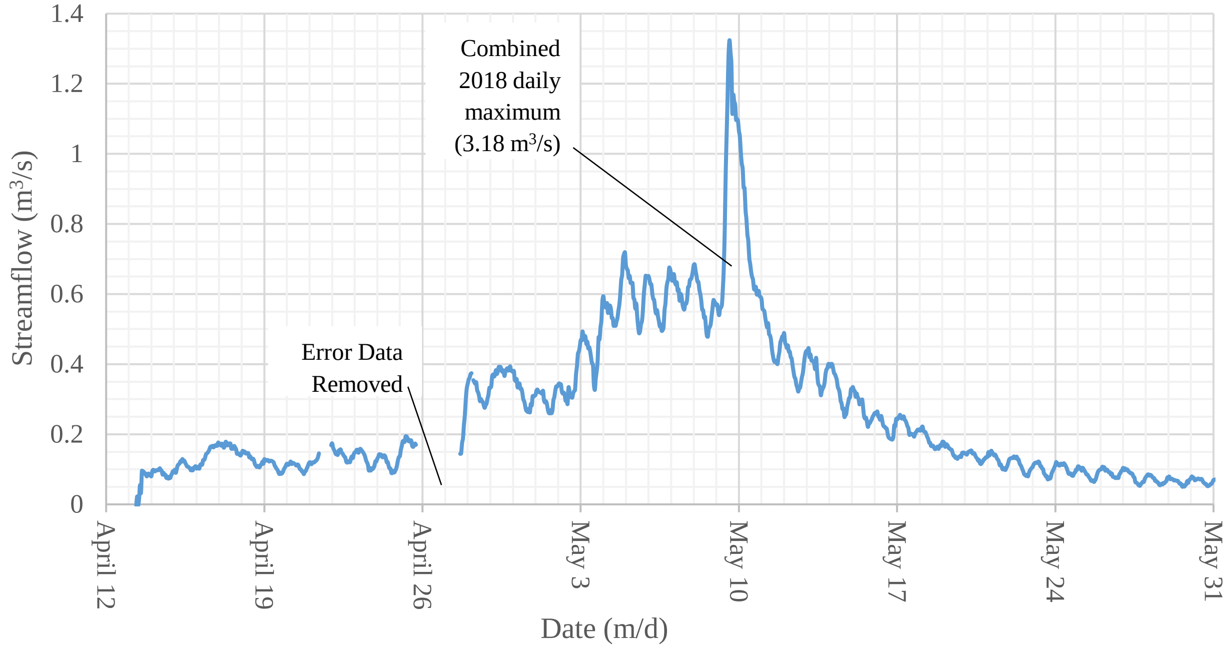
Figure AI-6-12: Deep Creek – Okanagan Street crossing – Station 2+400 (2018)

Figure AI-6-13: Deep Creek – Private crossing (3010 Wood Ave) – Station 2+790 (2018)

Figure AI-6-14: Deep Creek – Wood Avenue crossing – Station 2+810 (2018)

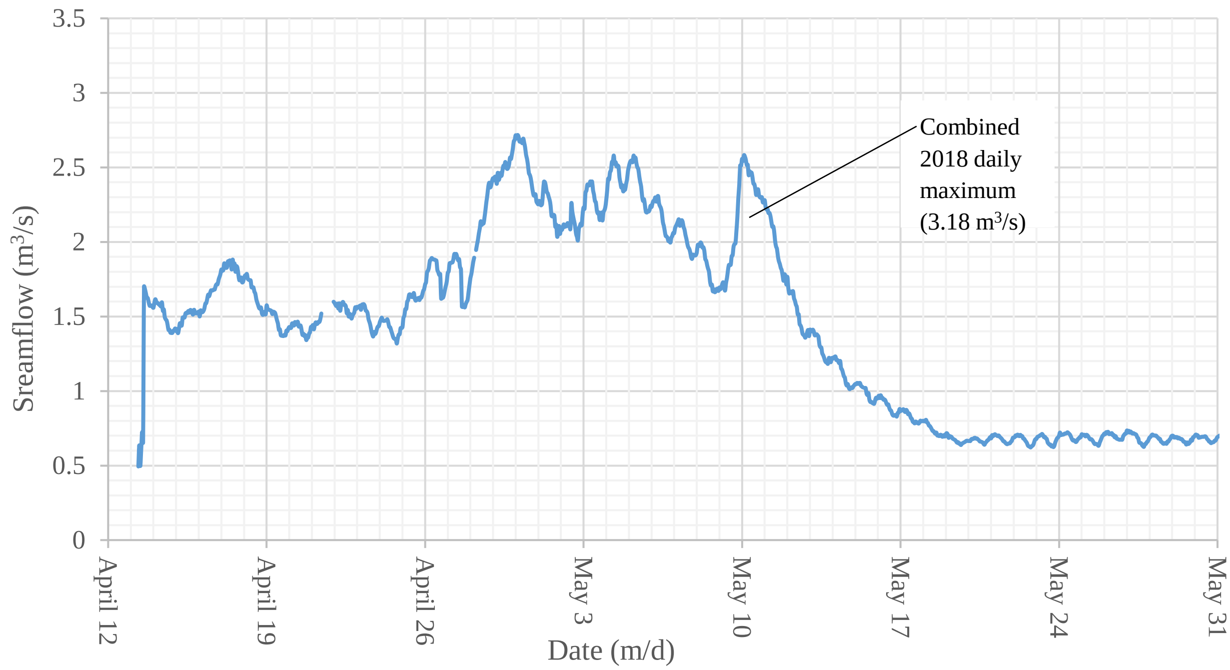
Figure AI-6-15: Deep Creek – Adair Street crossing – Station 3+300 (2018)

2018 Streamflow Logger Data:



Note: Gaps show times when logger was temporarily removed for data downloading.

Figure AI-6-16: Meighan Creek Streamflow Log (2018)



Note: Gaps show times when logger was temporarily removed for data downloading.

Figure AI-6-17: Deep Creek Streamflow Log (2018)

Hydrometric Annual Maximum Streamflow – Dataset Checks:

```
      --- RUN TEST FOR GENERAL RANDOMNESS ---

                 DEEP AT ARMSTRONG
ANNUAL MAXIMUM DAILY FLOW SERIES     1 TO   23  DRAINAGE AREA =  135.0000

THE NUMBER OF RUNS ABOVE AND BELOW THE MEDIAN (RUNAB) = 12
      THE NUMBER OF OBSERVATIONS ABOVE THE MEDIAN(N1) = 11
      THE NUMBER OF OBSERVATIONS BELOW THE MEDIAN(N2) = 11
Range at 5% level of significance:  8. to 16.    NOT SIGNIFICANT

Interpretation: The null hypothesis is that the data are random.

At the 5% level of significance, the null hypothesis cannot be
rejected. That is, the sample is significantly random.

Press <RETURN> to continue , <CTRL> P to obtain hard copy
```

```
      --- SPEARMAN TEST FOR INDEPENDENCE ---

                 DEEP AT ARMSTRONG
ANNUAL MAXIMUM DAILY FLOW SERIES     1 TO   23  DRAINAGE AREA =  135.0000

SPEARMAN RANK ORDER SERIAL CORRELATION COEFF =  .055    D.F.= 20
                   CORRESPONDS TO STUDENTS T =  .245
                CRITICAL T VALUE AT 5% LEVEL = 1.725    NOT SIGNIFICANT
                    -    -    -    -  1%   -  = 2.528    NOT SIGNIFICANT

Interpretation: The null hypothesis is that the correlation is zero.

At the 5% level of significance, the correlation is not significantly
different from zero.  That is, the data do not display significant
serial dependence.

Press <RETURN> to continue , <CTRL> P to obtain hard copy
```

```
  --- MANN-WHITNEY SPLIT SAMPLE TEST FOR HOMOGENEITY ---

                 DEEP AT ARMSTRONG
ANNUAL MAXIMUM FLOW SERIES     1 TO   23   DRAINAGE AREA=  135.0000

SPLIT BY TIME SPAN, SUBSAMPLE 1 SAMPLE SIZE= 11
                    SUBSAMPLE 2 SAMPLE SIZE= 12

                               MANN-WHITNEY U =  51.0
     CRITICAL U VALUE AT 5% SIGNIFICANT LEVEL =  38.0    NOT SIGNIFICANT
      -   -   -   -   -  1%      -         -  =  28.0    NOT SIGNIFICANT

Interpretation: The null hypothesis is that there is no
                location difference between the two samples.

At the 5% level of significance, there is no significant
location difference between the two samples. That is, they
appear to be from the same population.

Press <RETURN> to continue , <CTRL> P to obtain hard copy_




     --- SPEARMAN TEST FOR TREND ---

                 DEEP AT ARMSTRONG
ANNUAL MAXIMUM DAILY FLOW SERIES     1 TO   23  DRAINAGE AREA =  135.0000

SPEARMAN RANK ORDER CORRELATION COEFF = -.354    D.F.= 21
            CORRESPONDS TO STUDENTS T =-1.733
         CRITICAL T VALUE AT 5% LEVEL =-2.080    NOT SIGNIFICANT
             -    -   -   -  1%   -   =-2.831    NOT SIGNIFICANT

Interpretation: The null hypothesis is that the serial(lag-one) correlation
                is zero.

At the 5% level of significance, the correlation is not significantly
different from zero. That is, the data do not display significant
trend.

Press <RETURN> to continue , <CTRL> P to obtain hard copy_
```

Statistical Frequency Analysis – CFA Solution Check:

```
*** FREQUENCY ANALYSIS PROGRAM ***

WSC STATION NO =
WSC STATION NAME = DEEP AT ARMSTRONG

NUMBER OF OBSERVATIONS =    23

C.S. of lnX series =     -.3170
LOWER OUTLIER LIMIT of X =       .300
UPPER OUTLIER LIMIT of X =      5.235
NOTE:  0 LOW OUTLIER(S) DETECTED.
       0 HIGH OUTLIER(S) DETECTED.

Do you want to alter the number of low outliers? : N


         FREQUENCY ANALYSIS - LOG PEARSON TYPE III DISTRIBUTION
                     DEEP AT ARMSTRONG

                            SAMPLE STATISTICS
                    MEAN       S.D.        C.V        C.S.       C.K.
     X SERIES      1.462       .831       .569       1.133      4.545
  LN X SERIES       .226       .584      2.579       -.317      3.744

  X(MIN)=       .309                        TOTAL SAMPLE SIZE=  23
  X(MAX)=      3.620                      NO. OF LOW OUTLIERS=   0
  LOWER OUTLIER LIMIT OF X=      .300       NO. OF ZERO FLOWS=   0


Press <RETURN> to continue , <CTRL> P to obtain hard copy_
```

```
*** FREQUENCY ANALYSIS PROGRAM ***
    --- SAMPLE STATISTICS ---

WSC STATION NO.=
WSC STATION NAME=DEEP AT ARMSTRONG
DRAINAGE AREA=    135.00
NUMBER OF OBSERVATIONS=   23

         X series   lnX series
MEAN        1.462       .2264
S.D.         .831       .5837
C.V.        .5685      2.5785
C.S.       1.1326      -.3170
C.K.       4.5454      3.7441

You should always check :
>  that the data are accurate
>  for historic information
>  that the data and historic information are up to date

Press <RETURN> to continue
```

```
             SOLUTION OBTAINED VIA MAXIMUM LIKELIHOOD
             DISTRIBUTION IS UPPER BOUNDED AT M=  33.20
    LP3 PARAMETERS: A= -.9985E-01 B=  32.81     LOG(M)=  3.502
                                                  M =  33.20

                        FLOOD FREQUENCY REGIME

                 RETURN        EXCEEDANCE        FLOOD
                 PERIOD        PROBABILITY

                  1.003           .997            .210
                  1.050           .952            .460
                  1.250           .800            .780
                  2.000           .500           1.30
                  5.000           .200           2.04
                 10.000           .100           2.55
                 20.000           .050           3.03
                 50.000           .020           3.64
                100.000           .010           4.10
                200.000           .005           4.54
                500.000           .002           5.13

Press <RETURN> to continue , <CTRL> P to obtain hard copy
```

Frequency Analysis Distribution Ranking:

Table AI-6-1: Ranking of Frequency Distributions

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Log-Pearson III (LP3)[NOTE]	0.08974	2	0.14126	3	0.07565	1
Lognormal (3P)	0.094	3	0.12819	1	0.46629	3
Gumbel Max	0.08717	1	0.14803	4	0.21461	2
General Extreme Value (GEV)	0.10073	4	0.12887	2	1.2554	4
NOTE: The distribution in bold was selected for the design flood determination.						

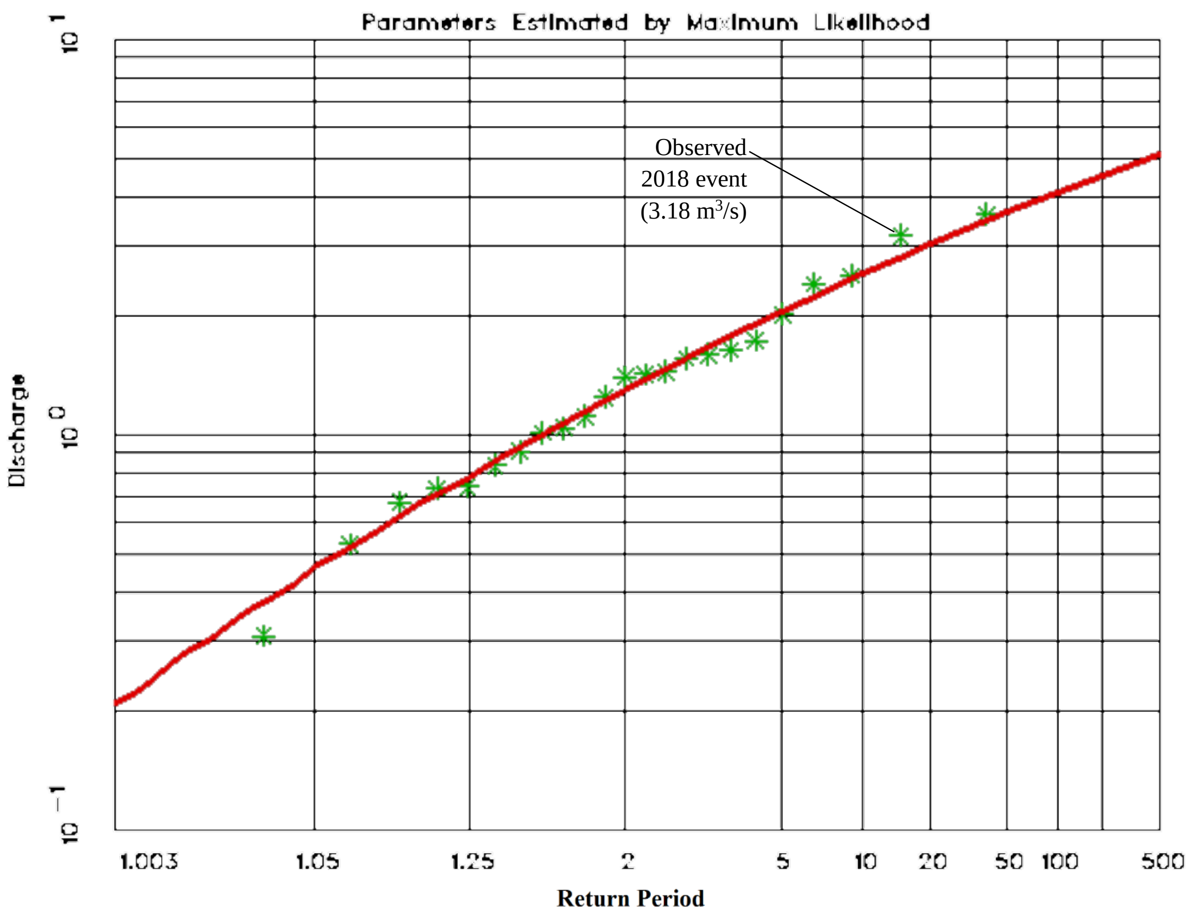
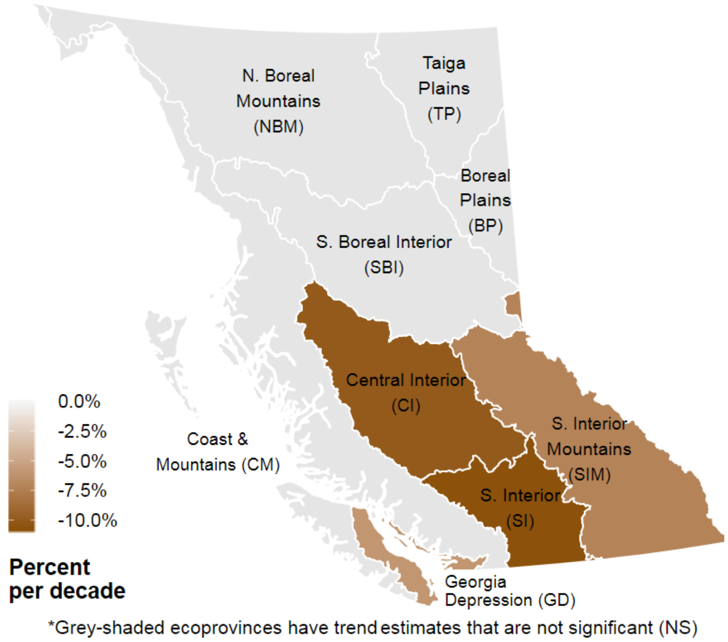


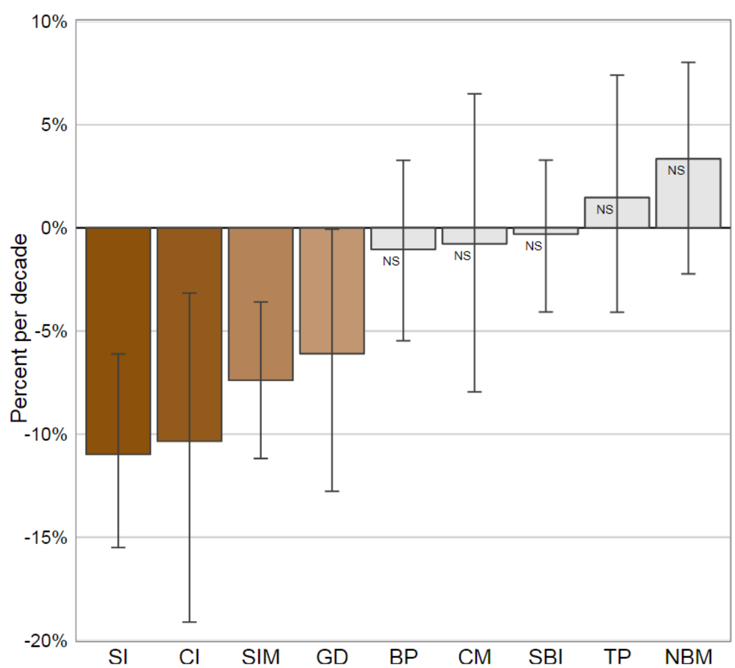
Figure AI-6-18: CFA LP3 Solution (Check)

Observed climate change data for BC:



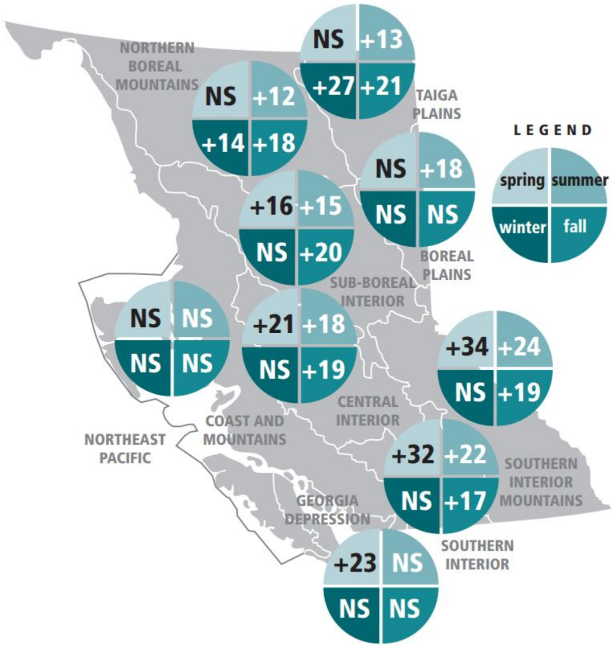
Note: There is a trend of -11% snow water equivalent per decade for the Southern Interior.

Figure AI-6-19: Observed change in Snow Water Equivalents for 1950-2014 (Province of BC, 2018)



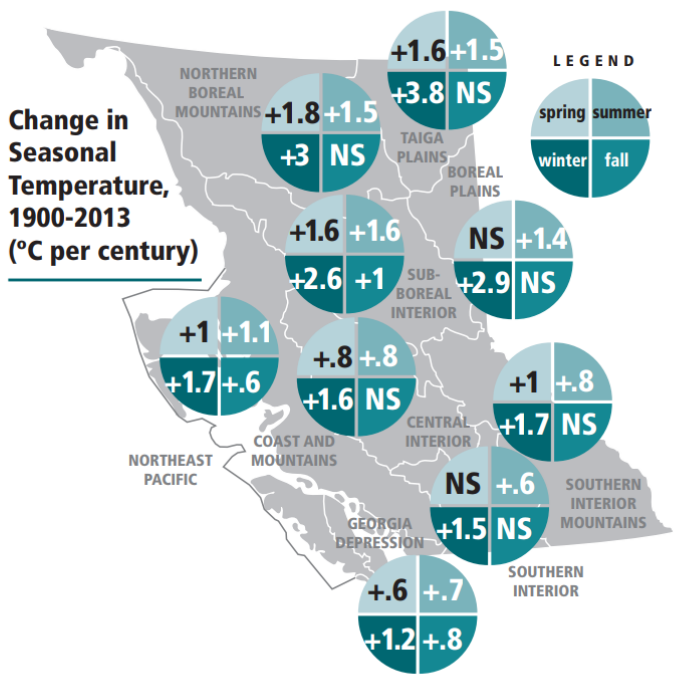
Note: There is a trend of -11% snow water equivalent per decade for the Southern Interior.

Figure AI-6-20: Observed change in Snow Depth for 1950-2014 - Graph (Province of BC, 2018)



Note: The springtime average precipitation increase for the Southern Interior is +32% per century (year-round average increase of +17% per century).

Figure AI-6-21: Observed change in annual temperature for 1900-2013 (Province of BC, 2016)



Note: The springtime average temperature increase for the Southern Interior is +1.2˚C per century (year-round average increase of +0.9˚C per century).

Figure AI-6-22: Observed change in annual temperature for 1900-2013 (Province of BC, 2016)

Five (5) largest floods on record having greater than 2.0 m^3/s maximum daily streamflows:

Table AI-6-2: Known floods and antecedent average rainfall

Date	Annual Daily Max (m^3/s)	Antecedent Avg. Rainfall (mm/day)								
		Armstrong ID 1160450			Enderby ID 1162680			Armstrong North ID 1160485		
		Day of event	1 day earlier	2 days earlier	Day of event	1 day earlier	2 days earlier	Day of event	1 day earlier	2 days earlier
May 2, 1974	2.01	0.0	0.3	1.8	0.0	0.0	4.3	0.0	0.3	3.3
May 13, 1975	2.53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
May 1, 1978	2.40	-	-	-	0.5	0.0	0.0	0.0	0.0	0.0
May 18, 1982	3.62	-	-	-	-	-	-	0.0	6.0	T
		Silver Creek ID 1167337			Vernon North ID 1128583			Silver Star Mountain ID 1128584		
May 6, 2017	unknown	0.0	13.9	13.9	0.0	15.0	18.8	-	-	-
May 10, 2018	3.18	3.2	16.2	0.6	14.6	11.4	1.4	17.9	13.6	0.0

T-trace precipitation

Under these antecedent conditions, sub-basins response times (time of concentrations) were estimated to be approximately 5-6 hours and 26-30 hours for Meighan Creek and Deep Creek respectively. Although all large flood events are snowmelt induced, the flood events of 2017 and 2018 were exasperated by rainfall.

Streamflow 1/200-year Input Hydrographs:

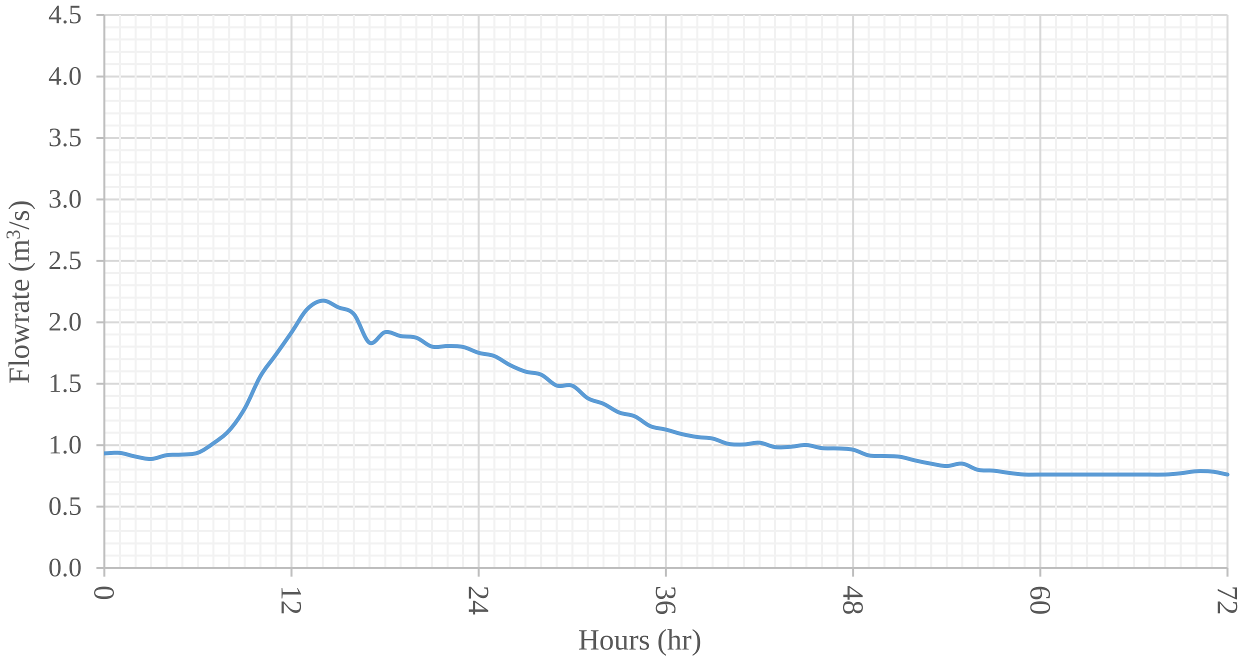


Figure AI-6-23: Meighan Creek 1/200-year Input Hydrograph (2018)

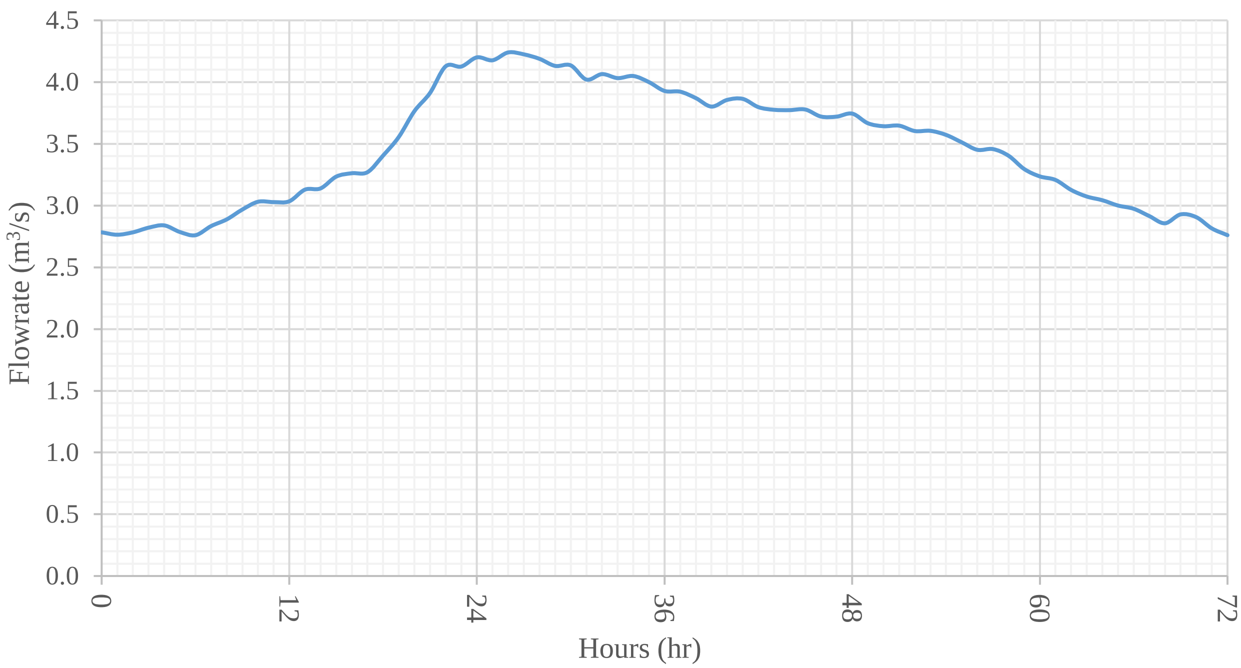


Figure AI-6-24: Deep Creek 1/200-year Input Hydrograph (2018)

Streamflow 1/20-year Input Hydrographs:

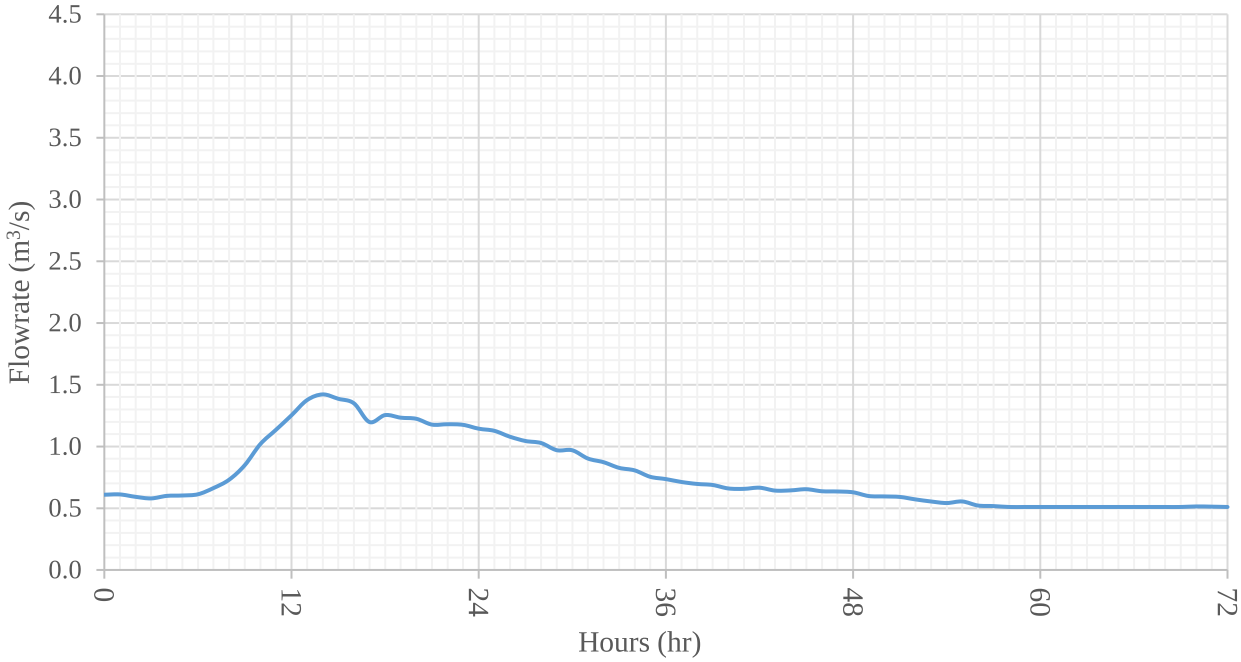


Figure AI-6-25: Meighan Creek 1/20-year Input Hydrograph (2018)

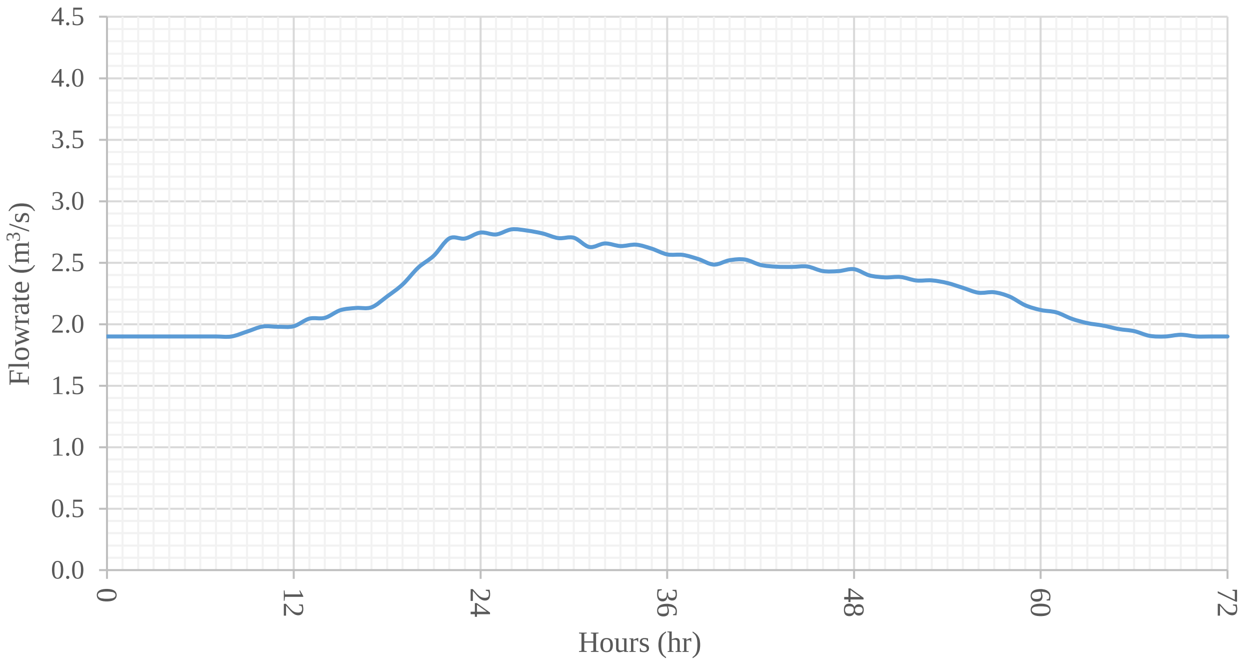


Figure AI-6-26: Deep Creek 1/20-year Input Hydrograph (2018)

Table AI-6-3: Flood Mapping Model Inputs – Manning Coefficients (USACE, 2010)

	Manning n		
Description	**Minimum**	**Normal**	**Maximum**
Natural Stream Main Channels			
a. Clean, Straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches or floodways with heavy timber stand and brush	0.070	0.100	0.150
Excavated or Dredged Channels - Earth, Straight and Uniform			
a. Clean, recently completed	**0.016**	**0.018**	**0.020**
b. Clean, after weathering	0.018	0.022	0.025
c. Gravel, uniform section, clean	0.022	0.025	0.030
d. With short grass, few weeds	0.022	0.027	0.033
Excavated or Dredged Channels - Earth, Winding and Sluggish			
a. No vegetation	0.023	0.025	0.030
b. Grass, some weeds	0.025	0.030	0.033
c. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.034
d. Earth bottom and rubble side	0.028	0.030	0.035
e. Stony bottom and weedy banks	0.025	0.035	0.040
f. Cobble bottom and clean sides	0.030	0.040	0.050
Channels not maintained, weeds and brush			
a. Clean bottom, brush on sides	0.040	0.050	0.080
b. Same as above, highest stage of flow	0.045	0.070	0.110
c. Dense weeds, high as flow depth	0.050	0.080	0.120
d. Dense brush, high stage	0.080	0.100	0.140
Flood Plains			
a. Pasture no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080

Table AI-6-3: Flood Mapping Model Inputs – Manning Coefficients (USACE, 2010)

4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
2. Same as above, but heavy sprouts	0.050	0.060	0.080
3. Heavy stand of timber, little undergrowth, flow below branches	0.080	0.100	0.120
4. Same as above, but with flow into branches	0.100	0.120	0.160
5. Dense willows, summer, straight	0.110	0.150	0.200
Pipe and Conduit Materials			
a. Concrete, steel forms	0.009	0.011	0.013
b. Concrete, wooden forms	0.012	0.015	0.018
c. Concrete, centrifugally spun	0.012	0.013	0.015
d. Corrugated metal	0.020	0.022	0.040
e. Steel, smooth	0.010	0.012	0.014
f. Steel, riveted	0.017	0.019	0.021
g. Wood	0.012	0.014	0.016
h. Masonry	0.022	0.025	0.028

Frequency Analysis Solution for daily maximum streamflows at Deep Creek at Adair Street:

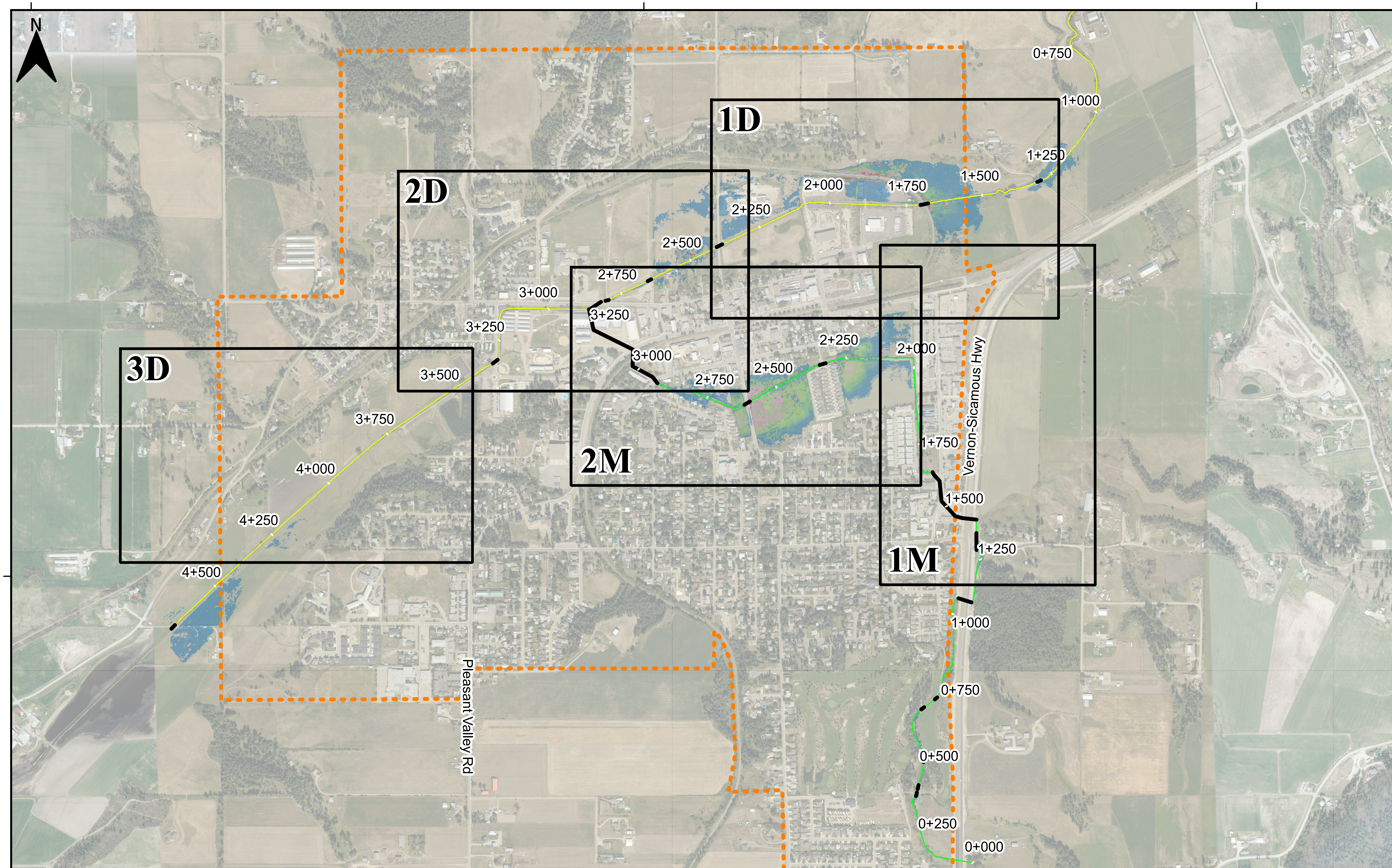
(includes climate-factors)

Year	Probability	Flood
1	1.0000	1.007
5	0.2000	2.270
10	0.1000	2.850
20	0.0500	3.409
30	0.0333	3.717
40	0.0250	3.947
50	0.0200	4.134
60	0.0167	4.270
70	0.0143	4.393
80	0.0125	4.499
90	0.0111	4.593
100	0.0100	4.676
110	0.0091	4.753
120	0.0083	4.822
130	0.0077	4.886
140	0.0071	4.945
150	0.0067	5.000
160	0.0063	5.051
170	0.0059	5.100
180	0.0056	5.145
190	0.0053	5.188
200	0.0050	5.216

This page intentionally left blank

APPENDIX II: FLOOD MAPS

This page intentionally left blank



LEGEND

- Culverts
- Meighan Creek
- Deep Creek

Cadastre

- City Boundary

Flood Depth (m)

- < 0.30
- 0.30-0.60
- 0.60-0.90
- 0.90-1.20
- 1.20-1.50
- 1.50-1.80
- 1.80-2.10
- 2.10-2.40
- 2.40-2.70
- > 2.70

NOTES

-North American Datum of 1983(NAD83) and Canadian Geodetic Vertical Datum (CGVD28) for horizontal and vertical datums respectfully

-Base mapping imagery and property line data is approximate and for general reference only

CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019

PROJ.NO.: 0130.05

GIS: CRD ENG: ABH

0 100 200 300 400 METRES

SCALE 1:20000 NAD 1983 UTM 11N

SEAL: SEE REPORT

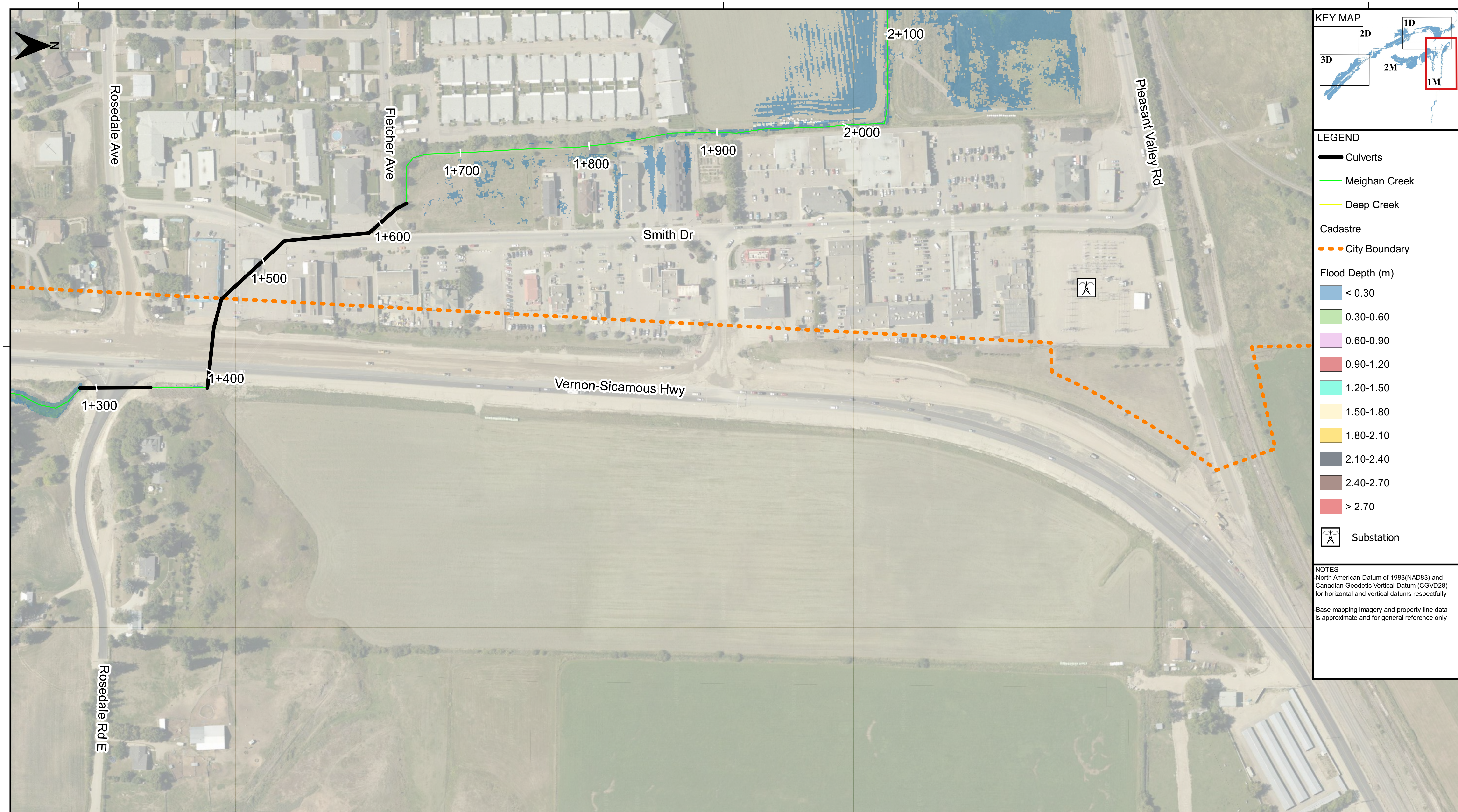
TITLE

KEY MAP FLOOD DEPTH

20 YEAR INUNDATION MAPPING

MAP NO. N/A

342000 344000 346000



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

DEEP CREEK FLOOD DEPTH

20 YEAR INUNDATION MAPPING

MAP NO. 1M

5590000 5590500 5591000

344000 344500 345000

5590500 5590500

CONSULTANT
Interior Dams

CLIENT
City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

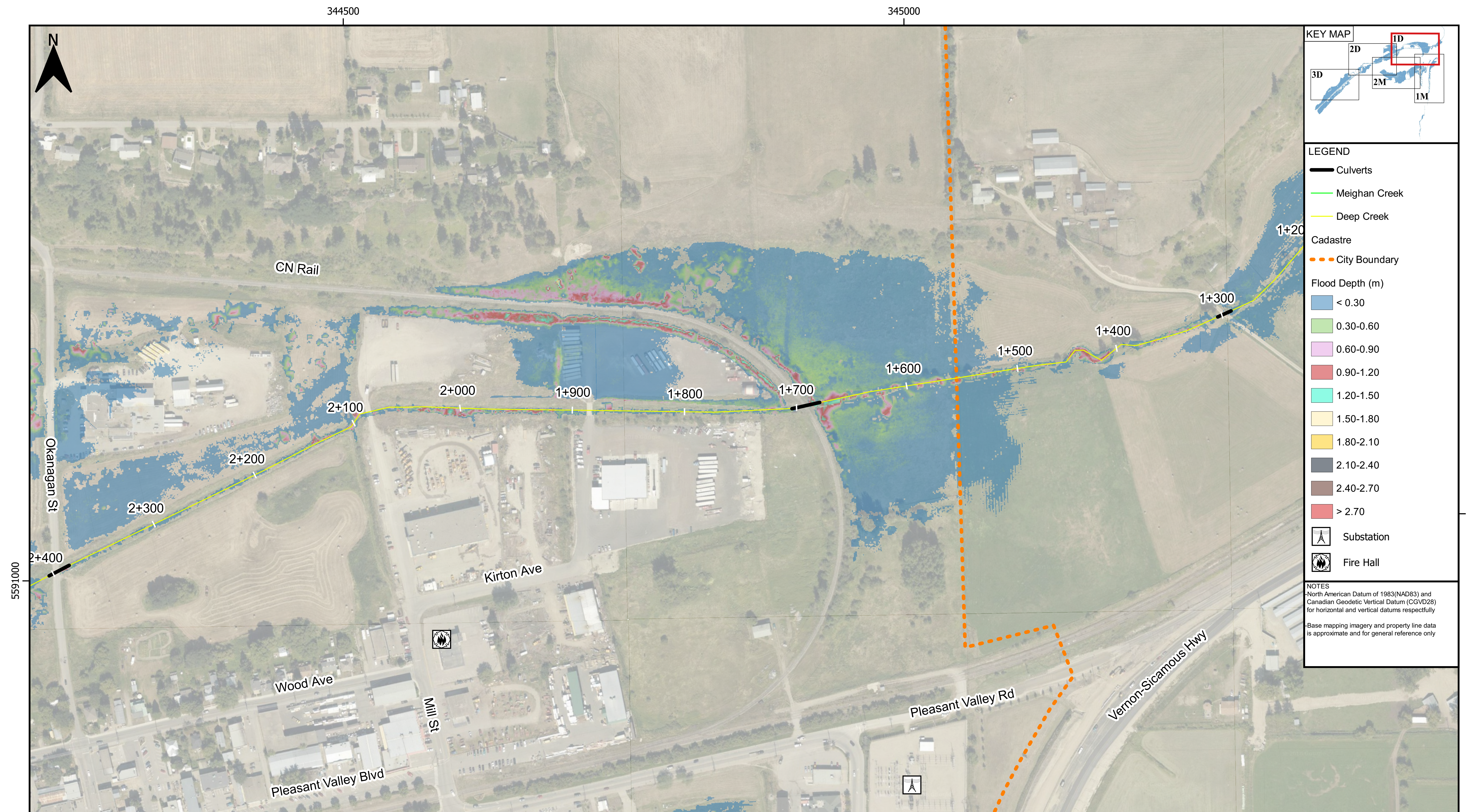
DATE JAN 21, 2019
PROJ.NO. 0130.05
GIS CRD
ENG ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL
SEE REPORT

TITLE
DEEP CREEK FLOOD DEPTH
20 YEAR INUNDATION MAPPING

MAP NO.
2M

344000 344500



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS: CRD
ENG: ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

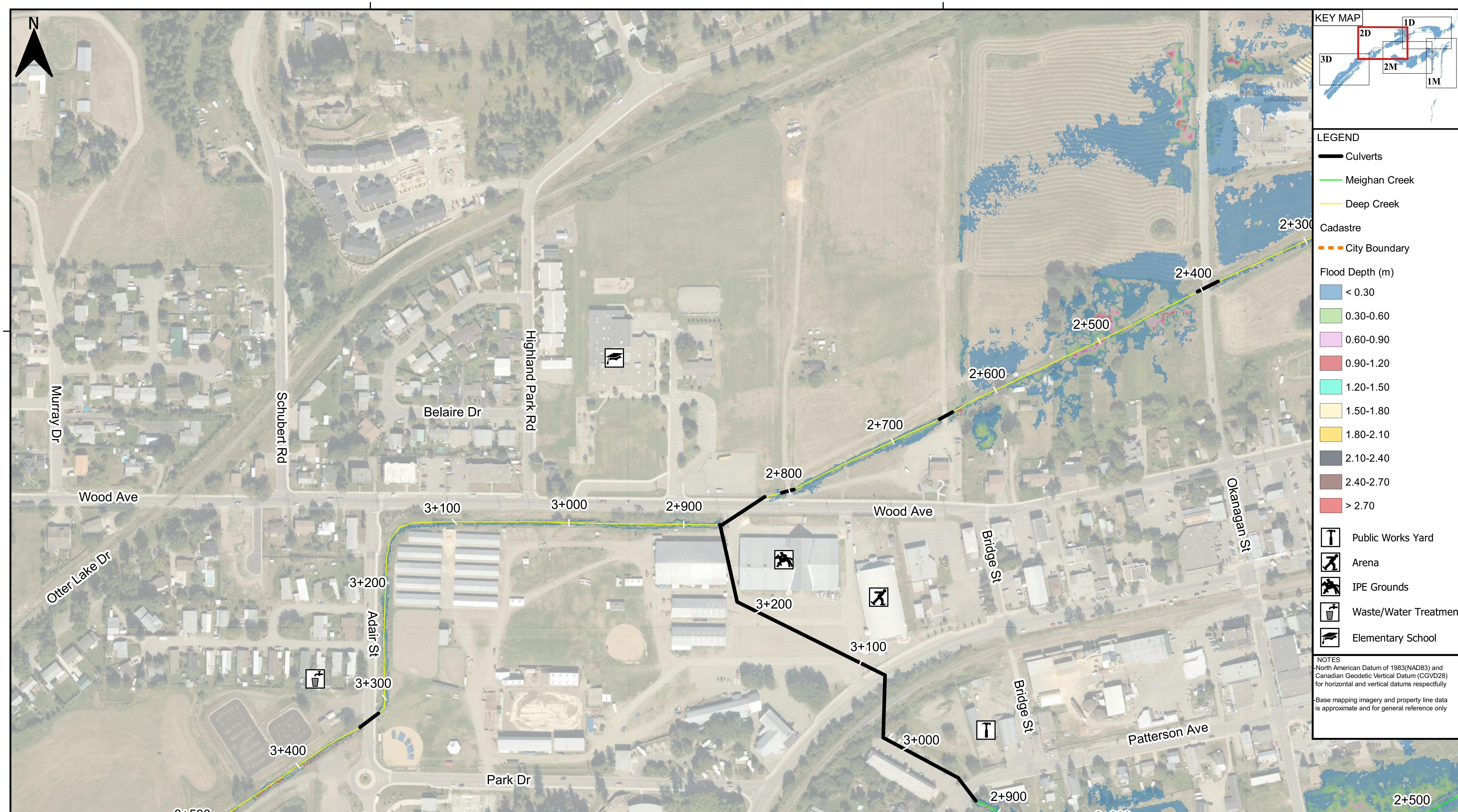
SEAL: SEE REPORT

TITLE

DEEP CREEK FLOOD DEPTH

20 YEAR INUNDATION MAPPING

MAP NO. 1D



CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	DEEP CREEK FLOOD DEPTH	2D
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		20 YEAR INUNDATION MAPPING	
				GIS CRD / ENG ABH			
				0 25 50 75 100 METRES			
				SCALE 1:5000 NAD 1983 UTM 11N			

343500 344000
5590500 5590500

CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

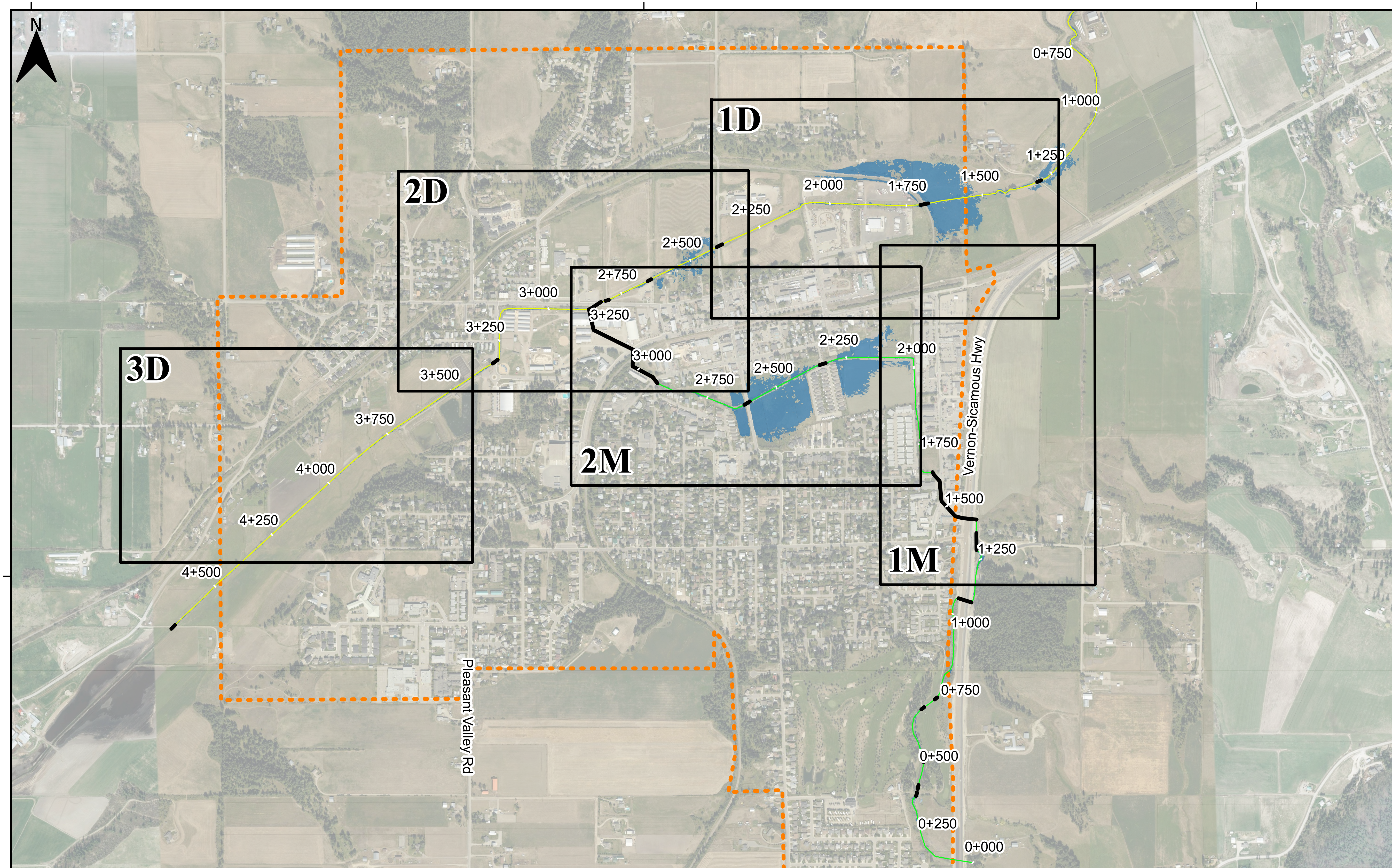
TITLE:

DEEP CREEK FLOOD DEPTH

20 YEAR INUNDATION MAPPING

MAP NO. 3D

342500 343000 343500



LEGEND

- Culverts
- Meighan Creek
- Deep Creek
- Cadadstre
- City Boundary

Hazard Index

- < 0.75
- 0.75-1.25
- 1.25-2.00
- > 2.00

NOTES

-North American Datum of 1983(NAD83) and Canadian Geodetic Vertical Datum (CGVD28) for horizontal and vertical datums respectfully

-Base mapping imagery and property line data is approximate and for general reference only

CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD ENG: ABH

0 100 200 300 400 METRES

SCALE 1:20000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

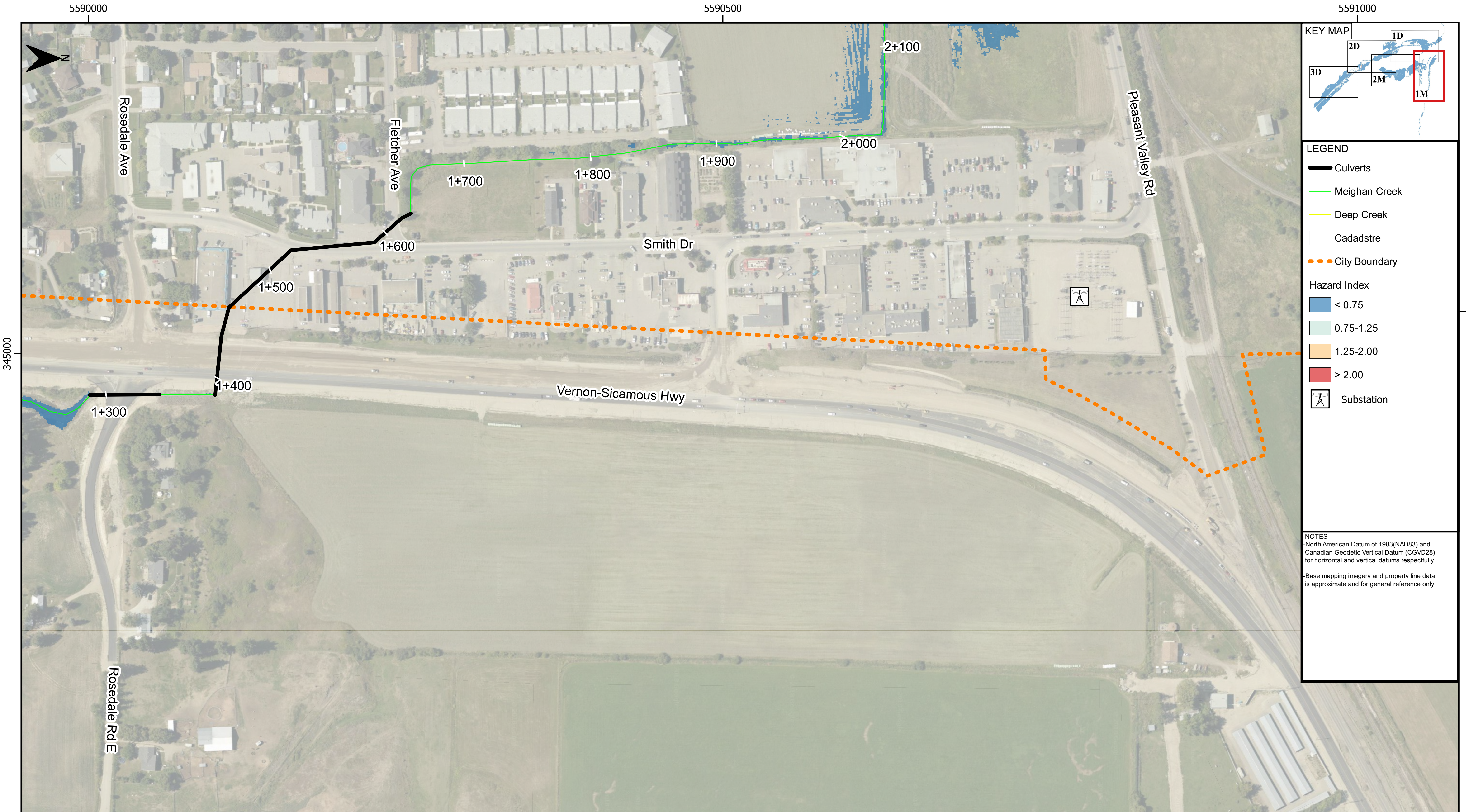
KEY MAP
HAZARD INDEX

20 YEAR HAZARD MAPPING

MAP NO.

N/A

342000 344000 346000



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019

PROJ.NO.: 0130.05

GIS: CRD | ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

DEEP CREEK HAZARD INDEX

20 YEAR HAZARD MAPPING

MAP NO. 1M

CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

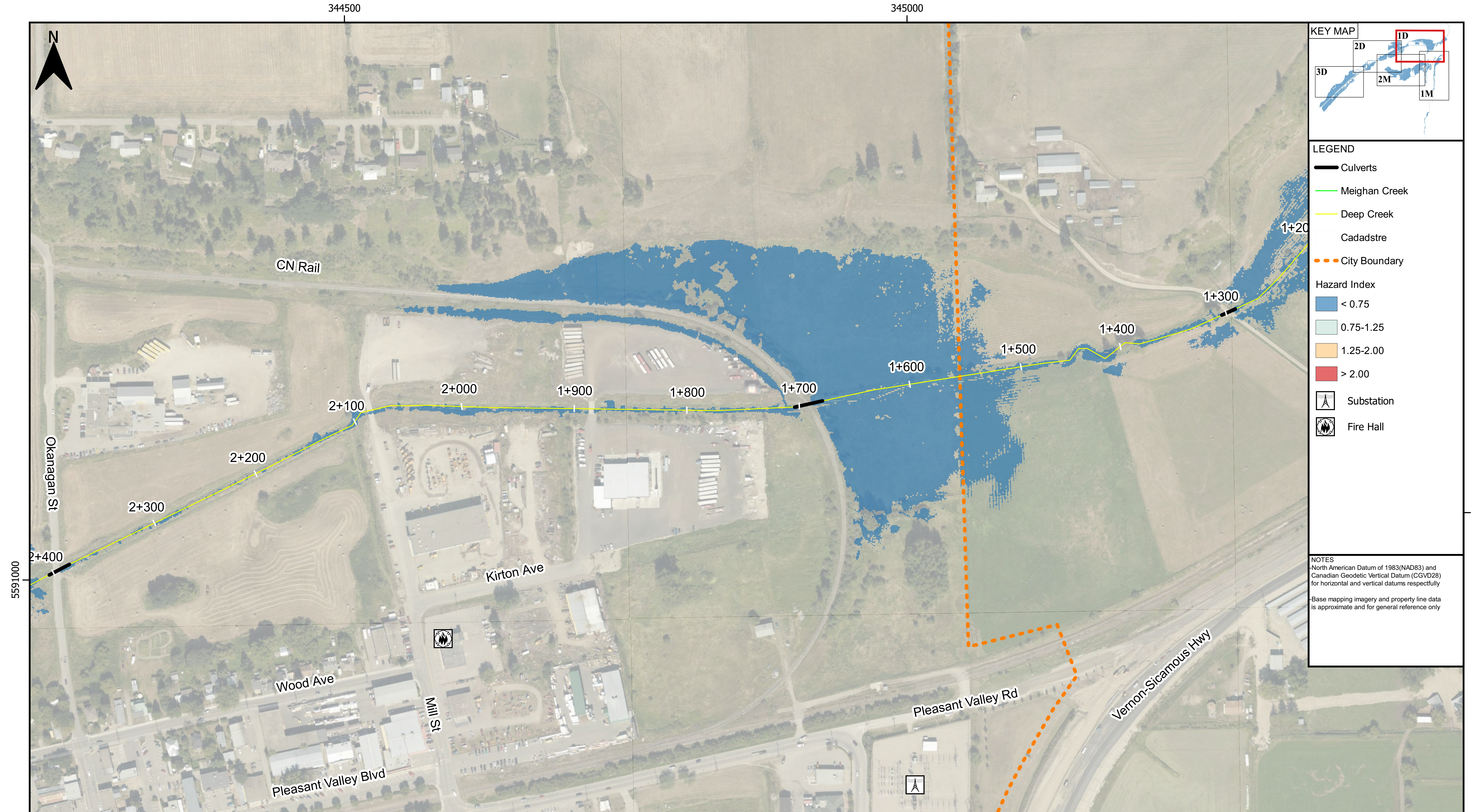
TITLE

DEEP CREEK HAZARD INDEX

20 YEAR HAZARD MAPPING

MAP NO. 2M

344000 344500



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/12
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

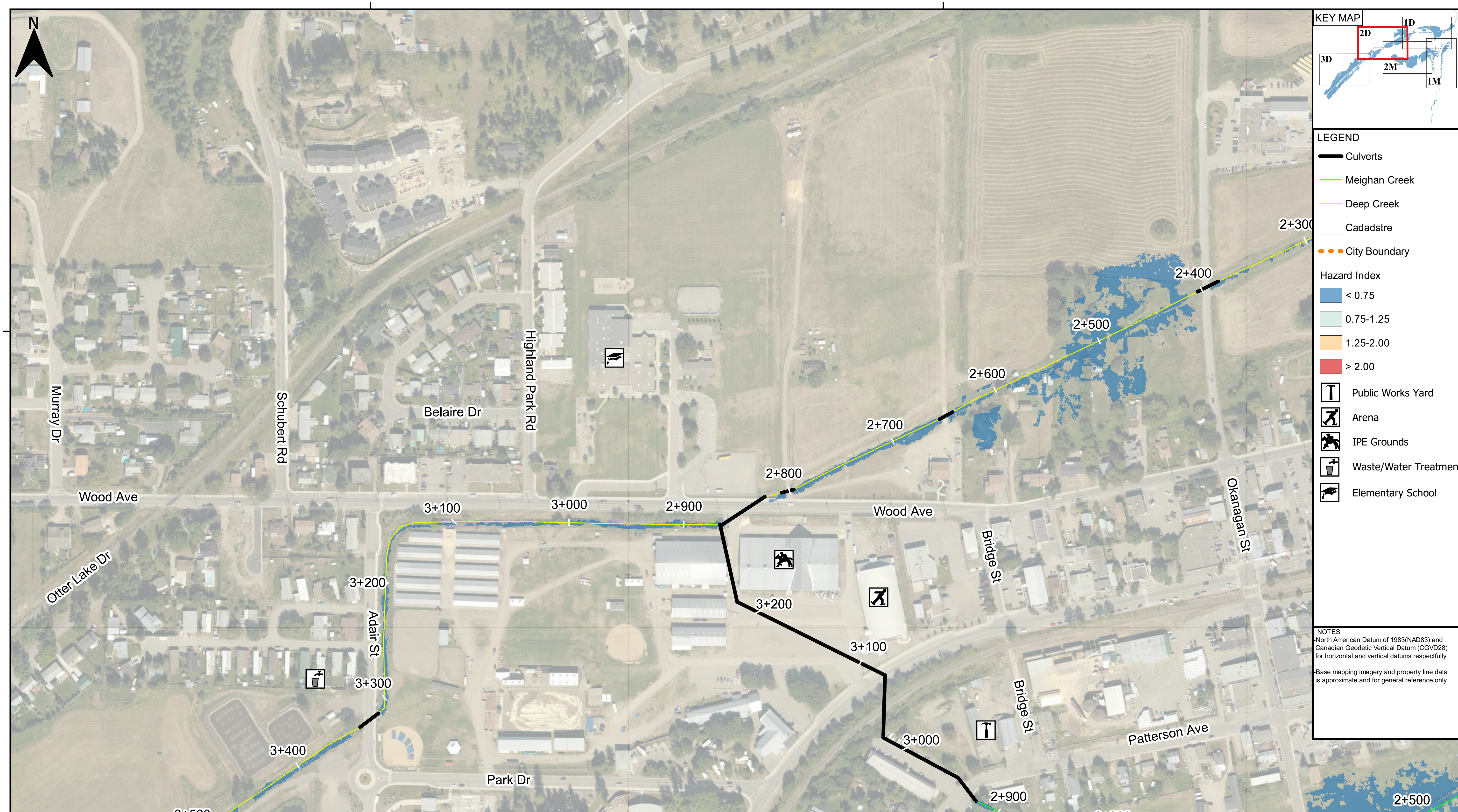
TITLE

DEEP CREEK HAZARD INDEX

20 YEAR HAZARD MAPPING

MAP NO. 1D

344500 345000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

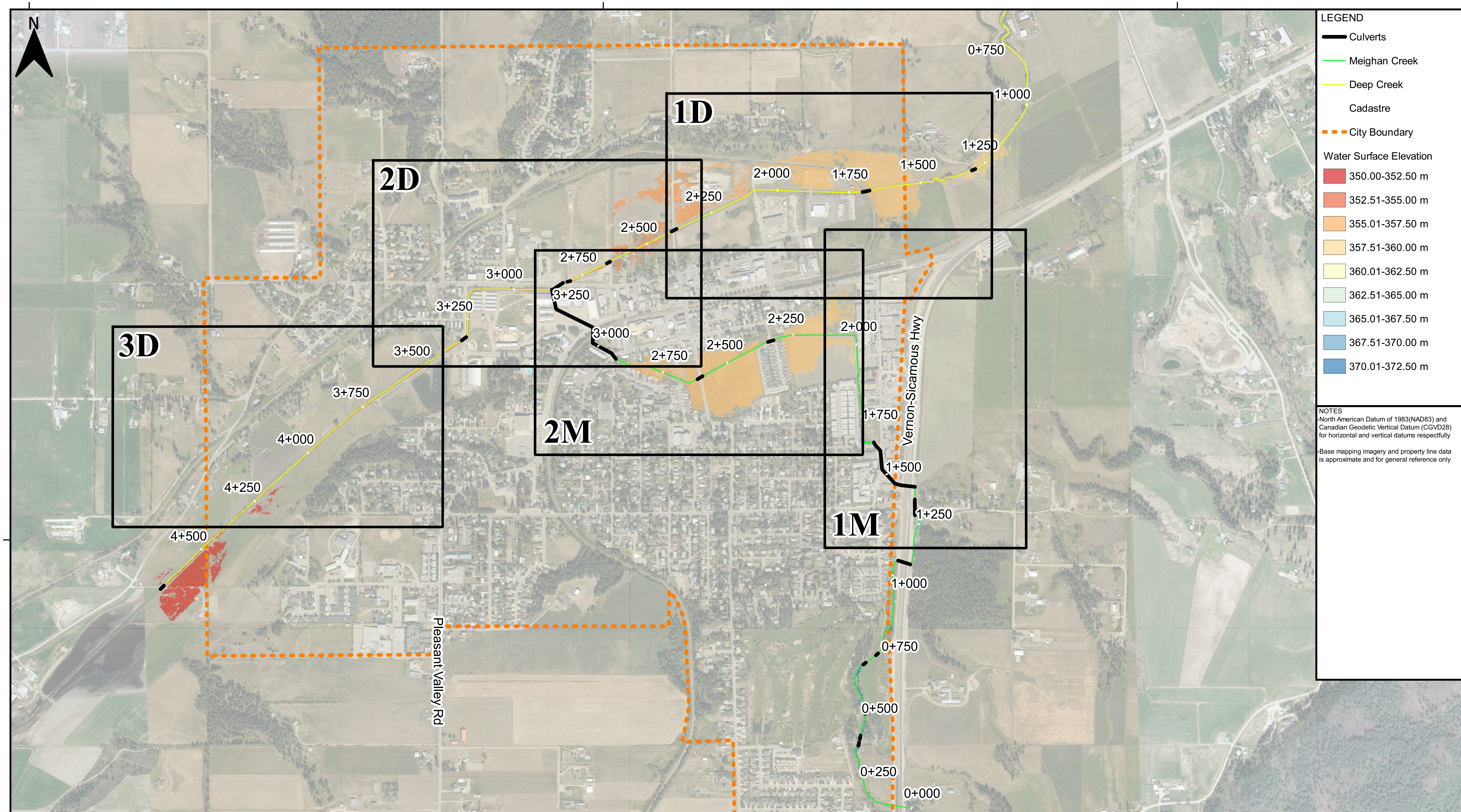
DEEP CREEK HAZARD INDEX

20 YEAR HAZARD MAPPING

MAP NO. 2D

CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	DEEP CREEK HAZARD INDEX	3D
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		20 YEAR HAZARD MAPPING	
				GIS CRD ENG ABH			
				0 25 50 75 100 METRES			
				SCALE 1:5000 NAD 1983 UTM 11N			

342500 343000 343500



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD ENG: ABH

0 100 200 300 400 METRES

SCALE 1:20000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

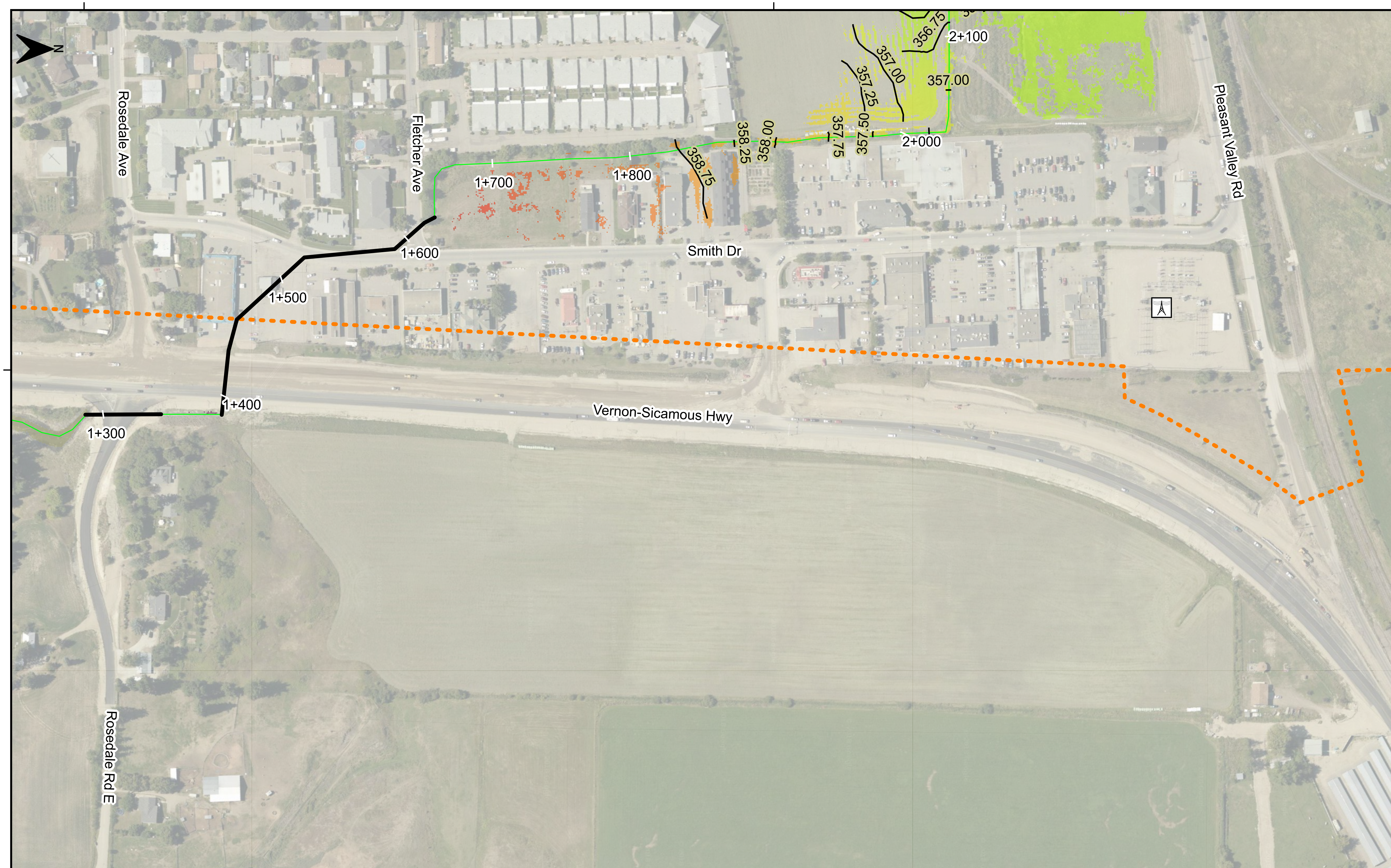
KEY MAP WATER SURFACE ELEVATION

20 YEAR INUNDATION MAPPING

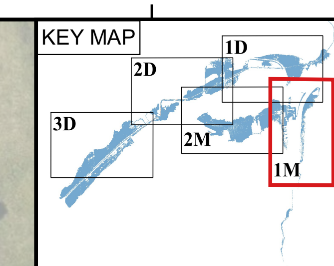
MAP NO. N/A

342000 344000 346000

5590000 5590500 5591000



345000



LEGEND

- Culverts
- 0.25m Contours
- Meighan Creek
- Deep Creek
- Cadastre
- City Boundary

Water Surface Elevation

- 357.01-358.00 m
- 358.01-359.00 m
- 359.01-360.00 m
- 360.01-361.00 m
- 361.01-362.00 m
- 362.01-363.00 m
- 363.01-364.00 m
- 364.01-365.00 m
- 365.01-366.00 m
- Substation

NOTES

-North American Datum of 1983(NAD83) and Canadian Geodetic Vertical Datum (CGVD28) for horizontal and vertical datums respectfully

-Base mapping imagery and property line data is approximate and for general reference only

CONSULTANT Interior Dams

CLIENT City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE JAN 21, 2019

PROJ.NO. 0130.05

GIS CRD ENG ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL

SEE REPORT

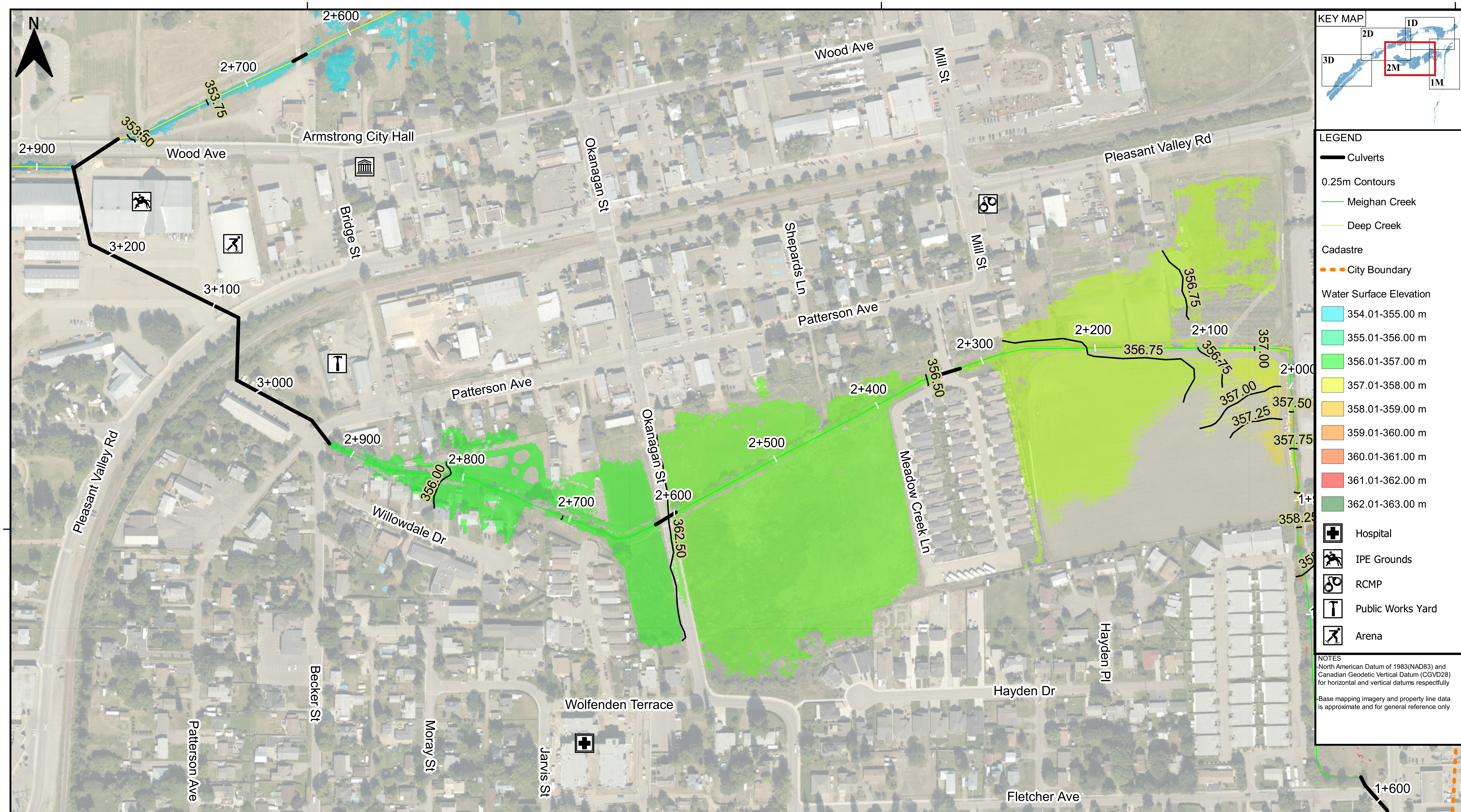
TITLE

DEEP CREEK WATER SURFACE ELEVATION

20 YEAR INUNDATION MAPPING

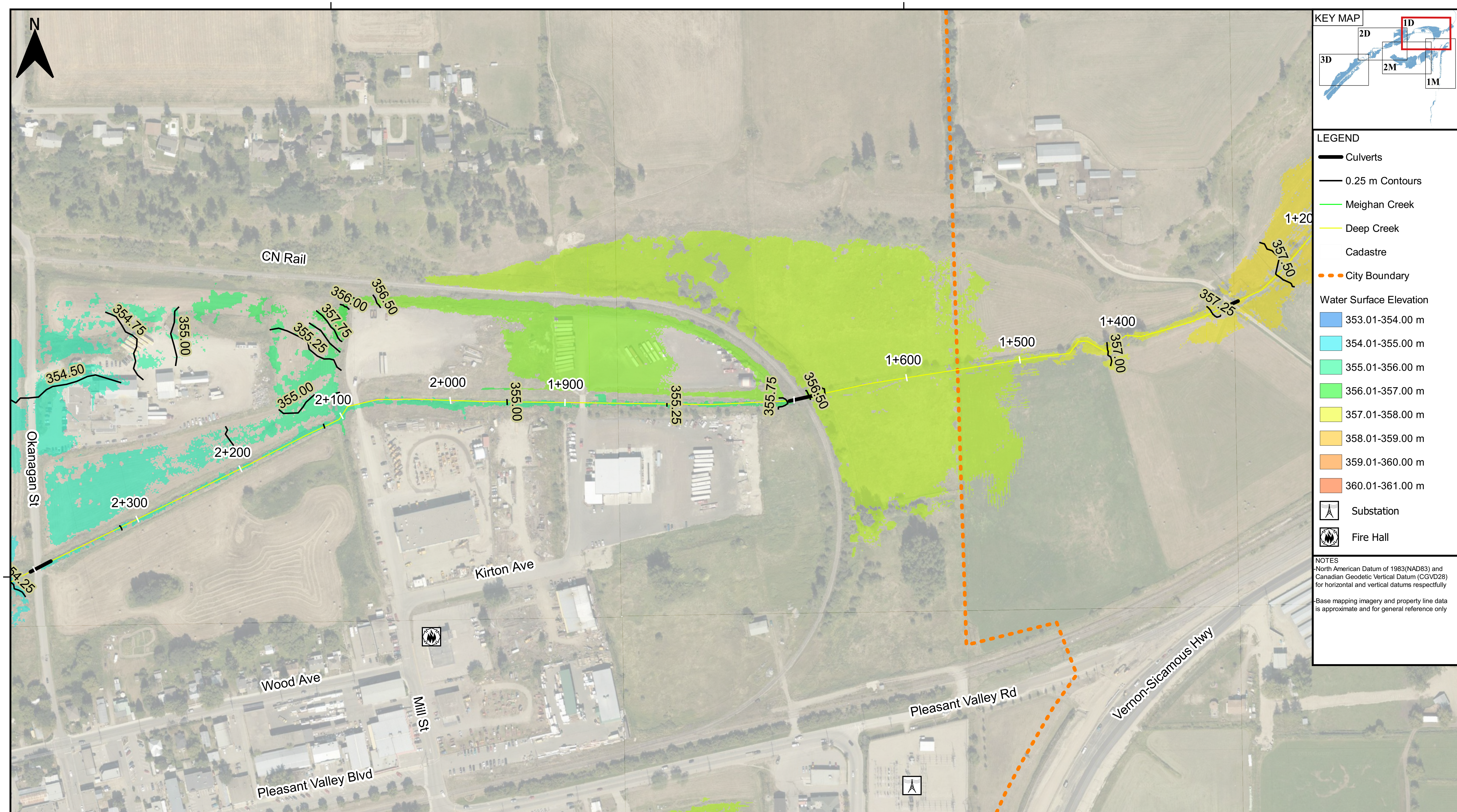
MAP NO. 1M

5590000 5590500 5591000



CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	DEEP CREEK WATER SURFACE ELEVATION	2M
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		20 YEAR INUNDATION MAPPING	
				GIS CRD / ENG ABH			
				0 25 50 75 100 METRES			
				SCALE 1:5000 NAD 1983 UTM 11N			

344000 344500



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS: CRD ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

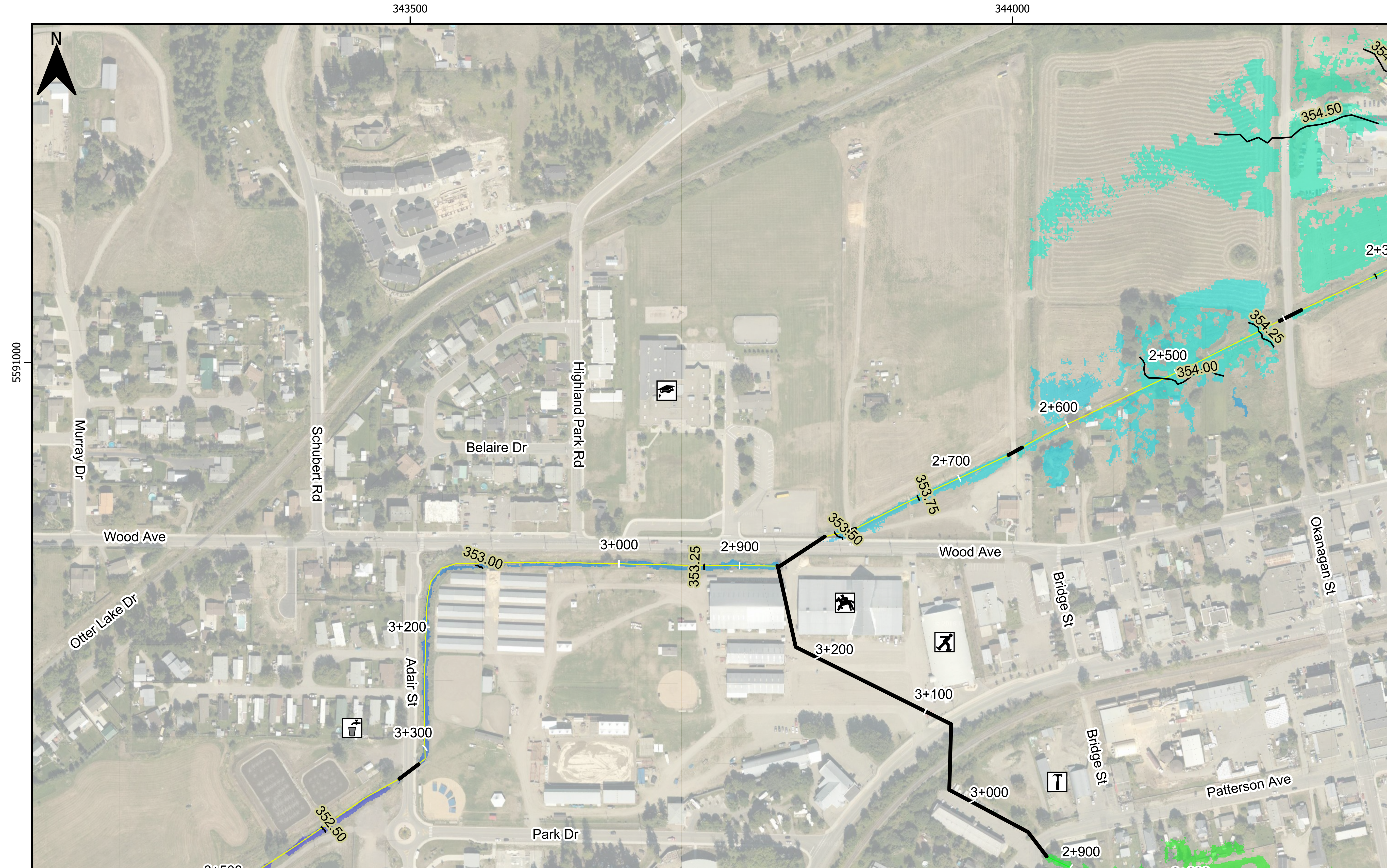
TITLE

DEEP CREEK WATER SURFACE ELEVATION

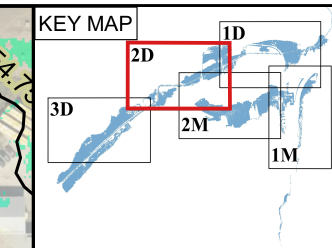
20 YEAR INUNDATION MAPPING

MAP NO. 1D

344500 345000



KEY MAP



LEGEND

- Culverts
- 0.25m Contours
  - Meighan Creek
  - Deep Creek
- Cadastre
  - City Boundary
- Water Surface Elevation
  - 351.01-352.00 m
  - 352.01-353.00 m
  - 353.01-354.00 m
  - 354.01-355.00 m
  - 355.01-356.00 m
  - 356.01-357.00 m
  - 357.01-358.00 m
  - 358.01-359.00 m
  - 359.01-360.00 m
- Public Works Yard
- Arena
- IPE Grounds
- Waste/Water Treatment
- Elementary School

NOTES

-North American Datum of 1983(NAD83) and Canadian Geodetic Vertical Datum (CGVD28) for horizontal and vertical datums respectfully

-Base mapping imagery and property line data is approximate and for general reference only

CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
	1	ISSUED FOR USE	2019/01/21
CLIENT: City of Armstrong			

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

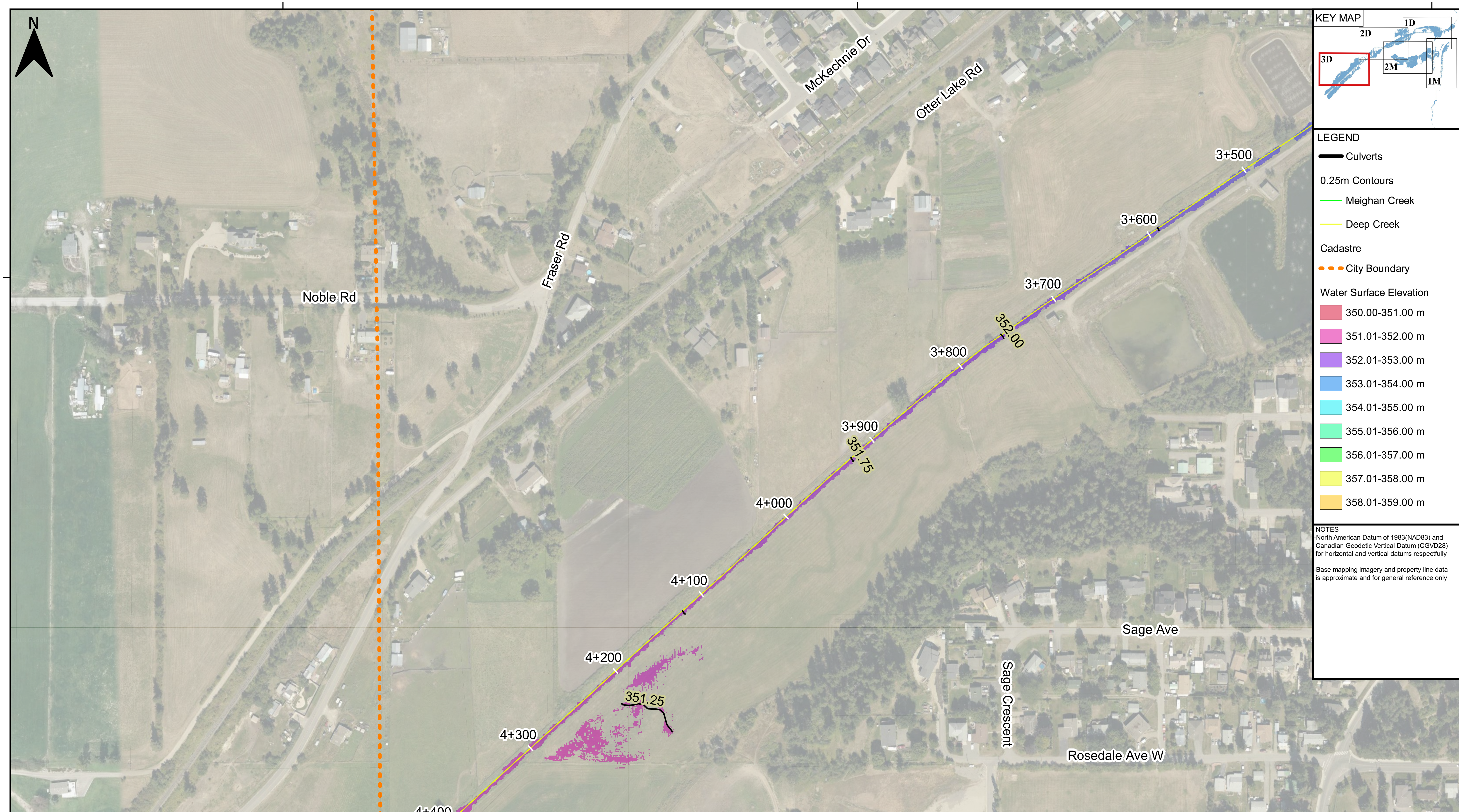
SEAL: SEE REPORT

TITLE

DEEP CREEK WATER SURFACE ELEVATION

20 YEAR INUNDATION MAPPING

MAP NO. 2D



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
	1	ISSUED FOR USE	2019/01/21
CLIENT: City of Armstrong			

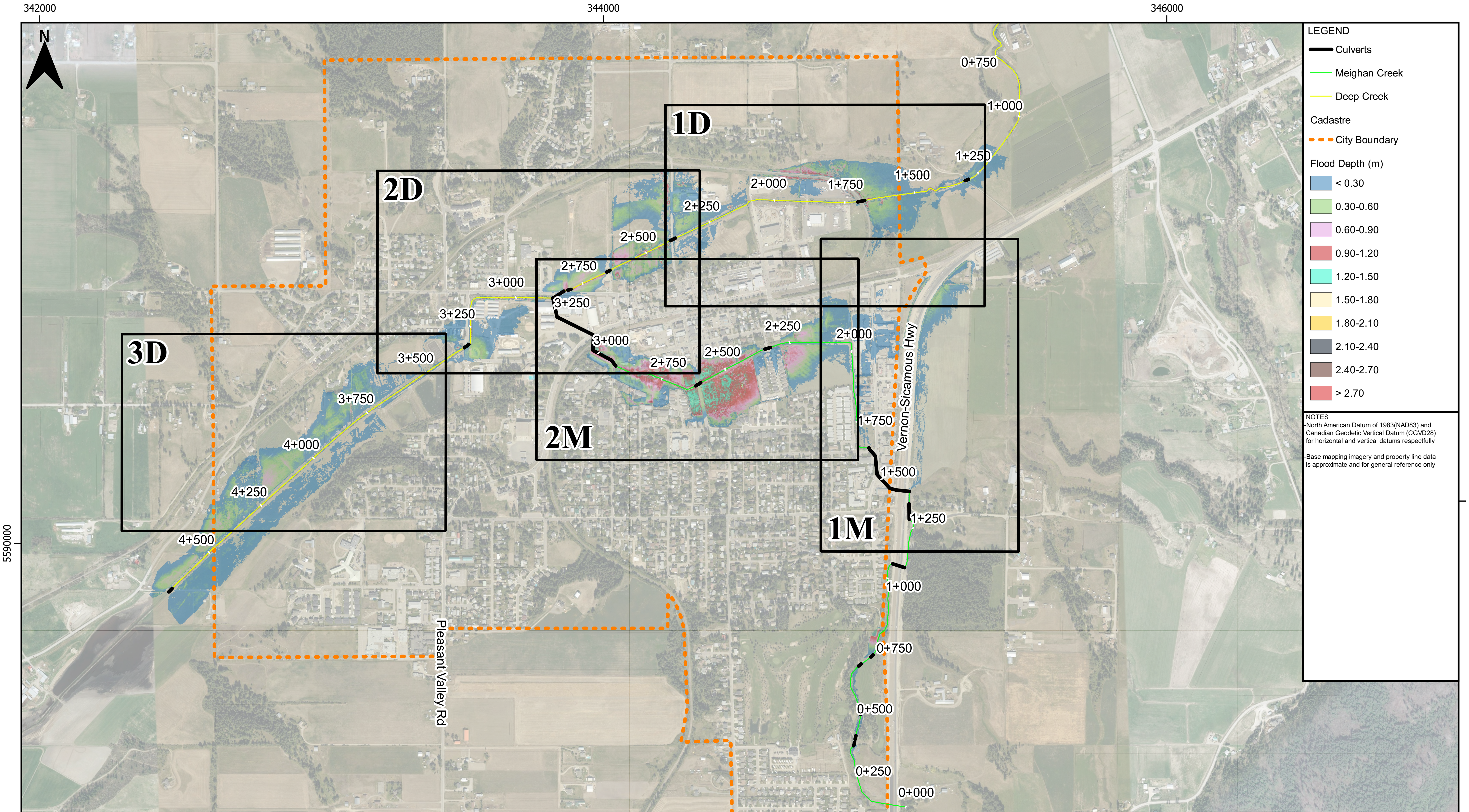
DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD ENG: ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE:
DEEP CREEK WATER SURFACE ELEVATION
20 YEAR INUNDATION MAPPING

MAP NO. 3D

342500 343000 343500
5590000



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019

PROJ.NO.: 0130.05

GIS: CRD ENG: ABH

0 100 200 300 400 METRES

SCALE 1:20000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE:

KEY MAP
FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO.: N/A

342000 344000 346000

CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019

PROJ.NO. 0130.05

GIS: CRD ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

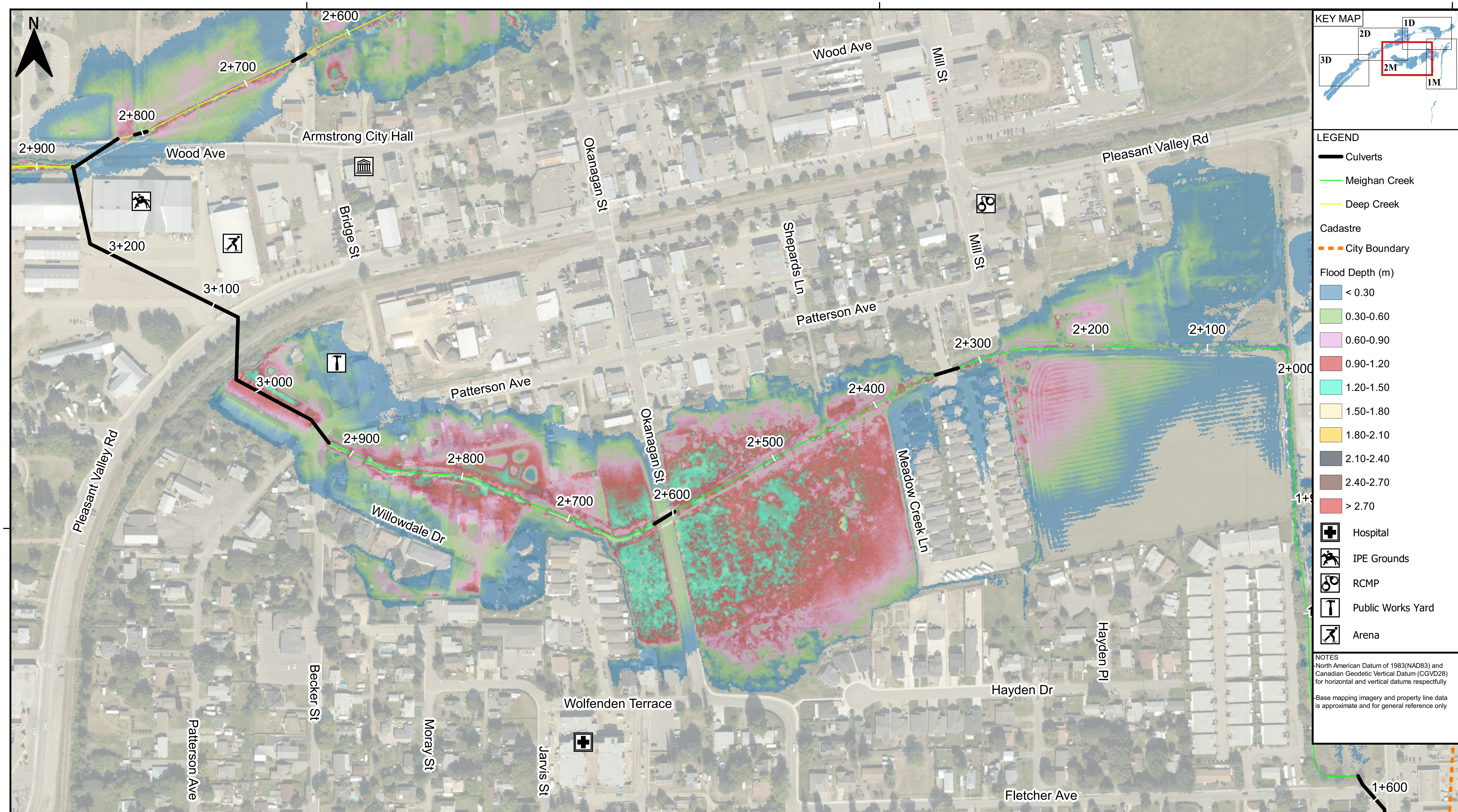
TITLE

DEEP CREEK FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO. 1M

5590000 5590500 5591000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS: CRD ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

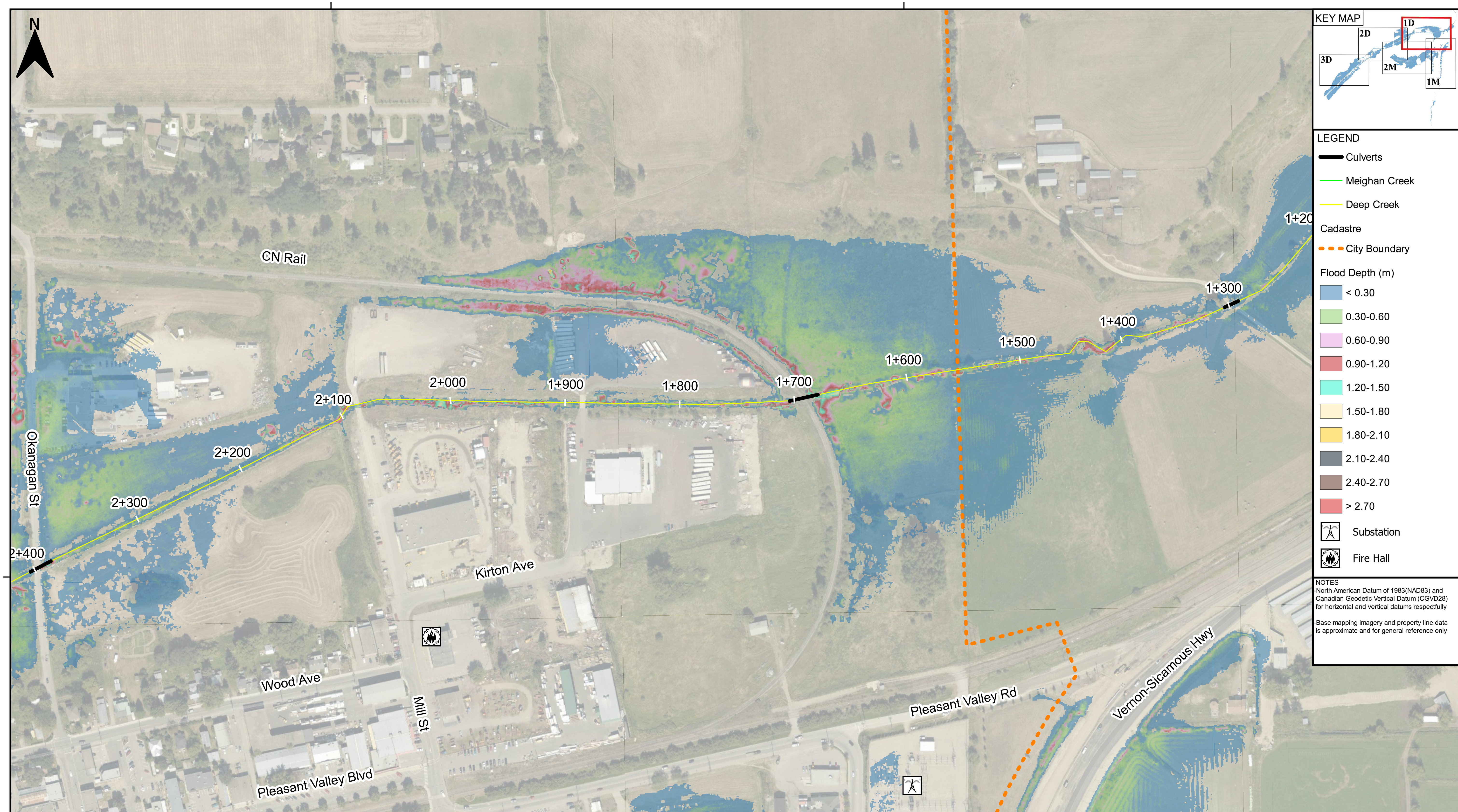
DEEP CREEK FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO.

2M

344000 344500



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS: CRD ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

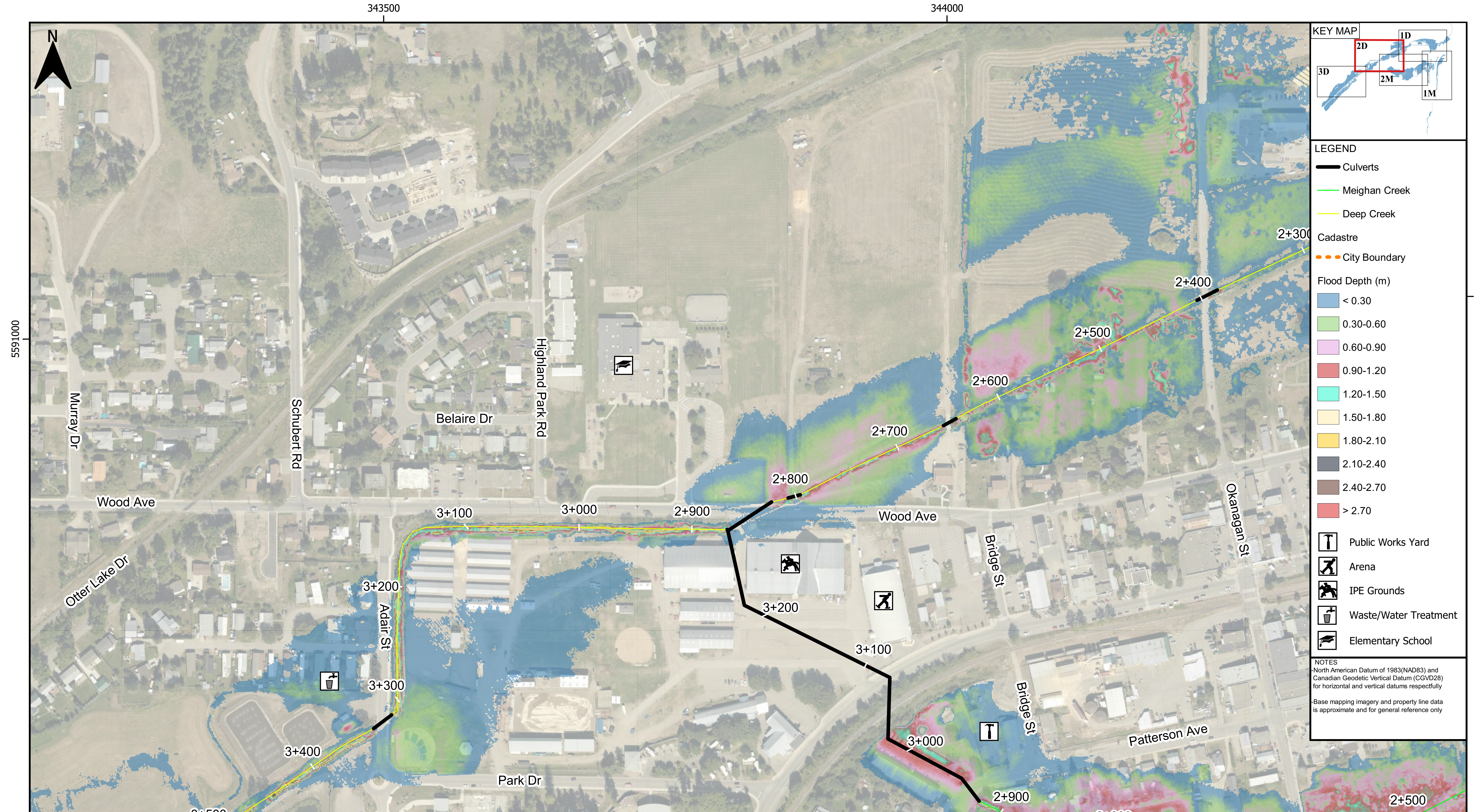
TITLE

DEEP CREEK FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO. 1D

344500 345000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019

PROJ.NO.: 0130.05

GIS: CRD — ENG: ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

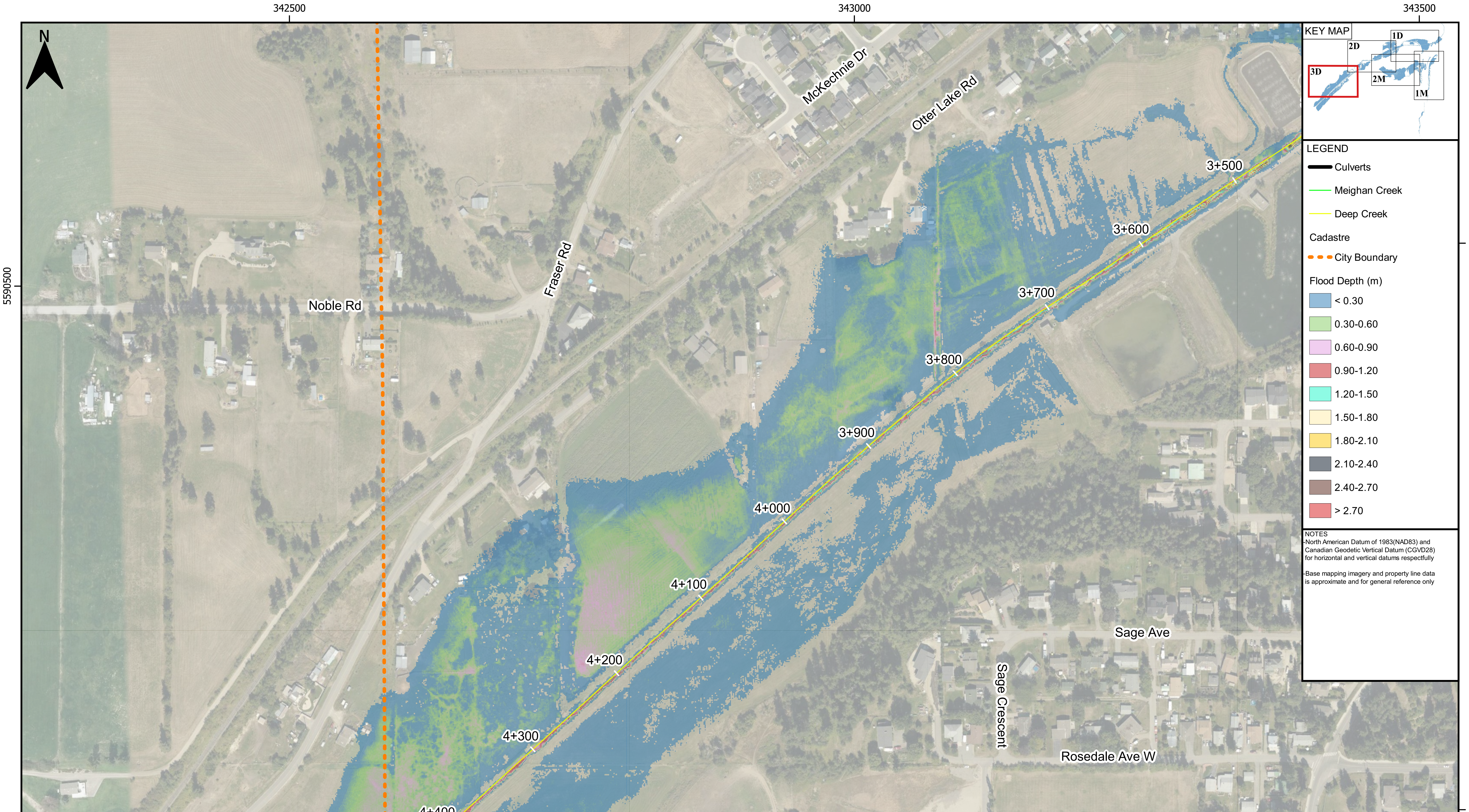
SEAL: SEE REPORT

TITLE

DEEP CREEK FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO. 2D



CONSULTANT

Interior Dams

CLIENT

City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE JAN 21, 2019

PROJ.NO. 0130.05

GIS CRD ENG ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL

SEE REPORT

TITLE

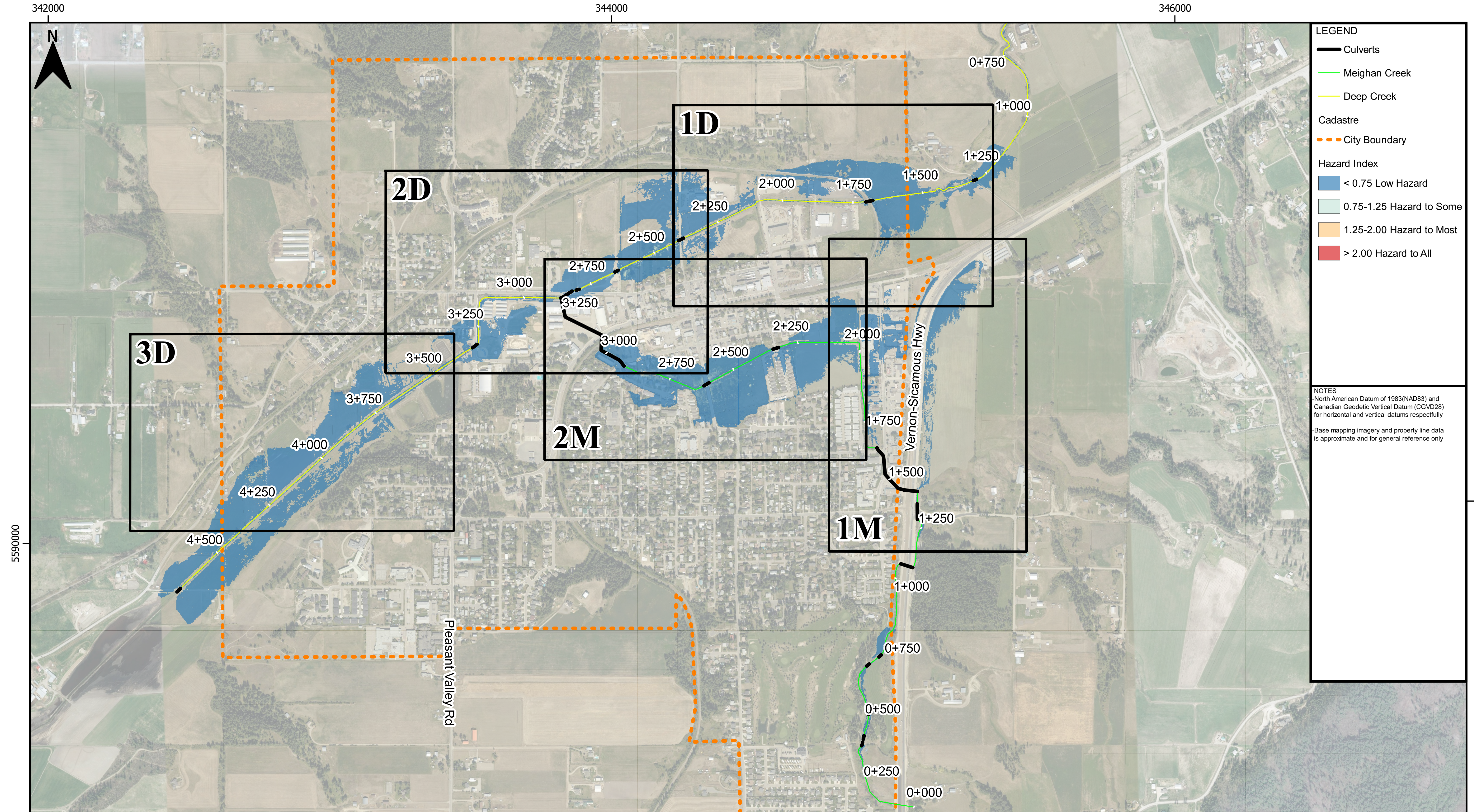
DEEP CREEK FLOOD DEPTH

200 YEAR INUNDATION MAPPING

MAP NO.

3D

342500 343000 343500



CONSULTANT: Interior Dams

CLIENT: City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 100 200 300 400 METRES

SCALE 1:20000 NAD 1983 UTM 11N

SEAL: SEE REPORT

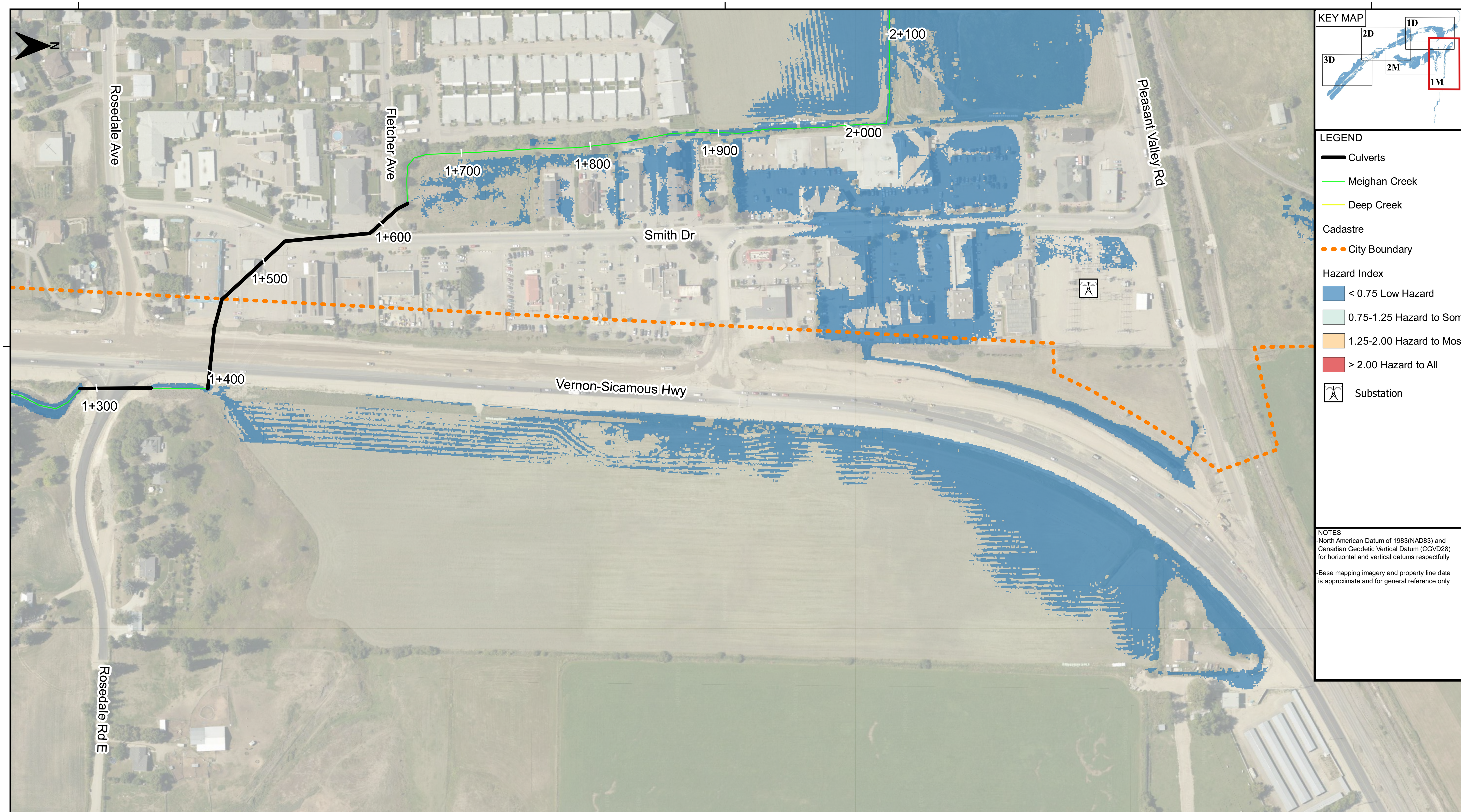
TITLE

KEY MAP
HAZARD INDEX

200 YEAR HAZARD MAPPING

MAP NO. N/A

342000 344000 346000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

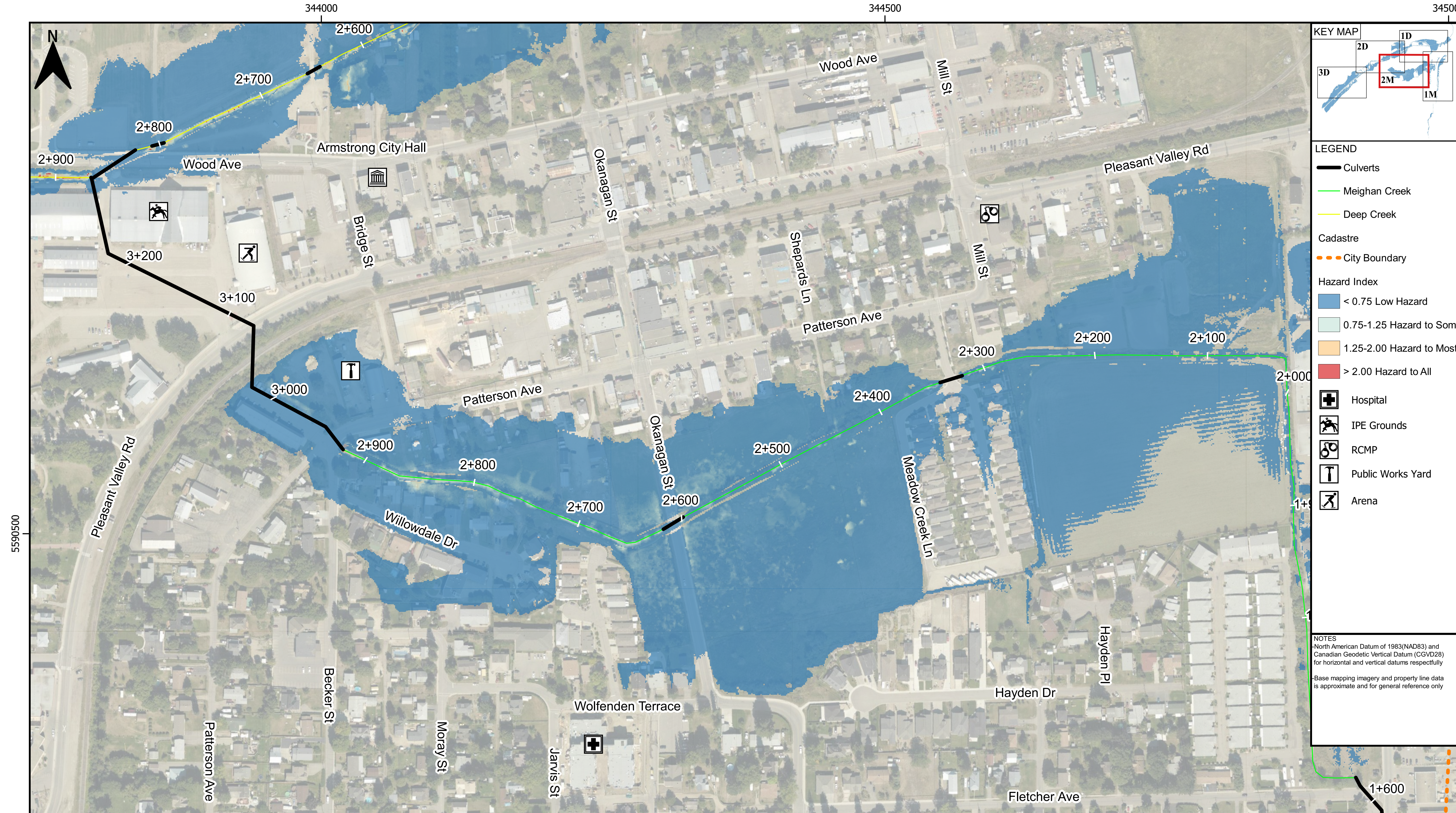
TITLE

DEEP CREEK HAZARD INDEX

200 YEAR HAZARD MAPPING

MAP NO. **1M**

5590000 5590500 5591000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE JAN 21, 2019

PROJ.NO. 0130.05

GIS CRD ENG ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

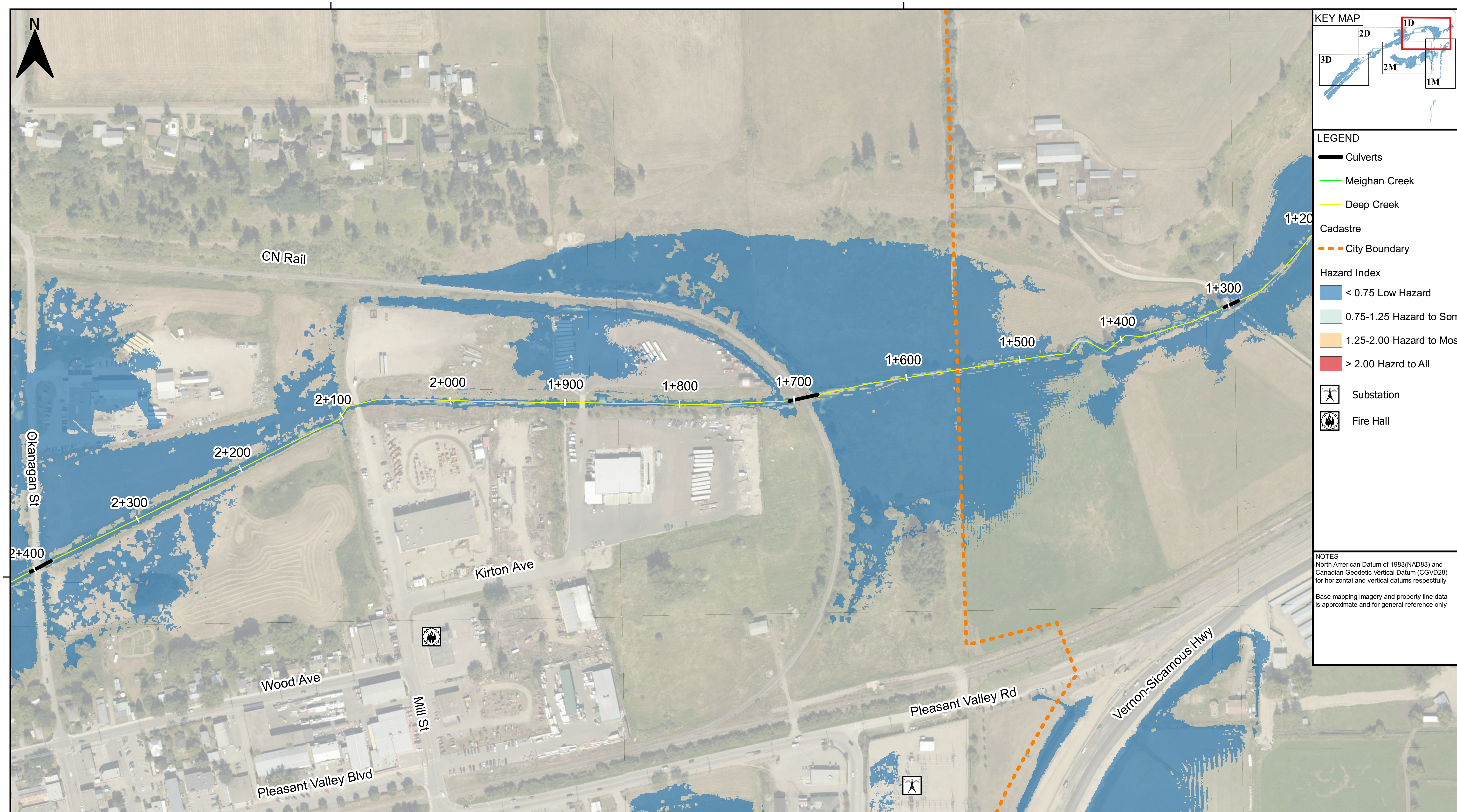
TITLE

DEEP CREEK HAZARD INDEX

200 YEAR HAZARD MAPPING

MAP NO. **2M**

344000 344500



CONSULTANT

Interior Dams

CLIENT

City of Armstrong

REV	NOTES	DATE Y/M/D
0	ISSUED FOR DRAFT	2018/12/15
1	ISSUED FOR USE	2019/01/21

DATE JAN 21, 2019

PROJ.NO. 0130.05

GIS CRD ENG ABH

0 25 50 75 100 METRES

SCALE 1:5000 NAD 1983 UTM 11N

SEAL

SEE REPORT

TITLE

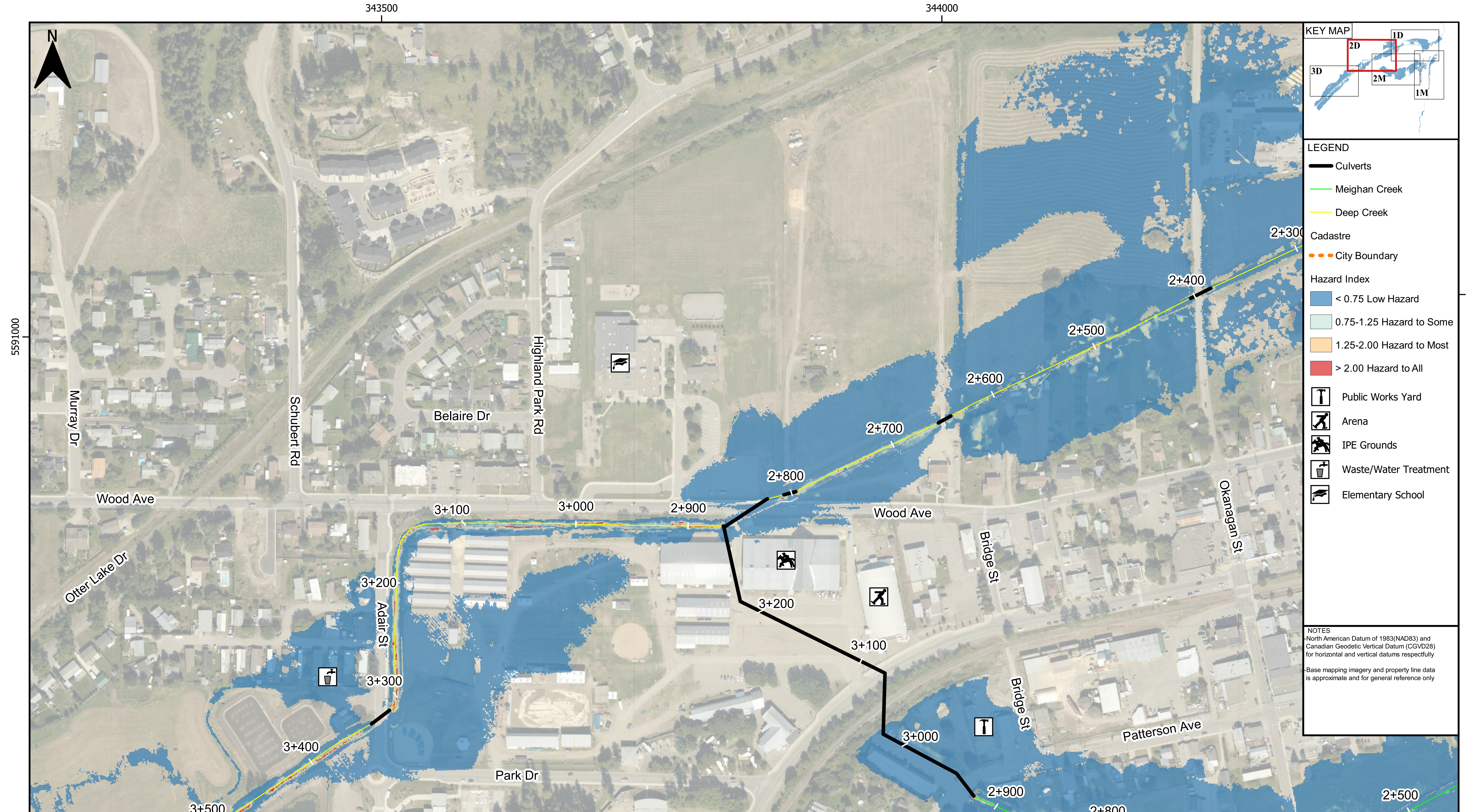
DEEP CREEK HAZARD INDEX

200 YEAR HAZARD MAPPING

MAP NO.

1D

344500 345000



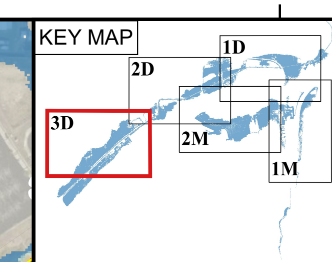
CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
	1	ISSUED FOR USE	2019/01/21
CLIENT: City of Armstrong			

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE
DEEP CREEK HAZARD INDEX
200 YEAR HAZARD MAPPING

MAP NO.
2D



LEGEND

- Culverts
- Meighan Creek
- Deep Creek

Cadastre

- City Boundary

Hazard Index

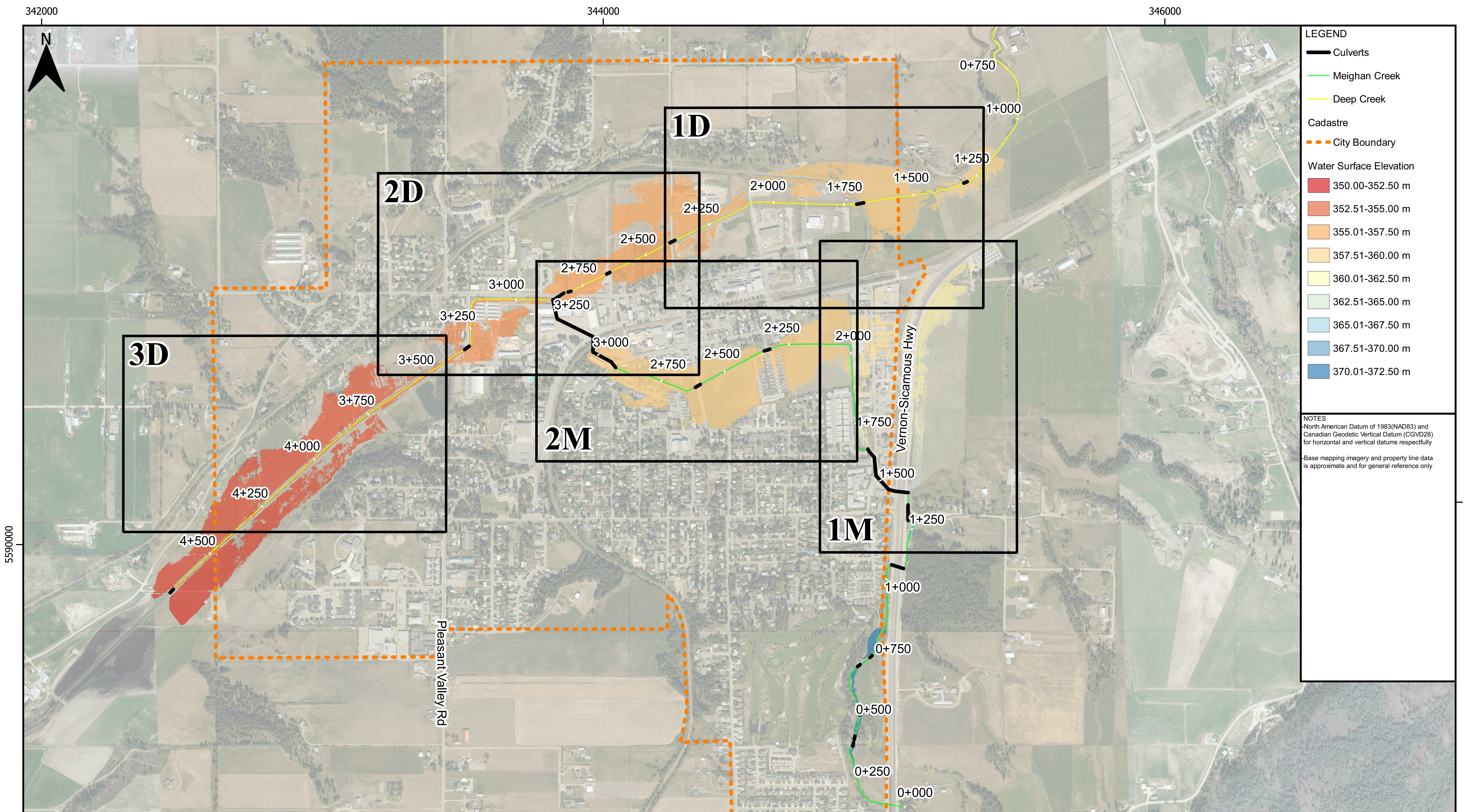
- < 0.75 Low Hazard
- 0.75-1.25 Hazard to Some
- 1.25-2.00 Hazard to Most
- > 2.00 Hazard to All

NOTES
-North American Datum of 1983(NAD83) and Canadian Geodetic Vertical Datum (CGVD28) for horizontal and vertical datums respectfully

-Base mapping imagery and property line data is approximate and for general reference only

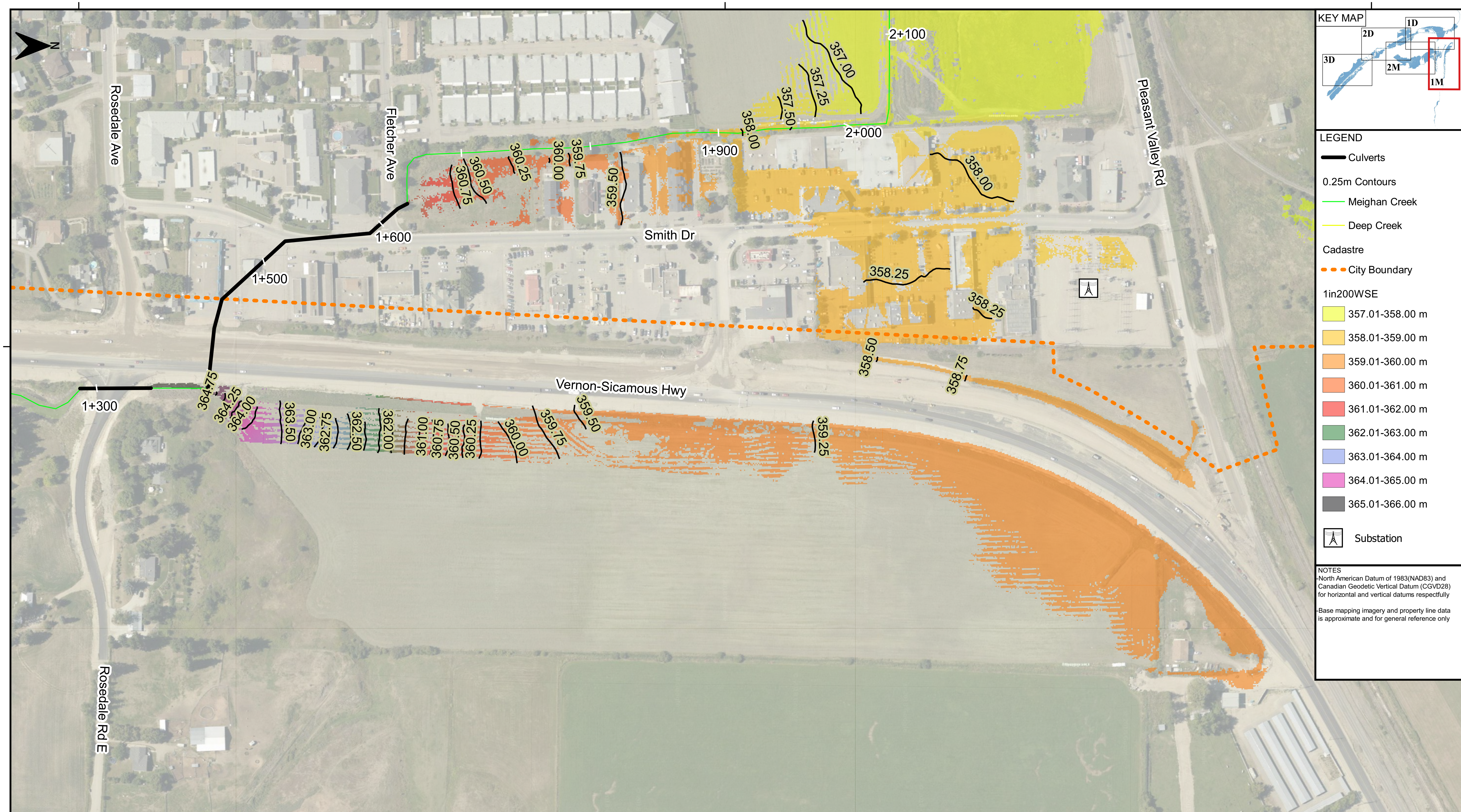
CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	DEEP CREEK HAZARD INDEX	3D
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		200 YEAR HAZARD MAPPING	
				GIS CRD / ENG ABH			
				0 25 50 75 100 METRES			
				SCALE 1:5000 NAD 1983 UTM 11N			

342500 343000 343500



CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	KEY MAP WATER SURFACE ELEVATION	N/A
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		200 YEAR INUNDATION MAPPING	
				GIS CRD / ENG ABH			
				0 100 200 300 400 METRES			
				SCALE 1:20000 NAD 1983 UTM 11N			

342000 344000 346000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS CRD ENG ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

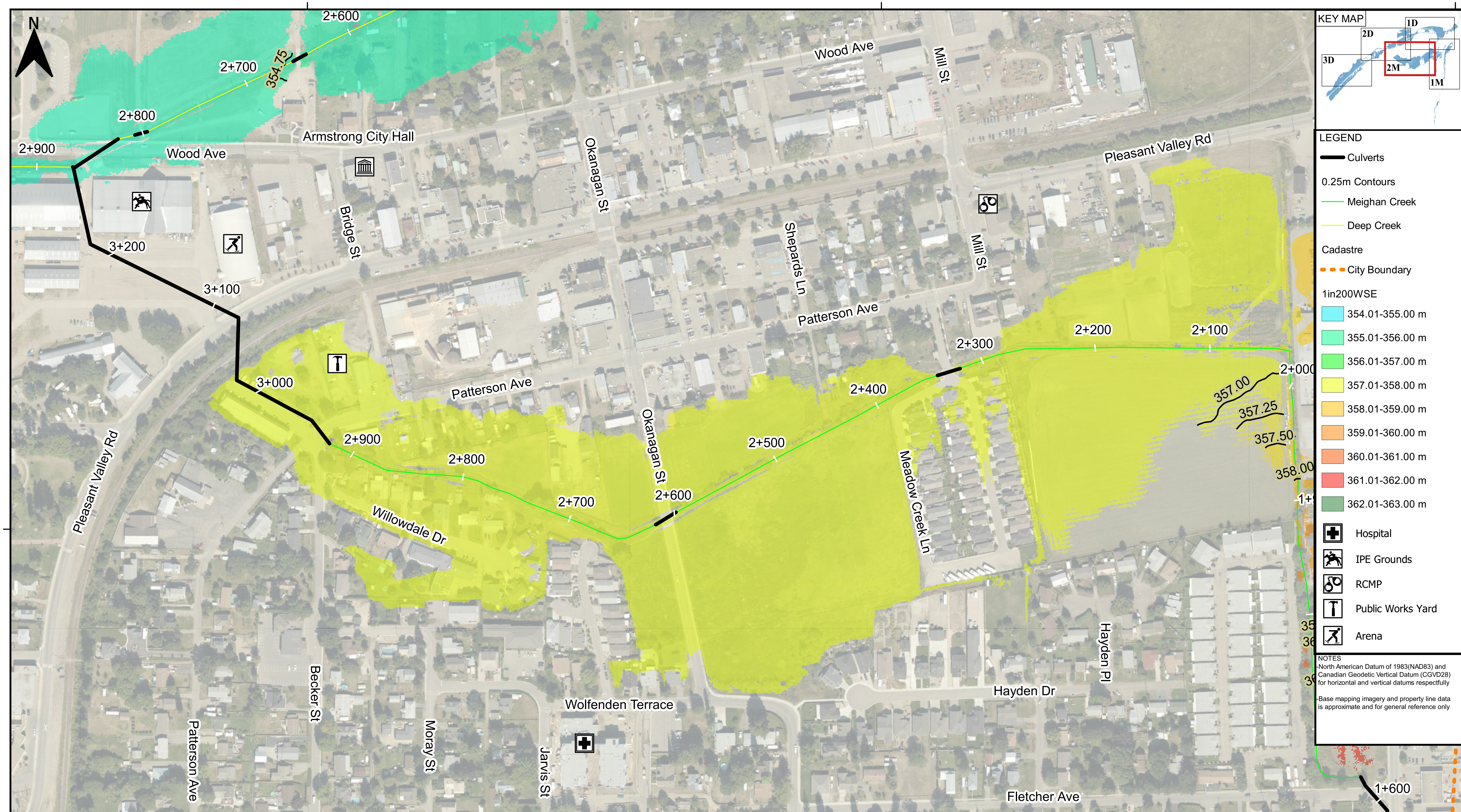
SEAL: SEE REPORT

TITLE

DEEP CREEK WATER SURFACE ELEVATION

200 YEAR INUNDATION MAPPING

MAP NO. 1M



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO. 0130.05
GIS: CRD ENG: ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

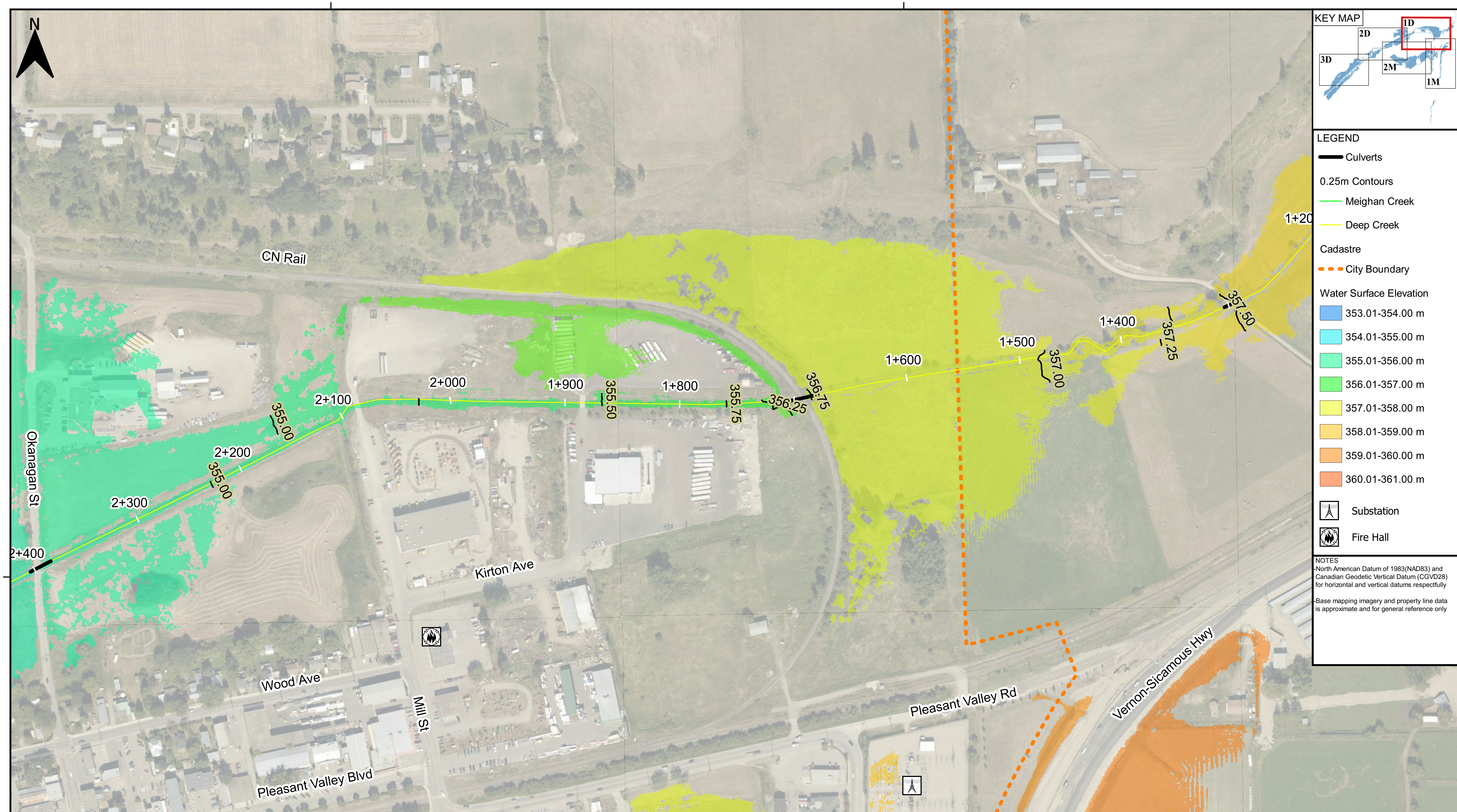
DEEP CREEK WATER SURFACE ELEVATION

200 YEAR INUNDATION MAPPING

MAP NO. 2M

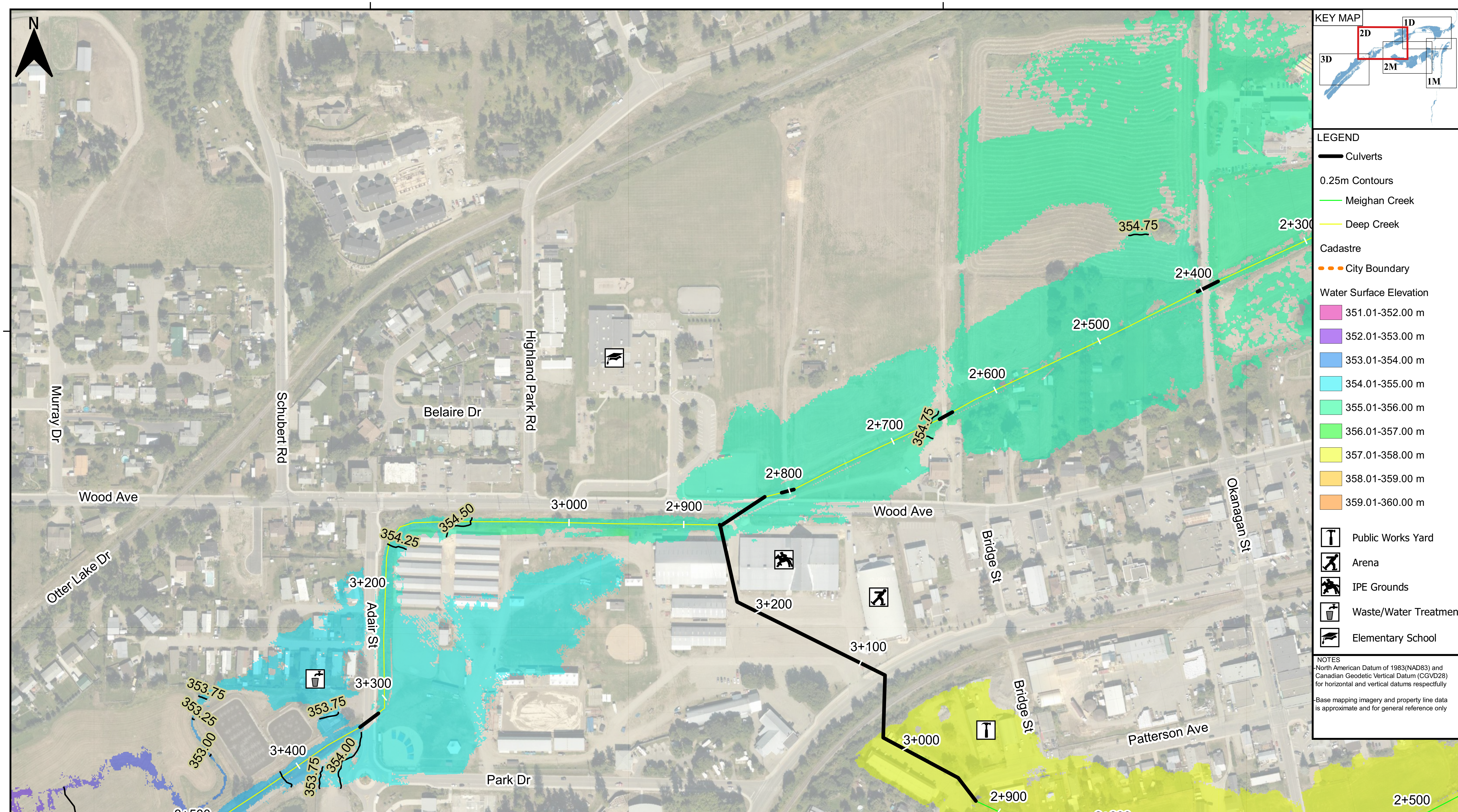
344000 344500

344500
345000



CONSULTANT	REV	NOTES	DATE Y/M/D	DATE	SEAL	TITLE	MAP NO.
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	JAN 21, 2019	SEE REPORT	DEEP CREEK WATER SURFACE ELEVATION	1D
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	PROJ.NO. 0130.05		200 YEAR INUNDATION MAPPING	
				GIS CRD / ENG ABH			
				0 25 50 75 100 METRES			
				SCALE 1:5000 NAD 1983 UTM 11N			

344500
345000



CONSULTANT	REV	NOTES	DATE Y/M/D
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD ENG: ABH
0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

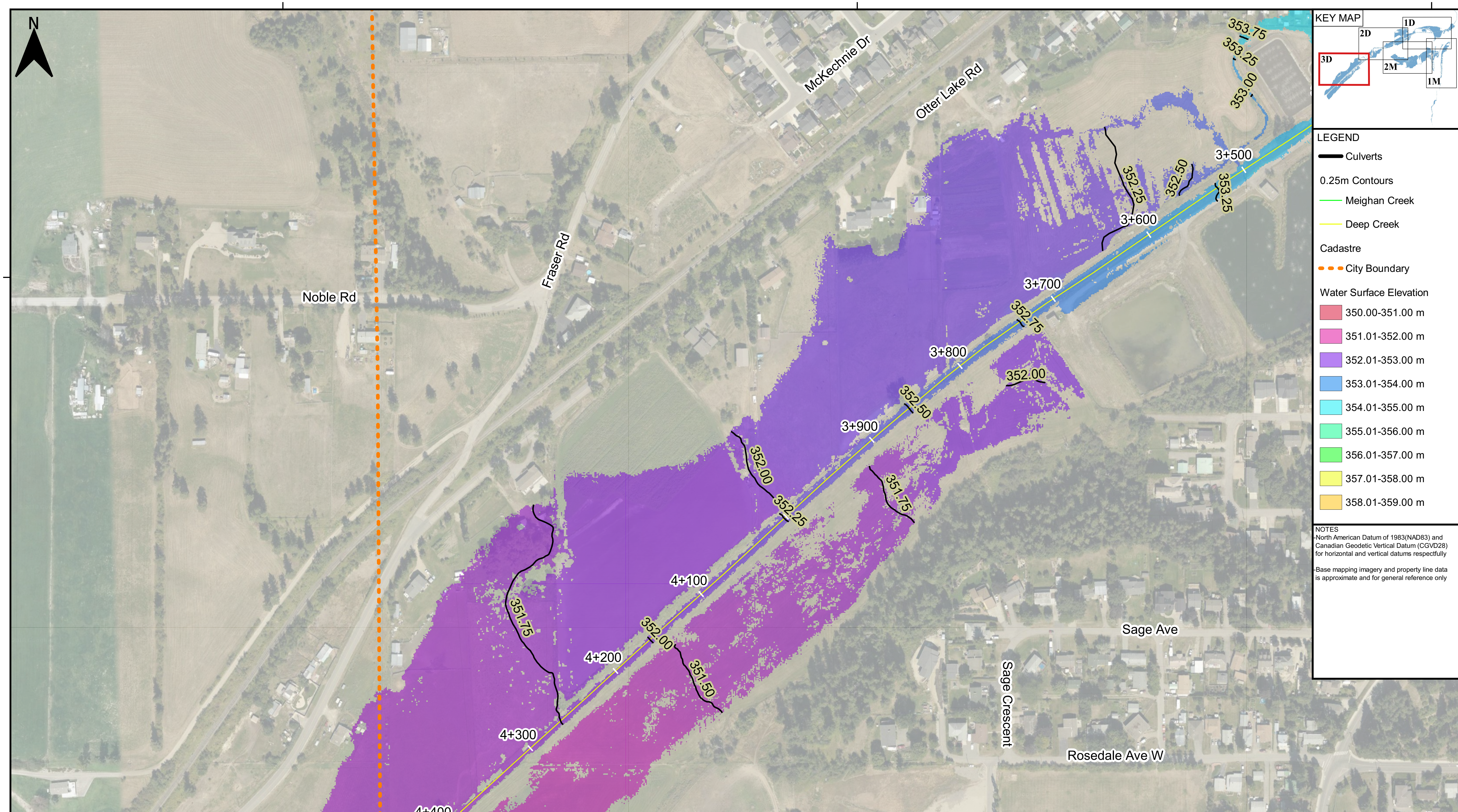
TITLE

DEEP CREEK WATER SURFACE ELEVATION

200 YEAR INUNDATION MAPPING

MAP NO. 2D

5590500
343500
344000



CONSULTANT	REV	NOTES	DATE Y/M/D	
Interior Dams	0	ISSUED FOR DRAFT	2018/12/15	
CLIENT: City of Armstrong	1	ISSUED FOR USE	2019/01/21	

DATE: JAN 21, 2019
PROJ.NO.: 0130.05
GIS: CRD
ENG: ABH

0 25 50 75 100 METRES
SCALE 1:5000 NAD 1983 UTM 11N

SEAL: SEE REPORT

TITLE

DEEP CREEK WATER SURFACE ELEVATION

200 YEAR INUNDATION MAPPING

MAP NO. 3D

342500 343000 343500
5590000

APPENDIX III: FLOOD MAPPING ASSURANCE STATEMENT

This page intentionally left blank

To: The Client

Date: January 21, 2019

Doug MacKay - Public Works Manager

Name (print)

City of Armstrong

3570 Bridge Street, Armstrong, BC, V0E 1B0

Address (print)

Flood Mapping Project:

City of Armstrong - Flood Mapping and Risk Assessment Report

The undersigned hereby gives assurance that he/she is an APEGBC registered professional and the Qualified Professional for the project identified above.

I have signed, sealed and dated the attached report in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*. The report supports and accurately reflects the assurances made in this Assurance Statement.

I have completed the following activities:

(Check the applicable items)

Activity	
X	Reviewed the relevant provincial legislation and local government regulations, policies, and floodplain bylaws
X	Reviewed available and relevant background information, documentation and data
X	Visited the site and reviewed the conditions in the field that may be relevant
X	Considered the need for, and scale of, investigations that address future land use changes and climate change
X	Developed and executed the flood mapping in accordance with the criteria established by the client
X	Addressed any significant comments arising from internal or peer reviews
X	Prepared a flood mapping report along with the accompanying digital information

I hereby give assurance that the attached flood mapping report and supporting digital documentation have been produced in accordance with the *APEGBC Professional Practice Guidelines – Flood Mapping in BC*.

Aaron Hahn, P. Eng.
Name (print)

January 21, 2019
Date

Signature

13890 Forest Hills Drive, Lake Country, BC, V4V 1A5
Address (print)

(778) 480-6063
Telephone

ahahn@interiordams.com
(email)

(Affix Professional Seal here)

PROFESSIONAL PROVINCE OF A. B. N. HAHN # 40045 BRITISH COLUMBIA ENGINEER

2019-01-21

If the APEGBC Qualified Professional is a member of a firm, complete the following:

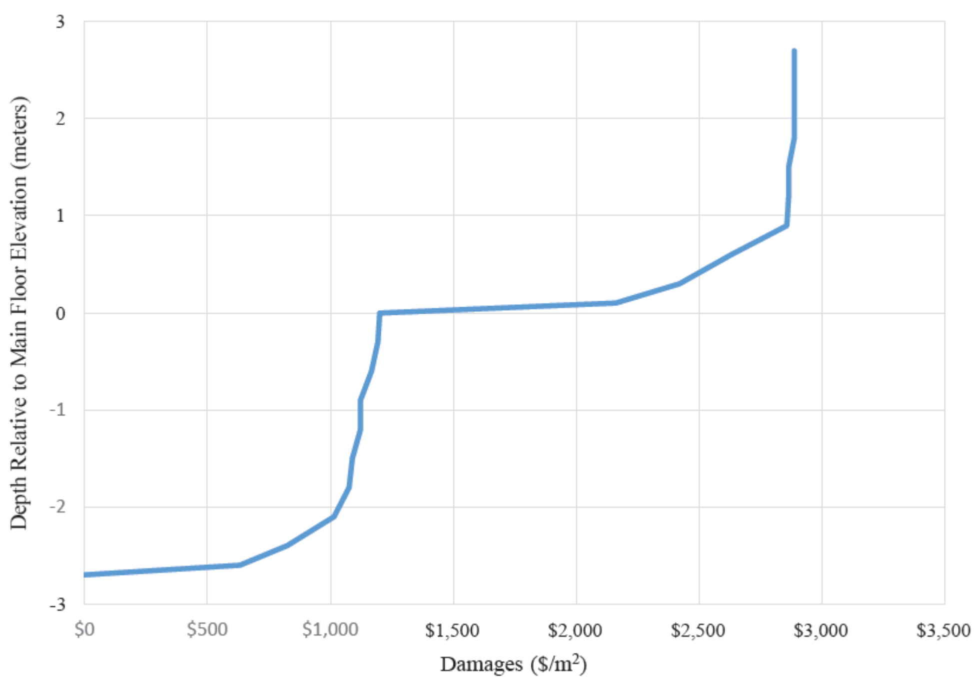
I am a member of the firm Interior Dams Incorporated (Print name of firm), and I sign this letter on behalf of the firm.

APPENDIX IV: SUPPORTING RISK ASSESSMENT DATA

This page intentionally left blank

Residential Damage Function for Class A One-Storey (NRC, 2017):

Class A - Residential One-Storey					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$400	$231	$632
-2.4	$0	$0	$554	$271	$825
-2.1	$0	$0	$715	$299	$1,015
-1.8	$0	$0	$778	$299	$1,077
-1.5	$0	$0	$784	$305	$1,090
-1.2	$0	$0	$786	$335	$1,122
-0.9	$0	$0	$788	$335	$1,123
-0.6	$0	$0	$810	$356	$1,167
-0.3	$0	$0	$836	$357	$1,193
0	$0	$0	$836	$365	$1,201
0.1	$373	$588	$836	$365	$2,162
0.3	$624	$594	$836	$365	$2,420
0.6	$758	$674	$836	$365	$2,633
0.9	$809	$848	$836	$365	$2,858
1.2	$816	$848	$836	$365	$2,865
1.5	$816	$848	$836	$365	$2,865
1.8	$839	$848	$836	$365	$2,888
2.1	$839	$848	$836	$365	$2,888
2.4	$839	$848	$836	$365	$2,888
2.7	$839	$848	$836	$365	$2,888

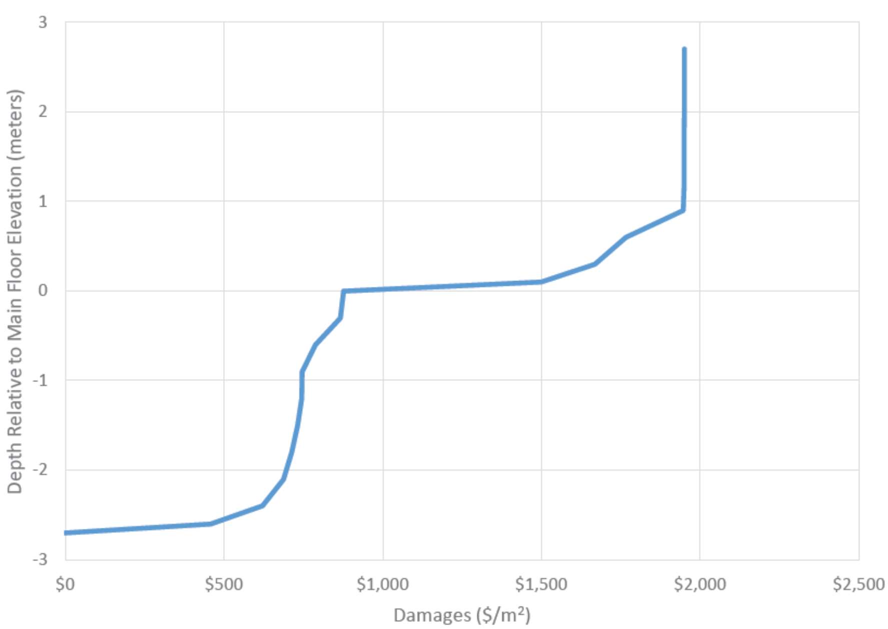


Residential Damage Function for Class A Two-Storey (NRC, 2017):

Class A -Residential Two-Storey					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$226	$241	$467
-2.4	$0	$0	$354	$354	$708
-2.1	$0	$0	$395	$406	$802
-1.8	$0	$0	$437	$406	$843
-1.5	$0	$0	$440	$429	$869
-1.2	$0	$0	$442	$466	$908
-0.9	$0	$0	$444	$466	$910
-0.6	$0	$0	$475	$506	$980
-0.3	$0	$0	$523	$507	$1,030
0	$0	$0	$523	$522	$1,045
0.1	$343	$665	$523	$522	$2,053
0.3	$545	$676	$523	$522	$2,266
0.6	$663	$826	$523	$522	$2,534
0.9	$748	$1,051	$523	$522	$2,845
1.2	$766	$1,051	$523	$522	$2,862
1.5	$767	$1,051	$523	$522	$2,863
1.8	$767	$1,051	$523	$522	$2,863
2.1	$767	$1,051	$523	$522	$2,863
2.4	$767	$1,051	$523	$522	$2,863
2.7	$767	$1,051	$523	$522	$2,863

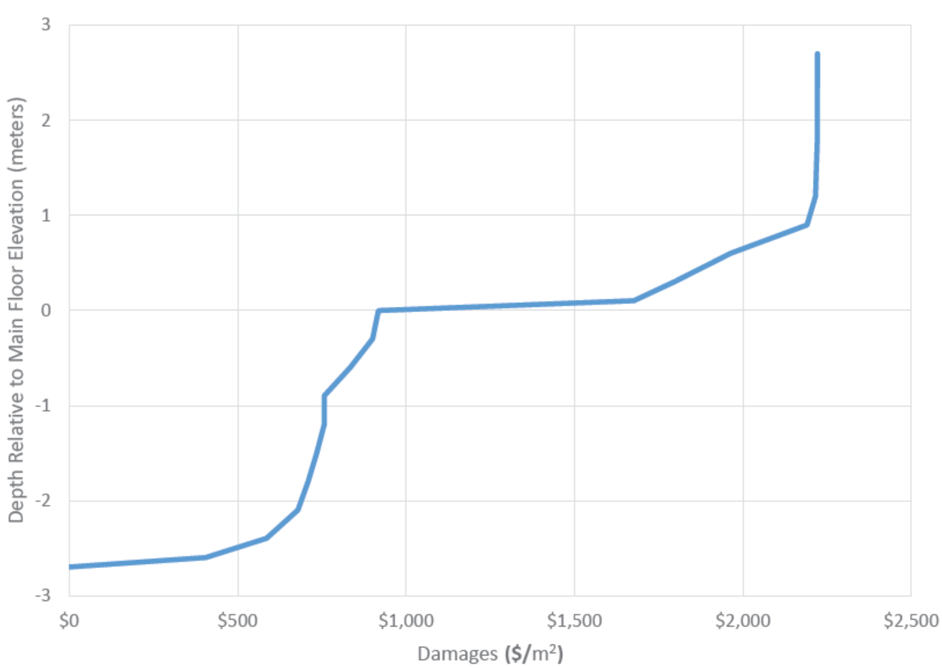
Residential Damage Function for Class B One-Storey (NRC, 2017):

Class B - Residential One-Storey					
Depth relative to main floor[1]	Main Floor Contents	Main Floor Structure	Basement Contents[2]	Basement Structure[2]	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$226	$232	$458
-2.4	$0	$0	$339	$282	$621
-2.1	$0	$0	$375	$312	$687
-1.8	$0	$0	$401	$312	$713
-1.5	$0	$0	$410	$322	$732
-1.2	$0	$0	$411	$334	$745
-0.9	$0	$0	$412	$334	$746
-0.6	$0	$0	$426	$362	$788
-0.3	$0	$0	$504	$363	$867
0	$0	$0	$504	$374	$877
0.1	$221	$400	$504	$374	$1,498
0.3	$384	$407	$504	$374	$1,668
0.6	$431	$457	$504	$374	$1,765
0.9	$492	$578	$504	$374	$1,947
1.2	$494	$578	$504	$374	$1,949
1.5	$494	$578	$504	$374	$1,949
1.8	$495	$578	$504	$374	$1,950
2.1	$495	$578	$504	$374	$1,950
2.4	$495	$578	$504	$374	$1,950
2.7	$495	$578	$504	$374	$1,950



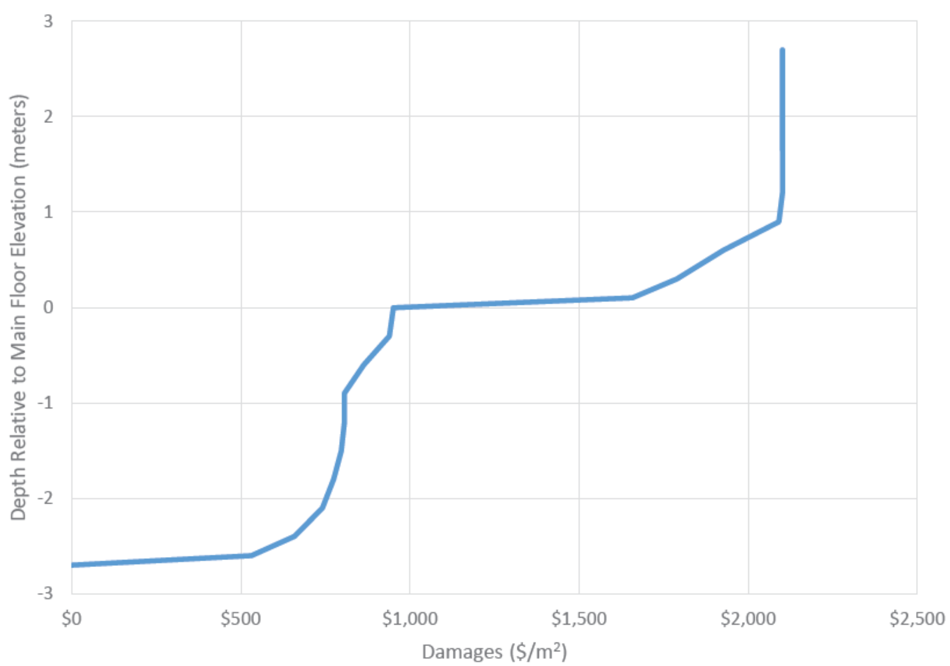
Residential Damage Function for Class B Two-Storey (NRC, 2017):

Class B - Residential Two-Storey					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$163	$242	$405
-2.4	$0	$0	$255	$331	$586
-2.1	$0	$0	$294	$385	$678
-1.8	$0	$0	$324	$385	$709
-1.5	$0	$0	$332	$402	$735
-1.2	$0	$0	$336	$420	$756
-0.9	$0	$0	$336	$420	$756
-0.6	$0	$0	$364	$470	$833
-0.3	$0	$0	$427	$473	$900
0	$0	$0	$427	$490	$917
0.1	$235	$524	$427	$490	$1,676
0.3	$342	$536	$427	$490	$1,795
0.6	$422	$625	$427	$490	$1,964
0.9	$481	$792	$427	$490	$2,190
1.2	$507	$792	$427	$490	$2,216
1.5	$508	$792	$427	$490	$2,217
1.8	$511	$792	$427	$490	$2,220
2.1	$511	$792	$427	$490	$2,220
2.4	$512	$792	$427	$490	$2,221
2.7	$512	$792	$427	$490	$2,221



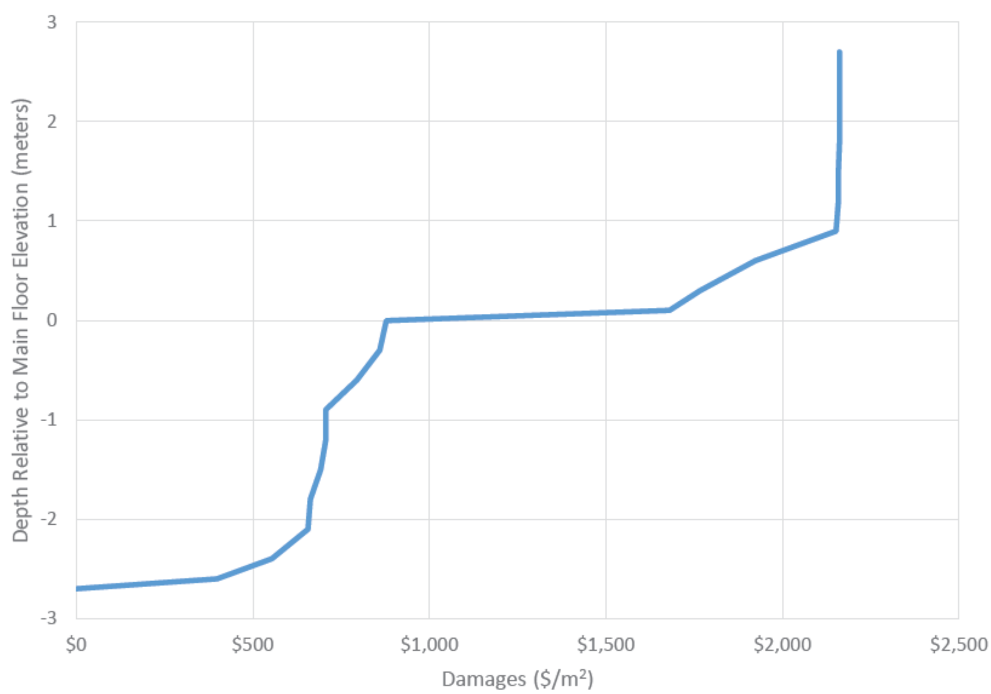
Residential Damage Function for Class C One-Storey (NRC, 2017):

Class C - Residential One-Storey					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$294	$237	$530
-2.4	$0	$0	$350	$309	$659
-2.1	$0	$0	$385	$356	$741
-1.8	$0	$0	$418	$356	$774
-1.5	$0	$0	$422	$374	$796
-1.2	$0	$0	$422	$383	$806
-0.9	$0	$0	$423	$383	$806
-0.6	$0	$0	$439	$424	$863
-0.3	$0	$0	$511	$427	$938
0	$0	$0	$511	$439	$950
0.1	$240	$467	$511	$439	$1,657
0.3	$360	$479	$511	$439	$1,789
0.6	$420	$557	$511	$439	$1,927
0.9	$468	$672	$511	$439	$2,090
1.2	$479	$672	$511	$439	$2,100
1.5	$479	$672	$511	$439	$2,101
1.8	$479	$672	$511	$439	$2,101
2.1	$479	$672	$511	$439	$2,101
2.4	$479	$672	$511	$439	$2,101
2.7	$479	$672	$511	$439	$2,101



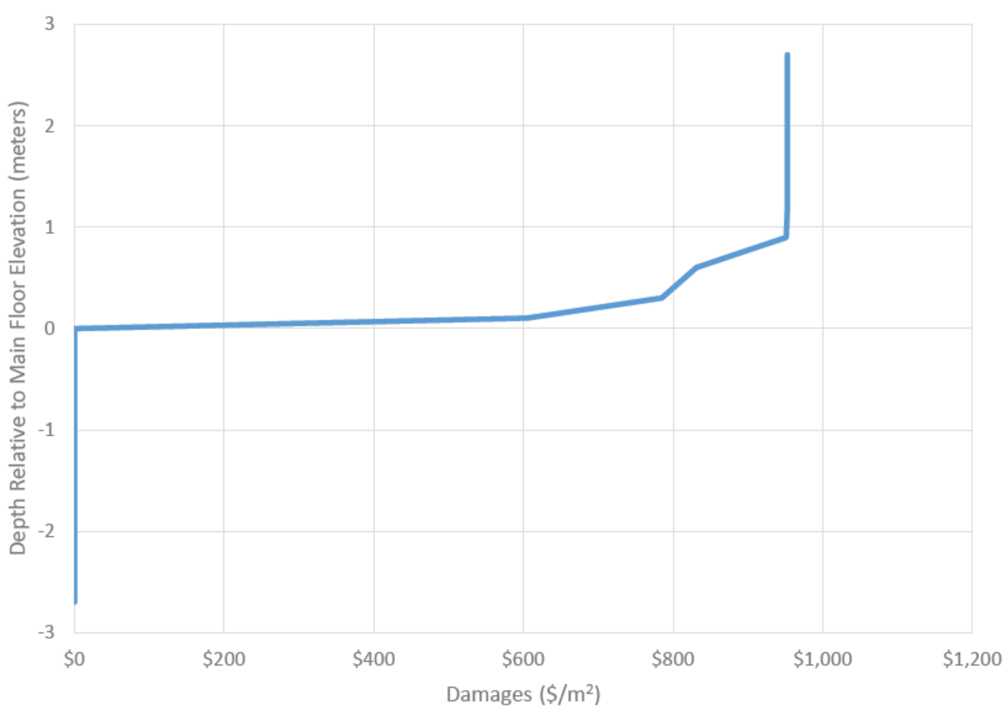
Residential Damage Function for Class C Two-Storey (NRC, 2017):

Class C - Residential Two-Storey					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$191	$207	$398
-2.4	$0	$0	$232	$322	$554
-2.1	$0	$0	$257	$399	$656
-1.8	$0	$0	$264	$399	$663
-1.5	$0	$0	$264	$428	$692
-1.2	$0	$0	$264	$442	$706
-0.9	$0	$0	$264	$442	$706
-0.6	$0	$0	$287	$508	$794
-0.3	$0	$0	$346	$512	$858
0	$0	$0	$346	$532	$878
0.1	$204	$599	$346	$532	$1,681
0.3	$271	$619	$346	$532	$1,767
0.6	$301	$744	$346	$532	$1,923
0.9	$376	$897	$346	$532	$2,152
1.2	$383	$897	$346	$532	$2,158
1.5	$384	$897	$346	$532	$2,159
1.8	$386	$897	$346	$532	$2,161
2.1	$386	$897	$346	$532	$2,161
2.4	$386	$897	$346	$532	$2,161
2.7	$386	$897	$346	$532	$2,161



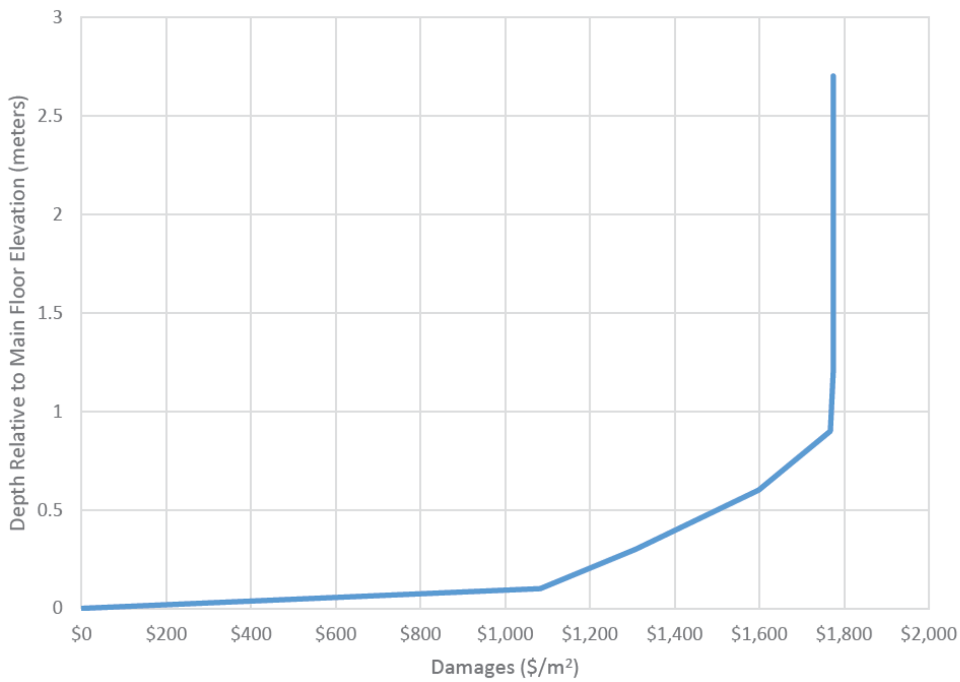
Residential Damage Function for One-Storey Mobile Homes (NRC, 2017):

One Storey Mobile Home (No Basement)					
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Basement Contents	Basement Structure	Total
-2.7	$0	$0	$0	$0	$0
-2.6	$0	$0	$0	$0	$0
-2.4	$0	$0	$0	$0	$0
-2.1	$0	$0	$0	$0	$0
-1.8	$0	$0	$0	$0	$0
-1.5	$0	$0	$0	$0	$0
-1.2	$0	$0	$0	$0	$0
-0.9	$0	$0	$0	$0	$0
-0.6	$0	$0	$0	$0	$0
-0.3	$0	$0	$0	$0	$0
0	$0	$0	$0	$0	$0
0.1	$243	$362	$0	$0	$605
0.3	$379	$405	$0	$0	$785
0.6	$426	$405	$0	$0	$831
0.9	$481	$470	$0	$0	$951
1.2	$483	$470	$0	$0	$953
1.5	$483	$470	$0	$0	$953
1.8	$483	$470	$0	$0	$953
2.1	$483	$470	$0	$0	$953
2.4	$483	$470	$0	$0	$953
2.7	$483	$470	$0	$0	$953



Residential Damage Function for One-Storey Mobile Homes (NRC, 2017):

Apartment Building with Four Floors or Less			
Depth relative to main floor	Main Floor Contents	Main Floor Structure	Total
0	$0	$0	$0
0.1	$260	$822	$1,082
0.3	$394	$914	$1,307
0.6	$494	$1,105	$1,599
0.9	$565	$1,203	$1,768
1.2	$571	$1,203	$1,774
1.5	$571	$1,203	$1,774
1.8	$571	$1,203	$1,774
2.1	$571	$1,203	$1,774
2.4	$571	$1,203	$1,774
2.7	$571	$1,203	$1,774



Calculation table for Figure 3-9, Figure 3-10, and Figure 3-11 (Example Only):

Flood Hazard Severity (Return Period)	Probability of Occurrence	Impact of Hazard ($*1000)	Impact of Hazard ($ Millions)	Risk ($*1000))	Cumulative Risk ($*1000))
1	1.0000	0.00	0.00	0.0	0
5	0.2000	0.00	0.00	0.0	0
10	0.1000	0.00	0.00	0.0	0
20	0.0500	0.00	0.00	0.0	0
30	0.0333	1180	1.18	39.3	39
40	0.0250	2361	2.36	59.0	98
50	0.0200	3541	3.54	70.8	169
60	0.0167	4722	4.72	78.7	248
70	0.0143	5902	5.90	84.3	332
80	0.0125	7083	7.08	88.5	421
90	0.0111	8263	8.26	91.8	513
100	0.0100	9444	9.44	94.4	607
110	0.0091	10624	10.62	96.6	704
120	0.0083	11804	11.80	98.4	802
130	0.0077	12985	12.98	99.9	902
140	0.0071	14165	14.17	101.2	1003
150	0.0067	15346	15.35	102.3	1105
160	0.0063	16526	16.53	103.3	1209
170	0.0059	17707	17.71	104.2	1313
180	0.0056	18887	18.89	104.9	1418
190	0.0053	20068	20.07	105.6	1523
200	0.0050	21248	21.25	106.2	1630

This page intentionally left blank

APPENDIX V: REGULATIONS

This page intentionally left blank

Excerpt from Section 39 of the WSA Water Sustainability Regulation (Province of BC, 2018):

NOTE: Sections that do not apply have been removed.

Authorized changes

39 (1)The following changes in and about a stream are authorized changes:

(a) the installation, maintenance or removal of a culvert for crossing a stream for the purposes of a road, trail or footpath, if all the following conditions are met:

(i) the equipment used for site preparation, or for installation, construction, maintenance or removal of the culvert, is situated in a dry stream channel or operated from the top of the bank;

(ii) if the stream is fish-bearing, the culvert allows fish in the stream to pass up or down stream under all flow conditions;

(iii) the culvert inlet and outlet incorporate measures to protect the structure and the stream channel against erosion;

(iv) debris can pass through the culvert;

(v) the installation, maintenance or removal of the culvert does not destabilize the stream channel;

(vi) the culvert and its approach roads do not produce a backwater effect or increase the head of the stream;

(vii) the culvert capacity is equivalent to the hydraulic capacity of the stream channel or is capable of passing the 1 in 200 year maximum daily flow without the water level at the culvert inlet exceeding the top of the culvert;

(viii) the culvert has a minimum equivalent diameter of 600 mm;

(ix) if the culvert has an equivalent diameter of 2 m or greater, or has a design capacity to pass a flow of more than 6 m^3 per second, the culvert is designed by an engineering professional and constructed in conformance with that design;

(x) the culvert is installed in a manner that permits the removal of obstacles and debris within the culvert and at the culvert ends;

(xi) if the changes in and about the stream are related to a right of way, the stream channel, except the portion within the right of way, is not altered;

(xii) embankment fill materials do not, and are unlikely to, encroach on culvert inlets and outlets;

(xiii) the culvert has a depth of fill cover that is at least 300 mm or as required by the culvert manufacturer's specifications;

(xiv) the maximum fill heights above the top of the culvert do not exceed 2 m;

(xv) the culvert is made of materials that meet the applicable standards of the Canadian Standards Association;

(e) the construction, maintenance or removal by the Crown in right of either Canada or British Columbia of a flow or water level measuring device in a stream;

(h)the restoration or maintenance of a stream channel by a municipality or regional district;

(i) the mechanical or manual cutting of annual vegetation within a stream channel;

(j) the restoration or maintenance of fish habitat by the Crown in right of either Canada or British Columbia;

(k) the repair or maintenance of existing dikes or existing erosion protection works to their original state, if the dikes or works were functional during the previous year;

(o) the construction or placement, under the direction of the Crown in right of British Columbia, a municipality or a regional district, or an agent of any of them,

of erosion protection works or flood protection works during an emergency declared under the *Emergency Program Act* that involves flooding;
(p)the clearing of an obstruction from a bridge or culvert by the Crown in right of British Columbia, a municipality or a regional district during a flood, if the obstruction is causing or has the potential to cause a significant risk of harm to public safety, the environment, land or other property;
(q) the installation or cleaning of drainage outlets;
(u) the removal of a beaver dam under section 9 of the *Wildlife Act*, if the removal is carried out in such a manner that downstream flooding and erosion do not occur;
(v)the construction of a temporary ford for vehicular traffic across a stream, if

(i) the construction occurs at a time in the year during which the construction can occur without causing a risk of significant harm to fish, wildlife or the aquatic ecosystem of the stream,
(ii) the 1 in 10 year maximum daily flow over the ford is accommodated without the loss of the ford and without eroding the stream channel,
(iii) any culvert is designed and installed to pass the average low flow for the period of use,
(iv) the stream channel is protected against any anticipated erosion

(A)for the period of construction and use of the ford, and
(B)after the ford is removed,

(v) sediment from approach ditches does not enter the stream,
(vi) the driveable running surface is erosion-free,
(vii) the stream remains in its channel,
(viii) channel debris will pass over the ford, and
(ix) the ford is removed at the end of the period of use at a time when the removal can proceed without causing a risk of significant harm to fish, wildlife or the aquatic ecosystem of the stream;

(w) the construction of a temporary diversion around or through a worksite for the purposes of constructing or maintaining bridge abutments, constructing or maintaining piers other than bridge piers, maintaining bridge piers or constructing works authorized under this section, if

(i) the size of the worksite is minimized,
(ii) any pumps, pipes or conduits used to divert water around or through the worksite are sized to divert the 1 in 10 year maximum daily flow for the period of construction,
(iii) any pump or intake withdrawing water from a fish-bearing stream is screened to prevent potential loss of fish due to entrainment or impingement,
(iv) any cofferdams used to isolate successive parts of the construction occurring at the worksite are designed by an engineering professional and constructed in accordance with that design,
(v) the natural channel remaining outside of any cofferdams is adequate to pass the 1 in 10 year maximum daily flow for the period of construction,
(vi) the flow of water diverted around the worksite using ditches remains within the stream channel,
(vii) any ditches used to divert the flow of water around the worksite are designed and constructed to divert the 1 in 10 year maximum daily flow around or through the worksite and are protected from any anticipated erosion for the period of construction and use of the ditch, and
(viii) any ditches are completely backfilled and the area returned as closely as possible to the state that existed before the changes in and about the stream were made;

Excerpt from Section 524 of the Local Government Act (Province of British Columbia, 2015):

Requirements in relation to flood plain areas

524 (1) In this section:

"environment minister" means the minister charged with the administration of the *Environmental Management Act*;

"Provincial guidelines" means the policies, strategies, objectives, standards, guidelines and environmental management plans, in relation to flood control, flood hazard management and development of land that is subject to flooding, prepared and published by the environment minister under section 5 of the *Environmental Management Act*;

"Provincial regulations" means, in relation to a local government, any applicable regulations enacted under section 138 (3) (e) *[general authority to make regulations — flood hazard management]* of the *Environmental Management Act*.

(2) If a local government considers that flooding may occur on land, the local government may, by bylaw, designate the land as a flood plain.

(3) If land is designated as a flood plain under subsection (2), the local government may, by bylaw, specify

(a) the flood level for the flood plain, and

(b) the setback from a watercourse, body of water or dike of any landfill or structural support required to elevate a floor system or pad above the flood level.

(4) In making bylaws under this section, a local government must

(a) consider the Provincial guidelines, and

(b) comply with the Provincial regulations and a plan or program the local government has developed under those regulations.

(5) A bylaw under subsection (3) may make different provisions for one or more of the following:

(a) different areas of a flood plain;

(b) different zones;

(c) different uses within a zone or an area of a flood plain;

(d) different types of geological or hydrological features;

(e) different standards of works and services;

(f) different siting circumstances;

(g) different types of buildings or other structures and different types of machinery, equipment or goods within them;

(h) different uses within a building or other structure.

(6) If a bylaw under subsection (3) applies,

(a) the underside of any floor system, or the top of any pad supporting any space or room, including a manufactured home, that is used for

(i) dwelling purposes,

(ii) business, or

(iii) the storage of goods that are susceptible to damage by floodwater

must be above the applicable flood level specified by the bylaw, and

(b) any landfill required to support a floor system or pad must not extend within any applicable setback specified by the bylaw.

(7) Subject to the Provincial regulations and a plan or program a local government has developed under those regulations, the local government may exempt a person from the application of subsection (6), or a bylaw under subsection (3), in relation to a specific parcel of land or a use, building or other structure on the parcel of land, if the local government considers it advisable and either

(a) considers that the exemption is consistent with the Provincial guidelines, or

(b) has received a report that the land may be used safely for the use intended, which report is certified by a person who is

(i) a professional engineer or geoscientist and experienced in geotechnical engineering, or

(ii) a person in a class prescribed by the environment minister under subsection (9).

(8) The granting of an exemption, and the exemption, under subsection (7) may be made subject to the terms and conditions the local government considers necessary or advisable, including, without limitation,

(a) imposing any term or condition contemplated by the Provincial guidelines in relation to an exemption,

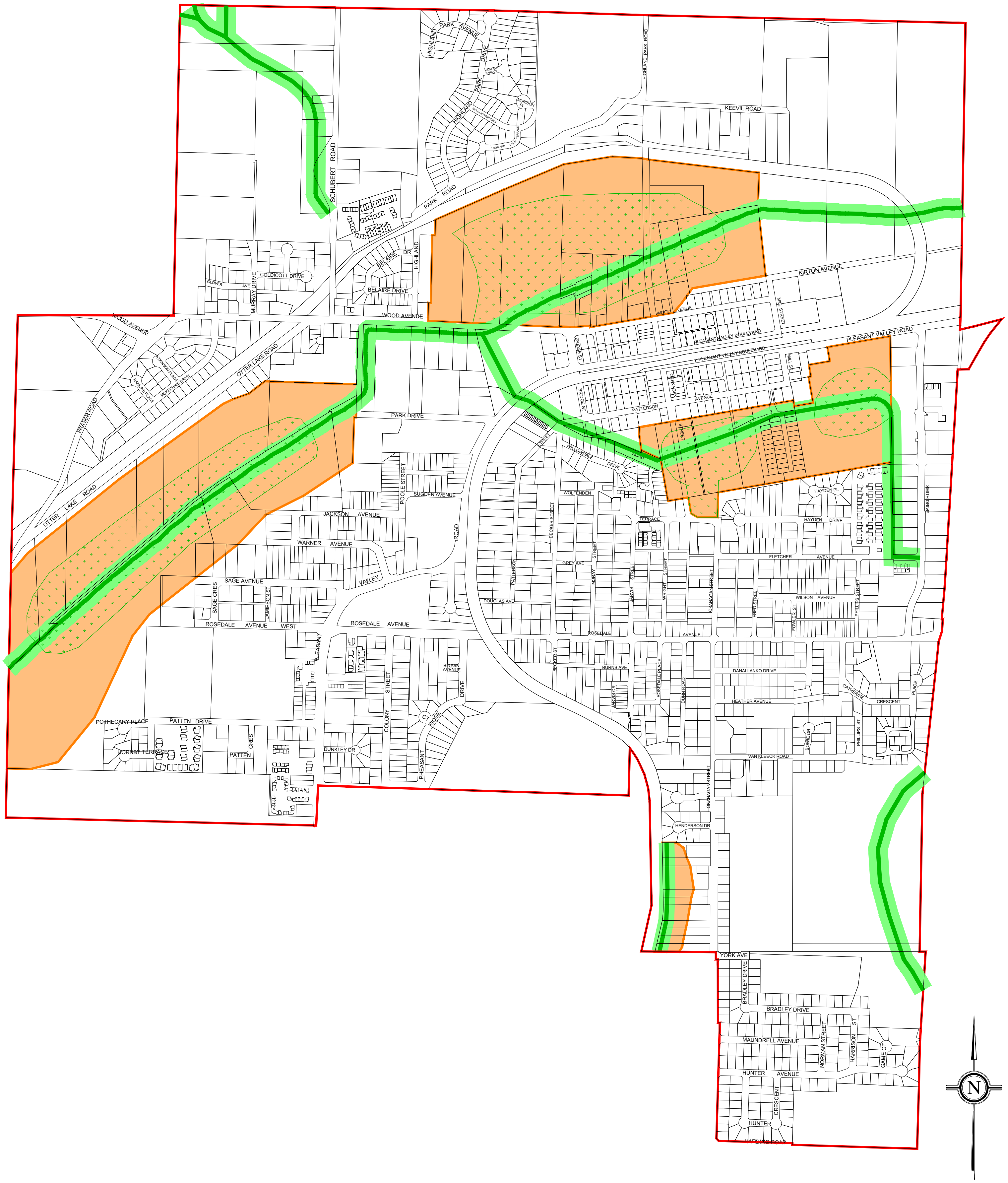
(b) requiring that a person submit a report described in subsection (7) (b), and

(c) requiring that a person enter into a covenant under section 219 of the *Land Title Act*.

(9) The environment minister may make regulations prescribing a class of persons the minister considers qualified, for the purposes of this section, to certify reports referred to in subsection (7) (b).

APPENDIX VI: CITY OF ARMSTRONG REFERENCE FILES

This page intentionally left blank



City of Armstrong

City of Armstrong

OFFICIAL COMMUNITY PLAN

9.4 Development Permit Areas

Natural Environment

Hazardous Condition

Commercial, Industrial/Business or Multi-Family and Infill Residential Form and Character

Draft Date: June 2014

100m 200m 300m 400m 500m

Digital Map Created By:

CGIS Spatial Solutions
52 South St
Perth, ON K7H 2G7
TEL: 613-368-4321
www.cgis.com

Note: The base information on this plan was prepared from a variety of map sources and was used by permission of the City of Armstrong. It is not a legal plan of survey. For precise location of plan features recourse should be had to the original source data.

STORM

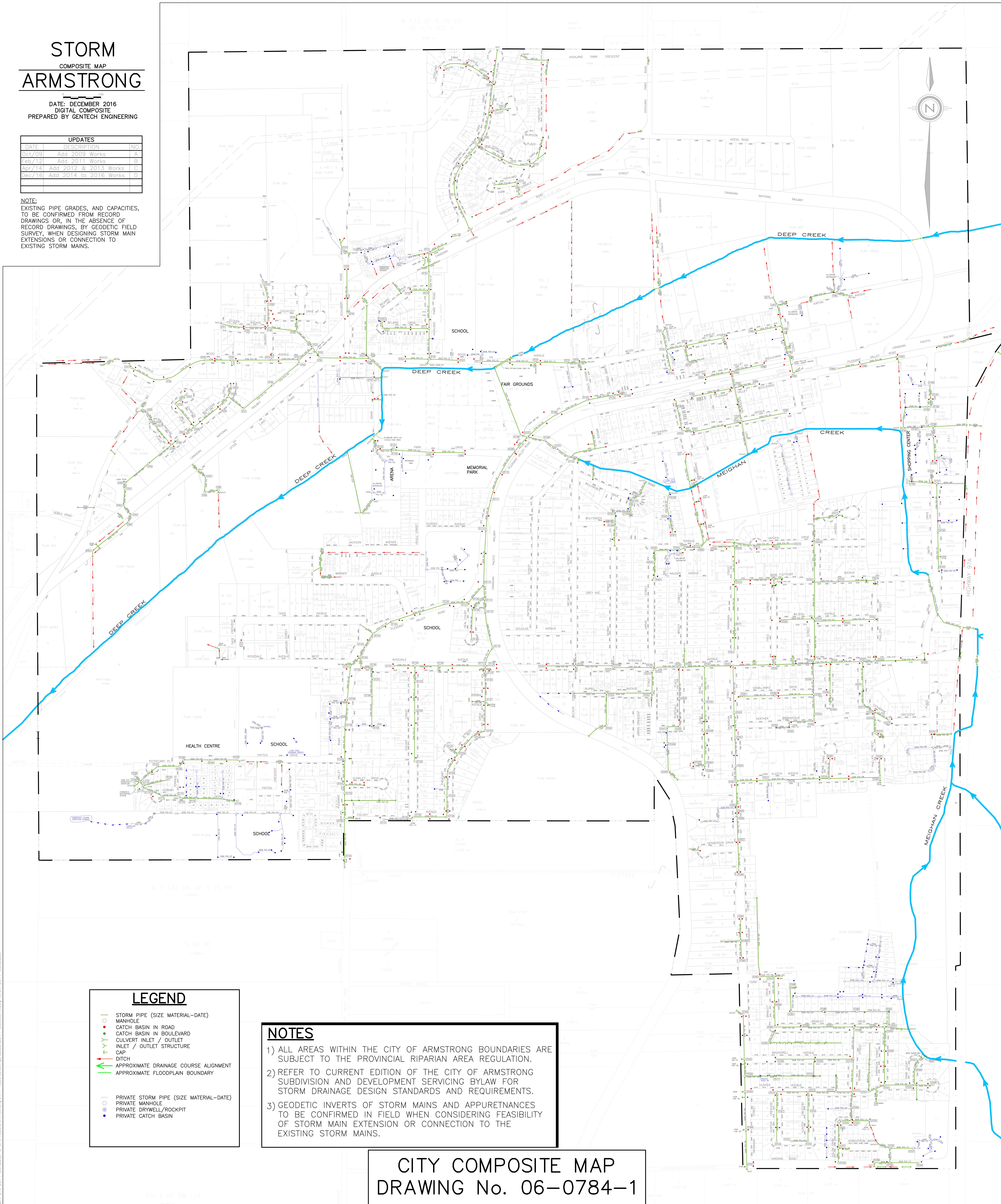
COMPOSITE MAP

ARMSTRONG

DATE: DECEMBER 2016
DIGITAL COMPOSITE
PREPARED BY GENTECH ENGINEERING

UPDATES		
DATE	DESCRIPTION	NO.
Oct/09	Add 2009 Works	A
Feb/12	Add 2011 Works	B
Apr/14	Add 2012 & 2013 Works	C
Dec/16	Add 2014 to 2016 Works	D

NOTE:
EXISTING PIPE GRADES, AND CAPACITIES, TO BE CONFIRMED FROM RECORD DRAWINGS OR, IN THE ABSENCE OF RECORD DRAWINGS, BY GEODETIC FIELD SURVEY, WHEN DESIGNING STORM MAIN EXTENSIONS OR CONNECTION TO EXISTING STORM MAINS.



LEGEND

- STORM PIPE (SIZE MATERIAL-DATE)
- MANHOLE
- CATCH BASIN IN ROAD
- CATCH BASIN IN BOULEVARD
- CULVERT INLET / OUTLET
- INLET / OUTLET STRUCTURE
- CAP
- DITCH
- APPROXIMATE DRAINAGE COURSE ALIGNMENT
- APPROXIMATE FLOODPLAIN BOUNDARY
- PRIVATE STORM PIPE (SIZE MATERIAL-DATE)
- PRIVATE MANHOLE
- PRIVATE DRYWELL/ROCKPIT
- PRIVATE CATCH BASIN

NOTES

1) ALL AREAS WITHIN THE CITY OF ARMSTRONG BOUNDARIES ARE SUBJECT TO THE PROVINCIAL RIPARIAN AREA REGULATION.

2) REFER TO CURRENT EDITION OF THE CITY OF ARMSTRONG SUBDIVISION AND DEVELOPMENT SERVICING BYLAW FOR STORM DRAINAGE DESIGN STANDARDS AND REQUIREMENTS.

3) GEODETIC INVERTS OF STORM MAINS AND APPURETNANCES TO BE CONFIRMED IN FIELD WHEN CONSIDERING FEASIBILITY OF STORM MAIN EXTENSION OR CONNECTION TO THE EXISTING STORM MAINS.

CITY COMPOSITE MAP
DRAWING No. 06–0784–1

WATER MANAGEMENT BRANCH

MINISTRY OF ENVIRONMENT

THE PROVINCE OF BRITISH COLUMBIA—WATER ACT

CONDITIONAL WATER LICENCE

City of Armstrong of Box 40 Armstrong, British Columbia, V0E 1B0

is hereby authorized to divert and drain water as follows:

(a) The sources of the water drainage are Meighan and Deep Creeks.

(b) The points of drainage are located as shown on the attached plan.

(c) The date from which this licence shall have precedence is 18th October 1956.

(d) The purpose for which this licence is issued is land improvement (drainage control).

(e) The maximum quantity of water which may be drained is the entire flow of Meighan and Deep Creek.

(f) The period of the year during which the water may be drained is the whole year.

(g) The land upon which the water is to be used and to which this licence is appurtenant is to the lands within the boundaries of the City of Armstrong, Kamloops Division of Yale District.

(h) The works authorized to be constructed are pipe and open ditch, which shall be located approximately as shown on the attached plan.

(i) The construction of the said works have been completed and the water shall be beneficially used on or before the 31st day of December, 1989.

(j) This licence is issued in substitution of Conditional Water Licence 23643.

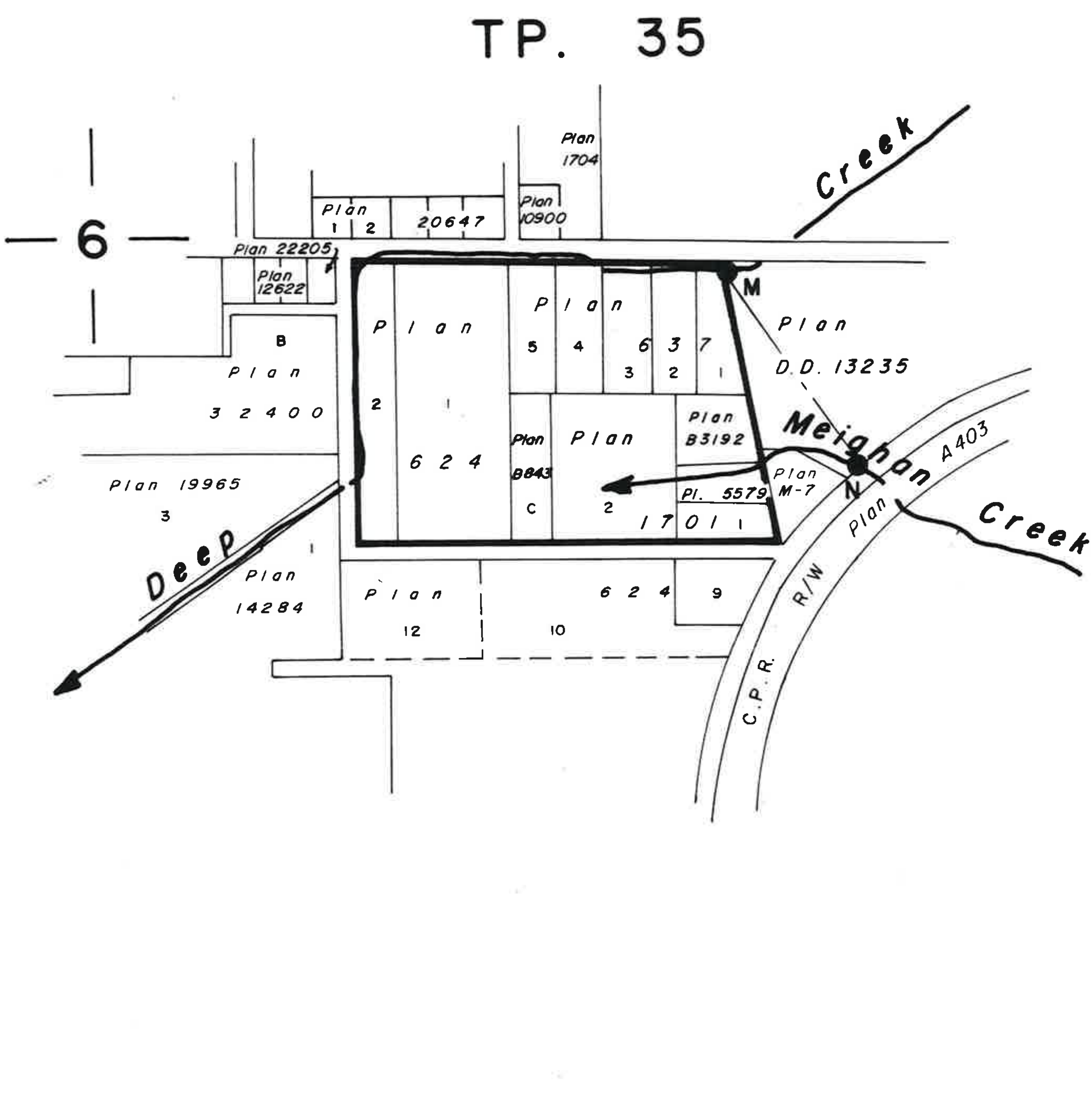
A. Zackodnik

A. Zackodnik, P.Eng.
Regional Water Manager
Southern Interior Region

File No. 0213837 Date issued JUL 14 1989 Conditional Licence 66582

M28-1246

Province of British Columbia



WATER DISTRICT :VERNON
PRECINCT :VERNON
LAND DISTRICT :KAMLOOPS DIVISION OF YALE

Signature A. Zachodnik

Date JUL 14 1989

C.L. 66582 for C.L. 23643
File 0213837

LEGEND
Scale : 1 : 5000
Point of Diversion : ●
Map Number : WR 82·L·045·1·3
Pipe and Ditch : ——— - ———

Within the City of Armstrong.

The boundaries of the land to which this licence is appurtenant are shown thus: ▬▬▬

V-733

~~A 1025~~

W.R.B. 13—0

PROVINCE OF BRITISH COLUMBIA

Water Rights Branch

DEPARTMENT OF LANDS AND FORESTS

CONDITIONAL WATER LICENCE

The City of Armstrong, of Armstrong, B. C.,

WATER RIGHTS BRANCH
LANDS DEPT.
JUN 10 1957
ENGINEER
KELOWNA, B. C.

is hereby authorized to divert water as follows:—

(*a*) The ~~source of the water supply is~~ sources are Meighan and Deep Creeks.

(*b*) The points of diversion are located as shown on the attached plan.

(*c*) The date from which this licence shall have precedence is 18th October, 1956.

(*d*) The purpose for which the water is to be used is Land improvement (drainage).

~~(e) The maximum quantity of water which may be~~

~~and such additional quantity as the Engineer may from time to time determine should be allowed for losses.~~

(*f*) The period of the year during which the water may be diverted is the whole year.

(*g*) ~~The land upon which the water is to be used and to which~~ this licence is appurtenant is to the Land Improvement (drainage) Undertaking of the City of Armstrong on Lots 1 - 5, Registered Plan 637; Lots 1 and 2 Registered Plan 624; Lots 1 and 2, Registered Plan 1701; Lot "C", Registered Plan B943, Kamloops Land Registration District, of part of Section 6, Township 38, Kamloops Division of Yale District.

(*h*) The works authorized to be constructed are the rediversion of Meighan and Deep Creeks by open channels and pipe,

and they shall be located approximately as shown on the attached plan.

(*i*) The construction of the said works shall be commenced on or before the 31st day of July, 1957, and shall be completed and the water beneficially used on or before the 31st day of December, 1960.

I, A. G. Sargent, being a person appointed by the Minister to execute the authority by Section 12 of the Water Act, vested in the Comptroller, do hereby certify the foregoing to be a true copy of Conditional Licence No. 23643 issued under the hand of the Comptroller on 1st day of May 1957

A G Sargent

A. F. Paget,
Comptroller of Water Rights.

File No. 0213837 Date issued May 1st, 1957. Licence No. 23643

SUPERSEDED BY C. 66582.

(269)

British Columbia

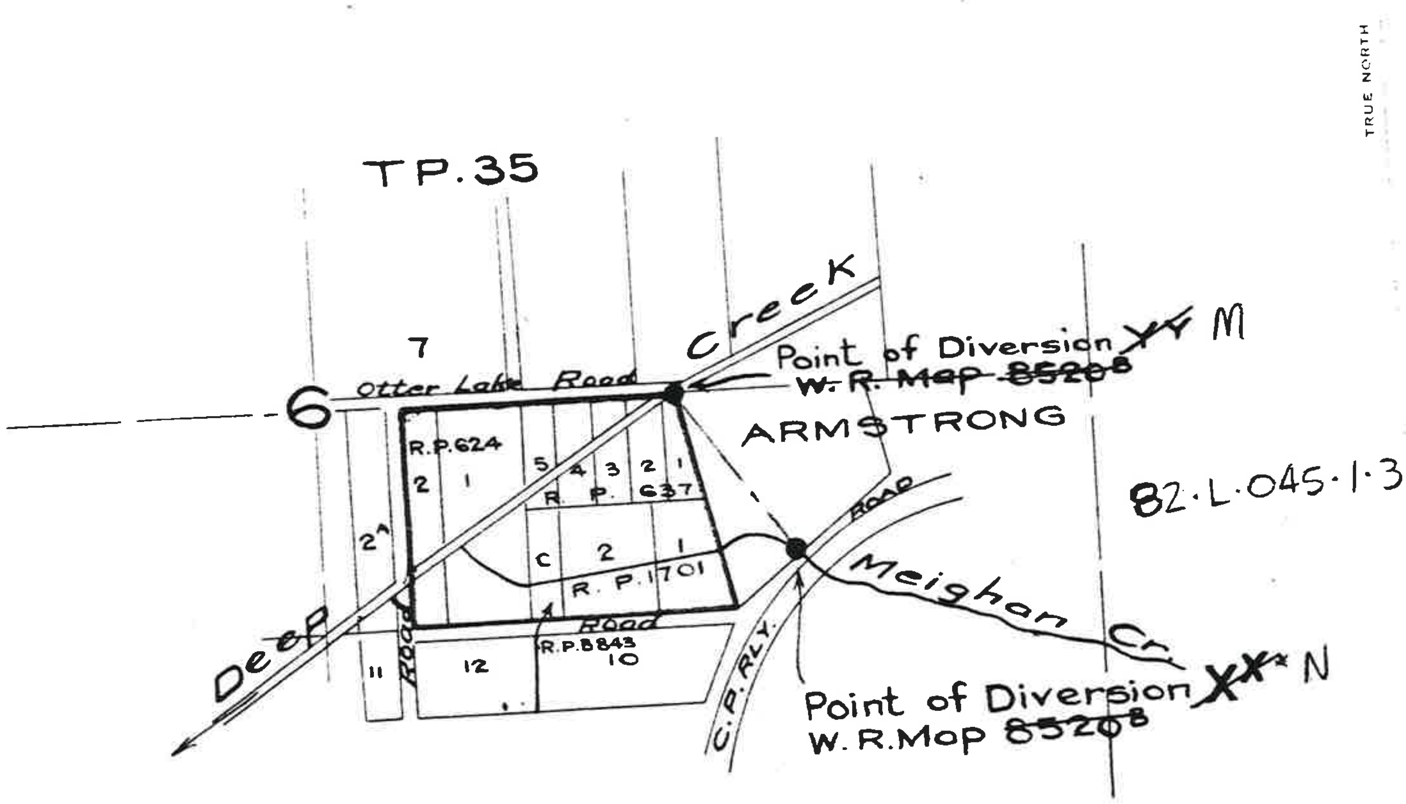
To accompany Conditional Licence No. 23643

VERNON WATER DISTRICT

Scale. 10 Chains to 1 Inch

N

KAMLOOPS DIV. OF YALE DISTRICT
KAMLOOPS LAND REG. DISTRICT



LEGEND

Point of Diversion ●

Pipeline & Open Channel — - —

The boundaries of the land to which this licence is appurtenant are shown thus: ▬▬▬

Signature [signature]

Date 1st May 1957

C.L. 23643
File 0213837

EXHIBIT "A"

SUPERSEDED BY

APPENDIX VII: LIDAR SPECIFICATIONS & TERMS OF USE

This page intentionally left blank

LiDAR Project Summary

Airborne Imaging
2700 - 61 Avenue SE
Calgary, Alberta, Canada
T2C 4V2
Telephone: (403) 215 2960
Fax: (403) 258 3189
www.airborneimaginginc.com

Project Information

Project Name:	Armstrong April 2018
Project Number:	14742
Client:	Tarin Resource Services

Project Type:	Local Area
Project Location:	Armstrong, British Columbia, Canada
Project Size:	6.4 sq km

Acquisition Projects

Project Name	Project Number	Vintage
Salmon Arm 2017	1655	Aug-Oct 2017
Salmon Arm 2016	1611	July-August 2016

Acquisition Parameters

Date (MM/DD/YY)	Mission	Flying Height (m)	Flying Speed (knots)	Pulse Rate Rep (kHz)	Scan Freq (Hz)	Scan Angle (degree)	Side Lap %	Point Density (pts/m²)	LiDAR System
07/29/16	5416211a	2500	160	800	168	50	50	8.0	Riegl Q1560
08/02/16	5416215a	2500	160	800	168	50	50	8.0	Riegl Q1560
08/18/17	6416230a	2300	160	800	178	50	50	8.0	Riegl Q1560
Multiple Return Capabilities:			YES		**Number of returns recorded:**				Maximum 4

Geodetic Control

Horizontal Datum:	Nad83 CSRS	**Vertical Datum:**	CGVD28
Geoid Model:	HT2.0	**UTM Zone:**	11
Note: We established a local geodetic network fixed to the following control:			
Station ID	**Lat**	**Long**	**Ellp Height (m)**
79C303	50 36 06.17775	-119 09 08.36193	345.949

Calibration Methodology

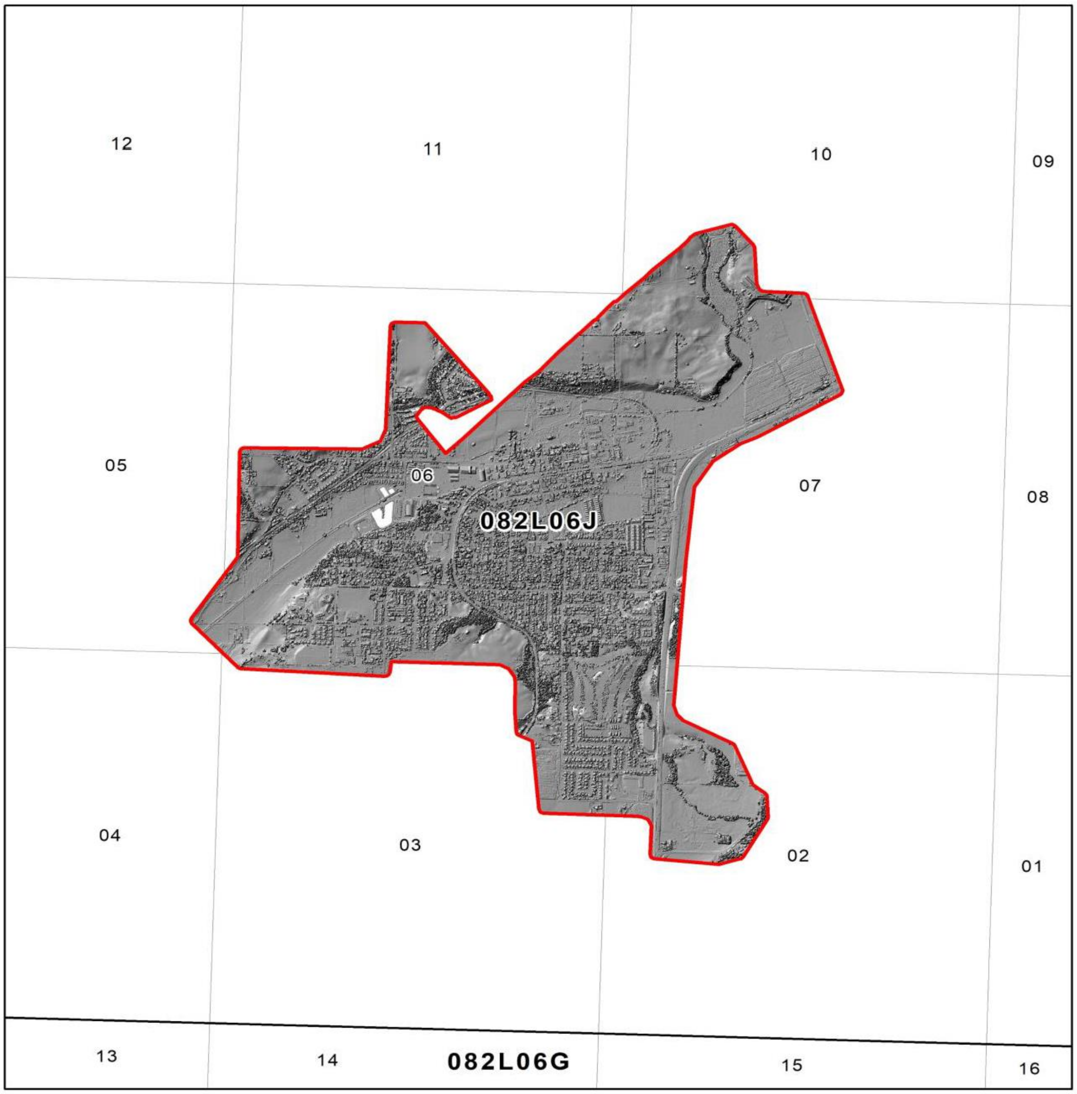
Airborne Imaging performs a complete calibration on every LiDAR acquisition flight, data is acquired over a calibration site flown with at least two passes in opposite directions before and after the flight. Any error in the attitude of the aircraft (roll, pitch and heading) can be observed and corrected for within system specifications. To statistically quantify the accuracy, we compare the LiDAR elevations with independently surveyed ground points. A GPS mounted truck collects data while driving on an open road. The kinematic positions on the road are post-processed from a nearby base station (common to the aerial survey)

Accuracy

Horizontal Accuracy, 95% or 2σ:	30 cm
Fundamental Vertical Accuracy (on flat hard surfaces), 95% or 2σ:	15 cm

Deliverables
1m Grids (ARCINFO Binary), Bare Earth and Full Feature
1m Grids (XYZ ASCII), Bare Earth and Full Feature
1m Grids (Surfer v7), Bare Earth and Full Feature
Point Cloud (LAS v1.2, ASPRS Classes)
1m Contours (dxf and shp)
Hillshade Images (Geotiffs), Bare Earth and Full Feature

Projected in UTM 11 NAD 83 CSRS Summary Produced: April 11, 2018



14742 - Armstrong, April 2018 - Tarin Resource Services

The Red outline represents the extent of the data delivered.

End User LiDAR Data License Agreement

Airborne Imaging, a Clean Harbors Company, is a body corporate duly incorporated pursuant to the laws of the Province of Alberta

By downloading, installing or using **Airborne Imaging** supplied LiDAR**,** you acknowledge that you have read this agreement and agree to be bound by its terms and conditions.

Whereas **Airborne Imaging, a Clean Harbors Company** has collected and processed certain data, known as LiDAR data, and is the **Owner** of said data, and you as **Licensee (Customer)** is desirous of using said data for purposes to be determined solely by Licensee, in consideration of the mutual covenants contained herein, **Airborne Imaging** hereby grants to the Licensee a non-exclusive, non-transferable, royalty free license, subject to the following terms and conditions:

1. For the purpose of this license agreement, the word "Data" with respect to each LiDAR data shall have the following meaning:

    a. point derived data from the LiDAR survey, which data describes the location and height of the ground or of vegetation or other structures above the ground, in a digital format;

    b. graphic files derived from the point data, showing the area in a shaded form, in a digital format

2. Licensee recognizes that **Airborne Imaging** does not guarantee the accuracy or quality of the Data for a particular purpose and Licensee shall use the Data at its own risk. Owner shall not be liable to the Licensee for any loss or damage arising from the use of the Data whether arising from any defects, inaccuracies or incompleteness regardless of the reason or cause of any such defects, inaccuracies or incompleteness.

3. Licensee understands and agrees that **Airborne Imaging** has and retains ownership rights in the data and Owner shall continue to have the exclusive right to license, sell, trade, loan and use the Data for any purpose.

4. No part of the LiDAR or products derived there from, or any right granted under this Agreement may be copied, sold, rented, leased, lent, sub-licensed, disclosed, or transferred to any other person or entity. In the event the Licensee is purchasing the LiDAR data as a sub-contractor to a Final End User Licensee, the Licensee must make the final end user aware the data is licensed from Airborne Imaging and agree to the terms of this agreement. In this type of arrangement, it is the obligation of the Licensee to insure a copy of this agreement is delivered to their end client (end user licensee).

5. Licensee agrees that the Data and copies shall be for its own internal use and it will not sell, trade, and otherwise make available to any third parties any of the Data received by it under this agreement without the written consent of **Airborne Imaging**. This prohibition shall not preclude the Licensee from giving the Data to its parent or any subsidiary, a subsidiary of its parent company, any contractors or sub-contractors working for the Licensee in the area covered by the Data, providing such parent, subsidiary, contractor, or sub-contractor agrees to abide by the terms of this agreement.

6. Licensee agrees that if or when any additional partners desire to share the Data, it will require consent from **Airborne Imaging**, and an additional license fee for each partner will be charged by Owner, to be paid by each additional partner, and the use of the data by each additional partner shall be subject to the terms set out in this License Agreement.

7. If required by applicable Laws, Licensee may disclose the Data to appropriate governmental agencies having jurisdiction, provided that Owner consents in writing prior to the disclosure, which consent shall not be unreasonably withheld, and provided further that Licensee promptly informs Owner in writing of full details of each request for the Data, to whom the disclosure is to be made and the reason for such disclosure.

8. This Agreement is the complete and exclusive statement of the understanding between the Licensee and Airborne Imaging with respect to the LiDAR data and may be amended or modified only in a written instrument signed by a duly authorized representative of both parties. If any provision is determined to be invalid or unenforceable, the remaining provisions of this Agreement shall continue to be valid and enforceable. Without the prior written consent of Airborne Imaging, neither this Agreement nor any of the rights granted by it may be assigned or transferred by the Licensee. This restriction on assignments or transfers shall apply to assignments or transfers by operation of law, as well as by contract, merger or consolidation.

9. It is THE LICENSEE'S RESPONSIBILITY to ensure that its use of the LiDAR data complies with these terms and to seek prior written permission from Airborne Imaging for any uses not expressly permitted or not specified in this Agreement.