Photo source: NHC, Oct 2020

Park Rill Creek, Horn Creek and Kearns Creek Flood Mapping Final Report

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- Caleb W. Pomeroy — Principal Engineer, Watershed Engineering Ltd.
  RDOS' technical advisor and reviewer for this project

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- Dale Muir — Senior Project Review
- Derek Ray — Geomorphic Review
- Genevieve Brown — Hydrological Assessment
- Grant Lamont — Coastal Review
- Jason Ryerson — Survey
- Joe Drechsler — GIS Analysis
- Joel Trubilowicz — Hydrology Review
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- Seth Bryant — Consequence Characterization
- Vaughn Collins — Hydraulic Modelling Review

EXECUTIVE SUMMARY

The Park Rill Creek, Horn Creek, and Kearns Creek watersheds are subject to freshet peaks driven by snowmelt from the contributing mountains, groundwater, and rainfall. In recent years, these watersheds have experienced extensive flooding which has resulted in damage to homes, public infrastructure, loss of property and numerous evacuations. During the freshet of 2018, these watersheds saw extensive flooding and erosion due to the high flows.

The main objectives of this project were to:

- Complete hydrologic and hydraulic modelling of the watersheds.
- Prepare detailed floodplain and flood hazard maps for the areas of Twin Lakes, Willowbrook, and Sportsmens Bowl Road.
- Assess the associated consequences of flooding.
- Identify mitigation measures.
- Complete a visual inspection of a 12 km reach of Park Rill Creek between near Twin Lakes and Willowbrook.

Visual Inspection of Park Rill Creek

A preliminary geomorphic assessment, supported by a visual inspection, was completed for the 12 km reach of Park Rill Creek from the diversion outlet from Twin Lakes to Willowbrook Road. Areas of concern, where widespread erosion and under cutting have occurred, were identified. The findings suggest that channel stabilization processes could create a high sediment load which could create channel aggradation and blockages in Willowbrook and Sportsmens Bowl Road. It is strongly recommended that additional analysis be conducted to compare the current channel to its conditions immediately post-flood.

Hydrologic Modelling

A hydrological analysis was completed for Park Rill Creek and Lower Twin Lake. Recommended design flows, including the provision of climate change and inflow from Lower Twin Lake, were established for three locations within the Park Rill watershed based on a regional analysis. Although the values are more conservative than previous estimates for the watershed by Ecora and Dobson (2019a), NHC recommended use of these values along with a sensitivity analysis of flow for the hydraulic modelling component completed in Phase II. Conservatism was used in the selection of design flow estimates, due in part to a lack of adequate discharge and climate data within the project watersheds; to improve future estimates, the establishment of flow monitoring within the project watersheds is strongly recommended.

A conditional frequency analysis was performed to establish design levels for Lower Twin Lake to account for the significant autocorrelation in lake levels. The design levels are dependent on the selection of a pre-freshet level of Lower Twin Lake. Given the noticeable autocorrelation, NHC recommended that the observed historical maximum pre-freshet be used as the basis of the design levels. A sensitivity analysis of the water levels was also recommended for the Phase II flood mapping component.

Hydraulic Modelling

Two-dimensional (2D) hydraulic modelling of the Willowbrook and Sportsmens Bowl Road areas was completed to simulate the extents of flooding. Two Digital Elevation Models (DEMs) were prepared to be used as the model terrain. The DEMs combine air-borne lidar with bathymetric survey data of the watercourses to create a seamless surface. The survey was completed by NHC in August 2020. The models were assessed through sensitivity analysis and comparison of general flow patterns observed during the 2018 flood event. Calibration data was not available.

The hydraulic models were used to run a number of base runs, including 10-, 50-, 100- and 200-year return periods. All base runs were adjusted for end-of-century climate change. Depth, velocity, and hazard diagrams were prepared for all base runs and are included in Appendix A of this report. Results in GIS (raster) format were also prepared and submitted as part of the digital deliverables package that accompanies this report.

Floodplain Mapping

Flood maps were prepared for the Lower Twin Lake, Willowbrook, and Sportsmens Bowl Road areas, following the available federal and provincial mapping guidelines. These constitute the first flood mapping effort in the study areas. The maps represent a designated 200-year flood adjusted for an end-of-century climate change scenario. Preliminary observations on geomorphic characteristics and hazards are provided in this report; however, after discussion with the RDOS, it was decided that a detailed geomorphic assessment was not to be completed due to project budget limitations. The floodplain maps produced are limited to clear water flooding and do not account for geomorphic hazards. It is strongly recommended that a detailed geomorphic analysis be completed, and the flood maps reviewed considering potential geomorphic hazards in the study area as future work.

Flood mapping of the Lower Twin Lake area was based on the water level estimates obtained through hydrologic analysis. A wave runup analysis was completed to identify appropriate wave effect values to consider in flood mapping. The wave runup values were added to the water levels estimated through hydrologic analysis. The designated floodplain map includes a 0.6 m freeboard allowance added on top of the design water level and wave runup values.

For Willowbrook and Sportsmens Bowl Road areas, the HEC-RAS 2D hydraulic models were used to produce floodplain and hazard maps. Flood maps for these two areas include a 0.3 m freeboard allowance.

Consequence Assessment

A consequence characterization, or impact assessment, was completed for the three study areas. Impacts of flooding were estimated on buildings, roads, power infrastructure, and people, for the design event. Despite data limitations, this analysis provides a basis for decision-makers to inform mitigation and emergency response plans for the study areas.

Mitigation Measures

Structural and non-structural mitigation measures, both at a property and regional level, were discussed. Property scale options include elevating buildings, dry and wet building floodproofing, temporary measures, and developing an emergency plan. Regional scale structural options include:

temporary flood barriers, diverting flow from Kearns Creek in Willowbrook and Park Rill Creek in Sportsmens Bowl Road to increase conveyance capacity, installing new culverts and upgrade existing ones, and restoration of marshy areas to increase storage capacity upstream of the floodplain areas. Regional scale non-structural measures include land-use management, flood prediction and warning, flood emergency response planning, community recovery plans, and community awareness.

LIST OF ACRONYMS

AEP	Annual Exceedance Probability
APEGBC	Association of Professional Engineers of BC (now EGBC)
CGVD	Canadian Geodetic Vertical Datum
DEM	Digital Elevation Model
ECCC	Environment and Climate Change Canada
EGBC	Engineers and Geoscientists BC (previous APEGBC)
EPA	Emergency Program Act
FCL	Flood Construction Level
FHWA	Federal Highway Administration
GIS	Geographic Information Systems
HR	Hazard Rating
ICI Society	Integrated Cadastral Information Society
LNID	Lower Nipit Improvement District
MFLNRO	Ministry of Forests, Lands and Natural Resource Operations (now MFLNRORD)
MFLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development (previous MFLNRO)
MOE	Ministry of Environment
MOTI	Ministry of Transportation and Infrastructure
NAD	North American Datum
NHC	Northwest Hydraulic Consultants Ltd.
NRCan	Natural Resources Canada
NRCan PPP	National Resources Canada Precise Point Positioning
OSM	Open Street Map
QP	Qualified Professional
RDOS	Regional District of Okanagan-Similkameen
SIFT	BC Soil Information Finder Tool
StatCan	Statistics Canada
TIN	Triangular Irregular Network
UTM	Universal Transverse Mercator
WSC	Water Survey of Canada
WSE	Water Surface Elevation

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APPENDICES

1 INTRODUCTION

The Park Rill Creek, Horn Creek, and Kearns Creek watersheds are subject to freshet peaks due to snowmelt from the contributing mountains, groundwater, and rainfall. In recent years, these watersheds have experienced extensive flooding which has resulted in damage to homes, public infrastructure, loss of property and numerous evacuations. In spring 2018, the areas of Willowbrook, Sportsmens Bowl Road, and properties along Park Rill Creek downstream of Highway 97 to the confluence with the Okanagan River were heavily impacted due to high freshet flows. In the same year, high levels in Twin Lakes affected numerous properties surrounding Lower Twin Lake and it was necessary to pump water from Lower Twin Lake into Park Rill Creek, Figure 1.2 shows the pump and pipe alignment. Over 400 residents were affected by this event. Climate change is expected to increase the frequency and intensity of flooding in the region.

The main objectives of the Regional District of Okanagan Similkameen(RDOS)'s Park Rill Creek, Horn Creek and Kearns Creek Flood Mapping Project are to:

1. Prepare floodplain and flood hazard maps for the areas of Twin Lakes, Willowbrook, and Sportsmens Bowl Road (shown in Figure 1.1);
2. assess the associated consequences of flooding;
3. identify mitigation measures; and
4. complete a visual inspection of a 12 km reach of Park Rill Creek.

Flood mapping is a key tool for improving the understanding of the hazard and providing First Nations, governments, organizations, and individuals with a means to plan for potential floods and reduce their risk. The information developed in this study is intended to be used by RDOS for flood risk management (prevention and mitigation), land use planning and regulation (e.g., floodplain bylaws), public awareness and emergency preparedness . The flood mapping produced for this project constitutes the first set of flood maps in the study area.

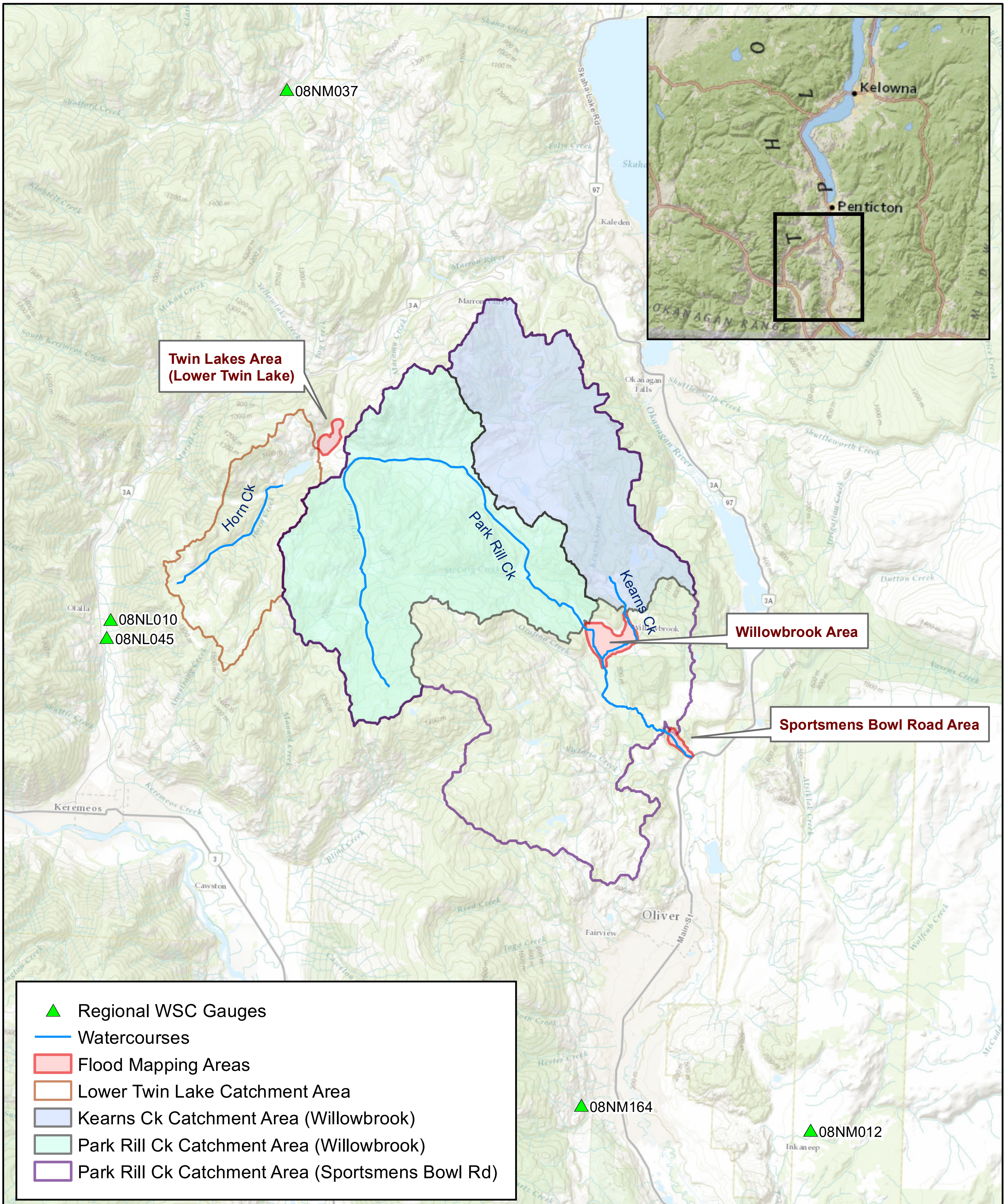
This report documents Phase I and Phase II of a two-phase project. Phase I of the project included:

- Survey (Section 2)
- Digital Elevation Model development (Section 3)
- Visual channel assessment of the 11-km reach of Park Rill Creek between the Lower Twin Lake area and Willowbrook Road (Section 4)
- Hydrological analysis (Section 5)

Phase II consisted of:

- Wave runup analysis for Lower Twin Lake (Section 6)
- Hydraulic modelling of the Willowbrook and Sportsmens Bowl Road areas and base model runs including 10-, 50-, 100-, and 200-year return period events (Section 7)

- Flood mapping of the Twin Lakes, Willowbrook, and Sportsmens Bowl Road areas (Section 8)
- Consequence characterization (Section 9)
- Assessment of flood mitigation measures (Section 10)



RDOS Regional District Okanagan-Similkameen

nhc northwest hydraulic consultants

SCALE - 1:175,000

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Coordinate System: NAD 1983 CSRS UTM ZONE 11N
Units: METERS

Job: 3005878

Date: OCT 2022

PARK RILL CK, HORN CK AND KEARNS CK FLOOD MAPPING

Project Overview

FIGURE 1.1

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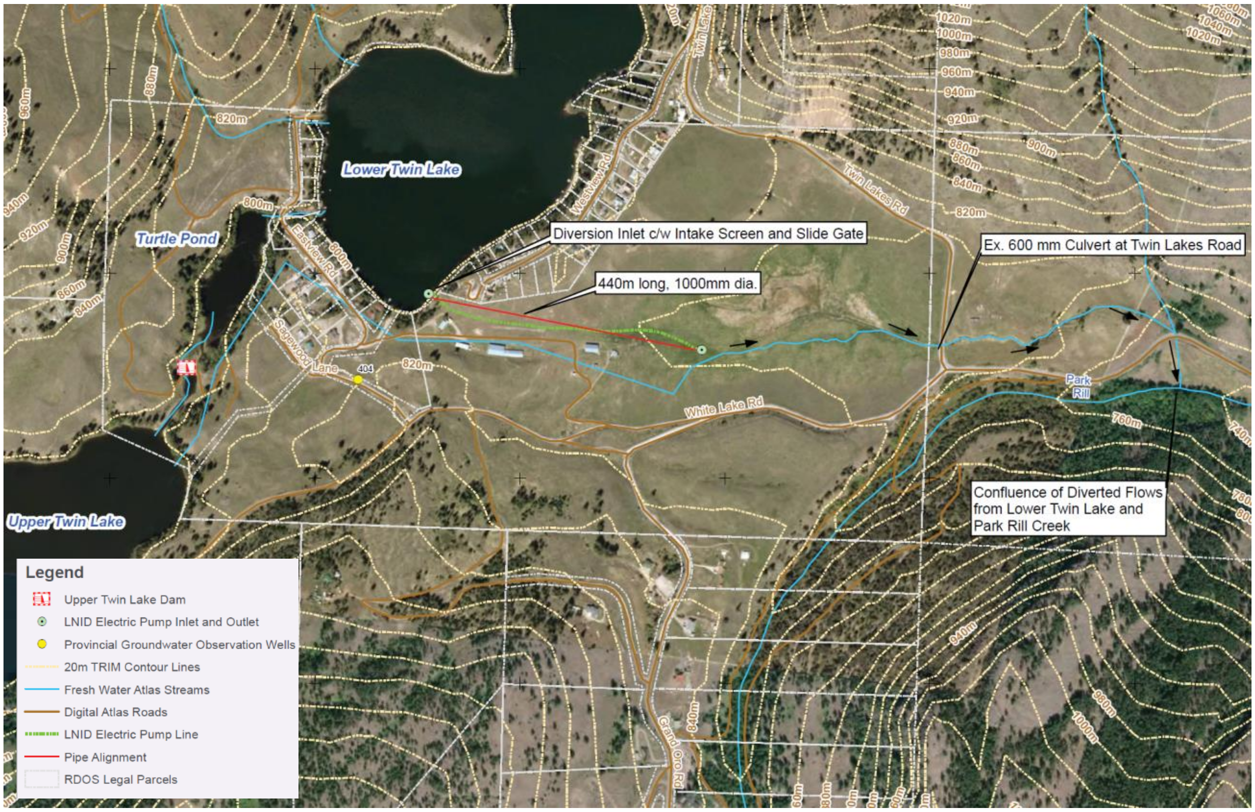

Figure 1.2 Outlet pump and pipe alignment from Lower Twin Lake to Park Rill Creek (adapted from Ecora and Dobson Engineering Ltd., 2019b)

1.1 Applicable Guidelines and Regulations

The following guidelines were considered in the development of this document:

- Flood Mapping in BC – Professional Practice Guidelines (APEGBC, 2017).
- Legislated Flood Assessments in a Changing Climate in BC – Professional Practice Guidelines (EGBC, 2018).
- Flood Hazard Area Land Use Management Guidelines (MFLNRORD, 2018).
- The Canadian Federal Flood Mapping Guidelines Series, currently under development (NRCan, 2018). There are several documents already published in this series. Of particular relevance to mapping standards are the Geomatics Guidelines for Flood Mapping (NRCan, 2019).
- Okanagan Floodplain Mapping Standards (NHC, 2020b)

1.2 2018 Flood Event

The 2018 flood event is the largest event documented in the study area in recent history. The extent of the damage was documented through footage and photographs, including drone captures. However, there are no hydrometric records available that allow quantification of the magnitude of the event (i.e., magnitude of flows or return period). The flooding produced large geomorphologic changes in Park Rill Creek. Specifically, upstream from Willowbrook where photos from 2018 show significant incision and deepening of the channel at some locations (see Section 4). Sediment was transported downstream to the floodplain areas, where sediment removal efforts were required. During the event a series of emergency works were put in place, including (Ecora and Dobson Engineering Ltd., 2019a):

- Pumping from Lower Twin Lake into the Park Rill Creek watershed (Figure 1.2) and extensive sandbagging and flood wall construction in the Twin Lakes area.
- Installation of temporary flood barriers such as sandbagging and tiger dams along roads and on private property to protect vulnerable infrastructure and properties in Willowbrook and Sportsmens Bowl Road areas.
- Removal of channel hydraulic restrictions in Park Rill Creek, such as private culvert crossings and creek side vegetation, and continual removal of sediment and debris.
- Removal of culverts in Willowbrook on Kearns Creek to increase flow capacity. These culverts were later upgraded in 2018 to box culverts.
- Installation of pump stations at several locations.
- Installation of two 800 mm culverts under Highway 97 discharging into a constructed emergency channel to increase flow capacity. This emergency channel, that discharged into the wetland area adjacent to Park Rill Creek, was removed later in 2018.
- Construction of a riprap roadside channel and installation of culverts along Sportsmens Bowl Road to contain flow to the channel and convey it downstream to the Highway 97 culverts.
- Ditching improvements and upgrade of all crossings to two 800 mm diameter culverts along the Sportsmens Bowl right-of-way and installation of a cattleguard which acts as a surface water intercept near Highway 97 to prevent flooding of Park Rill onto Highway 97.
- Installation of emergency overflow 800 mm culvert and pump on Seacrest Hill Road.
- Replacement of existing culverts with concrete box culverts at Park Rill Creek crossings at Goldtau Road, Jones Way, Yellowbrick Road, and Willowbrook Road.
- Installation of two 2700 mm corrugated still pipe (CSP) culverts at Seacrest Hill.
- Upgrades to Park Rill Dam to increase spillway capacities by the dam owner.

1.3 Geomorphic Hazard Discussion

Site inspection in combination with footage and photographs from the 2018 flood event showed evidence of geomorphic hazards in the study areas. A large section of Park Rill Creek was heavily eroded during 2018, creating a canyon-like channel upstream of Willowbrook (see Section 4 and Photos 1-3 in the Photographs Appendix). Despite this reach being outside of the flood mapping areas, it exhibits evidence of channel instability and the potential for channel degradation during future flood events. In addition to the risk of channel degradation within the study areas, sediment from upstream locations can be carried downstream, creating risk of channel aggradation, and possibly resulting in channel and culvert blockages.

Preliminary observations on geomorphic characteristics and hazards are included in Section 4. However, after discussion with the RDOS, it was decided that a detailed geomorphic assessment was not to be completed due to project budget limitations. The floodplain maps produced are limited to clear water flooding and do not account for geomorphic hazards. It is strongly recommended that a detailed geomorphic analysis be completed, and the flood maps reviewed considering potential geomorphic hazards in the study area.

2 SURVEY

NHC carried out survey work 20-26 August 2020 to collect bathymetric and topographic information of the three study areas shown in Figure 1.1. Additionally, the 11-km reach of Park Rill Creek was documented through a series of drone and GoPro videos and photos that support the geomorphic analysis completed as part of this project.

2.1 Data Collected

Table 2.1 summarizes the data collected by NHC and the formats in which it is stored. All the data listed in Table 2.1 was included as part of the deliverables package submitted with the Phase 1 report.

Table 2.1 Summary of survey data collected by NHC

Data	Description	Format
Cross sections	Cross sections of Kearns Creek and Park Rill Creek within the Willowbrook and Sportsmens Bowl Road study areas. In areas where the stream was uniform, the survey cross sections were spaced further apart than in areas of higher channel complexity.	xyz points in *.csv format
Thalweg profile	Thalweg elevation of Kearns Creek and Park Rill Creek within the Willowbrook and Sportsmens Bowl Road study areas.	xyz points in *.csv format
Crossings	Culvert crossing information (i.e. invert, obvert, diameter, material, condition) within the Willowbrook and Sportsmens Bowl Road study areas	xyz points in *.csv format
Topographic tie points	Lidar tie in points within the Twin Lakes, Willowbrook, and Sportsmens Bowl Road areas for comparison with GeoBC's lidar.	xyz points in *.csv format
WSC gauge benchmark	The Twin Lakes WSC gauge benchmark was surveyed to establish offset between gauge and survey datum.	xyz points in *.csv format
Park Rill Creek Footage	Drone and GoPro footage and photos of the 11-km of Park Rill Creek	*.mp4, *.jpeg

2.2 Coordinate System

Coordinate system details used in the project are:

- Horizontal Datum: North American Datum 83 (NAD83) CSRS
- Projection: UTM Zone 11 North
- Vertical Datum: CGVD2013
- Geoid Model CGG2013a

2.3 Survey Equipment

The survey equipment used to complete the survey work includes the following:

- Trimble R12 GNSS RTK GPS rover (accuracy ± 0.05 m)
- Trimble R10 GNSS RTK GPS base receiver w/ Trimble TDL 450 35-watt radio (accuracy ± 0.05 m)
- Trimble TSC3 controller w/ Trimble Access field software
- Trimble Business Center desktop software
- DJI Mavic Mini UAV
- GO-Pro Hero 8 Camera

2.4 Control Surveys

The control network for the project area was set using a static survey. A base receiver was set up daily at one of three different control sites. The resulting static data was submitted to the National Resources Canada precise Point Positioning post processing service. The coordinates obtained were used to shift the three different control locations. Redundant observations of tie points were compared to ensure continuity between the three survey control sites. Once the checks were completed all survey points were shifted to match the new control coordinate locations.

3 DIGITAL ELEVATION MODEL

Lidar data collected in 2018 by GeoBC was made available to NHC for the three project areas. Using data from tiles 82E022, 82E023, and 82E032, a seamless DEM file was created and included as part of the deliverable package submitted with this report. This lidar DEM was used for flood mapping of the Twin Lakes area and was the base of the Digital Elevation Models (DEMs) developed for hydraulic modelling of Willowbrook and Sportsmens Bowl Road areas, as described later in this report.

The lidar data was integrated with the surveyed bathymetry collected by NHC in August 2020 to develop two DEM files for hydraulic modelling of Willowbrook and Sportsmens Bowl Road areas. The DEM data sources are summarized in Table 3.1. Bare-earth data was used for this project.

Table 3.1 DEM data sources for Willowbrook and Sportsmens Bowl Road

Data Type	Format	Source	Acquisition Date	Coordinate System
Lidar DEM	Raster (1 m) *.TIFF	GeoBC (tiles 082E022, 082E023)	Mar-Nov, 2018	NAD 83(CSRS) UTM Zone11, CGVD 2013
Bathy/Topo	Points *.CSV	NHC	Aug 20-26, 2020	NAD 83(CSRS) UTM Zone11, CGVD 2013

For the Willowbrook and Sportsmens Bowl Road DEM, the GeoBC DEM was resampled from 1 metre to 0.5 metres to adequately capture the channel bed geometry once the bathymetric data was integrated. The main technique for forming the bathymetry from the survey sections was to connect the top of bank points, the toe of bank points, and the thalweg points as separate groups using grading tools in Civil 3D, and creating a series of 3D breaklines. A TIN (Triangular Irregular Network) surface was generated from the resulting line work, forming a trapezoidal channel.

The lake bathymetry in the upper portion of the Kearns Creek reach was formed using contour lines digitized from the survey data. The lake bathymetry included an island that was generated as a separate TIN and re-integrated into the DEM.

4 PARK RILL CREEK CHANNEL ASSESSMENT

As a response to severe flooding in the Twin Lakes area, pumping of water from Lower Twin Lake into Park Rill Creek has been permitted in past years. Pumping into Park Rill Creek started in 1952 and has been used since during high lake level years. During recent years, the pumping has become more frequent, and it was required in 2013 and then again from 2015 to 2018. The additional flow into Park Rill Creek has caused flooding in properties along this watercourse and has contributed to severe creek erosion observed within properties in upper Park Rill Creek upstream of Myers Flats (Ecora and Dobson Engineering Ltd., 2019b).

NHC completed a preliminary geomorphic assessment of the 12 km reach of upper Park Rill Creek from Willowbrook Road to the diversion outlet from Twin Lakes. The goals of the channel assessment was to:

- Identify areas that are susceptible to damage due to high peak flows and from future pumping from Twin Lakes;
- Identify areas along the creek where remediation or mitigation works are required to restore and improve the function of the creek during future high flow events; and
- Help inform decision-making and priority setting with regards to improvements or mitigation in the future.

4.1 Methods

Visual inspection of the creek was completed during a survey between 23-25 August 2020. This included the collection of georeferenced photos and drone and GoPro video along the 12 km reach of interest. All photos and videos have been provided with this report in digital format (Table 11.1).

The georeferenced photos and videos were analyzed in conjunction with the 2018 GeoBC lidar and photogrammetry data, previous reports of the area (Ecora and Dobson Engineering Ltd., 2019a, 2019b), and provincial soil and geology maps (BC Soil Information Finder Tool, SIFT and soil survey reports) to provide a preliminary geomorphic understanding of the 12 km reach upstream of the Willowbrook and Sportsmens Bowl Road flood mapping areas.

4.2 Results

4.2.1 Channel Classification

The channel was divided into five segments based on general geomorphological characteristics. Figure 4.1 shows the extent of each segment as well as representative photographs taken by NHC during the site investigation in August 2020.

1. Section 1 (sta. 6+400 to 12+100) extends from the headwaters to the White Lake basin. This is an old glacial meltwater channel, and the sediments are mapped as glaciofluvial in SIFT. The current creek is undersized relative to the outwash channel and in most places it sits well below the surrounding outwash channel floodplain. There is a lot of vegetation in the creek and widespread undercutting of root structures. There are intermittent grassier sections where it seems like much of the flow goes subsurface. These sections may act as local sediment traps.
2. Section 2 (sta. 4+900 to 6+400) extends from the end of Section 1 to what is suspected to be a paraglacial fan. The top of this reach marks the point where the glacial meltwater ran north past White Lake and through to the Moran Valley, whereas the current channel runs southeast. Here the channel is flowing in a more constrained area. There are terraces on the northeast side of the channel mapped as till, and the hill on the southwest side is mapped as colluvium in SIFT. This reach is distinguished from Section 1 by a mild break in slope and the soils on either side, however, sediment transport during current floods is expected to be similar to Section 1.
3. Section 3 (sta. 3+000 to 4+900) extends from the end of Section 2 to the end of the fields south of Yellowbrick Road. The channel in this reach flows primarily through agricultural areas. Crossings and artificial channel construction appear to be the dominant geometry and sediment influences. These are also likely the primary concern for both flooding and sediment transport. There are parts of this section where the channel has down cut and is quite deep, and other parts where it is depositing sediment and migrating. Agricultural withdraw and runoff effects on the creek are also considerations for how the creek functions in this section.
4. Section 4 (sta. 1+000 to 3+000) is the section of creek in between the agricultural area of Section 3 and Willowbrook. Here the channel is again undeveloped and flowing through mature-looking vegetation. The 2018 GeoBC lidar shows areas of downcutting and other areas of channel migration, all within a channel bounded by colluvium according to SIFT.

5. Section 5 (sta. 0 to 1+000) is agricultural area in and around Willowbrook, where the channel is again primarily affected by crossings and artificial alignments.

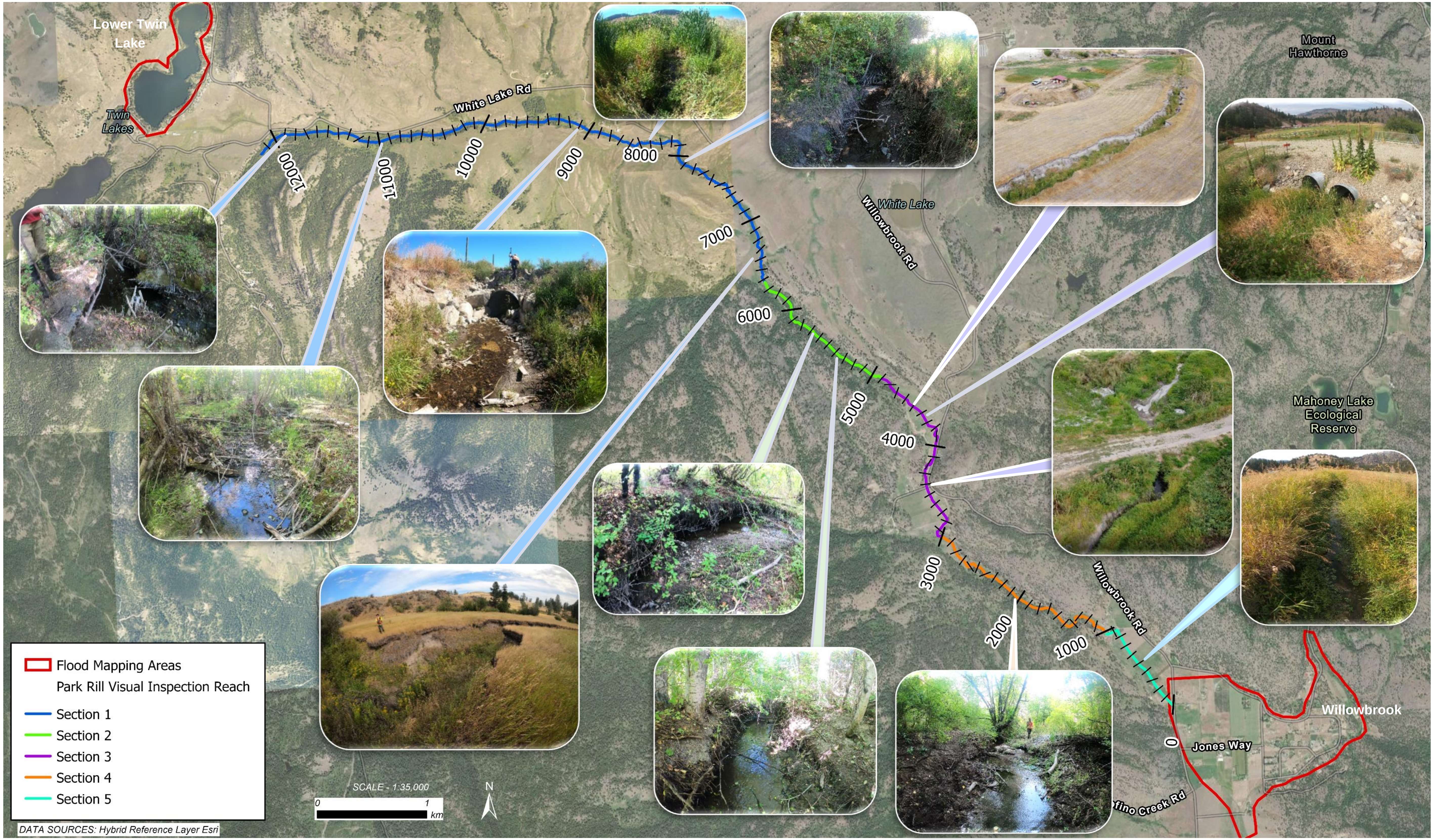

Figure 4.1 Park Rill Creek channel classification map. All photographs were taken by NHC in August 2020. Channel stationing in metres

4.2.2 Geomorphic Concerns for Flood Mapping

Photos from the 2018 flood event and from NHC's 2020 fieldwork show areas where the channel has incised and deepened significantly on private property as shown in Photo 1. This raises two main concerns. The first is that there is no clearly identifiable area within the 12 km study reach where sediment was deposited during the 2018 flood and there is a concern that some portion of the sediment may be transported downstream to the Okanagan River during future high flow events. Two known areas of deposition on the Willowbrook floodplain were identified by Caleb Pomeroy[1], both of which were below the 12 km study reach of this assessment. The location of these areas is shown in Figure 4.2. At the level of detail of this overview assessment there is not enough information available to verify these areas of deposition, or to rule out deposition elsewhere on the Willowbrook floodplain. The second concern is that of ongoing channel instability and adjustment that would be expected following the channel-forming flood of 2018. For instance, the areas of incision will provide higher-than-previous sediment inputs for years to come as the over-steepened banks adopt a more stable angle (through bank failure and regression) and that material becomes available to be transported downstream during subsequent flood events.

Figure 4.2 Relevant areas to the preliminary visual inspection. The pink line indicates the 12 km study reach for the visual inspection. The yellow line indicates the rough extents of the lower area for which Caleb Pomeroy reported sediment deposition

[1] Email correspondence between NHC and Caleb Pomeroy on 29 January 2021 (RE: Park Rill Creek Geomorph Assessment).

4.2.3 Areas Susceptible to Damage During High Peak Flows

Areas of previously reported flood damage remain susceptible to future damage during peak flows. The main areas are:

- Ray Stewart's property. Photos from 2018 show significant incision and deepening of Park Rill Creek at the upstream and middle parts of the property, and overland flow at the downstream end. Deposition may occur on at the downstream end where the channel widens and interfaces the Fairview White Lake Road, but this is uncertain due to dense vegetation cover encountered during the 2020 visual inspection. See Photo1 to Photo 3.
- Culvert crossings on the Willowbrook floodplain. Ecora and Dobson (2019a) reported that MOTI upgraded culverts in Willowbrook for both Park Rill Creek and Kearns Creek crossings during 2018 and 2019. However, sediment buildup could compromise the function of these crossings and further study should clarify whether this is likely to occur. Moreover, as noted in Section 7, the channels are undersized for the design flood, which could increase the probability of blockages. See Photo 4.

Additional susceptible areas include:

- The section of Fairview White Lake Road next to Ray Stewart's property. The channel widens as it reaches the downstream end of Ray Stewart's property and flanks the road. Channel migration might occur in this area if sediment from further upstream is deposited rather than transported downstream to the Okanagan River, and this channel migration may cause damage to the road. However, further assessment is required to determine if sediment is deposited in this area, and if so, whether it poses a risk to the Fairview-White Lake Road.
- Culvert crossing and nearby areas at White Lake Ranch. Ecora and Dobson (2019a) recommended stabilization and restoration of Park Rill Creek near White Lake Ranch but did not provide details about why or what the proposed works would specifically include, beyond indicating that properties along Park Rill Creek should be assessed for potential damage from Twin Lakes overflow discharge. NHC's visual inspection identified one road crossing (Photo 5) and several other culverts in the area. However, the visual inspection was limited by dense vegetation in the channel and it should be clarified with the landowners whether there is additional infrastructure near the creek.
- The two areas of deposition identified by Caleb Pomeroy are shown in Figure 4.2. Sediment deposition in these areas is known to have impacted Willowbrook before and is likely to do so again.

4.2.4 Areas Where Remediation/Mitigation Works are Required

Areas identified as susceptible to flood damage may require remediation or mitigation works to restore and improve the function of the creek during high flow events. However, additional work and more detailed assessments are required to provide recommendations about what this might include for any given area.

Flood mapping products should be revised if the results of the additional analysis strongly contradict the assumptions for hydraulic modelling. For example, if large loads of sediment are expected during future flood events posing a risk of channel aggradation and blockages.

4.3 Conclusions and Recommendations

The 2018 flood event resulted in large geomorphological changes in Park Rill Creek. Specifically, at Ray Stewart's property, where photos from 2018 show significant incision and deepening of the channel at the upstream and middle parts of the property, and overland flow at the downstream end. The channel was destabilized from that event and left susceptible to future widening and regrading of the banks. This would provide additional sediment to the downstream floodplains, which could further destabilize downstream channel reaches in Willowbrook and Sportsmens Bowl Road areas or obstruct flow within the channel or through crossings.

Mitigation could include stabilizing portions of bank (regrading, armouring, and or dense planting), as well as incorporating areas suitable to encourage deposition of excess sediment transport before reaching Willowbrook and Sportsmens Bowl Road.

5 HYDROLOGICAL ANALYSIS

To support floodplain modelling and mapping a hydrological analysis was completed for Park Rill Creek and Lower Twin Lake. Both catchments are located within the Okanagan River basin, with contributing areas of 164 km^2 and 20 km^2, respectively. The elevation of the basins ranges from 300 m near the confluence of Park Rill Creek and Okanagan River, to over 1,595 m in the mountainous headwaters. The average elevation of the Park Rill watershed is 850 m and 1,250 m for Lower Twin Lake. The land cover is primarily grassland and forest, with some residential development. Forest operations have occurred within the basin. The mean annual precipitation is estimated to be 419 mm, with approximately 60% falling during winter months (Wang et al., 2016). The mean annual temperature is 7.1°C.

Park Rill Creek has a number of small tributaries including Kearns Creek, Orofino Creek, Victoria Creek, and McCaig Creek. The watershed has a few small lakes as well as a number of earthen dams used for controlling water supply for conservation, commercial, and agricultural purposes. The dams and lakes are not expected to influence high peak flows, but may influence lower peak flows.

Horn Creek is the main tributary to the Upper and Lower Twin lakes, which are hydraulically connected through a dam and Turtle Pond. There is no outlet from Lower Twin Lake. Historical information indicates that an outlet in the southwest corner was infilled in the 1960s to help with low water levels (LNID, 2020). During years with high water levels, water from Lower Twin Lake is pumped such that water enters the Park Rill watershed.

Peak flows within the basins are expected to be dominated by spring snowmelt freshet, typically occurring in the period May to June. Reports and anecdotal observations of both Horn Creek and Park Rill Creek indicate that lower reaches of the stream can be dry while upper reaches contain water. This occurs in low flow months later in the summer but has also been recorded during the spring freshet period (LNID, 2020). Anecdotal information about the watersheds also indicate that flows can be much lower than similar nearby watersheds throughout the year (C. Pomeroy 2020, personal communication, September 14).

Examination of historical groundwater observation data within the watersheds, shown in Figure 5.1, show an annual pattern with levels increasing during the spring freshet period. This indicates that surface water and groundwater system are closely coupled. Water levels within Upper and Lower Twin Lake are likely tied closely to the groundwater system.

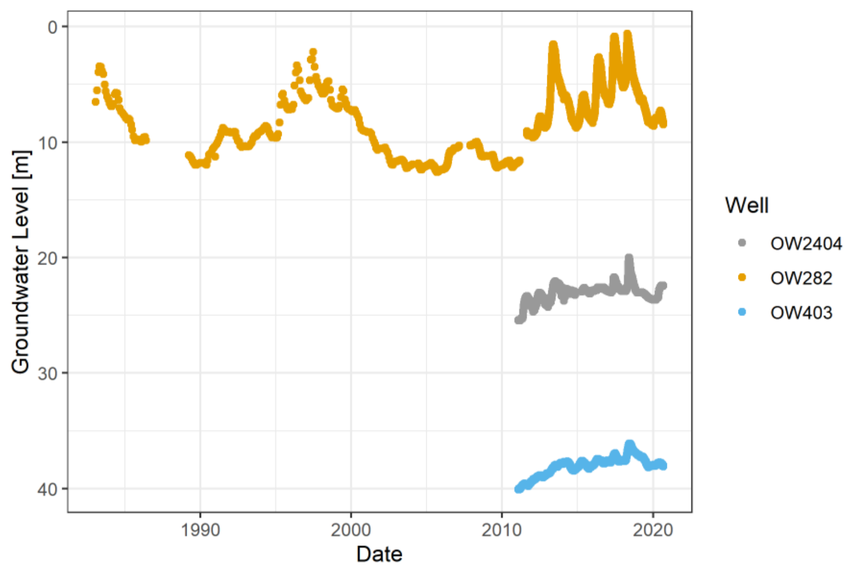

Figure 5.1 Groundwater levels at provincial observation wells within the Park Rill and Twin Lakes watersheds showing seasonal increases during freshet

5.1 Park Rill Creek

5.1.1 Overview

Flow was historically monitored on Park Rill Creek (08NM120) between 1951 and 1970 by the Water Survey of Canada (WSC) for a contributing area of 160 km^2. Examination of the gauge data shows that it is intermittent, estimated through manual measurements, and does not include any of the historic floods (2018, 2017, 2012, 1972). Therefore, the gauge data was deemed inappropriate for use in the frequency analysis.

Nearby gauges (within 25 km) with at least 15 years of data were examined for use in a regional frequency analysis. Table 5.1 summarizes the number of observations, drainage area, mean basin elevation, and mean annual precipitation for the nearby gauges[2]. The Park Rill gauge is included in the table for context.

Table 5.1 Regional WSC gauges based on proximity to Park Rill

Gauge ID	Gauge Name	Drainage Area (km^2)	Number of Observations	Mean Elevation (m)	Mean Annual Precipitation (mm)[3]
08NM120	Park Rill Creek near Oliver	160	-	822	412
08NM015	Vaseux Creek above Dutton Creek	255	29	1599	683
08NM006	Shuttleworth Creek near Okanagan Falls	85.2	17	1461	707
08NM164	Testalinden Creek in Canyon	13	18	819	343
08NM012	Inkaneep Creek near Oliver (Lower Station)	164	21	1251	525
08NM171	Vaseux Creek above Solco Creek	117	48	1690	704
08NL010	Keremeos Creek near Olalla	183	34	1310	497
08NL045	Keremeos Creek below Willis Intake	181	48	1349	503
08NM037	Shatford Creek near Penticton	101	63	1619	550

Overall, the nearby gauges are generally at higher elevations than the Park Rill catchment and as a result are expected to receive more precipitation. There is supporting anecdotal information that Park Rill generally has lower peaks than nearby watersheds. However, without reliable streamflow data for the basin NHC recommends a more conservative approach in the selection of watersheds for purposes of estimating extreme peak flows. On the other hand, gauges with mean annual precipitation greater than 680 mm (08NM015, 08NM006, and 08NM171) were excluded from the regional analysis given the sizable difference from the Park Rill watershed.

5.1.2 Statistical Analysis

Annual instantaneous observations were used from the selected gauges for the analysis. For years where instantaneous peaks were not available, a peaking factor – based on a gauge's average rank-rank instantaneous to daily ratio – was used to convert the daily peak to an instantaneous value. Figure 5.2 shows the annual instantaneous peak flows at the gauges.

[2] Mean annual precipitation is based on gridded data, which is an estimate, with no long-term Environment and Climate Change Canada climate station data available within the Park Rill watershed.

[3] Wang et al. (2016)

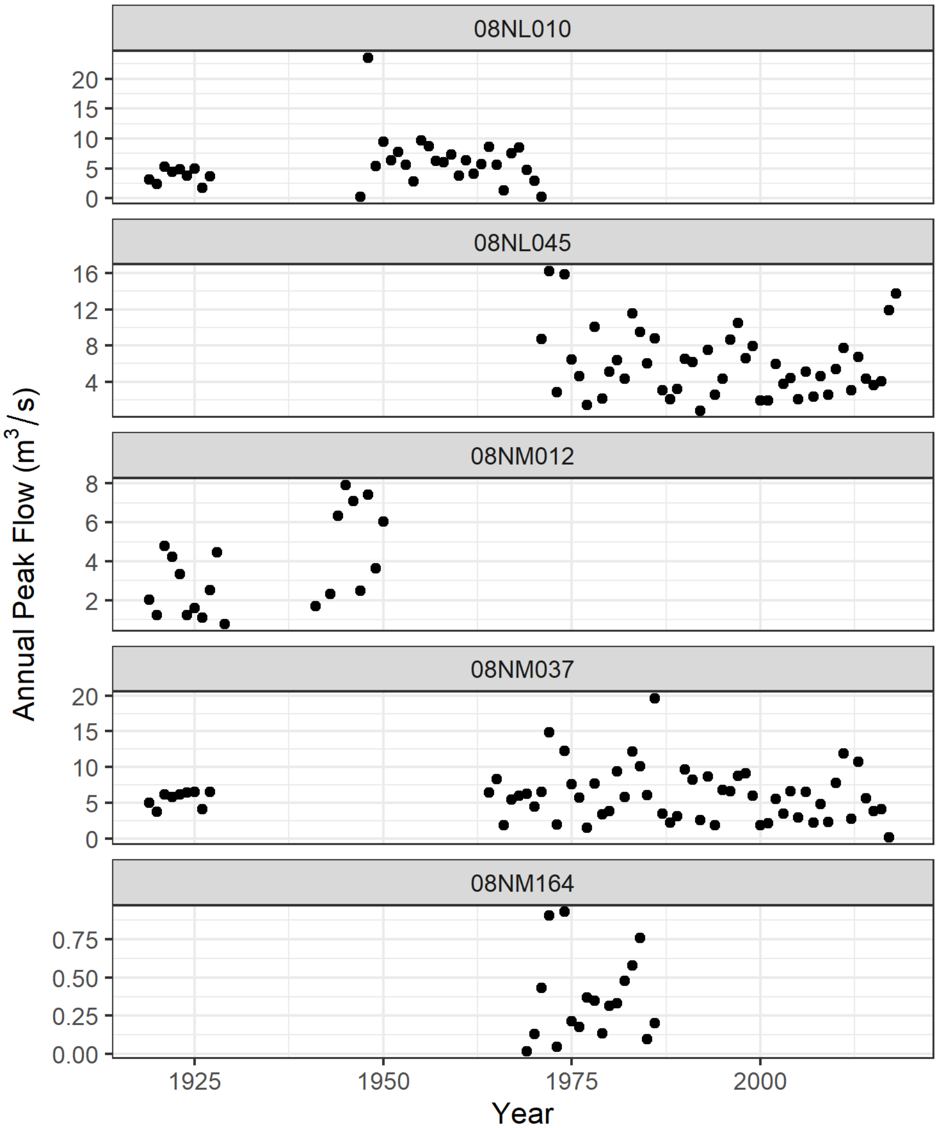

Figure 5.2 Annual instantaneous peaks at the five regional gauges used in the frequency analysis

The hydrometric data from all gauges were visually inspected for errors. A Mann-Kendall trend test was performed to check for stationarity (Kendall, 1975). The Mann-Kendall test indicated that there was no trend in the series. ($p > 0.05$). The gauge data was also checked for low and high outlier data using the multiple Grubbs-Beck low outlier test (Cohn et al., 2013) and a single sided Grubbs-Beck test for high outliers (Grubbs and Beck, 1972).

5.1.3 Regional Frequency Analysis

The regional frequency analysis was performed by fitting the Log-Pearson Type III distribution to the peak flow observations at the five WSC gauges using the method of L-moments in the statistical language 'R' (Hornik, 2016). A bootstrap resampling of 1,000 samples was used to determine the 90%

confidence interval of each distribution[4]. Low outliers were not included within the frequency analysis. Results are shown in Figure 5.3 for return periods up to the 200-year.

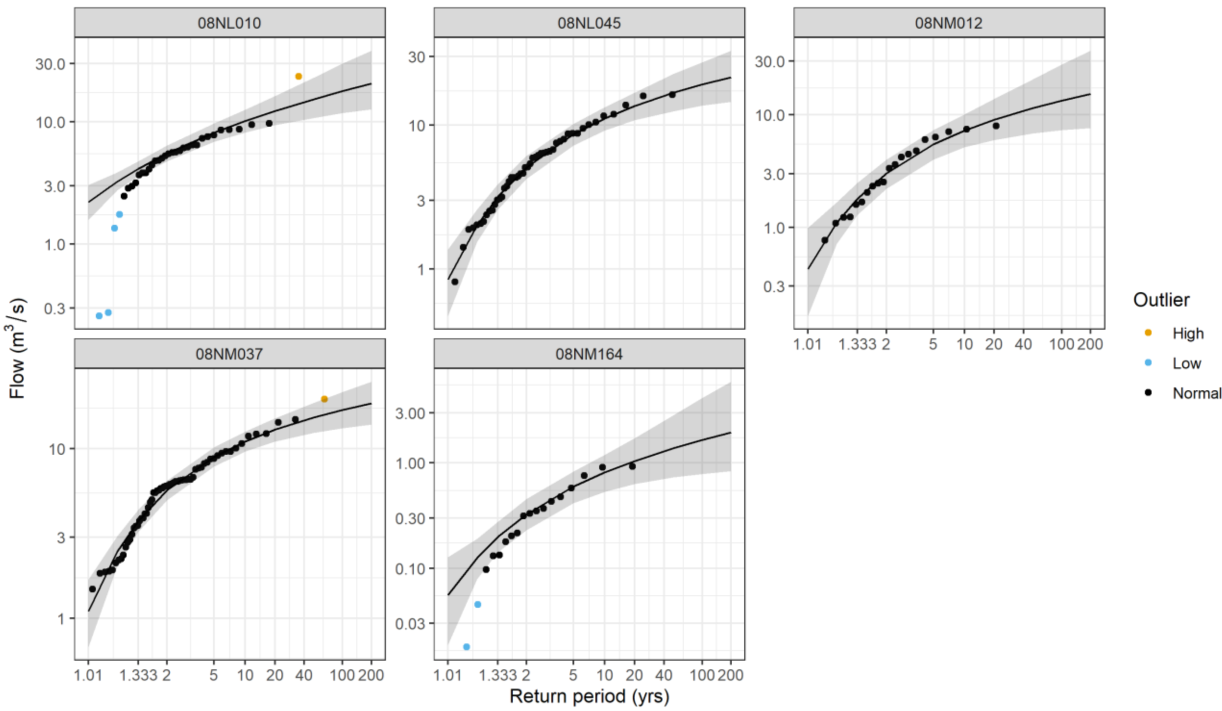

Figure 5.3 Frequency distributions for gauges used in the regional analysis

After calculating the regional distributions, a regional model of area versus peak flow for the desired return periods (10, 50, 100 and 200 years) was used to estimate peak flows in the Park Rill Creek watershed. Power models were fit to the regional data of the form:

$$Q = a * A^b$$

where Q is the peak flow estimate, A is the catchment area, and a and b are fitted coefficients. Figure 5.4 shows the resultant models for the four return periods of interest.

[4] http://headwateranalytics.weebly.com/blog/flood-frequency-analysis-in-r

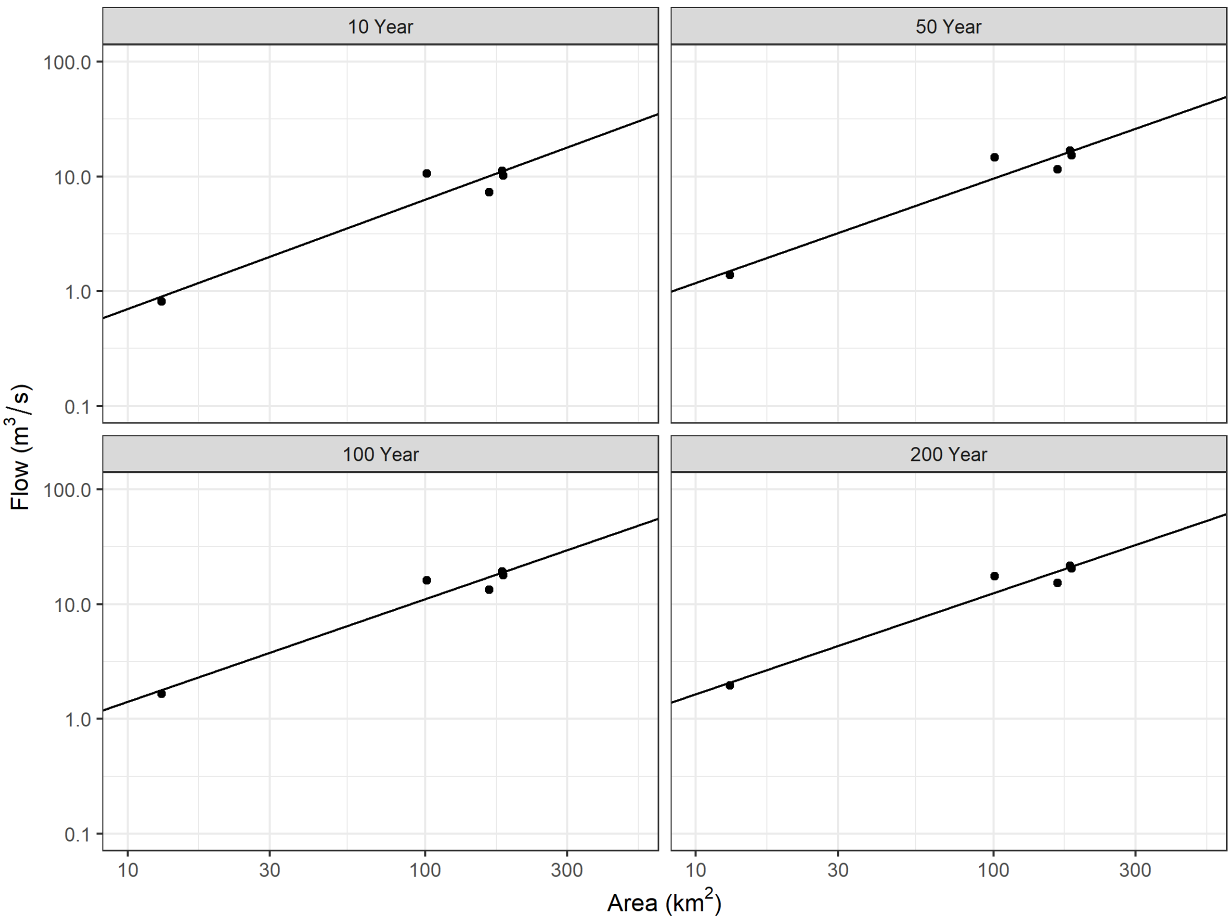

Figure 5.4 Fitted power models for the return periods of interest

The power models were used to estimate flood flows at the inflow locations to be used for flood mapping. The hydraulic model requires estimates at Kearns Creek above Willowbrook (39.5 km^2), Park Rill Creek above Willowbrook Road (64.2 km^2), and Park Rill Creek above Sportsmens Bowl Road (164 km^2). Low and high uncertainty estimates were developed based on the upper and lower bounds generated from the 90% confidence intervals from the frequency analysis.

To account for climate change, NHC utilized a previously developed Raven hydrological model of the Okanagan watershed authorized for use in this project by the Okanagan Basin Water Board (NHC, 2020a). The Raven model uses 50 climate ensembles that produce daily timestep weather for the period 1950-2100, produced via downscaling of CanESM2 climate model output provided by Environment and Climate Change Canada (ECCC). The model outputs from the model simulations were used to develop present day (2006-2035) and end of century (2071-2100) frequency analysis for gauges included in the model calibration. The average relative change between present day and end of century period for six nearby gauges was applied to Park Rill. The gauges (Trepanier Creek, Vaseux Creek above Solco Creek, Powers Creek, Penticton Creek, Shingle Creek and Shatford Creek) were selected based on their proximity and use in calibration. Figure 5.2 summarizes the relative changes at the four return periods. Figure 5.3 summarizes the peak flows for different return periods at the inflow locations.

Table 5.2 Relative change in peak flow due to projected climate change, based on present day (2006-2035) versus end of century (2071-2100)

Return Period	Relative Change (%)
10-year	9.8
50-year	9.6
100-year	12.4
200-year	12.9

Table 5.3 Flow estimates and uncertainty ranges for the 10-, 50-, 100-, and 200-year peak flow

Return Period	Location	Present (2006-2035)		Future (2071-2100)	
		Peak Flow Estimate (m^3/s)	Uncertainty Range (m^3/s)	Peak Flow Estimate (m^3/s)	Uncertainty Range (m^3/s)
10-year	Kearns Creek	2.6	1.8 - 3.5	2.9	2.0 - 3.8
	Park Rill (Willowbrook)	4.1	3.1 - 5.4	4.5	3.4 -5.9
	Park Rill (Sportsmens Bowl Rd)	10.1	8.0 - 12.4	11.1	8.8 -13.6
50-year	Kearns Creek	4.1	2.5 - 7.3	4.5	2.7 - 8.0
	Park Rill (Willowbrook)	6.4	4.1 - 10.6	7.0	4.5 - 11.6
	Park Rill (Sportsmens Bowl Rd)	15.1	10.6 - 22.0	16.5	11.6 - 24.1
100-year	Kearns Creek	4.8	2.6 - 9.9	5.4	2.9 - 11.1
	Park Rill (Willowbrook)	7.4	4.3 - 14.0	8.3	4.8 - 15.7
	Park Rill (Sportsmens Bowl Rd)	17.2	11.3 - 27.6	19.3	12.7 - 31.0
200-year	Kearns Creek	5.5	2.7 - 13.4	6.2	3.0 - 15.1
	Park Rill (Willowbrook)	8.5	4.5 - 18.4	9.6	5.1 - 20.8
	Park Rill (Sportsmens Bowl Rd)	19.4	11.9 - 34.1	21.9	13.4 - 38.5

The above flow estimates do not take into consideration the addition of pumping from Lower Twin Lake into the Park Rill watershed. In 2018, two diesel pumps were used along with the existing Lower Nipit Improvement District (LNID) pump to pump 17,500 m^3/day (~0.2 m^3/s) from Lower Twin Lake into the Park Rill watershed. Potential long term flood mitigation solutions for Lower Twin Lake include a gravity drain pipe to Park Rill Creek with a flow rate of 1.6 m^3/s (Ecora and Dobson Engineering Ltd., 2019b). NHC recommends that this inflow from Lower Twin Lake into Park Rill be included in the Park Rill Creek design flows.

NHC recommends that the 200-year return period adjusted for end-of-century climate change with the addition of an inflow from Lower Twin Lake of 1.6 m^3/s be used for flood modelling and flood mapping. **If the design flow rate from Lower Twin Lakes to Park Rill Creek is increased above the current design flow of 1.6 m^3/s, then the floodplain maps will need to be updated to account for the higher flow.** Table 5.4 summarizes NHC's recommended design flows.

Table 5.4 Recommend design flows for flood mapping based on 200-yr event under future climatic conditions

Location	Design Flow (m^3/s)
Kearns Creek	6.2
Park Rill Creek (at Willowbrook)	11.2
Park Rill Creek (at Sportsmens Bowl Rd)	23.5

According to EGBC (2018), Legislated Flood Assessments in a Changing Climate in BC, page 13:

> Few local governments currently have comprehensive bylaws to guide flood assessments. Over time, it is expected that many local governments will adopt such bylaws that consider these and other guidelines. In the absence of a national or provincial standard, it is also expected that local governments will establish an appropriate local standard (adopted level of flood safety) to guide preparation of QP [sic[5]] Flood Assessment Reports. This may include some or all of the following (for various types of hazards and/or development types):
>
> - Minimum design return periods
> - Risk Assessment criteria (such as discussed in Appendix E: Flood Risk Assessment)
> - Direction on when a QP may apply a standard based approach versus a Risk-based approach

The above applies to this project as follows: NHC has provided RDOS with recommended design flows for the floodplain mapping and RDOS selected the final values to use as shown in Table 5.4.

5.1.4 Design Flow Comparison

A comparison of NHC's recommended design flow estimates to previous reports and work done within the catchment are summarized in Table 5.5. For comparison, flow from Lower Twin Lake was excluded from the table.

[5] Qualified Professional

Table 5.5 Comparison of NHC's recommended design flows (without Lower Twin Lake flow) to previous estimates

Return Period	Location	NHC Flow (m^3/s)	MOTI Flow (m^3/s)	Ecora Flow (m^3/s)
100-Year	Park Rill (Sportsmens Bowl Rd)	19.3	11.55	-
200-Year	Kearns Creek	6.2	-	2.7
	Park Rill (Willowbrook)	9.6	-	3.5
	Park Rill (Sportsmens Bowl Rd)	21.9	-	5.9

The flow estimated by NHC is substantially greater than that estimated by MOTI (2019) and Ecora (Ecora and Dobson Engineering Ltd., 2019a). The design flows Ecora estimated are based on regional gauges with fewer observations than those selected by NHC, and as a result should have a higher uncertainty associated with them. NHC recommends a more conservative approach to the flood mapping with a sensitivity analysis of the inflow values be included in the hydraulic modelling component.

5.1.5 Design Hydrographs

To support the hydraulic modelling, event hydrographs were developed for the three inflow locations. The 5-minute WSC gauge data from Keremeos Creek below Willis Intake (08NL045) from 2018 was used as the basis of the design hydrographs, as this is the closest functioning gauge with data in 2018. The hydrograph was scaled based on the observed maximum and converted to an hourly timestep for use in the hydraulic model. The unitless hydrograph is shown in Figure 5.5.

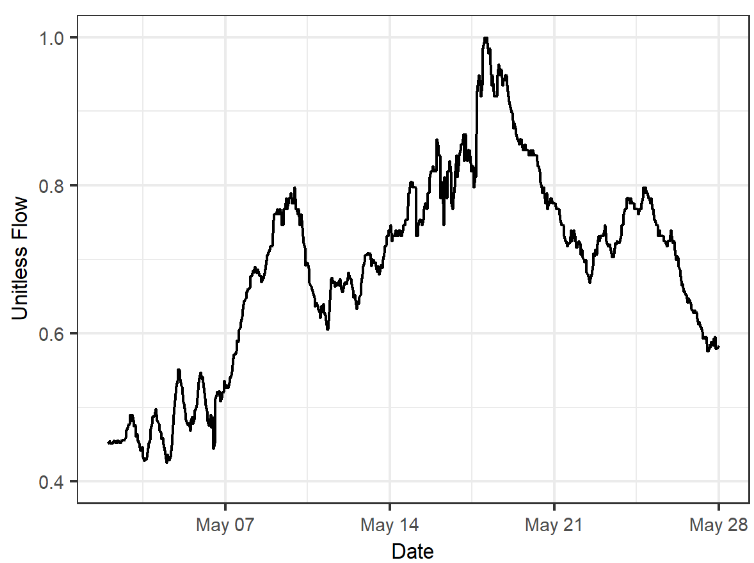

Figure 5.5 Unitless design hydrograph for Park Rill Creek

5.2 Lower Twin Lake

A frequency analysis was performed for Lower Twin Lake to determine the 10-, 50-, 100-, and 200-year lake levels.

5.2.1 Historical Data

Historical data from a pre-existing WSC gauge (08NM148) was combined with more recent data from the LNID to create a record of lake levels for Lower Twin Lake. The WSC gauge was active from 1968 to 1977. The LNID has compiled a record of historical lake levels from 1970 to present day (LNID, 2020). The record also includes indication of pumping and diversions that occurred each year. Within the record, annual peaks were recorded from 1997 to present day. The LNID has confirmed that the annual peaks are relative to the same datum as the WSC gauge.

Since 1997, Lower Twin Lake is pumped to negate high water levels. To account for pumping lowering the recorded peak water levels, annual peaks were converted to lake volumes using a stage-storage curve. The volumes pumped from the lake prior to the peak were added to the lake volume to determine the “naturalized” peak each year. In 2018, a 2.4 m (8’) high sandbag dike was in place around the lake, so a modified stage-storage curve was used.

The historical maximums and pre-freshet levels were taken from the naturalized data. Years in which only one measurement was taken, that did not indicate if it was the peak level, were excluded. Additionally, years of WSC gauge data were excluded if the maximum measured value was the observed first day or there was no observed rise due to freshet. A total of 23 years were used in the analysis.

No consideration was made for storage of water in Upper Twin Lake or Turtle Pond. Measurement of water levels in these locations has only started in recent years and therefore could not be used for a long-term analysis. Water can be stored within Upper Twin Lake to reduce the levels on Lower Twin Lake; therefore, the naturalized peaks may be underestimated in years where this occurred.

5.2.2 Frequency Analysis

A conventional frequency analysis of maximum water levels within a lake assumes that lake levels are stationary and independent. Independence means that the observation of water level for a specific time or event is not influenced by the water level at a previous time and are not autocorrelated. Both the historical maximums and pre-freshet levels observed at Lower Twin Lake are significantly autocorrelated. The level of the lake pre-freshet significantly influences what the maximum levels are in any given year.

To account for the autocorrelation of the data and show the influence of the pre-freshet lake levels on the design level estimates, a conditional frequency analysis using the methodology developed by Buchberger (1995) was performed.

For the analysis, the pre-freshet values considered were the static water level and the rise due to the freshet, the dynamic disturbance. Figure 5.6 shows the historical data for the annual maximums, pre-freshet levels, and freshet rise.

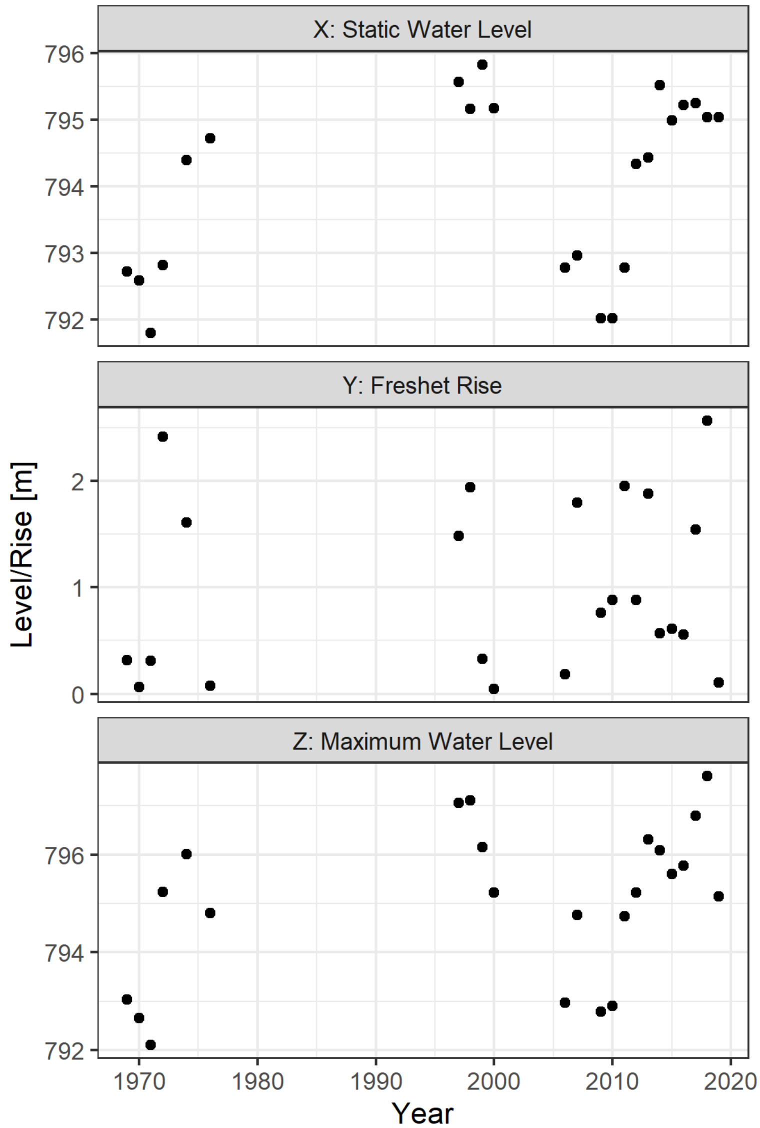

Figure 5.6 Static water levels (pre-freshet), freshet rise, and maximum water levels for Lower Twin Lake

The frequency analysis involves developing a conditional trajectory of the maximum lake levels depending on the initial conditions and the freshet rise. A range of elevations between the historical observed maximum and minimum pre-freshet levels were used in the analysis. Table 5.6 summarizes the 200-year design lake levels for the varying pre-freshet levels and how they compare to a traditional frequency analysis which does not consider the autocorrelation of the data.

Table 5.6 200-year design levels for varying pre-freshet lake levels

Pre-freshet Level (m)	200-Year Design Level (m)
791.83	796.06
792.83	796.90
793.83	797.74
794.83	798.58
795.83	799.42
Not Considered[1]	799.01

1. Log-pearson III distribution used on annual maximum recorded lake levels.

Table 5.6 shows that depending on what the pre-freshet levels are set as the design level will either be lower or higher than a traditional frequency analysis. When pre-freshet levels are low, results from a conventional frequency analysis would overestimate the design levels whereas when pre-freshet levels are high, the conventional frequency analysis would underestimate design levels.

To take into consideration climate change on the lake levels, the daily lake measurements from 2018 were used to create a scaled hydrograph. The pre-freshet and design levels from Table 5.7 were applied to create a hydrograph for each potential scenario. The relative changes calculated for the Park Rill analysis (Section 5.1.3) were applied to each hydrograph and converted back to an associated lake level and volume.

Table 5.7 summarizes the design levels for the various return periods and pre-freshet values. Two pre-freshet values are considered in the table: the historical maximum recorded in 1997 (795.82 m) and the mean value from 2013 to present day (795.12 m). The mean value from 2013 to present day was considered as this represents a period of high lake levels with current pumping operations. A sensitivity analysis of design levels will be included in the hydraulic modelling. However, given the significant autocorrelation within the data, NHC recommends that the more conservative results be applied and RDOS has selected these values as shown in the second row of applicable return periods in Table 5.7.

Table 5.7 Lower Twin Lake Design Levels for present day and future conditions

Return Period	Pre-Freshet Level (m)	Present (2006-2035) Design Level (m)	Future (2071-2100) Design Level (m)
10-year	795.12	797.38	797.56
	795.82	797.97	798.17
50-year	795.12	798.24	798.48
	795.82	798.83	799.09
100-year	795.12	798.54	798.90
	795.82	799.13	799.51

Return Period	Pre-Freshet Level (m)	Present (2006-2035) Design Level (m)	Future (2071-2100) Design Level (m)
200-year	795.12	798.82	799.23
	795.82	799.42	799.84

6 WAVE RUNUP ANALYSIS FOR LOWER TWIN LAKE

The purpose of this assessment is to identify appropriate wave effect values to consider for the Lower Twin Lake flood mapping. The wave runup values estimated were added to the design water level estimated through hydrologic analysis (799.84 m), as discussed in Section 5.

Historical hourly wind data for the region was downloaded for the three closest stations to the lakes:

- Keremos: Assumed location at Keremos Municipal Office at -119.8295 E, 49.2051 N with data from 2008- 2009.
- Apex Roadside: Maintained by the Ministry of Transportation and Infrastructure. Located at -119.9008 E, 49.3969 N with data from 1997 – present.
- Penticton Airport: Maintained by Environment Canada. Located at -119.6022 E, 49.4625 N with data from 1953 – present.

Data was retrieved from the database produced by the Pacific Climate Impacts Consortium (PCIC, 2021) and directly from Environment Canada for Penticton Airport. The Keremos Municipal Office Dataset was not used due to its limited duration and extremely low velocities recorded.

Extreme value frequency analyses were performed on both the Apex and the Penticton datasets to obtain wind speeds for design storms. The winds at Penticton Airport yielded a higher estimate and thus were selected to use for flood mapping. The Flood Hazard Area Land Use Management Guideline (MFLNRORD, 2018) recommends that wave effects should be based on storms with a 0.5% annual exceedance probability (AEP) which has an average return period of 200 years. This wind speed (23.8 m/s) was then rounded up to account for the fact that Twin Lakes is approximately 100 m higher than the Penticton Airport, resulting in a design wind speed of 25 m/s.

Open water exposure and the fetch (the distance that wind applies over) of Lower Twin Lake were assessed and loosely broken down into three groups:

1. Southern shoreline: exposed to the largest fetch from the north.
2. Northern shoreline: exposed to a minor fetch from the south.
3. East and west shorelines: exposed to minor fetch.

Note that some portions of the southern basin had similar fetch lengths to the north and have been treated as equal in the final results.

Using these fetch lengths and the design wind speed, a wave hindcast was performed to estimate wind-generated waves on the lake (Kamphuis, 2010). With the resulting significant wave heights and peak wave periods, the potential runup (the vertical distance that a wave reaches on the slope of a structure or shoreline, measured from the design water level) was then assessed using empirical equations (EurOtop, 2018). Runup is typically calculated as the elevation that 2% of the waves will exceed (R2%). The resulting recommended values for flood mapping are presented in Table 6.1 as well as graphically in Figure 6.1.

Table 6.1 Recommended wave parameters for use in floodplain mapping

Shoreline Segment	Significant Wave Height (m)	Peak Wave Period (s)	Runup, R2% (m)
South	0.4	1.7	0.4
North	0.3	1.3	0.3
East & West	0.2	1.2	0.2

Boat wakes were not considered in this analysis. Boat wakes can exceed the largest wind-waves on this lake. Boating activity (for example, speed) should be curtailed or restricted during high lake levels to avoid property damage.

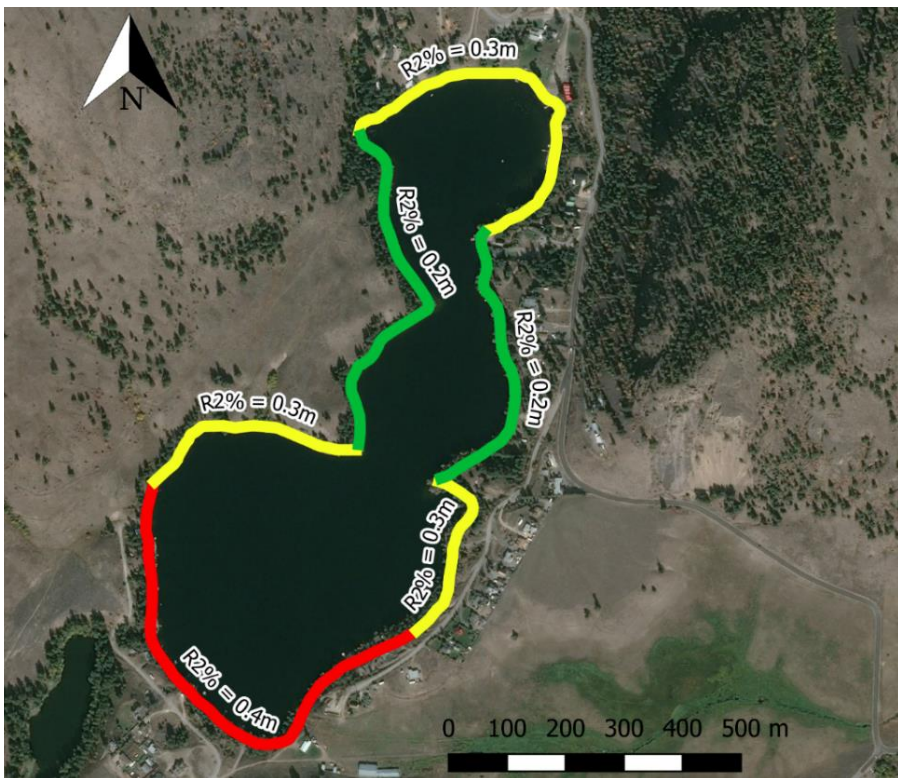

Figure 6.1 Recommended runup values for use in flood mapping

7 RIVERINE HYDRAULIC MODELLING

To assess the flood hazard in Willowbrook and Sportsmens Bowl Road areas, two independent 2-dimensional (2D) hydraulic models were developed. A 2D hydraulic model is a key tool for simulating flood levels and improving the understanding of flood hazards, risks, and mitigation options. This type of model is suitable for representing complex flow patterns without sharp changes in slope; this includes confluences, eddies, bends, bank overtopping, and multi-directional flow across floodplains. Results from model simulations indicate flood extents, depths, and velocities under different flood scenarios. Model simulations can also be used to evaluate the effectiveness of structural flood mitigations.

The 2D module of HEC-RAS, developed by the Hydrologic Engineering Center of the US Army Corps of Engineers, was used for this purpose. HEC-RAS was selected due to a number of significant advantages over other popular hydraulic modelling software such as MIKE 21 or TELEMAC 2D, namely:

- Superior graphic user interface.
- The ability to model the effects of pressurized flow and overtopping flow at culverts.
- The sub-grid modelling approach used by HEC-RAS allows for a larger cell size while adequately capturing topographic controls on the floodplain such as roads or dikes.
- Open source and wide user base.

7.1 Model Development

Model development involves the following steps (Figure 7.1):

1. defining inflow hydrology and lake levels;
2. connecting the river channel bathymetry to lidar data to develop a DEM;
3. defining a cell size for hydraulic modelling and building the model geometry; and
4. undertaking model verification.

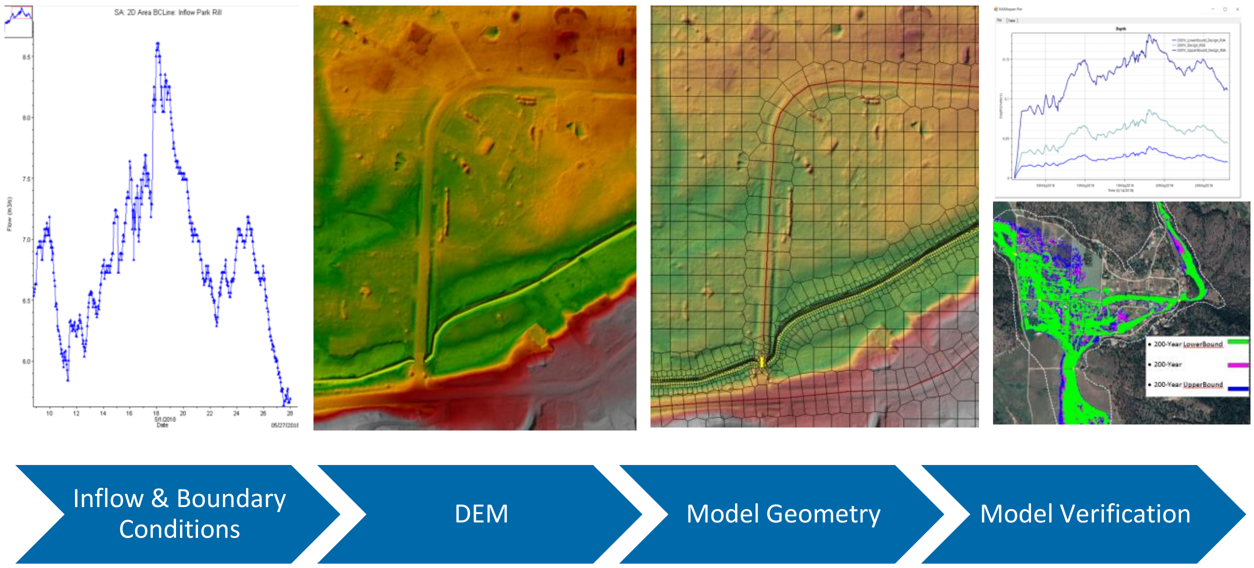

Figure 7.1 Overview of steps undertaken for development of the HEC-RAS 2D models

The model layout for the Willowbrook and Sportsmens Bowl Road 2D models are shown in Figure 7.2 and Figure 7.3, respectively. Channel bathymetry was connected to 2018 GeoBC lidar in order to create a seamless representation of the terrain, as described in Section 3. The resulting DEMs form the main building block of the models. Model geometry was generated using various cell sizes to balance model accuracy with computation times. A nominal cell size of 2 m was used in the main channels and of up to 20 m in the floodplain. To improve representation of hydraulic control structures such as roads and other topographical features, breaklines were digitized along these features. Culvert structures were added at crossing locations and culvert parameters were based on field observations. Culverts are assumed to be unblocked. Roughness coefficients based on river characteristics, land use, and ground cover were assigned and then verified during the model verification process described in Section 7.2. Final roughness coefficients (Manning's n) are summarized in Table 7.1 and land use spatial distribution is shown in Figure 7.4 and Figure 7.5.

Table 7.1 Roughness coefficients (Manning's n) used for hydraulic modelling

Land Use	Willowbrook	Sportsmens Bowl Rd
Brush	0.05	0.05
Forest	0.08	0.08
Grass	0.05	0.04
Road	0.02	0.02
Urban	0.045	0.045
Water	0.04	0.04

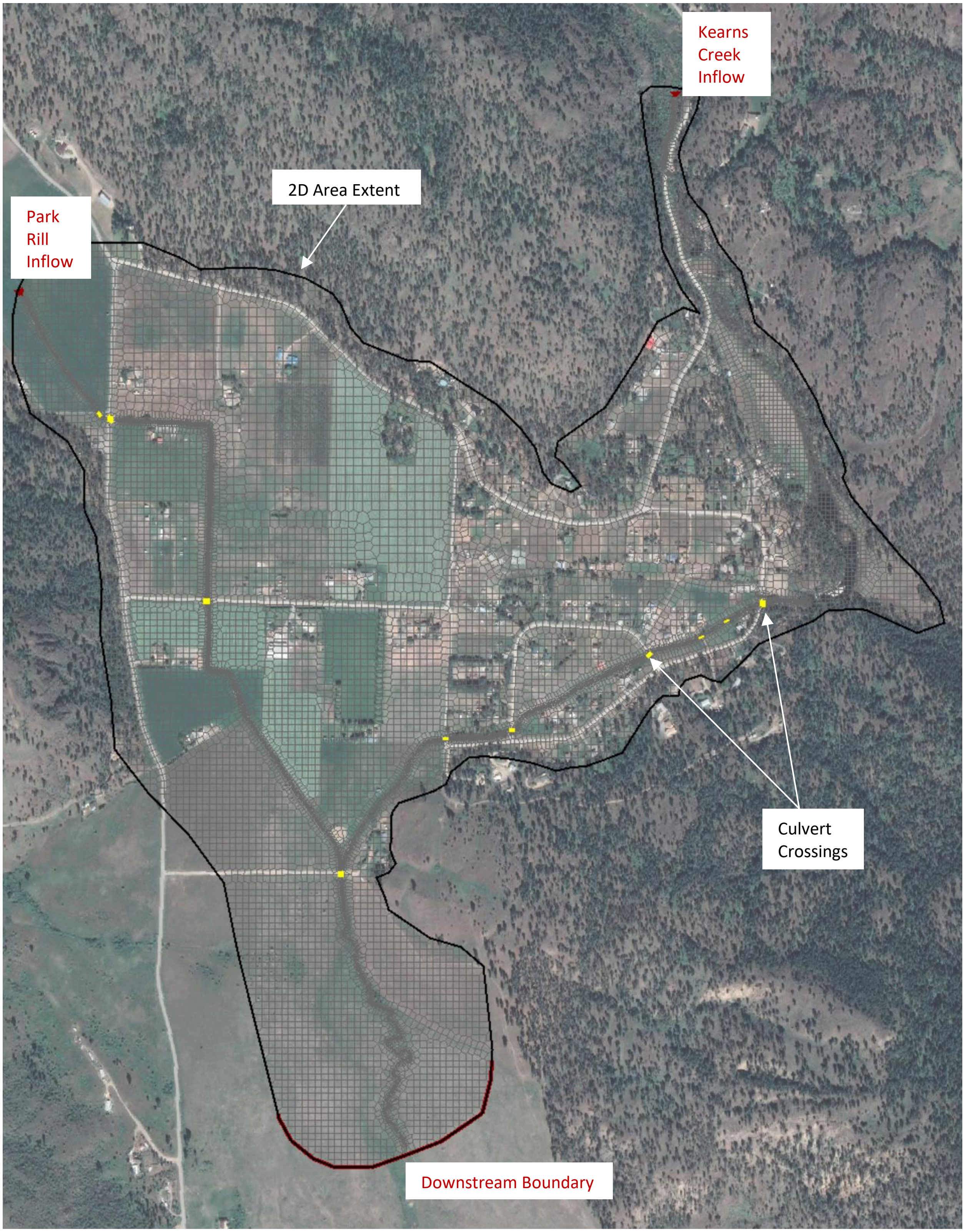

Figure 7.2 Willowbrook 2D model layout

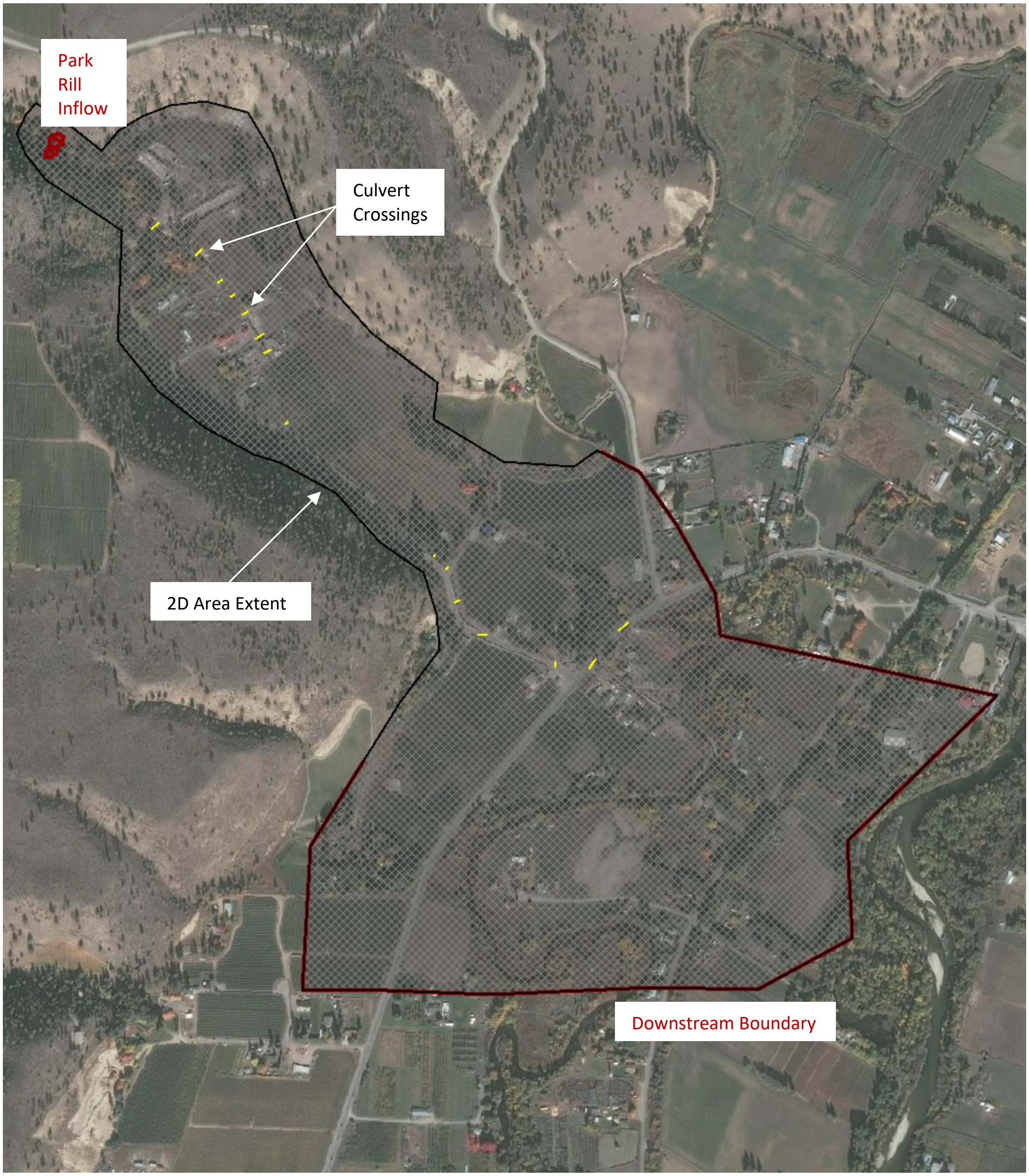

Figure 7.3 Sportsmens Bowl Road 2D model layout

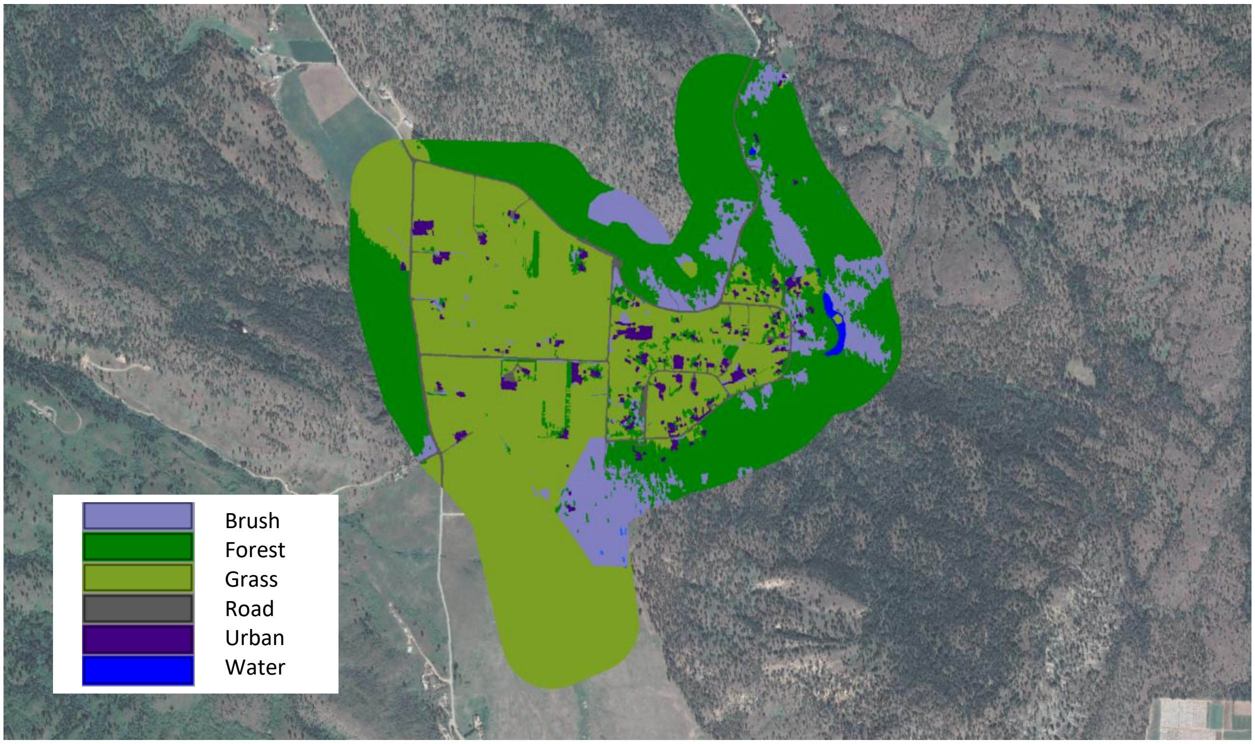

Figure 7.4 Willowbrook land use map

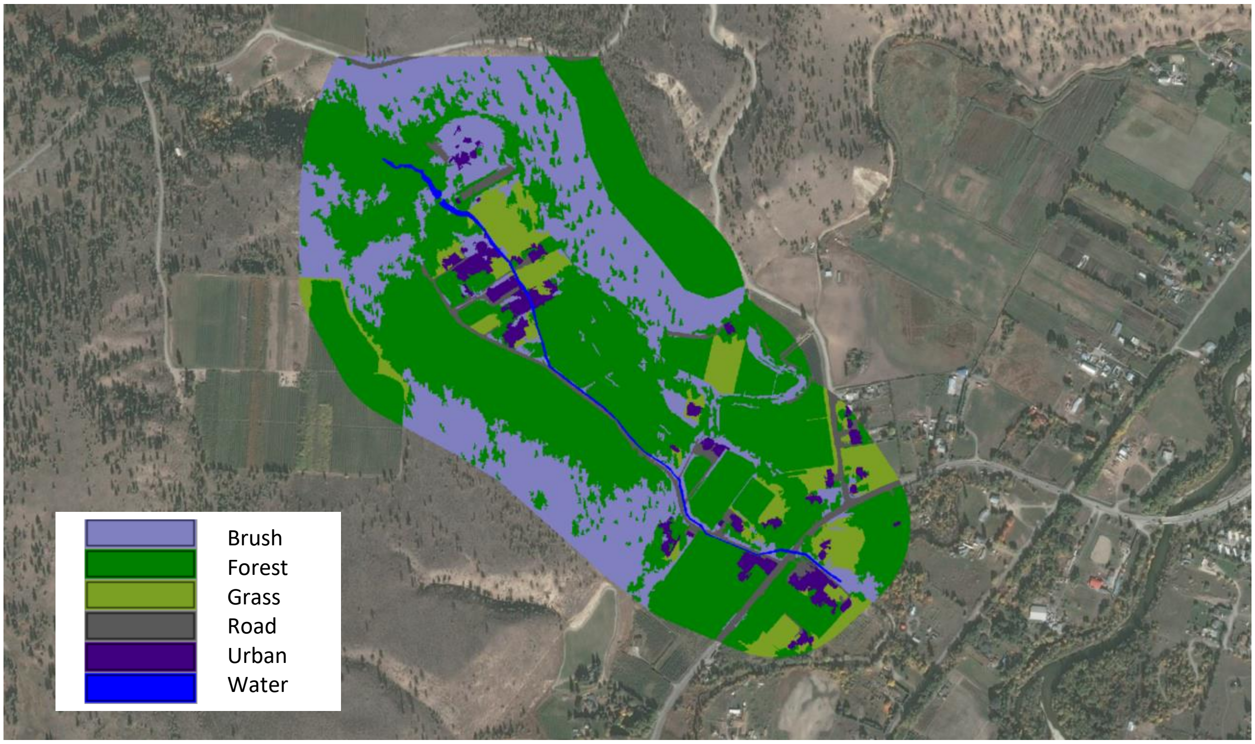

Figure 7.5 Sportsmens Bowl Road land use map

7.2 Model Verification (Sensitivity Testing)

Due to lack of measured data for calibration and validation, verification of the models was completed through sensitivity testing. Sensitivity testing provides an understanding of how the model reacts to specific changes in the model inputs. The sensitivity testing process includes the following steps (FHWA, 2019):

1. Adjust estimated model parameters.
2. Observe changes to the model results.
3. Compare changes to pre-adjusted model condition.
4. Determine preferred parameters for specific analysis.

For Willowbrook and Sportsmens Bowl, roughness coefficients and inflows constitute the two main sources of uncertainty. Other parameters such as mesh resolution and hydraulic structure parameters were also tested but were found to have a minor impact on model results and were not included herein. Adjustments to parameters should be made within the extreme ranges of reasonable error. Initial roughness coefficients were selected based on land use characteristics and were then globally varied by ±25%. The inflow test was based on the hydrologic uncertainty range discussed in Section 5. Results of the sensitivity tests are described below.

In addition to the sensitivity tests described in the subsections below, modelled flow paths were compared to those observed in photographs and footage from the 2018 flood event. Figure 7.6 shows modelled and observed flow patterns at two locations within the Sportsmens Bowl Road area.

Figure 7.6 Comparison of modelled flow paths with 2018 flood drone footage for Sportsmens Bowl Road area. Top: flooding through fields between Park Rill Creek main channel and Sportsmens Bowl Road. Bottom: flooding through Park Rill Creek old channel alignment.

7.2.1 Roughness Inflow Sensitivity Testing

For each model, three scenarios were simulated to understand the sensitivity of the models to changes in the Manning's n roughness values. These were 1) base scenario, 2) base scenario +25%, and 3) base scenario -25%. The base scenario roughness coefficients were selected based on the land cover and physical characteristics of the area. The roughness values were globally varied for scenarios 2 and 3.

Figure 7.7 and Figure 7.8 show the maximum variation in water level, or water surface elevation (WSE) range, resulting from comparing results for runs 1 and 3, for each model. For Willowbrook, the WSE generally ranges between 0.03 and 0.05 m in the floodplain. The Kearns Creek channel upstream of the residential area is more sensitive to roughness changes, varying by up to 0.15 cm. The results for Sportsmens Bowl are similar, with general differences of a few cm in the floodplain and a difference of up to 0.11 m in the channel.

Note that the WSE ranges were calculated based on the extreme scenarios. This means that the difference between the base scenario and the two extreme scenarios (+25% and -25%) is about half of the total WSE range. The models are considered to be robust with respect to the roughness parameter. The differences found are within typical calibration targets (i.e., 0.10 to 0.20 m) and would be sufficiently compensated by the freeboard allowance. For this reason, the base roughness coefficients are considered adequate for modelling.

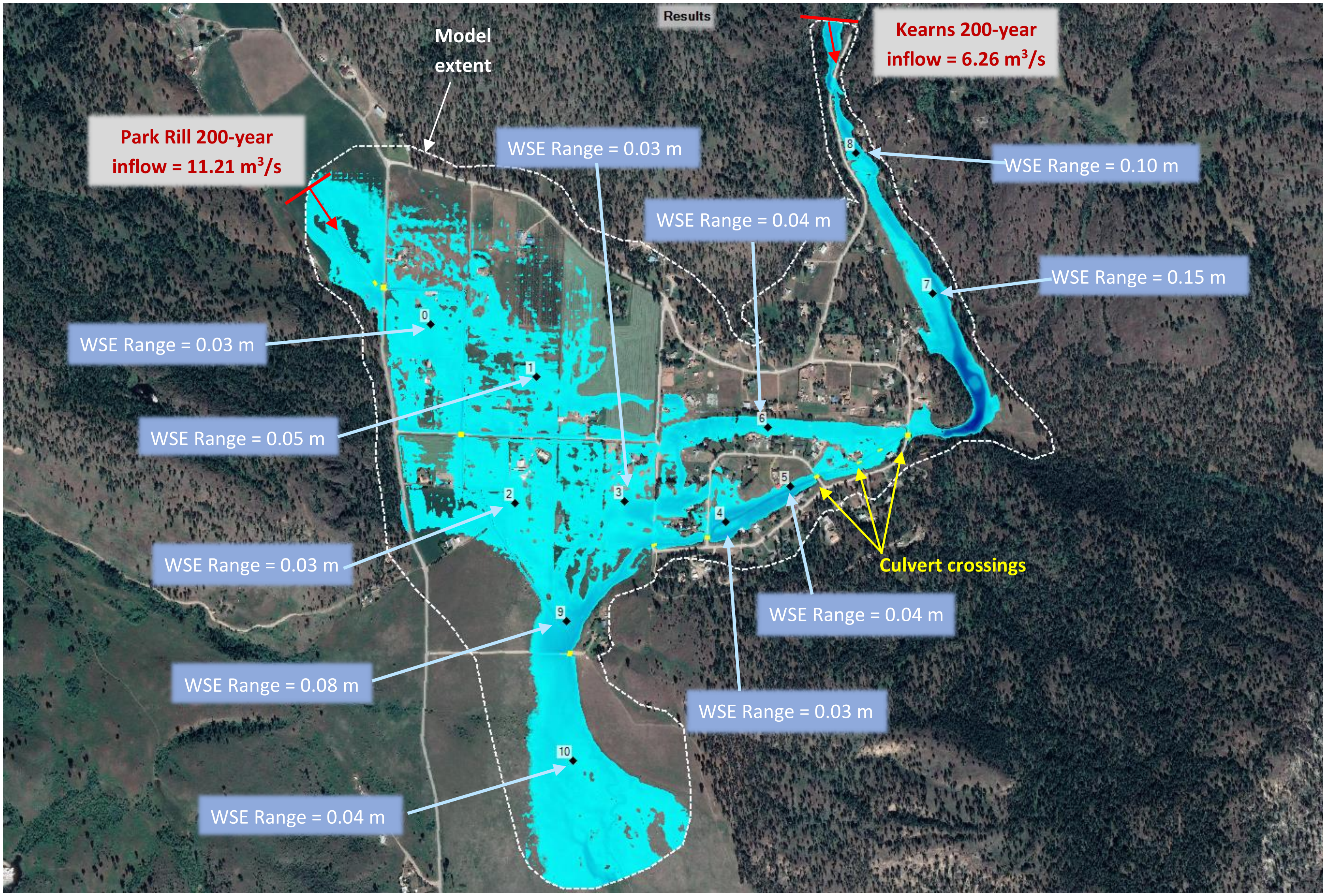

Figure 7.7 WSE variance for roughness sensitivity testing at Willowbrook

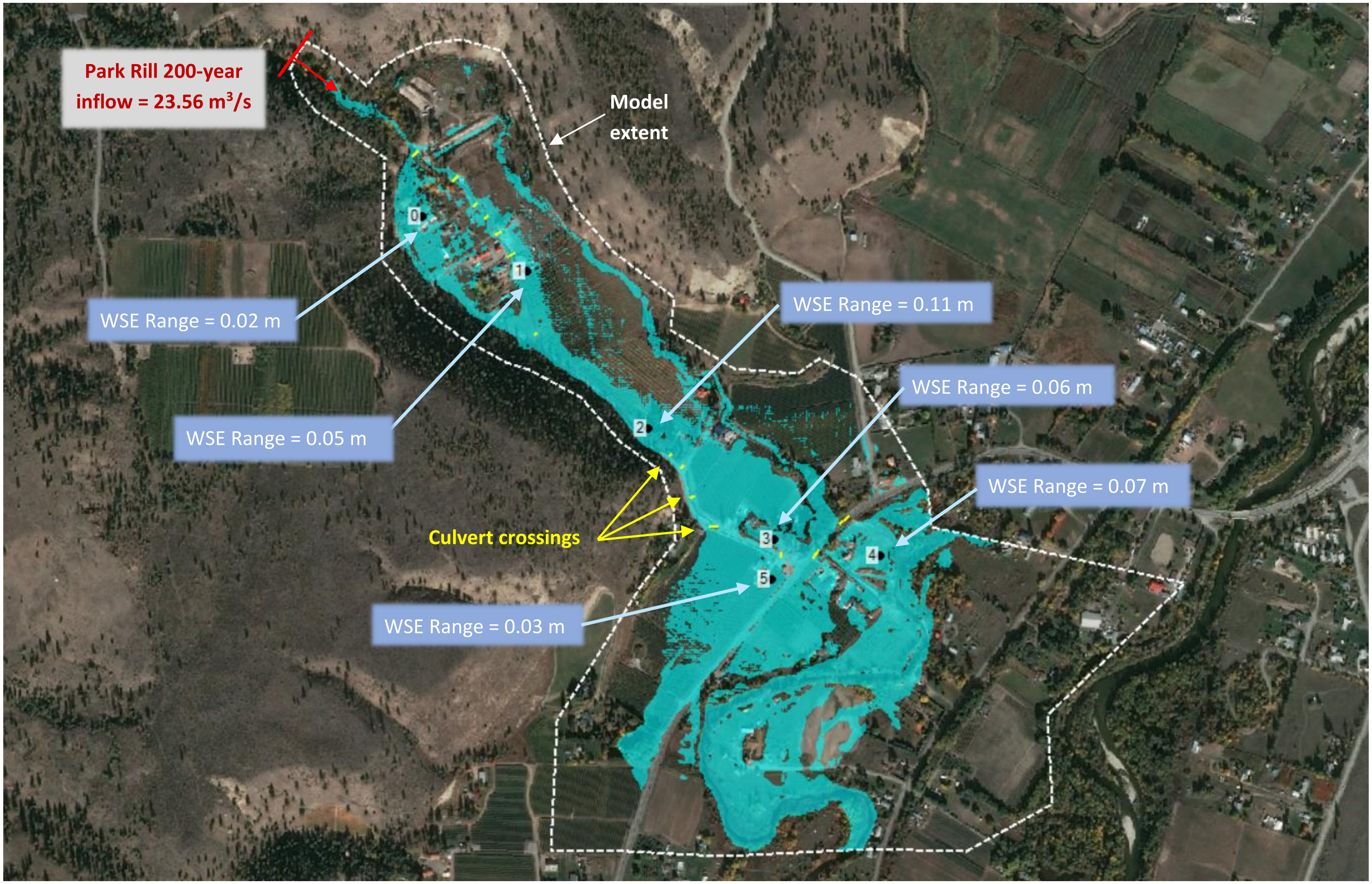

Figure 7.8 WSE variance for roughness sensitivity testing at Sportsmens Bowl Road

7.2.2 Inflow Sensitivity Testing

To test the model's sensitivity to changes in flow, three inflow scenarios were simulated for each model: 1) 200-year base scenario, 2) 200-year upper bound scenario, and 3) 200-year lower bound scenario. The base roughness coefficients were used in all simulations. The corresponding flows are summarized in Table 7.2. These are based on the uncertainty range presented in Table 5.3 for the future (2071-2100) time frame. Park Rill flows were increased by 1.6 m^3/s to account for the additional discharge coming from Twin Lakes.

Table 7.2 Flows used for sensitivity testing

	Future (2071-2100) Flow Estimate (m^3/s)		
Location	**200-year base**	**200-year upper bound**	**200-year lower bound**
Kearns Creek	6.2	15.1	3.0
Park Rill (Willowbrook)	11.2	22.4	6.7
Park Rill (Sportsmens Bowl Rd)	23.5	40.1	15.0

Figure 7.9 and Figure 7.10 show the maximum variation in WSE, or WL range, calculated as the difference between the upper and lower bound scenarios, for each model. For Willowbrook, the WSE generally ranges between 0.06 and 0.13 m in the floodplain. Differences in the channel range from 0.14 to 0.28 m. Similar to the roughness sensitivity testing, the Kearns Creek channel upstream of the residential area is also considerably more sensitive to inflow changes, varying by up to 0.49 cm. The results for Sportsmens Bowl show a WSE range around 0.05 m in the floodplain and 0.15 m on average in the channel.

Based on these results, the models are considered to be robust with respect to the flow range. The differences found are within the uncertainty tolerance of the models and would be sufficiently compensated by the freeboard allowance. In order to understand the implications of these differences in the flood extents, the maximum extents for all scenarios were compared. Figure 7.11 and Figure 7.12 show the comparison.

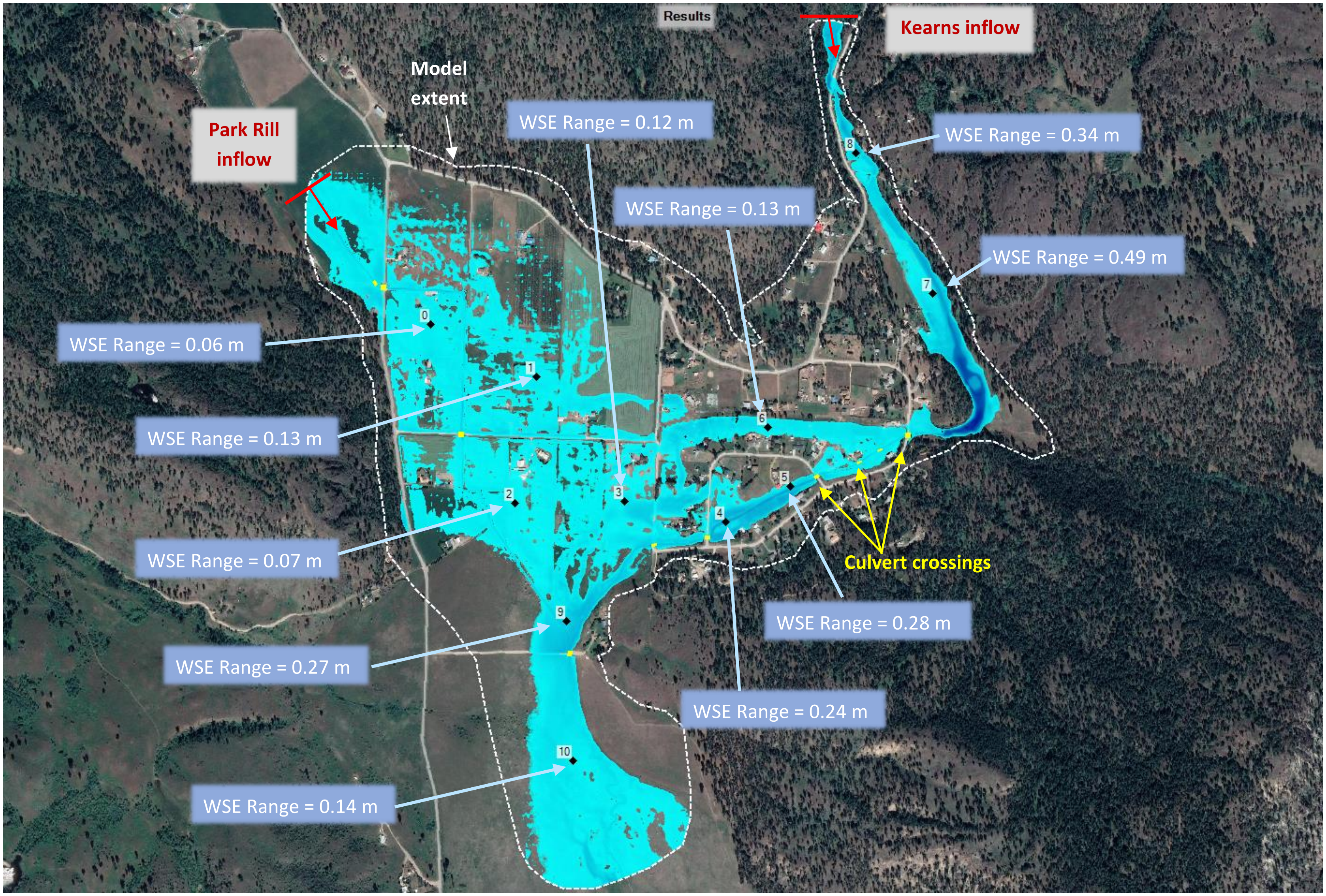

Figure 7.9 WSE variance for inflow sensitivity testing at Willowbrook

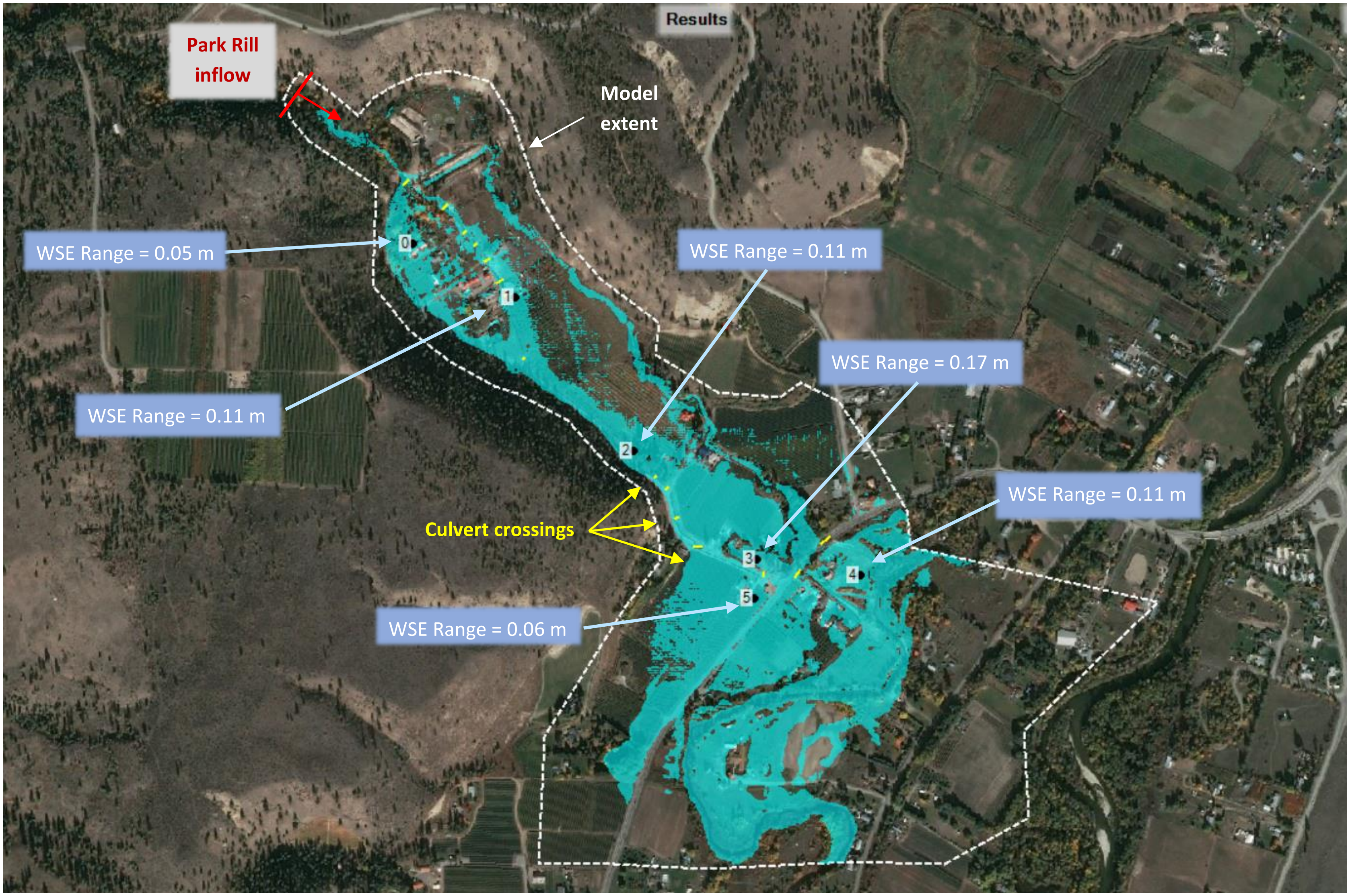

Figure 7.10 WSE variance for inflow sensitivity testing at Sportsmens Bowl Road

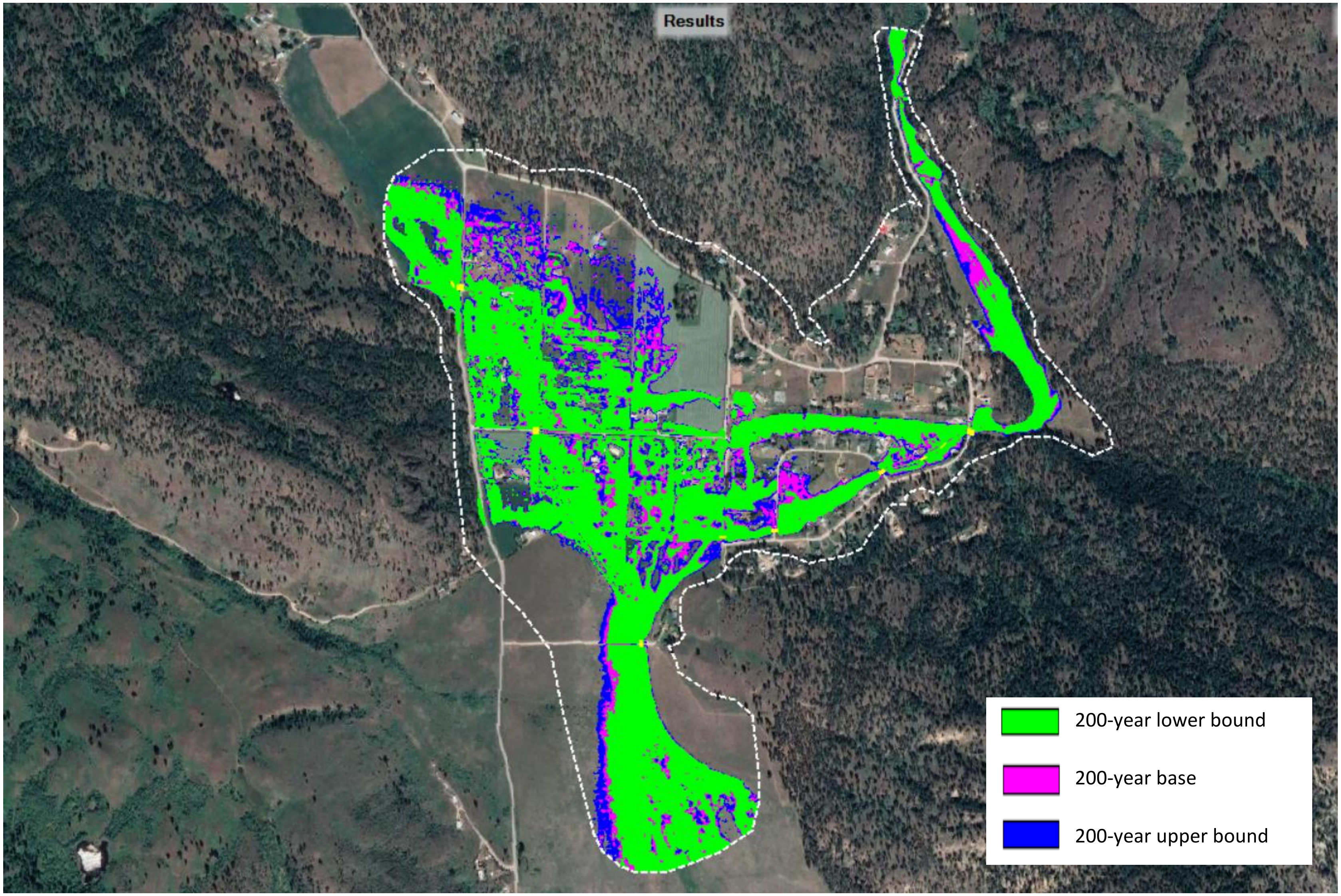

Figure 7.11 Inundation extent variance for inflow sensitivity testing at Willowbrook

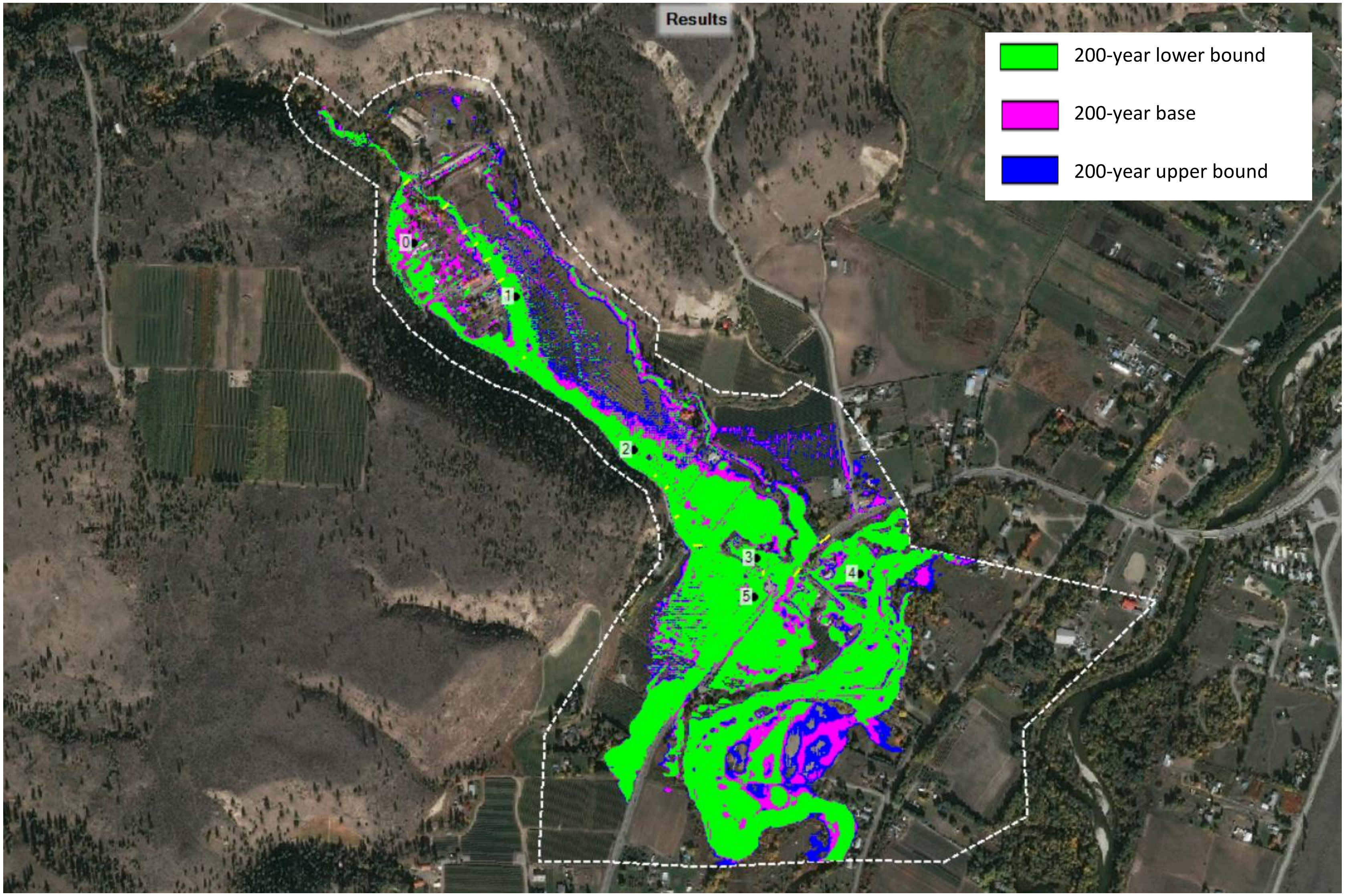

Figure 7.12 Inundation extent variance for inflow sensitivity testing at Sportsmens Bowl Road

7.3 Base Model Runs

After model verification was completed, runs were produced for a range of flow conditions. Table 7.3 summarizes the inflows used in the base runs. These inflows represent the peak of the hydrograph for each simulation. The hydrographs were based on the design hydrographs presented in Section 5.1.5.

Table 7.3 Summary of base model runs

		Upstream boundary condition - Inflow (m^3/s) End-of-century climate change conditions (2071-2100)			
Model	**Location**	**10-year**	**50-year**	**100-year**	**200-year**
Willowbrook	Kearns Creek	2.9	4.5	5.4	6.2
	Park Rill (Willowbrook)	6.1	8.6	9.9	11.2
Sportsmens Bowl Road	Park Rill (Sportsmens Bowl Rd)	12.7	18.1	20.9	23.5

Note: Park Rill Creek flows were increased by 1.6 m^3/s with respect to the values reported in Table 5.3, to account for additional flow from Lower Twin Lake during flood events.

Depth, velocity, and hazard diagrams for all base runs and for each model are included in Appendix A and discussed in Section 8.2.2. Hydraulic modelling results are also submitted in raster format, as listed in Table 11.1.

8 FLOOD AND HAZARD MAPPING

8.1 Flood Mapping Products

Based on the hydrologic analyses and hydraulic modelling, a variety of maps were produced to illustrate the results for Lower Twin Lake, Willowbrook, and Sportsmens Bowl Road areas. The designated event for flood mapping products corresponds to the '200-year under end-of-century climate change conditions' flood scenario, as selected by the RDOS following NHC's recommendation. The maps are displayed on a set of four 24"x36" map sheets at a 1:2,500 scale and are accompanied by a 1:25,000 scale index map which includes detailed map notes. The coordinate system used is UTM Zone 11N metres NAD 83 (CSRS) and vertical datum is CGVD2013.

The maps have been provided separately from this report. Mapping products include:

1. Floodplain maps for the design event. Flood Construction Levels (FCLs) and flood extents include a 0.6 m freeboard allowance in Lower Twin Lake and a 0.3 m freeboard allowance in Willowbrook and Sportsmens Bowl Road.

2. Flood depth maps for the design event. The extent and depth of the flooding does not include freeboard. These map sheets provide supplementary information to the floodplain maps, by classifying the computed water depths on the floodplain according to the hazard classification system summarized in Table 8.1. The depth map sheets do not include FCL values and are not intended to be used without the designated floodplain map sheets.

Mapping notes provide information on mapping symbology and boundary conditions. Mapping limitations include information on appropriate map use along with hydraulic accuracy uncertainties, considerations on other hazards, and assumptions about future conditions. The main limitations are as follows:

- The maps depict the designated flooding based on the ground conditions at the time of survey. Future changes to the channels, floodplain, and future climate change will render the maps obsolete. The information on the maps should be reviewed after 5 to 10 years have elapsed since publication or after any extreme flood occurrence or substantial change in watershed or floodplain development.
- The accuracy of the flood boundaries is limited by the lidar base mapping and orthophotography.
- The flood maps do not represent flooding from local stormwater runoff, ponding from rainwater on the floodplain, or groundwater seepage. Consequently, additional flooding may occur outside of the designated boundaries.
- Roads, railways, bridges, and future developments on the floodplain can restrict water flow and increase local water levels. Obstructions such as debris jams, channel sedimentation, and culvert blockages can also increase flood levels above the levels shown on the maps.
- The flood maps do not represent hazards due to erosion, deposition, degradation, aggradation, avulsion, or channel migration.
- The flood maps are an administrative tool that depict the potential flood extent and minimum recommended Flood Construction Level for the designated flood. A Qualified Professional (QP) must be consulted for site-specific engineering analysis.

Further information on hydraulic modelling limitations can be found in Section 6.

8.2 FCLs and Flood Extents

FCLs are used to keep living spaces and areas used for storage of goods damageable by floodwaters above flood levels. The FCL is calculated by adding a freeboard allowance to the simulated design water level. The freeboard accounts for uncertainty associated to the hydrologic and hydraulic modelling (e.g., inaccuracies in input data, inherent model simplifications). APEGBC (2017) suggests that a minimum freeboard of 0.3 m should be applied to the annual peak instantaneous (QPI) flows and 0.6 m to the annual max daily (QPD) flows. For Lower Twin Lake, a 0.6 m freeboard was applied to the design flood event. This freeboard is considered appropriate given the limited lake level data available. For Willowbrook and Sportsmens Bowl, a 0.3 m freeboard was applied. This freeboard is considered appropriate despite the limited calibration data. The sensitivity analyses described in Section 7.2, show that large changes in model parameters and flows, result in relatively low changes in water levels. This means that the model is relatively insensitive to uncertainties in hydraulic parameters and flows.

Like FCLs, flood extents depicted in the flood maps are based on model results plus freeboard. The difference between the modelled flood extents and the final flood extents with freeboard, is represented by a lighter shade of blue in the flood maps.

8.2.1 Use of FCL Isolines

FCLs are documented on the floodplain maps with labelled isolines. The FCL for a specific building or space is to be taken as the highest FCL applicable for that location, which is considered the FCL at the upstream end of the building or space. Where the upstream end of the building or space is located between isolines, two options exist for determining the applicable FCL:

- Approach 1: the FCL is taken as the value represented by the next upstream isoline.
- Approach 2: the FCL is calculated through linear interpolation between the two isolines in which the upstream face of the building or space is located. Results should be rounded up to the nearest 0.1 m.

Two examples are represented below based on the buildings and mapped isolines shown in Figure 8.1:

- The first step is to identify the upstream end of the buildings. This will be the point along the perimeter that is closest to the upstream (highest value) FCL. Building 1 represents a hypothetical future development and is located between two isolines. The northeast corner represents the upstream end as it Is closest to the upstream FCL. Building 2 is between three isolines, two of which have a value of 441 m. The third FCL has a value of 440.5 m. In this case, the north 441 m FCL has been selected to do the interpolation since it’s closer to the building.
- Once the upstream end is identified for each building, the shortest distance from this location to the upstream and downstream FCLs is measured. The upstream and downstream FCLs for both buildings have an elevation of 441 m and 440.5 m, respectively. The distances are shown in Figure 8.1 (purple dashed lines).
- The FCL for Building 1 can be calculated as follows:
    - Approach 1: 441 m
    - Approach 2: $440.5 + (441 - 440.5)\left(\frac{37}{37+25}\right) = 440.8\ m$
- The FCL for Building 2 can be calculated as follows:
    - Approach 1: 441 m
    - Approach 2: $440.5 + (441 - 440.5)\left(\frac{52}{52+106}\right) = 440.7\ m$

Floodplain areas that were higher than the FCL at the time of map development appear as dry “islands” (e.g., buildings just north of Carr Cres in Figure 8.1). If conditions were to change in the future, the approach described above should be applied to determine the FCL at these locations.

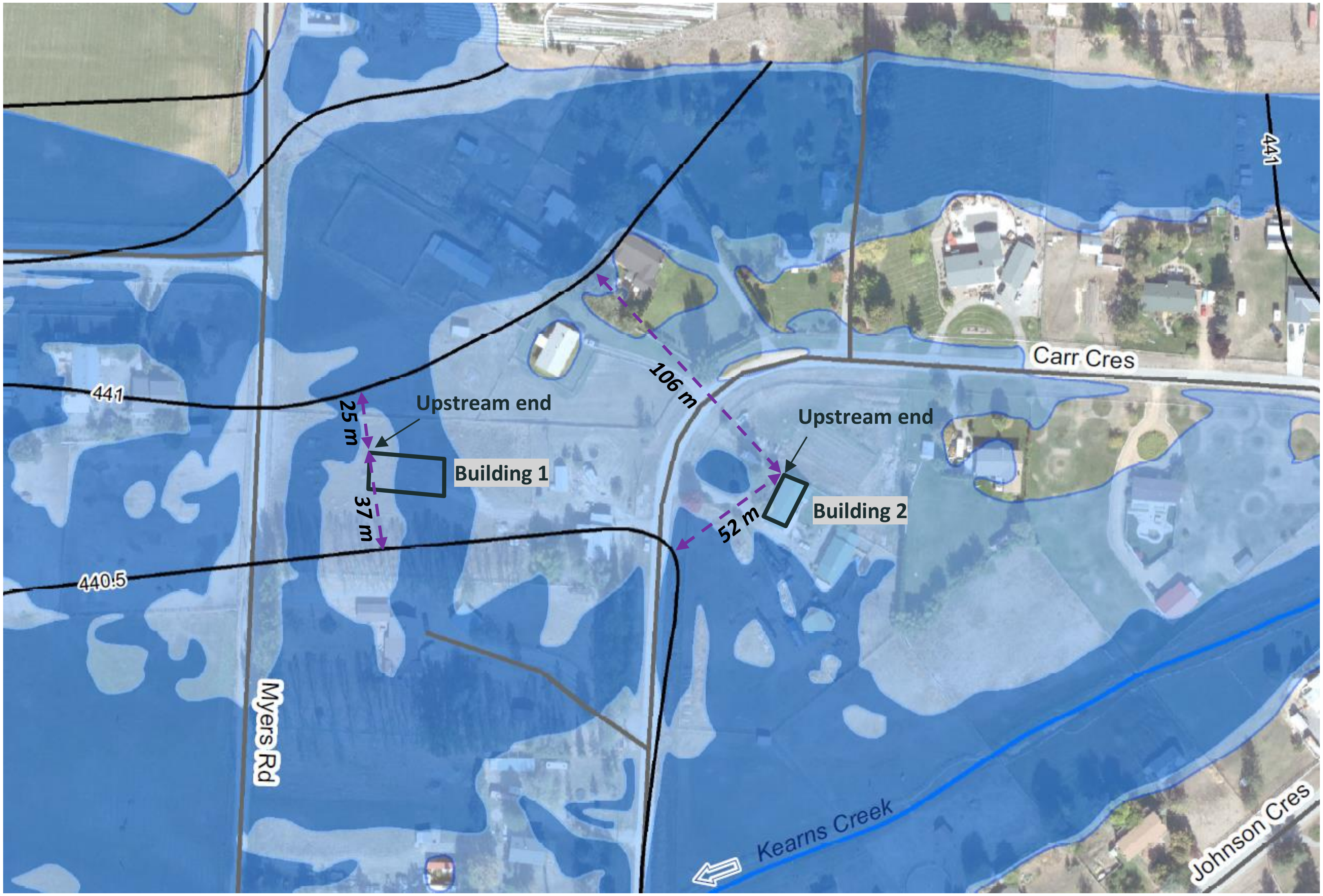

Figure 8.1 Example of FCL calculation for one hypothetical building and one existing building in Willowbrook

8.2.2 Flood Extents and Filtering

To add the freeboard to the flood extents, the FCL isolines are projected outside of the modelled extents. The final flood extent is calculated for each isoline and then interpolated in between to create a smooth flood extent polygon.

Filtering was used to remove isolated inundated areas and isolated elevated areas smaller than 100 m^2. This is typically done to improve the readability of the maps and to limit the reliance on slight variations in floodplain topography, which may change with time.

8.2.3 Setbacks

Setbacks from waterbodies are defined to maintain the floodway and limit the risk of future development being impacted by bank erosion. Additionally, setbacks may be increased in the areas where structural mitigation is recommended to ensure such areas are not taken for development. Setback recommendations have been included in the map notes on the index sheet.

MFLNRORD (2018) defined setbacks on small streams as 15 m from the natural boundary of the channel. A 15 m setback is also recommended from the natural boundary of lakes. The natural boundary is defined as (MFLNRORD, 2018):

> “The visible high watermark of any lake, river, stream or other body of water where the presence and action of the water are so common and usual and so long continued in all ordinary years as to mark upon the soil of the bed of the lake, river, stream or other body of water a character distinct from that of the banks thereof, in respect to vegetation, as well as in respect to the nature of the soil itself (Land Act, section 1). […] In addition, the natural boundary includes the best estimate of the edge of dormant or old side channels and marsh areas.”

8.3 Flood Hazard

Flood hazard can be characterized by the flood depth, flood velocity, or the product of the two. In addition to the flood depth maps produced for the design event and provided as part of the mapping products, a series of flood diagrams have been produced. These include flood depth, velocity, and hazard (i.e., product of depth and velocity) diagrams for the 10-, 50, 100-year, and 200-year floods under end-of-century climate change conditions, and are included in Appendix A. The diagrams were exported directly from the hydraulic model and do not include freeboard.

8.3.1 Flood Depths

Table 8.1 describes potential impacts for the depth categories displayed on the flood depth maps provided as part of the mapping package and diagrams provided in Appendix A. These impacts are general in nature and have not been validated with respect to the structures located within this study area.

Table 8.1 Description of flood depth categories (adapted from MLIT, 2005)

Depth (m)	Description of Typical Conditions
0 – 0.1	Most buildings are dry; underground infrastructure may be flooded
0.1 – 0.3	Most buildings are dry; walking in moving water or driving is potentially dangerous; underground infrastructure may be flooded
0.3 – 0.5	Most buildings are dry; walking in moving or still water or driving is dangerous; underground infrastructure may be flooded
0.5 – 1.0	Water on ground floor; underground infrastructure flooded; electricity failed; vehicles are commonly carried off roadways
1.0 – 2.0	Ground floor flooded; occupants evacuate
2.0 – 3.0	Ground floor flooded; first floor covered by water; occupants evacuate
> 3.0	First floor and often higher levels covered by water; occupants evacuate

8.3.2 Hazard Severity

Flood hazard diagrams were generated based on peak depth and velocity, according to the following formula:

Hazard Rating (HR) = depth x (velocity + 0.5)

This rating formula is based on standard methodology used by the UK Environment Agency and the UK Department for Environment, Food and Rural Affairs (HR Wallingford et al., 2006; Surendran et al., 2008; Udale-Clarke et al., 2005), with debris factor excluded. A debris factor between zero and one is occasionally added to the equation. Hazard rating categories are described in Table 8.2. Flood hazard diagrams are provided in Appendix A.

Table 8.2 Description of hazard rating categories

Hazard Rating	Degree of Flood Hazard	Description
≤ 0.75	Low	Caution: Flood zone with shallow flowing water or deep standing water
0.75 to 1.25	Moderate	Danger: Flood zone with deep or fast flowing water
1.25 to 2.0	Significant	Danger: Flood zone with deep fast flowing water
> 2.0	Extreme	Extreme danger: Flood zone with deep fast flowing water

9 CONSEQUENCE CHARACTERIZATION

Identifying the consequence of flooding helps public stakeholders and decision-makers understand the impact of flooding and provides context for technical flood analysis. The consequences of flooding can be understood by overlaying the hydraulic model output (flood extents, depth, and velocity) and exposed assets (i.e., elements at risk). The hydraulic modelling output described in Section 6 was used to identify elements at risk based on datasets containing the location of buildings, roads, power poles, and population. This section describes the consequence characterization completed for the three study areas of Lower Twin Lake, Willowbrook, and Sportsmens Bowl Road.

To evaluate the exposures of the 200-year flood event under end-of-century climate change conditions (the design event), data on physical assets was collected and used to construct four simple asset inventories. Using these inventories with the results of the hydraulic modelling, four exposure indicators were estimated for each area.

9.1 Data Collection

The data sources in Table 9.1 were identified and evaluated for use in the assessment. Because of the relatively small study area, many of the investigated sources had spatial resolutions too coarse for use in the assessment. Entries in grey were either unavailable, had no coverage within the study area, or were unsuitable.

Table 9.1 Data sources for consequence characterization

Provider	Layer	Description/Use
RDOS	zoning	land designation, coarse
RDOS	cadastral	parcels w/ assed land and improvement values
RDOS	OfficialCommunityPlan	similar to zoning, coarse
NRCan	NHSL_Physical_Exposure_polygon	lots of vulnerability data, very coarse
NRCan	NHSL_Risk_Dynamics	population of different years, very coarse
StatCan	Open Database of Buildings	no coverage
StatCan	Census 2016	dissemination blocks are very coarse
Microsoft	Building Footprints	pretty decent (trailers?)
ICI Society	Utilities.BCHydro.gdb	no coverage
ICI Society	Utilities.Enbridge.gdb	no coverage
ICI Society	Utilities.FortisBC_Electric	good coverage (no transformers in area)
ICI Society	Utilities.FortisBC_Gas	no coverage
ICI Society	Utilities.Infrastructure_Mains	no coverage
ICI Society	Utilities.Shaw	no coverage

Provider	Layer	Description/Use
ICI Society	Utilities.Telus	poles and UG conduit
OSM	Highways	decent coverage (no driveways), see MFLNRO
MFLNRO	Local and Regional Greenspaces	no coverage
MFLNRO	Archealogy/Historical registry	??
MFLNRO	Indian Reserve	none
MFLNRO	Other Land Cover	~10% coverage
MFLNRO	Recreation lines	none
MFLNRO	Recreation polygons	none
MFLNRO	Attributed Roads	better than OSM
MOE	Sensitive Ecosystems Inventory (SEI)	2/3 coverage. no useful data
Ministry of Health	BC Health Care Facilities (Hospital)	none
Ministry of Health	Residential Care Facilities	none
Ministry of Agriculture	Agricultural Land Reserve	no attribute, just shows reserve
BC Assessment		property attributes

Land use in the three study areas is a mix of low-density residential and agriculture with a small amount of commercial use, as shown in Table 9.2.

Table 9.2 Improvement value and land use in the study areas

Study Area	Business	Farm	Non-profit	Residential	Utilities	Total
Lower Twin Lake				$ 14,489,500		$ 14,489,500
Willowbrook	$ 141,000			$ 25,939,900		$ 26,080,900
Sportsmens Bowl Rd				$ 4,936,900		$ 4,936,900
Total	**$ 141,000**	**$ -**	**$ -**	**$ 45,366,300**	**$ -**	**$ 45,507,300**

The three areas hold roughly 180, mostly one- and two-story, buildings, as summarized in Table 9.3.

Table 9.3 Building types and number of buildings in the study areas

Building Type	Lower Twin Lake	Willowbrook	Sportsmens Bowl Rd	Total
1 Sty Sfd - After 1960 - Modern Std	10	39	5	54
Unknown	9	13	3	25

Building Type	Lower Twin Lake	Willowbrook	Sportsmens Bowl Rd	Total
1 Sty Sfd - After 1930 - Std	6	6	1	13
1 Sty Sfd - New Standard	5	6	1	12
1 Sty Recr Home - All Ages - Substd	9	1		10
2 Sty Sfd - After 1960 - Modern Std	4	5	1	10
1 Sty Sfd - After 1930 - Fair	5	2	2	9
1 Sty Sfd - After 1930 - Semicustom		6	1	7
1 1/2 Sty Sfd - After 1930 - Std	5	1		6
1 Sty Recr Home - All Ages - Fair	5			5
1 1/2 Sty Sfd - After 1960 - Modern Std	2	2		4
2 Sty Sfd - New Standard	2	2		4
1 Sty Sfd - All Ages - Substd	1	1	1	3
Manufactured Home-Single Wide - Low Q	2	1		3
Other	8	12	3	23
Total	**73**	**97**	**18**	**188**

Notes: Sty = story, sfd = single family dwelling, substd = substandard, std = standard

Street view imagery shows a mix of foundation types, including basements and slab-on-grade.

The Twin Lakes study area is exclusively residential buildings, while Willowbrook and Sportsmens Bowl Road have some mixed-use properties. Aside from a fire hall at the northeastern corner of the Willowbrook study area, provincial data does not indicate any other critical facilities (e.g., hospitals, schools) within the study area.

The areas are serviced by a mix of district-maintained roads, as shown in Table 9.4.

Table 9.4 Road types and length (m) of road in the study areas

Study Area	Loose	Paved	Rough	Total
Lower Twin Lake	702	1,682	1,298	3,682
Willowbrook	941	7,032	5,047	13,020
Sportsmens Bowl Rd		1,300	164	1,463
Total	1,643	10,014	6,509	18,166

Power for the study area is provided by FortisBC mainly through overhead lines. No major power production facilities are within the study area.

9.2 Asset Inventories

In flood impact modelling, asset inventories provide the spatial data used to calculate asset presence and other attributes of interest in a form recognized by the modelling platform. Because no built-for-purpose flood modelling datasets are readily available for most study areas in Canada, asset inventories generally must be constructed for each study from available data. The simplest asset inventories are selections of large data sets maintained for non-flood uses (e.g., building footprints), which are adapted with some field manipulations and cleaning. More complex inventories require combining multiple data sets or completing additional data analysis.

For this study, the four inventories summarized in Table 9.5 were constructed from the collected data sources.

Table 9.5 Constructed asset inventories

Name	Data Source	Depth Threshold (m)	Sampling	Impact Metric
Buildings	Microsoft Building Footprints	N/A	centroid/ polygon	# of buildings exposed
Roads	MFLNRO Attributed Roads	0.1	% inundated	m of roads inundated
Power poles	ICI Utilities.FortisBC_Electric	0.1	centroid	# of power poles exposed
Population	Microsoft Building Footprints & StatsCan Census 2016	0.1	centroid	# displaced persons

The 'buildings' inventory was constructed from the centroids of the footprints found in the Microsoft Building Footprints dataset. An additional inventory was constructed from the polygons themselves to evaluate sampling sensitivity. The Microsoft dataset was generated using the best available public aerial imagery in 2019 and an image processing algorithm; this is the best available estimate of building footprints. The data was spot checked for the study area against available aerial imagery and found to be satisfactory. The data does not discriminate between building types (e.g., house vs. shed).

The height of a building above grade is generally a significant variable in modelling flood vulnerability. For example, a building with a basement would be much more vulnerable to flood damage (at a given depth) than an elevated building or one with a crawl space. Because this information was not available, the exposure calculations presented below considered multiple depth thresholds to provide a range of possible exposure counts to communicate this uncertainty.

The 'roads' inventory was constructed from provincial data of road center lines. The sampling is performed to calculate the length in metres of road center line inundated beyond the threshold depth.

The ‘power poles’ inventory is a simple asset presence inventory meant to indicate when power poles may be threatened. Data was obtained through RDOS’s subscription to the Integrated Cadastral Information (ICI) Society, which hosts the FortisBC data.

The ‘population’ inventory uses building location and 2016 census data to calculate an estimate of the number of persons displaced by the design flood. To construct this inventory, the total population of each dissemination area is divided by the total number of buildings (with area greater than 50 m^2) within the census geometry. This estimate of the average persons per structure is then mapped back onto the buildings inventory to create the population inventory. Demographics were not evaluated as part of this consequence assessment.

9.3 Exposure Modelling

Natural Resources Canada’s CanFlood[6] flood risk modelling toolbox was selected for the exposure modelling. This open-source QGIS plugin contains tools to automate modelling tasks and provides a standard data format to enhance reproducibility and future expansion of the assessment. The ‘batch scripting’ function of CanFlood was used to perform the calculations on each of the asset inventories with the design water surface level rasters and the project DEM.

9.4 Results and Discussion

This section presents the results of the exposure assessment of the four inventories discussed in the previous section. These results were calculated using the hypothetical design event maximum WSE calculated for each area through hydraulic modelling (Section 7). Therefore, the uncertainty and limitations associated with the hydraulic modelling results is also present in the exposure calculation. For example, blockage of key culverts by debris could significantly influence inundation extents and depths, especially around roads. Of special note is the influence of emergency response measures like temporary barriers. While not considered here, these interventions would likely significantly influence the exposure of assets within the study area given the relatively shallow depths produced by the design event.

The study area will be subject to events of lesser and greater magnitude than the design event in the future — therefore, the reader should expect potential impacts to also be lesser and greater than those estimated below for future events. As a separate note, the estimates below are based on current conditions and do not account for likely future changes in the hazard (e.g., climate changes different from the ones considered) or assets (e.g., new developments). A map of exposure results for ‘buildings’, ‘roads’, and ‘power poles’ impacts are provided in Appendix B.

9.4.1 Buildings

Flood depth at buildings can be calculated through different sampling methods, which include point or area sampling. Point sampling extracts the flood depth at a spot location, usually at the centroid of the

[6] https://github.com/IBIGroupCanWest/CanFlood

building footprint polygon. Area sampling considers the depth variation within the footprint polygon and calculates the maximum, minimum, or mean depth within the building area. Different results can be obtained depending on the sampling method used.

Outside of water channels, the design event depths within the study area are generally less than 0.5 m. This makes the centroid sampling method very sensitive to the selected depth threshold and the DEM values under the building footprint. During creation of the bare-earth lidar DEM (by GeoBC) these values are extrapolated using an object-removal algorithm whose accuracy can be reduced in the presence of vegetation and small local-grading, common around foundations. Similarly, the hydraulic calculations are performed against the bare-earth DEM, ignoring any obstruction posed by structures. Figure 9.1 provides an example of two buildings that the hydraulic modelling results suggest would be partially exposed, but only one of these is detected by the centroid sampling method. For larger studies, variations introduced by these nuances are generally negligible.

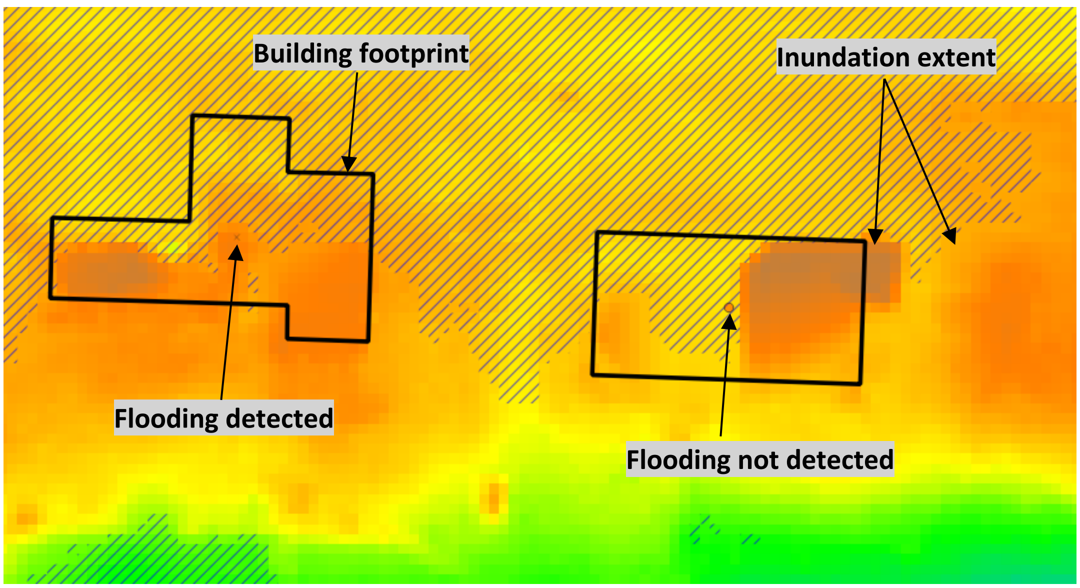

Figure 9.1 Partially flooded building missed by centroid sampling

To investigate the differences between different area sampling methods, an inventory of the raw building footprint polygons was sampled using the minimum, mean, and maximum depth value within the polygon. Results for all three areas for the three types of sampling are combined and shown in Figure 9.2. Each box plot displays the 25th, 50th, and 75th percentile represented by three horizontal lines. The minimum and maximum values of the whiskers indicate the 25th and 75th percentile plus or minus 1.5 times the interquartile range. Observations outside of the minimum and maximum whisker values, indicated as dots, are considered outliers.

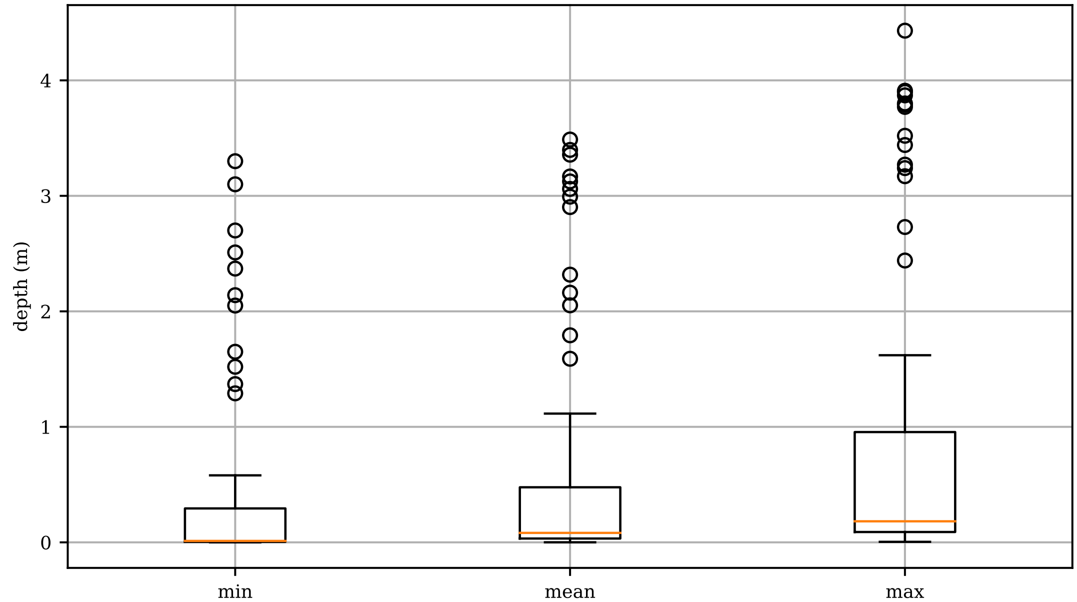

Figure 9.2 Box plot of building exposure for three types of area sampling

This demonstrates the sensitivity in the depth sample across the building footprints. For comparison, Table 9.6 and Table 9.7 show building exposure values and counts for centroid and maximum area sampling, respectively. Building exposure values and counts are provided for two depth thresholds.

A map showing the depth of exposure at each building centroid is provided in Appendix B.

Table 9.6 Building counts calculated for two flood depth thresholds – centroid sampling

Study Area	# of Buildings	Average Flood Depth (m)	Building Count for 0.1 m Threshold	Building Count for 0.5 m Threshold
Lower Twin Lake	27	1.42	17	17
Willowbrook	132	0.02	7	5
Sportsmens Bowl Rd	21	0.02	3	0
Total	**180**	**0.23**	**27**	**22**

Table 9.7 Building counts calculated for two flood depth thresholds – maximum sampling

Study Area	# of Building	Average Flood Depth (m)	Building count with 0.1 m Threshold	Building count with 0.5 m Threshold
Lower Twin Lake	27	2.02	19	18
Willowbrook	132	0.07	28	6
Sportsmens Bowl Rd	21	0.25	11	5

Study Area	# of Building	Average Flood Depth (m)	Building count with 0.1 m Threshold	Building count with 0.5 m Threshold
Total	**180**	**0.39**	**58**	**39**

Absent building height and foundation data, it is difficult to determine which exposure calculation method is more reasonable. This is especially relevant in Willowbrook and Sportsmens Bowl Road where the depth of flooding is relatively small. Table 9.8 shows the lower and upper bounds of all the threshold and exposure calculation methods considered here.

Table 9.8 Lower and upper bound building counts

Area	# of Buildings	Building Count – Lower Bound	Upper Count – Lower Bound	% Change
Lower Twin Lake	27	17	19	11%
Willowbrook	132	2	28	93%
Sportsmens Bowl Rd	21	0	11	100%
Total	**180**	**19**	**58**	**67%**

For floods like the design event, structure collapse is unlikely for all structures except one identified[7]. However, high velocities around structures could cause erosion that undermines the foundation in extreme cases, necessitating some structural repair.

9.4.2 Population

The 'population' displacement estimate was obtained by multiplying the per-building estimate (see previous section) with the lower- and upper-bound building exposure counts. Results are provided in Table 9.9, showing the total population estimated in each area, and the number displaced (i.e., population count) within the two bounds.

Table 9.9 Lower and upper bound population counts

Study Area	Population Per-building (mean)	Total Population	Population Count – Lower Bound	Population Count – Upper Bound
Lower Twin Lake	2.24	52	38	43
Willowbrook	1.53	164	3	43
Sportsmens Bowl Rd	1.36	27	0	15
Total		**243**	**41**	**101**

[7] A small building in Willowbrook along Kearns Creek could be vulnerable to collapse

While a range in exposure count is provided based on building sampling considerations, uncertainty in the per-building population is not considered quantitatively here. The assessment would be improved if finer resolution census data or a bedrooms-per-parcel dataset were available.

Displacement outcomes can be sensitive to complex social (e.g., household income), building vulnerability (e.g., height of living space above ground), and emergency management (e.g., evacuation mandates) factors that were not included in this assessment. For example, in the event of a large flood, like the design event, it is likely evacuation orders would be issued for a relatively large area, displacing many for a short period. Following this, residents would return home, and only those with significant damage would continue to be displaced and require some alternate shelter. For high-income households, sourcing alternate shelter is typically relatively easy; however, for low-income households, finding shelter can be very difficult and some government assistance would likely be required.

In addition to displacement considerations, members of the exposed population could be subject to short and long-term indirect consequences (e.g., Post Traumatic Stress Disorder, lost income, injury, etc.) and in rare cases fatalities. Recent research suggests victims attempting to drive through flooded sections of road account for upwards of 90% of flood fatalities[8]. Because the design event would result in sections of flooded road separating drier areas (see next section), the risk of fatalities, although still low, is not negligible.

9.4.3 Roads

The total meters of roads inundated (beyond the 0.1m depth threshold) are provided per-area in Table 9.10.

Table 9.10 Length of road inundated per road type (m)

Study Area	Loose	Paved	Rough	Total
Lower Twin Lake	-	340	114	454
Willowbrook	-	254	143	397
Sportsmens Bowl Rd	-	812	59	871
Total	**-**	**1,406**	**316**	**1,722**

Frequent and prologued inundation cycles or high velocities can damage roads, requiring immediate repair or additional maintenance. Culverts generally require repair following an event near their design discharge.

The disruption of road transportation by a flood event can be influenced by physical (e.g., culvert blockage, crossing damage), emergency response (e.g., road closures and detours, evacuation orders), traffic network (e.g., time of day, route significance, availability of detours) and emergency maintenance

[8] Sharif, Hatim O., Terrance L. Jackson, Md. Moazzem Hossain, and David Zane. 2015. "Analysis of Flood Fatalities in Texas." Natural Hazards Review 16 (1): 04014016. https://doi.org/10.1061/(ASCE)NH.1527-6996.0000145.

(e.g., debris removal) factors not considered by this simplified exposure assessment. However, the quantitative results above and the qualitative discussion below provide some indication of the consequences that could be realized by the occurrence of the design event.

At Twin Lakes, the lakeside Westview and Eastview roads and some unnamed local access roads would be submerged during the design event, disrupting access to some flooded and un-flooded properties.

In Willowbrook, road crest elevations are all above the design event water surface level, with the exception of Myers Road which could be bypassed by most traffic. The five major crossings (i.e., culverts) of Kearns Creek are vulnerable to damage and potential overtopping if severe blockage occurs.

In the Sportsmens Bowl Road area, most of the main access road (Sportsmens Bowl Road) would be inundated by the design event, disrupting road access to the area for the duration of the event and a repair period. Downstream, the culvert at Highway 97 would likely be damaged or overtopped, forcing a detour onto Island Road to the East, further disrupting local and regional access.

9.4.4 Power

Minimal data was available to evaluate the impacts to power supply and distribution from the design event. No major power production facilities or distribution lines are within the study area, so any flooding here would likely only result in local disruptions to service. However, the impacts of flooding outside the study area could damage power facilities — this was not evaluated. Approximately 40 utility poles would be exposed to flood waters during the design event, but only those subject to high velocities would pose a threat to power service. The data obtained from the ICI Society indicates no underground conductors would be in inundated areas. No data was available to evaluate the vulnerability of local and private power connections downstream of FortisBC's network. It is expected that FortisBC would likely temporarily cut power to flooded and non-flooded properties in the study area as a precautionary measure during an extreme event.

9.5 Conclusion and Limitations

Large floods can cause massive physical, social, cultural, and ecological disruption with some disruptions continuing for years or decades. This study focused on evaluating elements with readily available data, omitting the majority of consequences and assets that would be realized were the design event to occur. However, this analysis should provide decision-makers sufficient data to inform mitigation and emergency response plans for the study area.

The following is a list of limitations and recommendations associated to the data available. It is recommended that these considerations be incorporated in future work:

- **Velocity** – Both Willowbrook and Sportsmens Bowl Road areas have relatively shallow depths. It is possible that velocity would represent a more critical flood hazard metric in these areas. Completing an impact assessment based on velocities (instead of depths) will likely yield different results, highlighting new risk areas.

- **Crop loss** – Crop loss is a major component of potential flood damage in Willowbrook and Sportsmens Bowl Road. Data to assess crop loss was not available for use in this analysis. It is recommended that subsequent stages of the flood impact analysis include crop loss.
- **Archaeology** – Archeological site information was requested to the province with no success. It is recommended that this information be included in subsequent flood impact work.
- **BCAssessment data** – The BCAssessment data provided by RDOS for this project was missing key fields for a detailed flood building and population impact assessment (i.e., foundation type, bedrooms, basements). It is recommended that this information be incorporated in future analysis.
- **Additional flood events** – Focusing on a range of event magnitudes provides a better picture of the full range of possibilities in relation to flood impacts. It is recommended that future work incorporates a probabilistic risk analysis based on the different return period events modelled as part of this project.

10 FLOOD MITIGATION MEASURES

Mitigation measures are typically categorized as structural and non-structural. Structural measures are physical works designed to reduce the magnitude of the flood hazard (e.g., reduce the flood depth or prevent floodwaters from reaching a particular area). Dikes and river engineering works, such as channel diversions and widening, are common examples. Floodproofing individual buildings is also a form of structural mitigation. Non-structural measures, on the other hand, aim to reduce the exposure to the hazard and its consequences. Examples include land-use regulation, emergency planning and recovery plans. Table 10.1 lists mitigation measures typically used in BC.

Table 10.1 Examples of mitigation measures

Non-Structural ***Reducing Exposure & Vulnerability***	**Structural** ***Reducing Flood Hazard***

• Hazard and risk assessment
• Land use planning
  ○ Zoning
  ○ Bylaws
  ○ Relocation or retreat
• Public awareness and education
• Emergency routing and safe zone delineation
• Emergency preparation and planning
  ○ Community flood response plan
  ○ Community preparedness
  ○ Home and business response plan
  ○ Individual preparedness
• Monitoring and warning systems
	• Barrier to the hazard
	  ○ Dikes (new or improved)
	  ○ Flood gates
	  ○ Temporary tiger dams or sandbag dikes
	• Armouring against hazard
	  ○ Riprap banks/dikes
	  ○ Spurs and groynes
	• Conveyance improvements
	  ○ Channel dredging and widening
	  ○ Dike set back
	  ○ Removing constrictions (culverts, bridges)
	  ○ Reducing channel roughness
	  ○ Pumps

Non-Structural *Reducing Exposure & Vulnerability*	Structural *Reducing Flood Hazard*
• Maintenance	• Flood flow ◦ Diversion of flow ◦ Upstream storage ◦ Infiltration

Large structural measures such as dikes and river engineering works are relatively expensive to implement and entail high maintenance costs. Moreover, experience in BC and globally has shown that these types of works can be associated to a series of potential problems such as dike failures, river avulsions, transfer of risks upstream, environmental impacts, and increased exposure by creating a false sense of security; which in turn increase the risk of flooding in specific areas. Recent research has shown that allowing the water to take its natural course is a more effective long-term strategy, than artificially restricting the flow[9]. Maintaining the flood function of the floodplain should be considered in development of an implementation plan for any measure designed to manage flood risk (AIDR, 2017).

The flood mapping and consequence characterization of the Lower Twin Lake, Willowbrook, and Sportsmens Bowl Road areas is a useful tool to support land use planning and identify potential strategies for flood risk mitigation. The remainder of this section discusses techniques towards the goal of managing flood risk.

10.1 Property Owner Strategies

Property owner strategies include structural and non-structural options that can be used standalone or in conjunction with other larger scale measures. Implementation of these strategies is typically accomplished through bylaw requirements or guidelines. Local government adoption of a floodplain bylaw under Section 524 of the Local Government Act and construction of the habitable areas of new homes to the FCL is a common mitigation approach in BC. Raising awareness on flood hazards and providing tools for property owners to take action are key steps in the successful implementation of bylaws and guidelines.

A number of flood mitigation strategies are available to property owners who have experienced flooding in the past or whose property is within the inundation extents shown on the flood maps. These range from permanent structural works to temporary or non-structural low-cost solutions.

Some examples of structural alternatives are depicted in Figure 10.1 and explained below. Floodproofing refers to design or construction measures at the property level that make buildings and their contents more resistant or resilient to flood damage. Raising a building or dry floodproofing techniques can help keep water out of a building, whereas wet floodproofing lets water in while minimizing damage.

[9] Room for the River program https://www.rijkswaterstaat.nl/en/about-us/gems-of-rijkswaterstaat/room-for-the-river

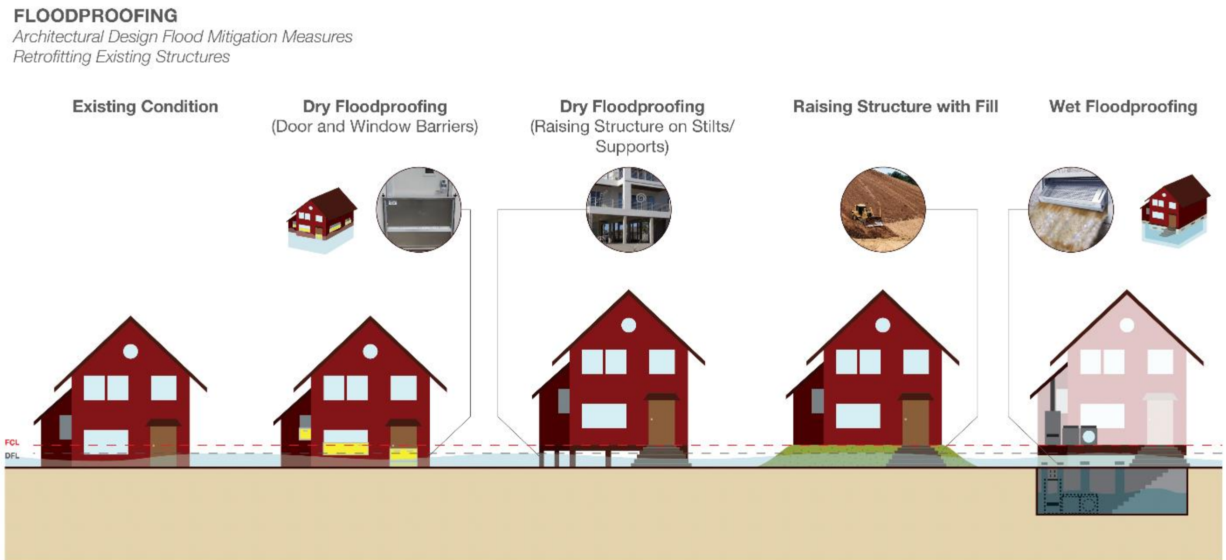

Figure 10.1 Building floodproofing schematic (FBC, 2020)

Property level measures do not reduce the likelihood of floodwaters arriving at a particular property – rather, they limit harm to life and damage to property. Their effective implementation can reduce losses from damage to a building and its contents, clean-up and recovery time, and in some cases, the likelihood of injury or death from drowning, electrocution, unsanitary conditions, and debris.

10.1.1 Elevating Buildings

Flood maps are typically used by municipalities in conjunction with the floodplain bylaw to implement regulations that require constructing or raising buildings to the FCL.

Options for elevating buildings to meet the FCL requirements include:

- Constructing a new foundation to elevate the entire structure
- Raising land
- Filling or abandoning a basement

Figure 10.2 Example of elevated structure
Source: http://2030palette.org/elevated-structures/

Elevating buildings can come with some challenges for both existing and new developments. Raising of existing buildings can be structurally or economically unfeasible. While elevated new developments can cause a negative impact to adjacent old developments by constricting the flow and potentially raising velocities and water levels.

Alternatives such as dry or wet proofing of the portion of structures located below the FCL, in many cases provide a more practical approach to property owners. This is especially true where flood depths are relatively low (less than 1 m).

10.1.2 Dry Floodproofing

Dry floodproofing refers to the use of design and construction measures to prevent floodwaters from entering a building, keeping the structure and its contents dry. Elevating buildings is a form of dry floodproofing; however, other alternatives are available for cases when elevating is unfeasible.

Like elevating buildings, permanent or "passive" dry floodproofing measures do not require action at the time of a flood. These techniques are effective only for structurally sound buildings in areas of shallow, low-velocity flooding (i.e., low hazard). Examples include:

- Elevating windows and doors and sealing cracks
- Sealing floors
- Installing flood shields or barriers for basement and ground-level windows and doors. The top of basement shields should extend above ground level
- Building a flood wall around the perimeter of the property to prevent floodwaters from reaching the structure

Figure 10.3 Example of a dry floodproofing barrier at a machine company

Source: https://www.resilientdesign.org/fundamentals-of-resilient-design-dry-floodproofing/

In addition to floodproofing measures for the building, landscaping techniques can help water drain away from the foundation and basement walls. This should be done in a way that does not simply divert the water to neighbouring properties.

10.1.3 Wet Floodproofing

Wet floodproofing involves fitting a building with wall openings and flood-resistant building materials to let water flow in and out, while reducing damage and losses to the building and its contents. It is designed to make a building more "flood resilient." Wet floodproofing tends to be a less expensive option and its use should be limited to low flood hazard areas where other options are not feasible.

Wet floodproofing requires careful design and implementation and is to be undertaken only with

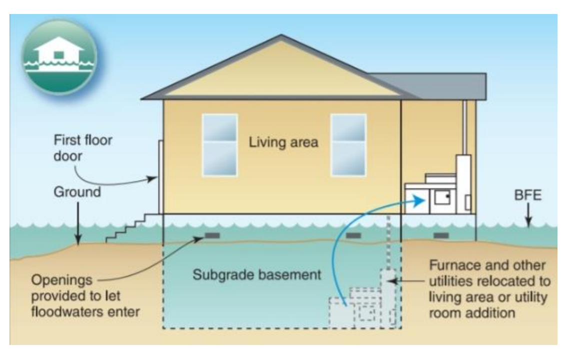

Figure 10.4 Wet floodproofing schematic (FEMA, 2014)

professional advice and if permitted by building codes. Examples include:

- Leaving the space below the FCL unfinished
- Using water-resistant materials, such as stainless steel, plastic or solid wood
- Using tiled flooring rather than fitted carpets
- Raising large appliances, furnaces, hot water heaters, and electrical panels up on wood or cement blocks above the potential water level
- Raising electrical sockets, fuse boxes, wiring, service units and panels
- Anchoring potential floating assets to the floor. In a flood, for example, a fuel tank can tip over or float, causing fuel to leak and potentially catch fire. Vents and fill-line openings must be above the FCL

10.1.4 Temporary Measures

Temporary or "active" dry floodproofing measures are a cost-effective alternative for property owners who are in low hazard areas and will be able to react before the flood reaches their property. Or this reason, temporary measures are most suited to flood hazards that have a longer warning time. Examples include:

- Guards (to fill gaps) that can be quickly installed when flooding is imminent
- Covers that can be fitted over ventilation bricks
- Watertight doors or floodwalls that can be closed or fitted right before a flood
- Creating an emergency sandbag or water-filled barrier

Figure 10.5 Example of a water-filled temporary barrier (FEMA, 2014)

10.1.5 Make an Emergency Plan

Emergency planning at the property level should go hand in hand with other forms of mitigation such as floodproofing and municipal or district scale strategies. Following is a list of key items that must be identified in the plan (Government of Canada, 2011):

- Safe exits from building and neighbourhood
- Meeting places to reunite with family or roommates
- Designated person to pick up children should the main caretakers be unavailable
- Contact persons close-by and out-of-town
- Health and insurance information
- Places for pets to stay
- Risks in the region

- Location of fire extinguisher, water valve, electrical panel, gas valve and floor drain
- Emergency kit

10.1.6 Resources for Property Owners

The information provided in this section is based on resources published by different levels of government and organizations. These provide useful information for property owners within the floodplain area.

- Okanagan Flood Story by the Okanagan Basin Water Board:

  https://okanagan-basin-flood-portal-rdco.hub.arcgis.com/

- FloodWise by the Fraser Basin Council:

  https://floodwise.ca/protect-your-home-business/floodproofing/

- Be Prepared for Floods by the BC Government:

  https://www2.gov.bc.ca/gov/content/safety/emergency-management/preparedbc/know-your-hazards/floods

- Floods – What to do? By Public Safety Canada:

  https://www.getprepared.gc.ca/cnt/rsrcs/pblctns/flds-wtd/index-en.aspx

- Flood Ready Campaign by the Canadian Government:

  https://www.canada.ca/en/campaign/flood-ready.html

10.2 Structural Mitigation

Structural flood mitigation are physical works that influence the hydraulic or hydrology of a flood event. This section describes structural mitigation measures that could provide risk reduction in the study areas and their typical use in BC. With the increase in flooding anticipated due to climate change, temporary structural mitigations will not provide the same level of protection as they have in the past. As such, it is important to consider improved temporary mitigations, implementation of permanent structural mitigations, or use of non-structural mitigation measures as discussed in Section 10.3.

10.2.1 Flow Conveyance Improvements

Flow conveyance improvements can be achieved through straightening, widening, dredging, and clearing the channel; upgrading and maintaining road crossings; or implementing bypass channels to divert a portion of the total flow. Improving conveyance with these techniques reduces the flood elevation within a given area, thus reducing the extent of the inundation for a specified design flood. However, as stated above, maintaining the flood function of the floodplain is a key consideration when designing a flood mitigation plan. Modifying the channel geometry could potentially result in increased erosion hazard and even flood risks in the future. Moreover, these types of interventions are relatively expensive and adequate maintenance must be

Flow conveyance improvement options are listed below for Willowbrook and Sportsmens Bowl Road and refer to Figure 10.6 below. These are based in recommendations made by Ecora and Dobson Engineering Ltd. (2019a).

- **Option 1:** Improve conveyance on Park Rill Creek to handle the design event, including channel and crossing improvements within Willowbrook and Sportsmens Bowl Road. 'Option 1' in (Ecora and Dobson Engineering Ltd., 2019a).
- **Option 2:** Improve conveyance on Kearns Creek channel in Willowbrook from Johnson Crescent to the confluence with Park Rill Creek. In 2018 most culverts were upgraded in Willowbrook in response to the flood event that year. The hydraulic model shows that the capacity of the culverts is larger than the hydraulic capacity of the channel.
- **Option 3:** Reactivate the original (prior to 2018) Park Rill Creek alignment in the Sportsmens Bowl Road area, to be used as a bypass channel during large floods, as shown in Figure 10.6. The channel would convey the flow to the two emergency 800 mm CSP culverts on Highway 97. This option is similar to 'Reach 2 – Alignment B' in (Ecora and Dobson Engineering Ltd., 2019a).

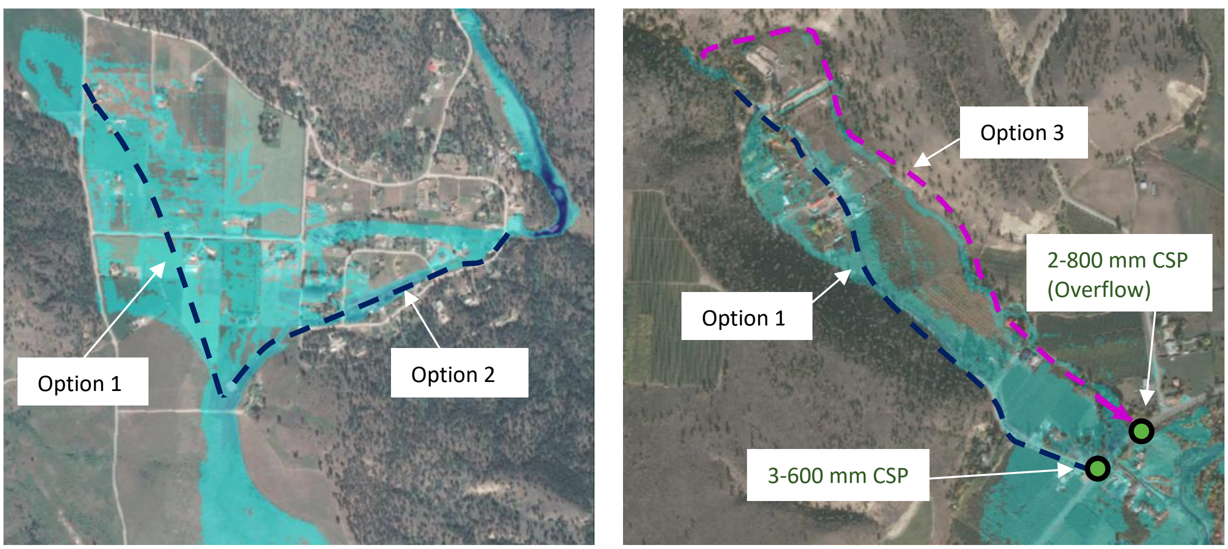

Figure 10.6 Flow conveyance improvement concepts for Willowbrook (left) and Sportsmens Bowl Road (right). Proposed upgrade reaches are shown in blue and diversion alignments in pink

10.2.2 Flood Flow Reduction

Upstream storage can be used to attenuate flood flows. A water level trigger could be established for Lower Twin Lake to start releasing water into Park Rill Creek in anticipation of a high flow event. This would increase the storage capacity of Lower Twin Lake during high freshet flows, reducing the Park Rill Creek peak discharge. The increased storage capacity of Lower Twin Lake and expected inflow volumes during a flood event would need to be further studied to evaluate the potential for mitigating peak flows downstream. However, knowing when to lower the lake levels can be very challenging due to the uncertainty in the timing and magnitude of future flows expected with climate change.

The addition of dams upstream of the floodplain or on substantial tributaries could provide further flood mitigation. However, the large financial costs associated with this option make it unfeasible for flood mitigation in Willowbrook and Sportsmens Bowl Road (Ecora and Dobson Engineering Ltd., 2019a). Moreover, there are large environmental, and societal costs as well as increased risks (such as potential for dam failure) associated with development of new dams. Therefore, this option is not recommended.

Upstream wetland restoration and recreating marshy areas increases flood storage and habitat values while naturally attenuating flood events. These techniques simultaneously increase flood storage while providing habitat value. This strategy could be implemented along sections of the 12 km reach of Park Rill Creek upstream of Willowbrook or in Myers Flats, to attenuate regularly occurring (i.e., low return period) Park Rill Creek flows.

10.2.3 Temporary Flood Barriers

Temporary flood barriers are physical systems which are implemented in response to a potentially forecasted flood. They can include temporary dikes, pre-planned sandbag walls and other temporary flood barriers. Temporary flood barriers should be pre-planned through a flood mitigation plan which should include consideration of the foundation and procurement of the temporary structure.

Photo 10.1 Sandbagging in the Sportsmens Bowl Road area during the 2018 flood

Source: https://globalnews.ca/video/4136734/local-government-official-warns-of-potential-

Sandbagging was used during the 2018 flood (Ecora and Dobson Engineering Ltd., 2019a), as shown in Photo 10.1. Correct and timely installation is critical, and these measures are much more suitable for low-velocity locations such as lakeshores than higher velocity locations such as along flowing channels. As with other physical mitigation measures, if placed in the wrong location, they can have an adverse affect on flood behaviour in other areas, impact local drainage, and impede emergency access.

10.2.4 Erosion Protection

Erosion protection is typically the armouring of banks, often with angular rock riprap. Erosion protection on its own does not provide protection from high water levels but can limit erosion and channel migration which can threaten roads, homes and other infrastructure located near fast flowing water. Photo 10.2 shows erosion threatening the stability of the Park Rill Creek bank in Sportsmens Bowl Road.

Photo 10.2 Bank erosion on Park Rill Creek in Sportsmens Bowl Road area. Photo source: NHC, Aug 2020

Erosion protection has similar challenges to dikes, predominantly the cost of land acquisition, construction, monitoring, and maintenance, impact to riparian vegetation, installation of a barrier between terrestrial and aquatic habitat, and potentially constricting the natural width and migration of the river resulting in local scour or increased probability of lateral migration on the opposite bank. Some of the adverse environmental aspects of erosion protection can be reduced if the armouring is set back from the active channel or by incorporating planting of shrubs in benches, pockets, or riprap voids.

To remain functional, erosion control measures require annual inspections and maintenance (especially when large woody debris are incorporated).

10.2.5 Monitoring and Maintenance

Flood conditions may be exasperated by blockage of crossings. Monitoring and subsequent removal of debris and sediment from culverts and their entrances should be done routinely throughout the high flow season to ensure flow is not restricted at these locations.

10.3 Non-structural Mitigation

Non-structural mitigations reduce risk through reducing exposure and consequence. Non-structural mitigations include land-use management, flood proofing, flood preparedness, and community education. Non-structural mitigation is typically applied even if structural mitigation is used.

10.3.1 Land-Use Management

Land use planning can be used to reduce flood risk. The province has developed guidelines to help local governments develop and implement land-use management plans and make development decisions for flood hazard areas (MFLNRORD, 2018). A variety of land use planning tools are authorized by provincial acts and can be used, including zoning, development permit areas, and bylaws indicating setbacks from waterways. These tools are briefly discussed below. The flood maps developed through this project should serve as the basis for land use management and regulations within the region.

Zoning – Zoning can include measures such as limiting density increases through rezoning, developing no-build zones in the highest hazard areas, and limiting development within the floodplain to specific land uses (e.g., agriculture and recreation).

Development Permit Areas – Development permit areas are another land use management tool to ensure that specific requirements are met within hazard areas. They can specify conditions such as requiring building to the FCL indicated on the flood maps and requiring property-specific hazard assessments. These can be used in conjunction with zoning and other property-level mitigation measures, such as floodproofing (see Section 10.1), for new and existing buildings undergoing major renovations within the hazard area.

Setbacks from Waterways – Typically, mitigation measures include setback from the top of bank, water's edge, or dike by a defined amount. Setback as a mitigation measure should also consider remnant side channels that may reactivate during high flow events and groundwater conditions in the area. For lakes and small watercourses, such as Park Rill Creek and Kearns Creek, the recommended setback is 15 m (MFLNRORD, 2018).

Relocation or Managed Retreat – When a community decides to retreat from an area, development planning can operate over long time-horizons. Existing homes and infrastructure can relocate or gradually retreat with time. In areas deemed to high risk or too difficult to protect from flooding, relocation and retreat should be considered. This can include relocation over time through natural property turnover or government appropriation of properties.

Relocation of individual homes may be warranted when homes are located within an area at risk to erosion and channel migration. Ongoing maintenance and repair of bank armouring can be costly and difficult to reduce the risk to an acceptable level, particularly if the channel is actively migrating towards a house (in comparison to local erosion), if there is little bank remaining between the home and the river, or where the site is along a deep scour hole, relocation of one or more homes may be the least costly and most long-term approach to address the flood hazard.

10.3.2 Flood Prediction and Warning

Accurate and timely flood prediction and warning has a significant impact on short-term community preparedness. Adequate flood prediction and warning enables relocation of sensitive assets and vulnerable people, effective evacuation if required, and implementation of any temporary flood barriers. Flood prediction is possible for watersheds that experience freshet flooding, such as Horn, Park Rill, and Kearns. Adequate flood prediction requires robust scientific understanding; accurate, detailed measurements of snowfall and precipitation; snowpack monitoring and robust weather forecasting. Flood warning must be clear, consistent, and informative.

10.3.3 Flood Emergency Response Planning

Emergency response planning (ERP) is critical to identify what actions, when, and by whom need to occur during an emergency to ensure public safety. The ERP may be on a community or district scale. The floodplain mapping can help guide the RDOS ERP in identifying hazard zones and high ground safe areas. Of particular interest should be access routes (highways, railways, airports), emergency centres (RCMP, EOCs, fire stations, hospitals), and large social spaces such as schools and libraries. The hazard mapping may be used in advance of a flood or during a flood to identify likely high velocity and depth areas to avoid.

Preparation of ERPs by local authorities is mandated by the BC Emergency Program Act (Anon, 1996). The province provides guidance on planning for various aspects of flood emergency response including plan preparation, pre- and during-flood actions, and post-flood management. (BC, 2016; PEP, 1999).

10.3.4 Community Recovery Plans

Having a recovery plan in advance of a flood event can significantly improve the efficiency of flood recoveries through having designated roles, clear sources of funding, pre-organized volunteer networks, and plans to meet other anticipated community needs. A thorough community recovery plan decreases confusion and anxiety, facilitates effective coordination between individuals responsible and helps communities come together to help each other effectively after a flood.

BC is modernizing their emergency management legislation and practices to include a focus on recovery as a key pillar for emergency management alongside mitigation, preparedness, and response. Consideration of recovery plans and resources in advance of a flood or other hazard event is recommended. Recovery plans can include the identification of:

- Pre-determined roles for city personnel and community volunteers.
- Plans to access designated financial resources.
- Assistance agreements with neighbouring communities.
- Pre-prepared design of structural mitigation to apply for funding, when available.
- Disposal plans for debris.
- Identification of contractors to support engineering and construction needs.

10.3.5 Community Awareness

A provincial review of floods and wildfires (BCFWR, 2018) identified dissemination of awareness and education as one of the key pillars of a complete flood mitigation plan. Flood mapping is identified as the first step of awareness of the hazard (NRCan, 2018). Despite preparation of floodplain mapping for an area, distribution and education should shortly follow.

Education about flood risk can help inform property owners to help them be more prepared. Flood risk education can include:

- Presenting the new flood mapping and updated understanding of current and future flood hazard (i.e., floodplain FCL, depth, velocity, or hazard maps).
- How to prepare for and be aware of the timing and seasonality of floods.
- Where to find sources for information on floods and flood preparedness.
- Community resources with respect to flooding.
- Where to find real time forecasts of water level, water flow, and what it means.
- Local evacuation routes, notifications, procedures, and high ground.

Community outreach can take the form of websites, handouts, news articles, community meetings, and poster and booth presentations at community events.

11 DIGITAL DELIVERABLES

Table 11.1 summarizes the digital deliverables submitted to RDOS with this report.

Table 11.1 Summary of digital deliverables

Report Section	Digital Deliverable	Description	Format
2	Topographic and bathymetric survey	Xyz data showing the topo-bathy survey points along the channels	*.CSV
2	Photos	Photos taken during the survey in August 2020	*.JPG
3	DEM	DEM of the study areas including 2018 GeoBC lidar and bathymetric data collected by NHC	*.TIFF
7	Hydraulic models	HEC-RAS 2D hydraulic models of Willowbrook and Sportsmens Bowl Road areas	HEC-RAS file formats (*.PRJ, *.P0X, *.U0X, *.G0X, etc.)
7	Hydraulic modelling result layers	Water surface elevation, depth, velocity and hazard GIS-compatible raster layers for all base runs (10-, 50-, 100-, 200-year), for Willowbrook and Sportsmens Bowl Road areas	*.TIFF
8	Flood Mapping Products	Designated floodplain maps with FCLs and depth maps for the Lower Twin Lake, Willowbrook, and Sportsmens	*.PDF

Report Section	Digital Deliverable	Description	Format
		Bowl Road areas. Include map sheets at a 1:2,500 scale and an index sheet	
8	Supplementary flood mapping layers	GIS-compatible shapefile layers of the designated flood extents, with and without freeboard, and FCL isolines	*.shp
4	Photos and Drone/GoPro footage of Park Rill Creek visual assessment reach	Georeferenced photos and Drone/GoPro footage covering the full 12 km reach of Park Rill Creek	*.JPG, *.MP4

12 RECOMMENDATIONS AND NEXT STEPS

12.1 Recommendations

The designated floodplain maps should be adopted for flood planning purposes, including establishing flood construction levels.

Floodplain maps need to be updated periodically to account for topographic and channel changes, new developments, which affect hydraulic conditions, and new information related to future climate change. The maps should be reviewed after a period of 10 years or after the occurrence of any large flood event (return period greater than 30 years) or flood of record.

It is recommended that a detailed geomorphic analysis be completed to understand the potential effects of channel formation processes in future flood levels. The floodplain maps should be revised should the results of the geomorphic analysis contradict the assumptions used for hydraulic modelling.

12.2 Next Steps

The hydraulic models developed as part of this project are powerful tools for assessing flood damages and flood risks and for developing long-term flood mitigation strategies under future climate change. Some applications of the models are listed below:

- Implementing land use planning (through floodplain bylaw, Official Community Plan, or development permit areas) based on the floodplain maps to limit increased flood risk from unmitigated and/or unrestricted development of the floodplain. The maps should be updated, if needed, based on the results of the geomorphological assessment and should incorporate any major structural mitigation works, such as channel improvements and diversions.
- Establishing a flow and climate monitoring program within the project watersheds to support future floodplain management efforts and improve hydrologic estimates.

- Planning for future upgrades to roads and crossings. Despite most culverts in Willowbrook having sufficient capacity to convey the design event, some such as the Johnson Crescent crossing, have inadequate capacity under 200-year flood conditions with climate change. Most culverts in the Sportsmens Bowl Road area are inadequate to convey the design flow.
- Planning future flood mitigation strategies. At present the entire floodplain is unprotected and relies on temporary mitigation works such as pumping and sandbagging, to mitigate flood impacts. The concepts presented in this report are some examples of structural flood protection measures. However, additional hydraulic and risk modelling are required to assess their cost/benefit ratio.
- Assessing and designing channel maintenance measures such as sediment removal to ensure the capacity and stability of the watercourses. The models can be used to assess the economic benefits of channel maintenance by comparing the potential flood damages with and without maintenance.
- Structural flood protection should be paired with implementation of non-structural mitigation measures. Flood mapping is the first step of awareness of the hazard and should be followed by community education, implementation of land-use management plans, and flood emergency planning.
- There are other flood-related issues that should be assessed in the region that require other types of investigations and analysis. For example, local drainage and flooding on some portions of the floodplain appears to be caused by ponding of rainfall and seepage due to a high water table from groundwater inflows. These problems need to be assessed using other methods, including water level and rainfall monitoring and stormwater modelling.

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PHOTOGRAPHS

Photo source: Ray Stewart, June 2018

Photo 1 Upstream portion of Ray Stewart's Property, showing channel incision

Photo source: Ray Stewart, May 2018

Photo 2 Downstream end of Ray Stewart's property, showing overland flow

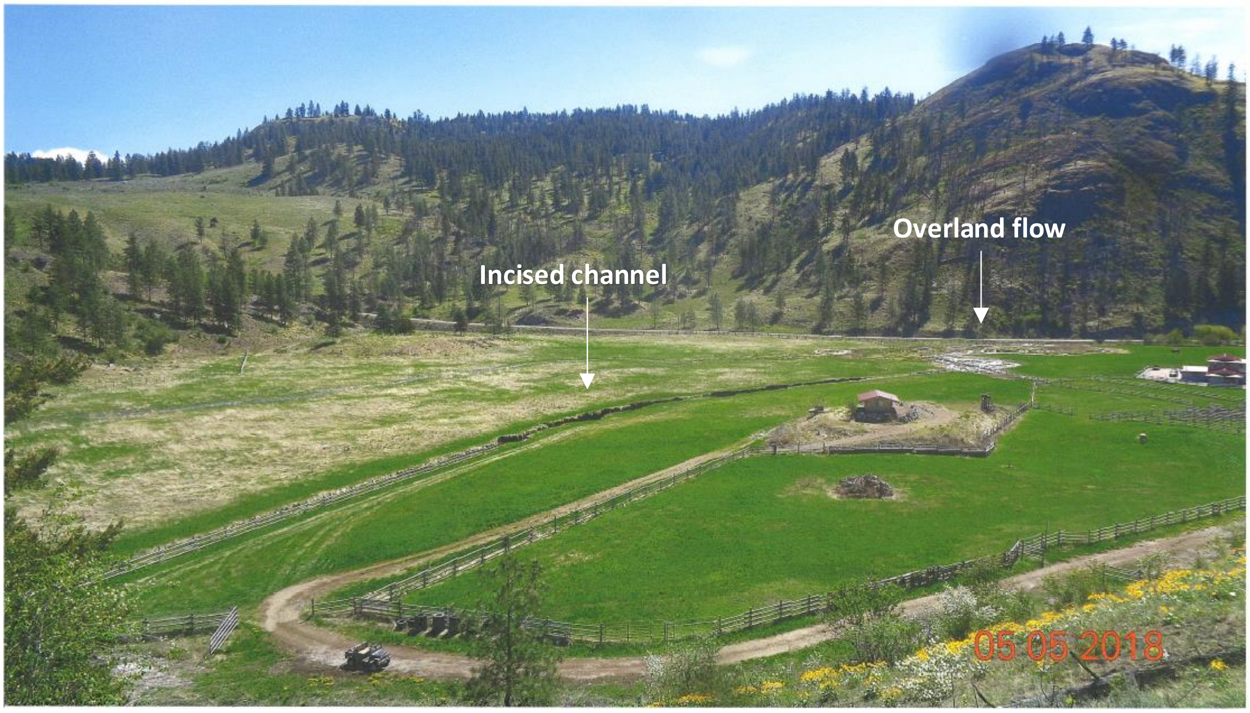


Photo source: Ray Stewart, May 2018

Photo 3 **Broad view of Ray Stewart's property, it shows incision at upstream end and overland flow with potential deposition near Fairview White Lake Road at the downstream end**

Photo source: NHC, Aug 2020

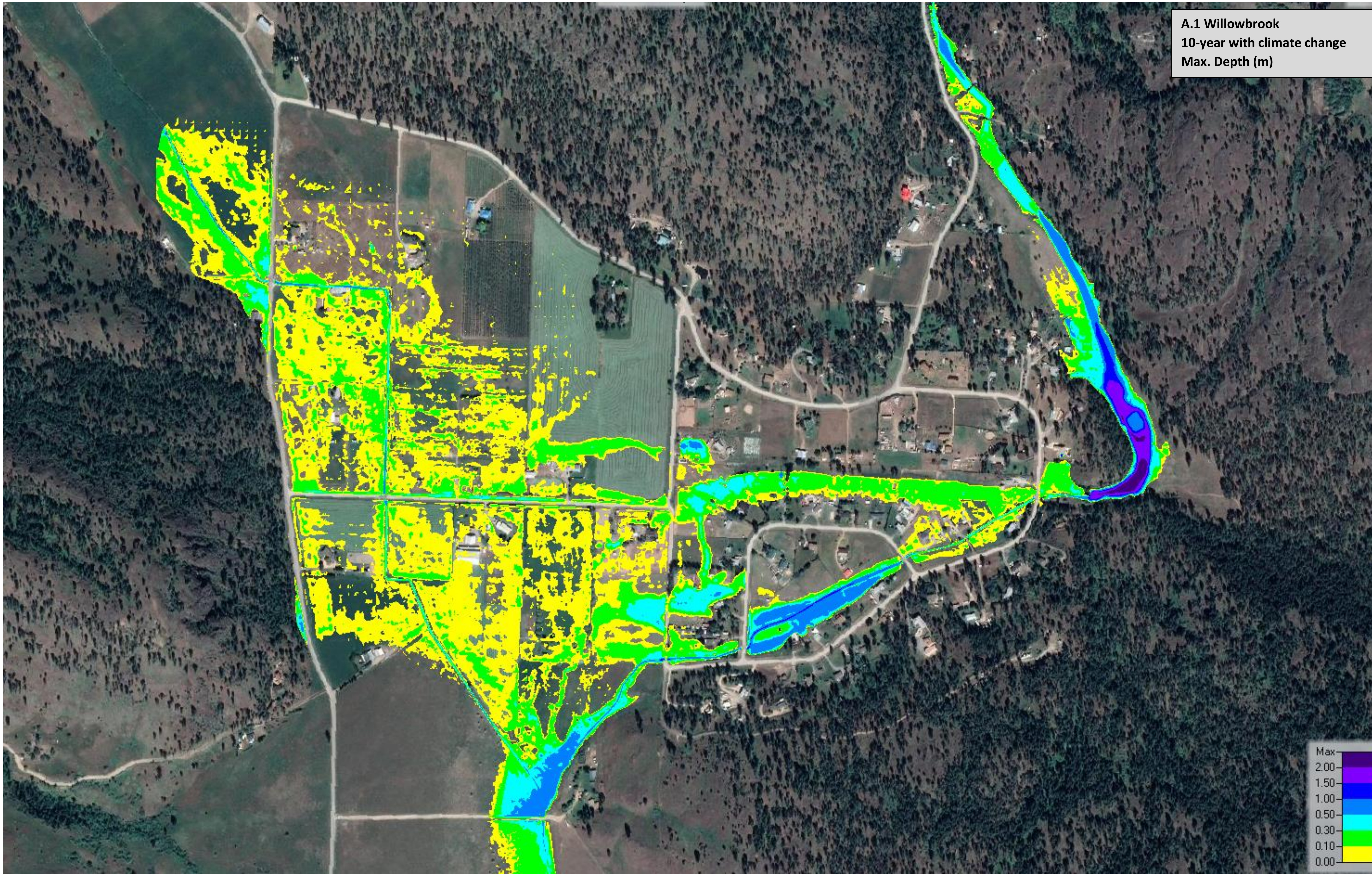
Photo 4 **Box culvert along Carr Crescent in Willowbrook, showing sediment deposition at culvert**

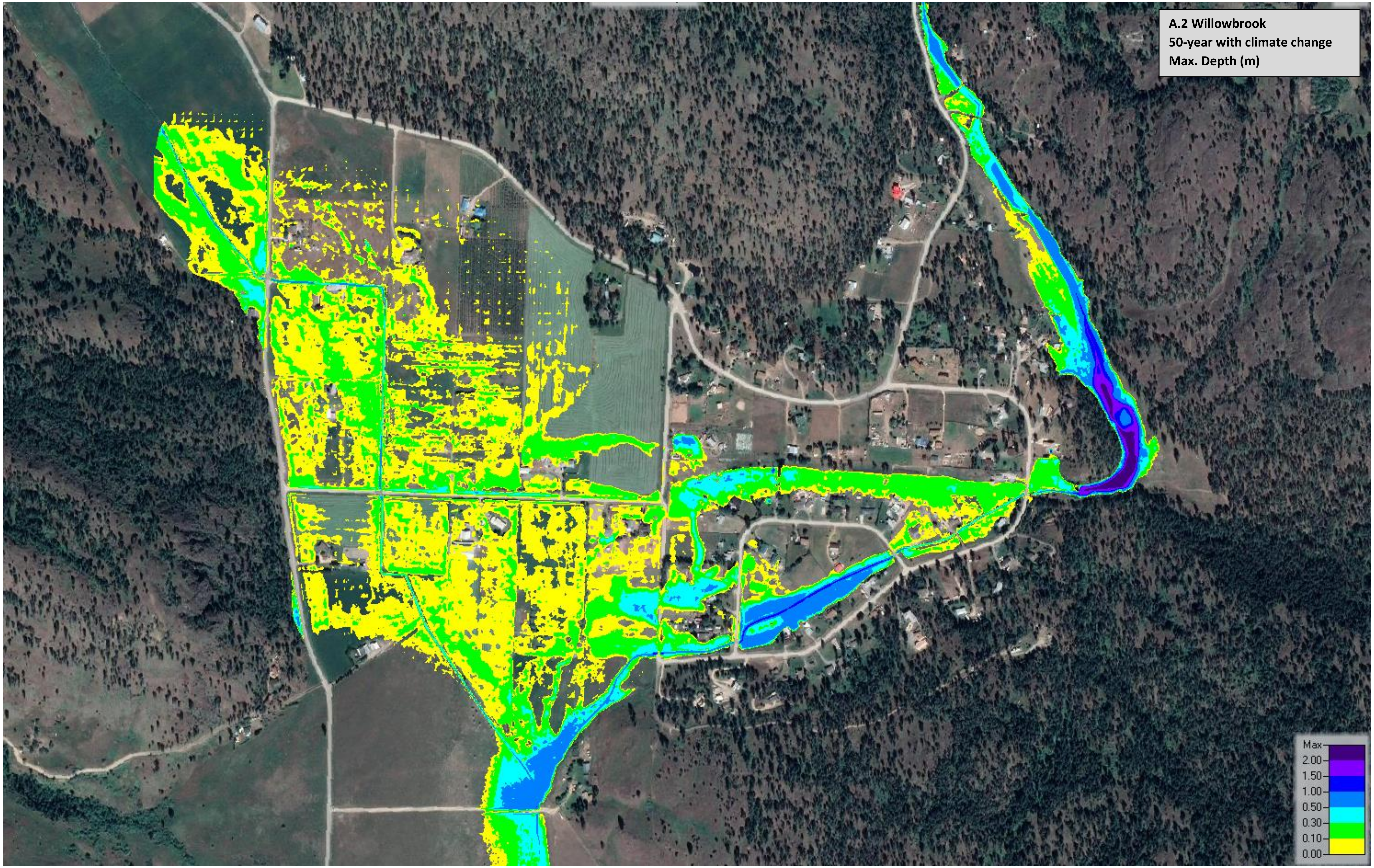
Photo source: NHC, Aug 2020

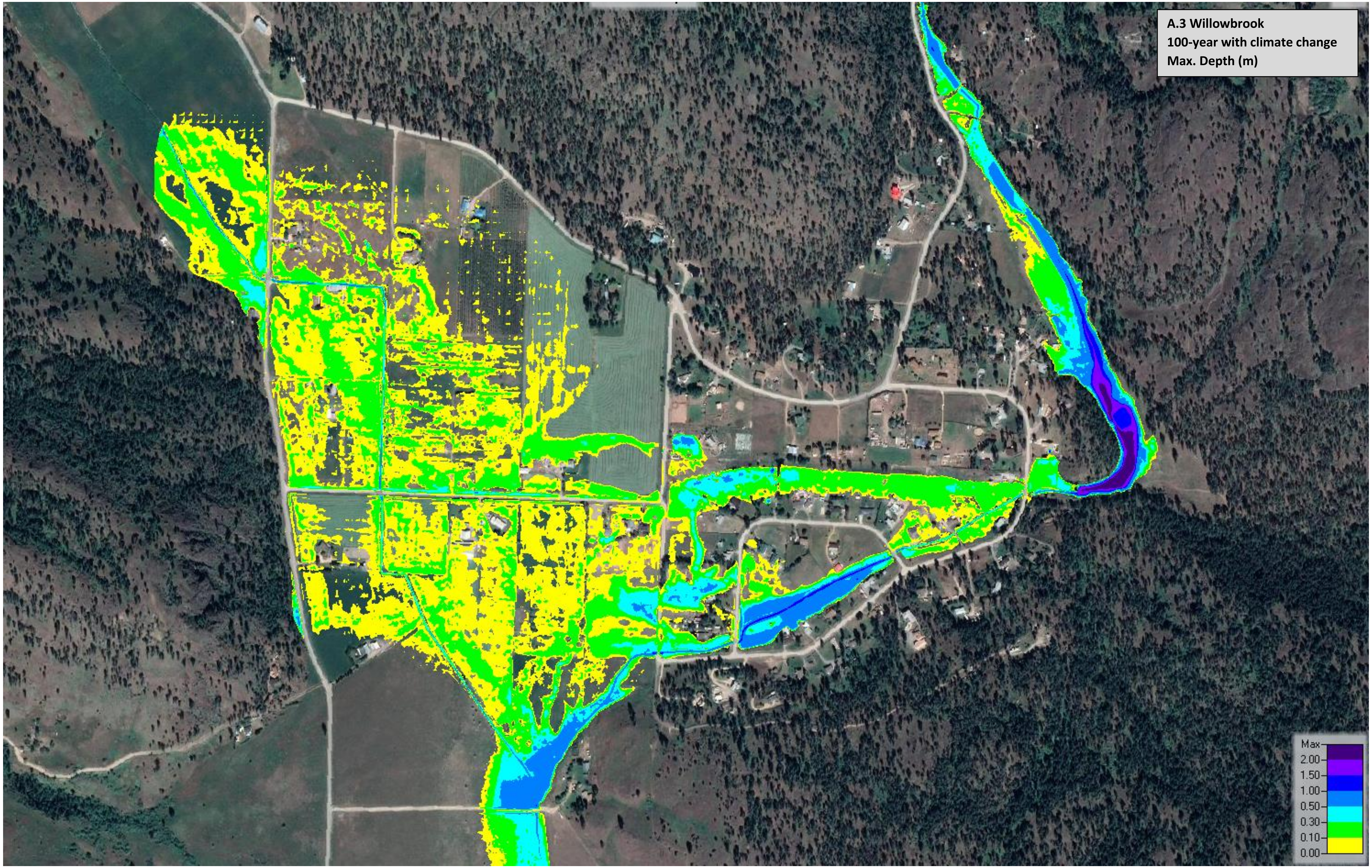
Photo 5 Culvert crossing at White Lake Ranch

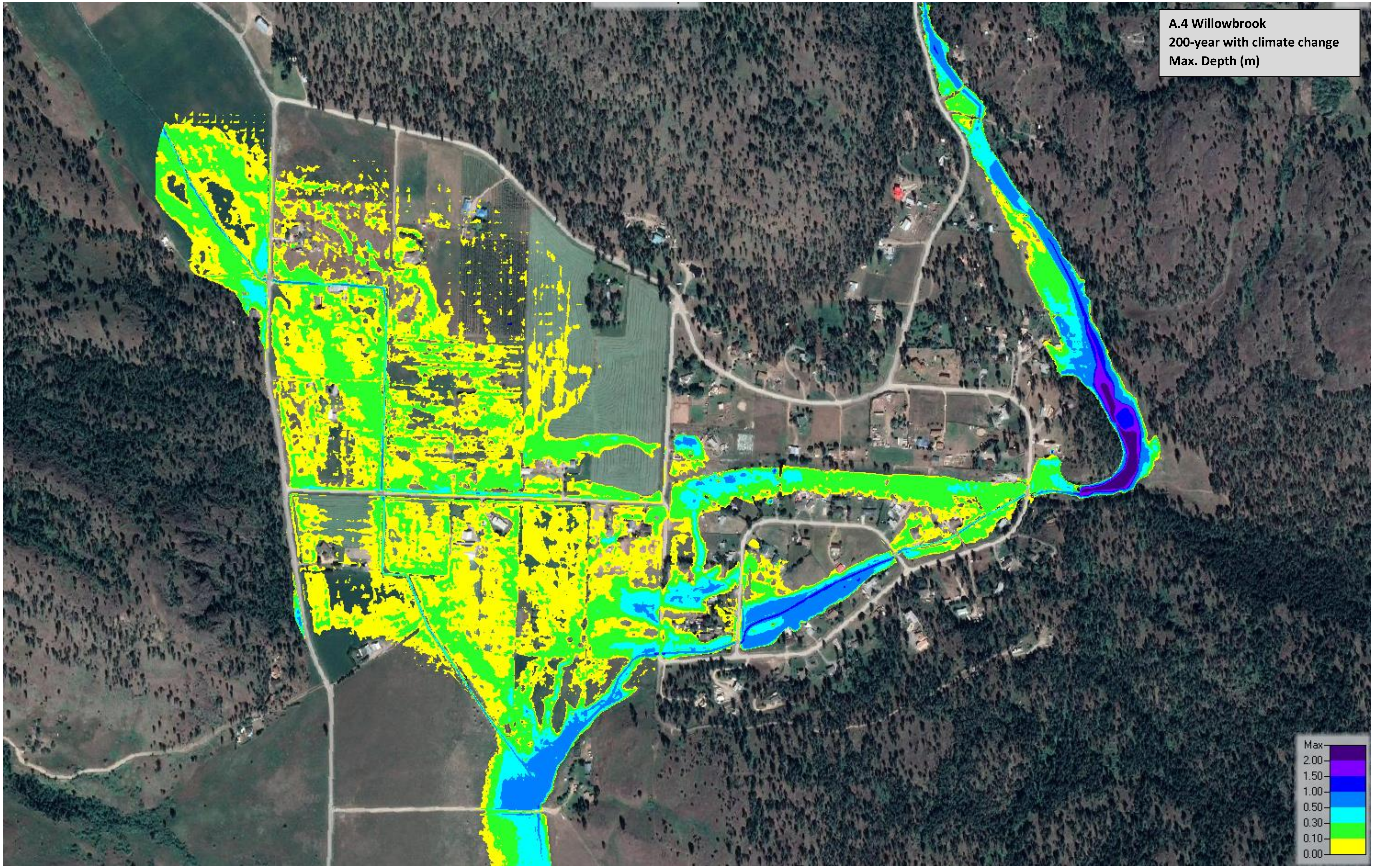
APPENDIX A

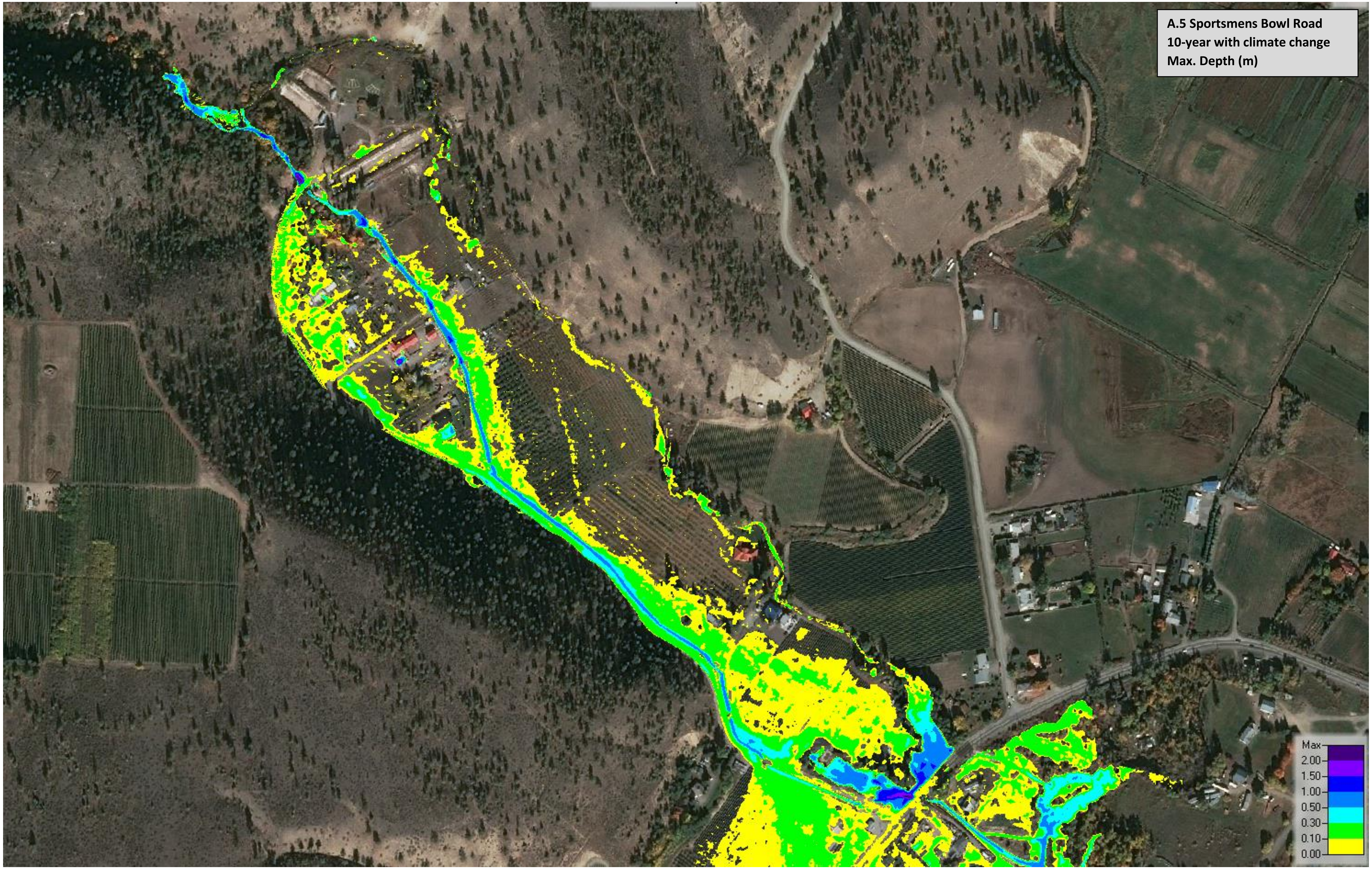
DEPTH, VELOCITY, AND HAZARD DIAGRAMS

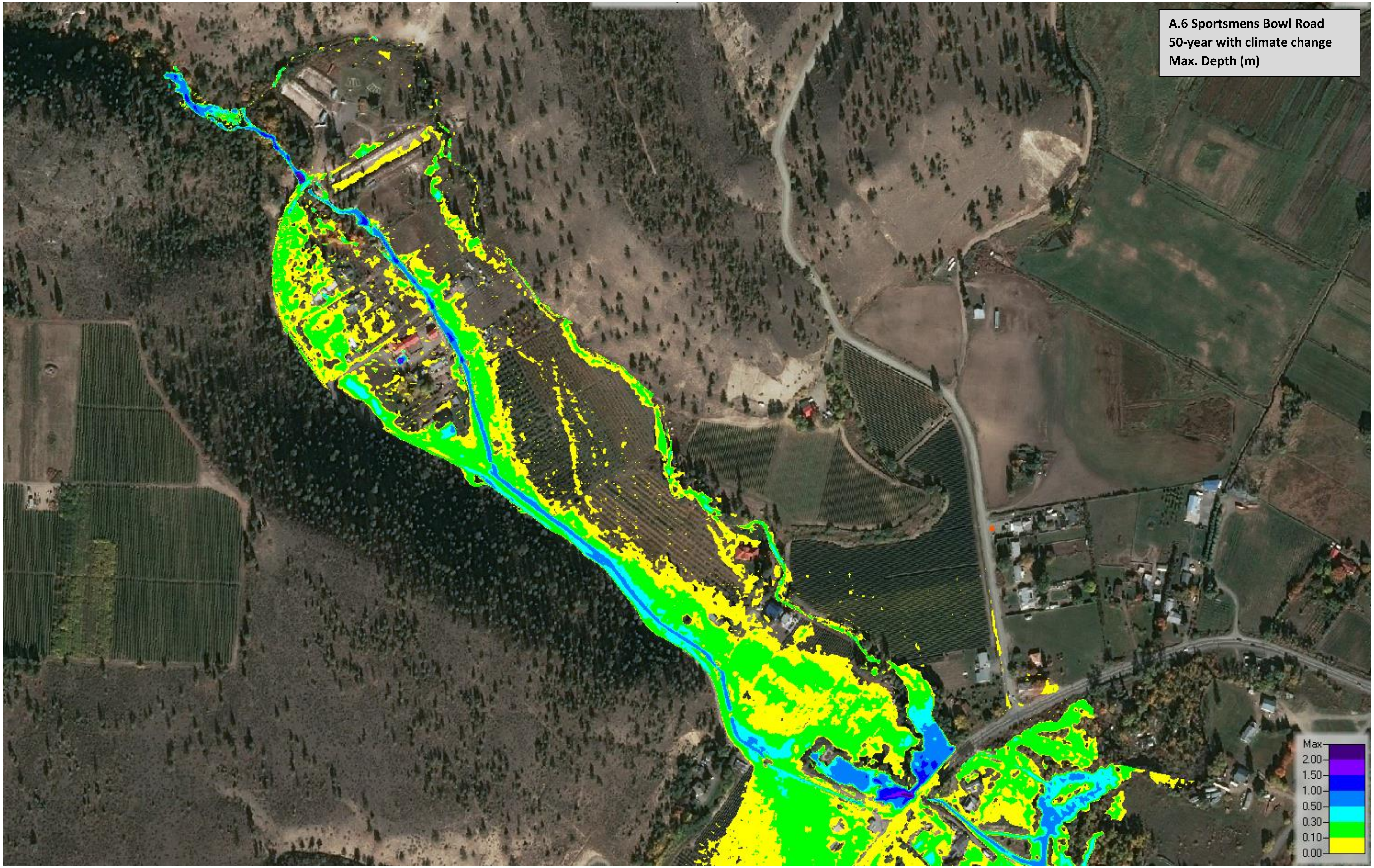

A.1 Willowbrook
10-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

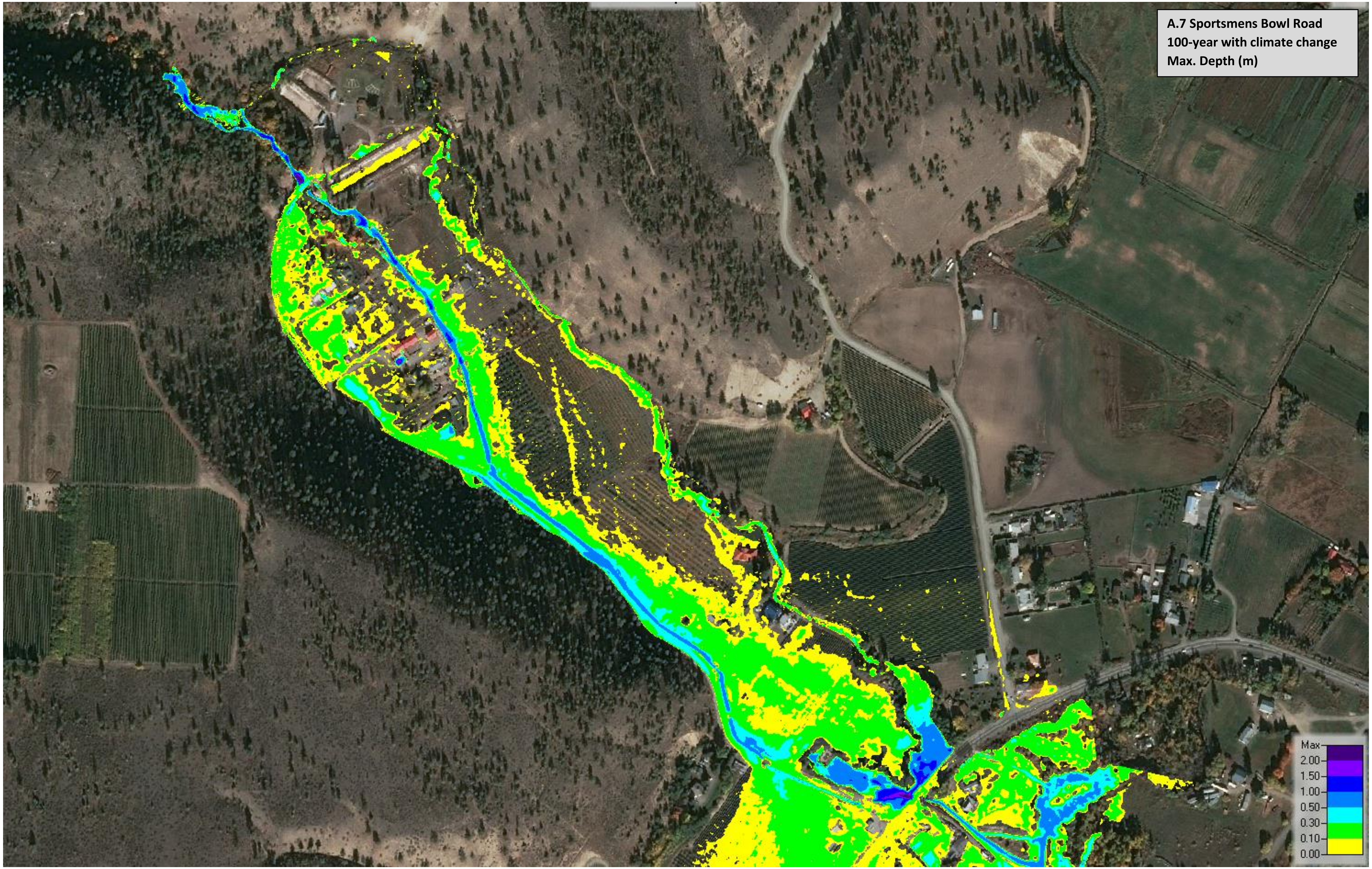

A.2 Willowbrook
50-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00


A.3 Willowbrook
100-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

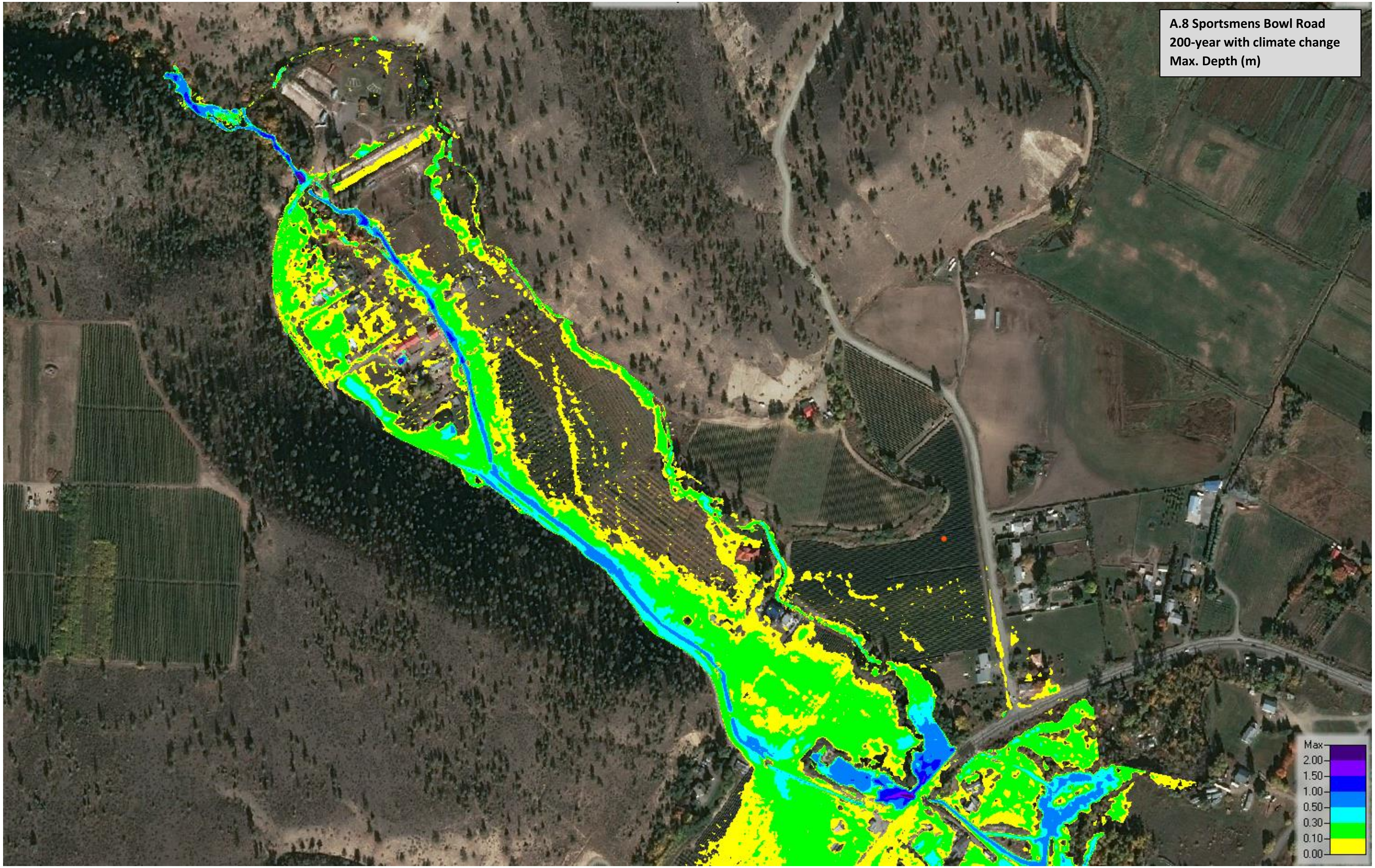

A.4 Willowbrook
200-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00


A.5 Sportsmens Bowl Road
10-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

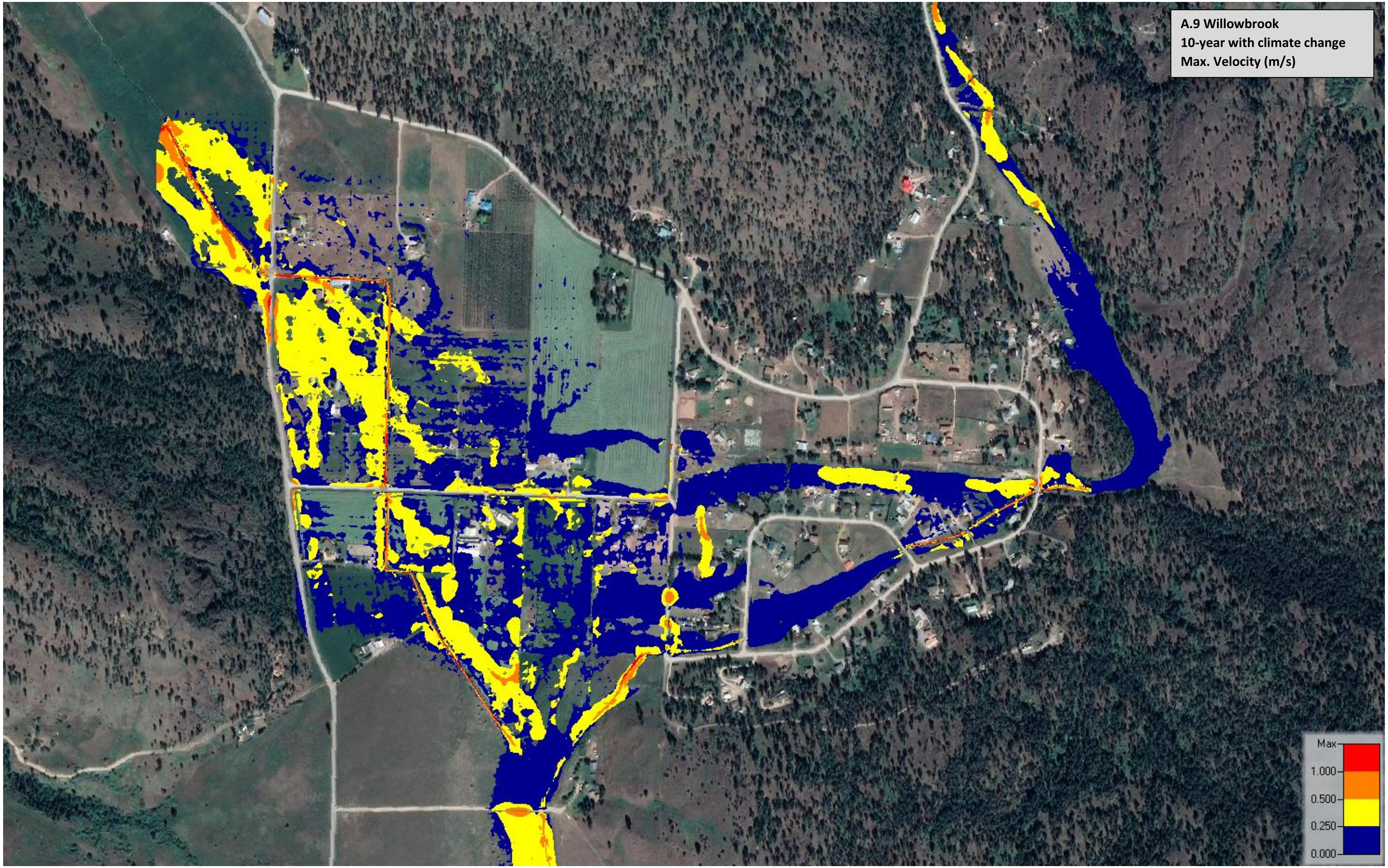

A.6 Sportsmens Bowl Road
50-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

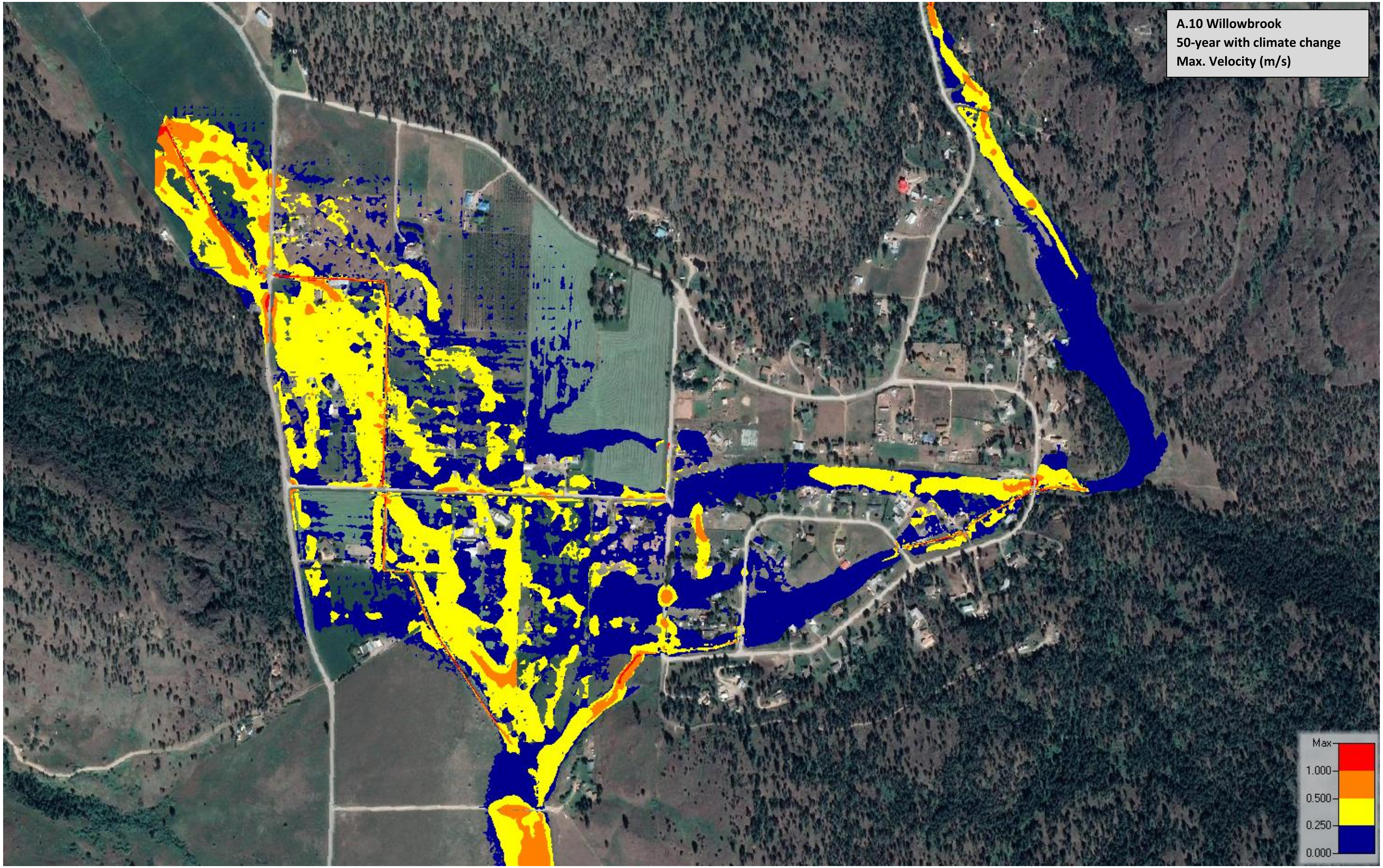


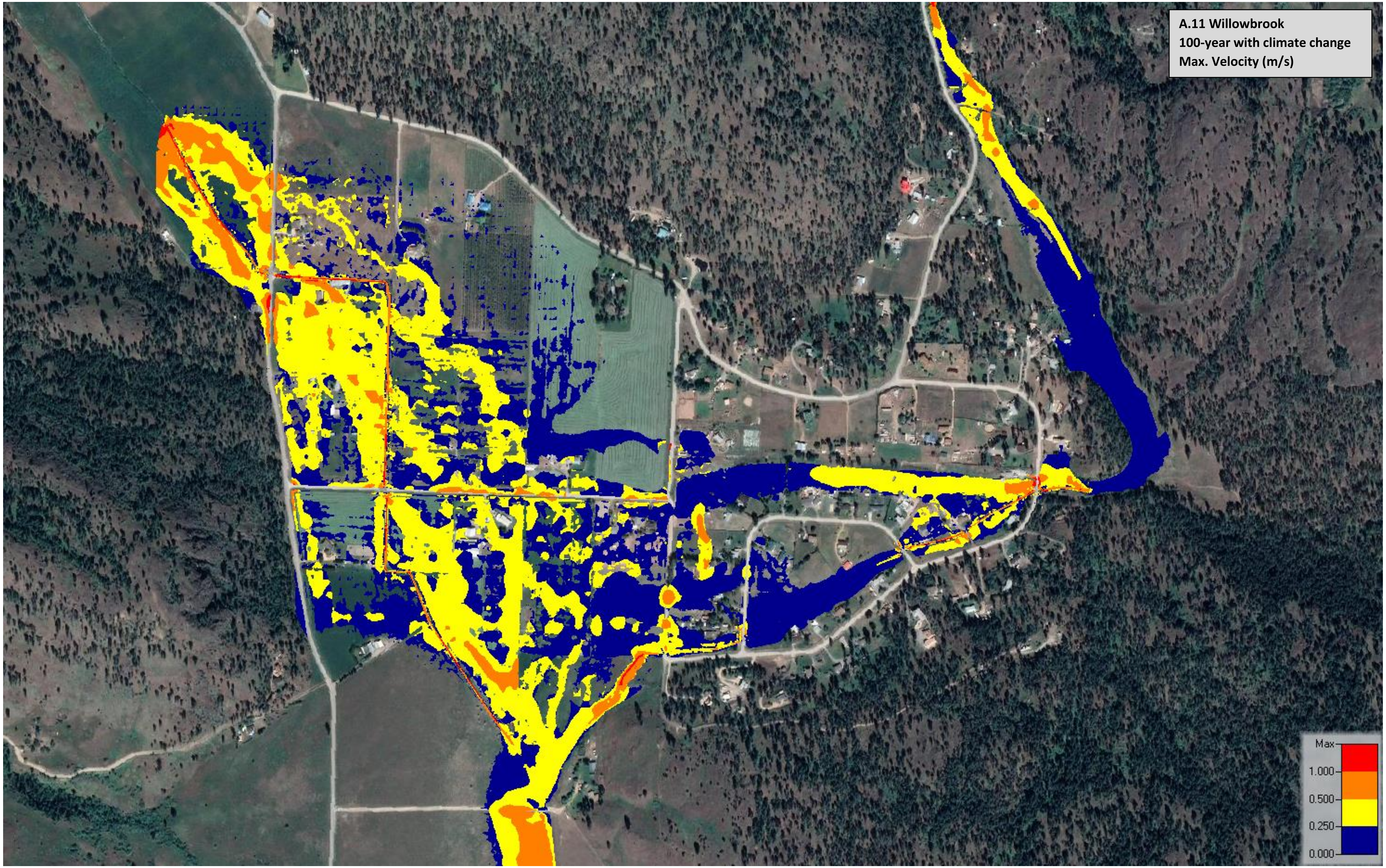
A.7 Sportsmens Bowl Road
100-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

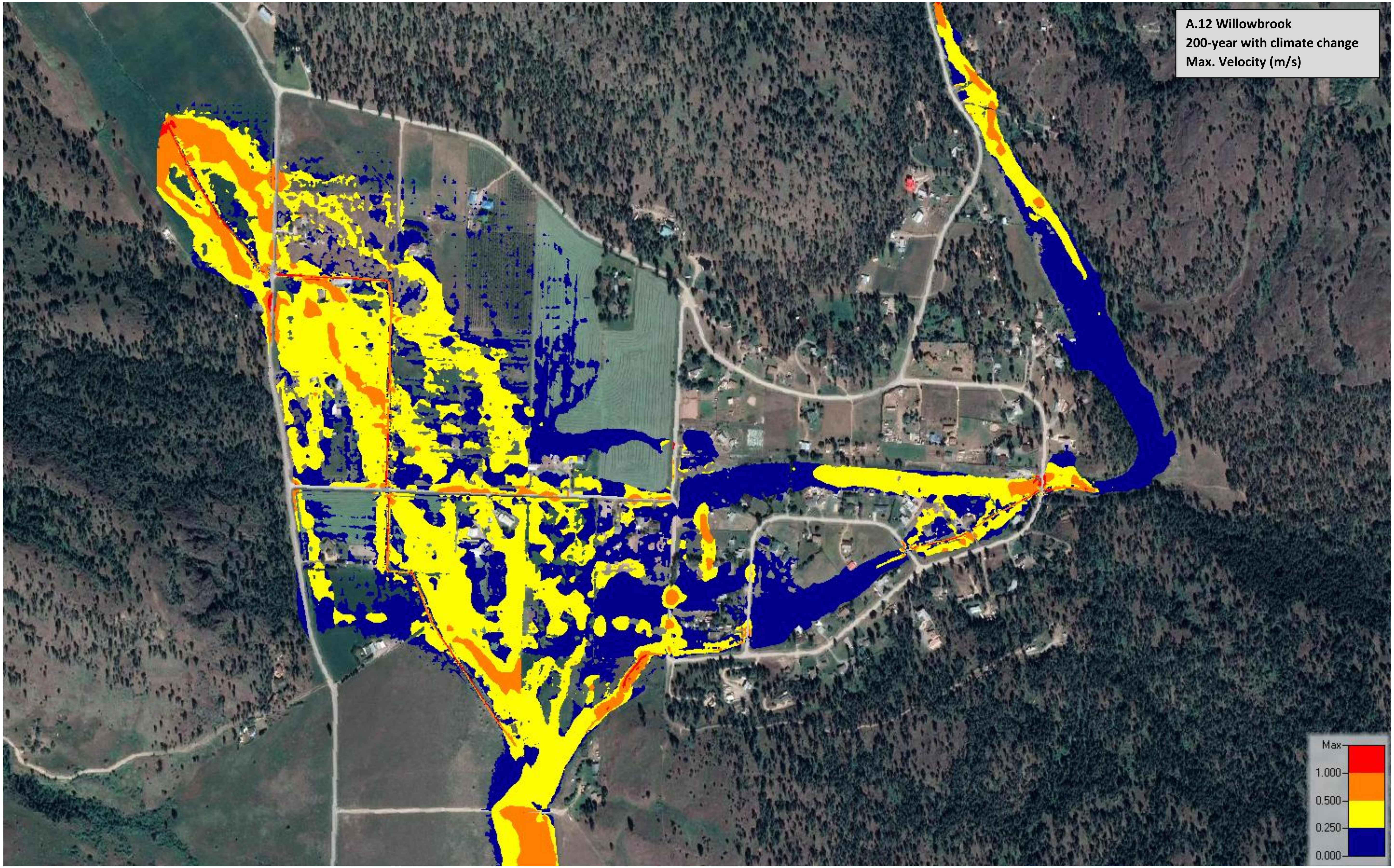


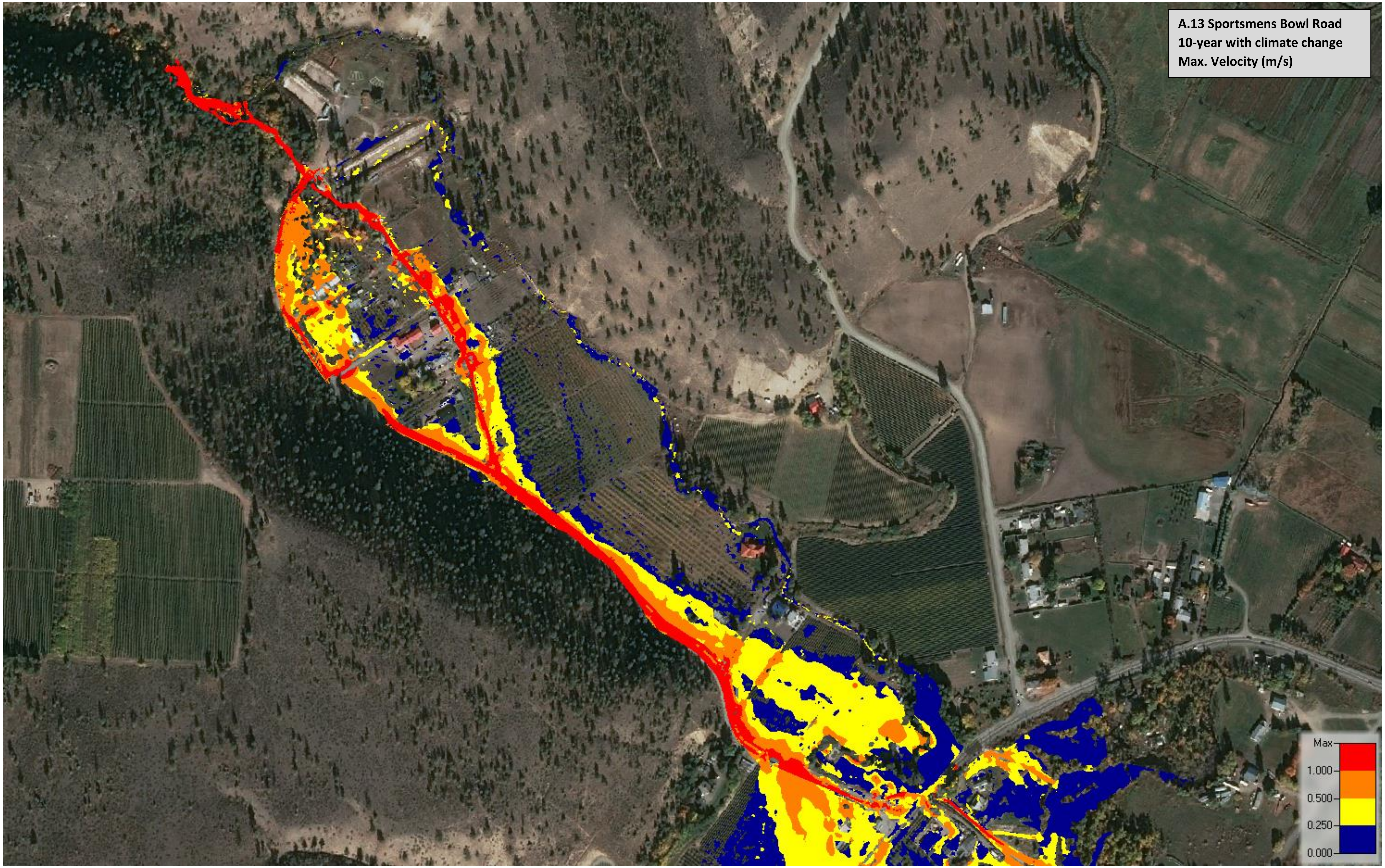
A.8 Sportsmens Bowl Road
200-year with climate change
Max. Depth (m)
Max
2.00
1.50
1.00
0.50
0.30
0.10
0.00

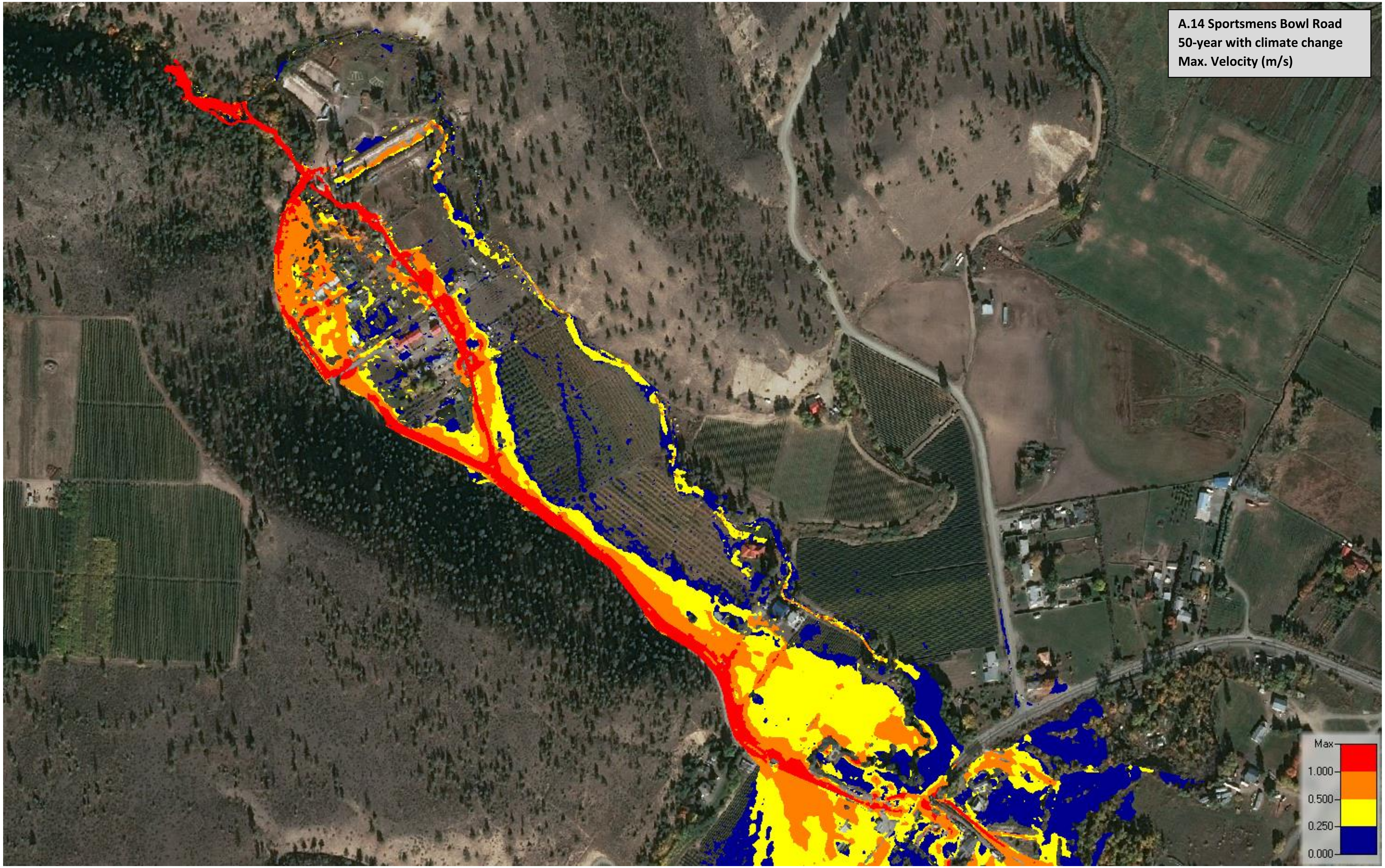

A.9 Willowbrook
10-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000

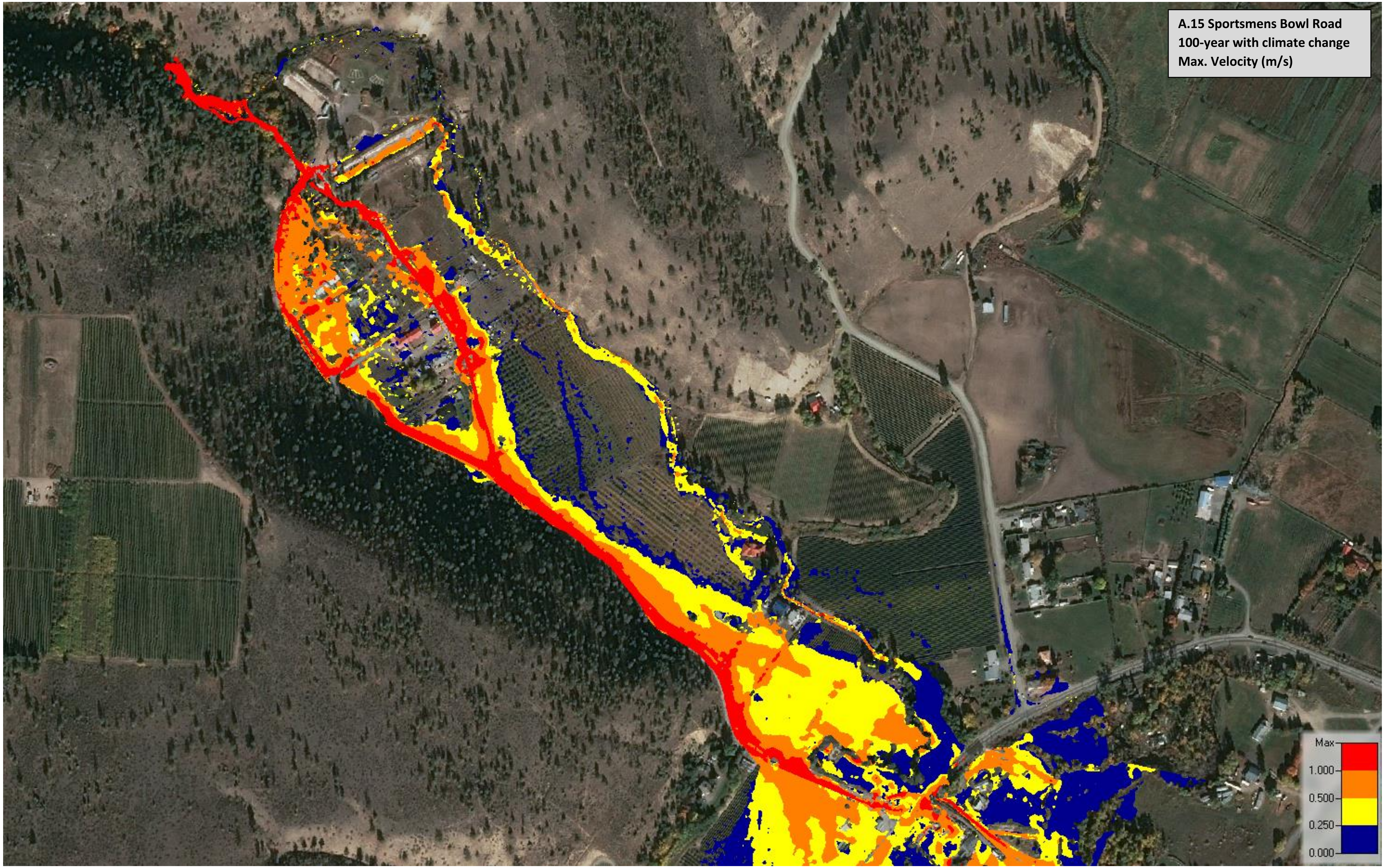

A.10 Willowbrook
50-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000


A.11 Willowbrook
100-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000

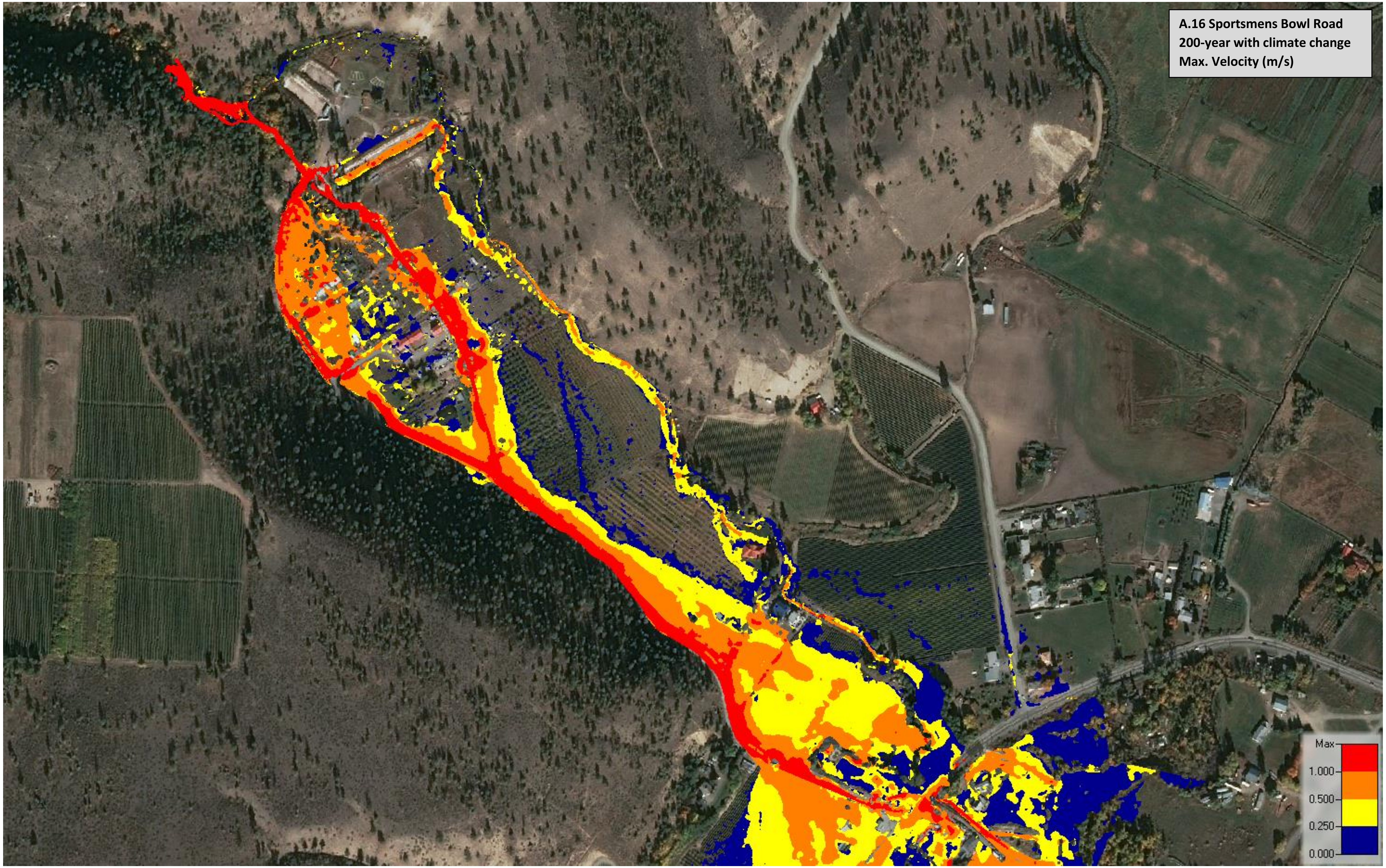

A.12 Willowbrook
200-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000


A.13 Sportsmens Bowl Road
10-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000

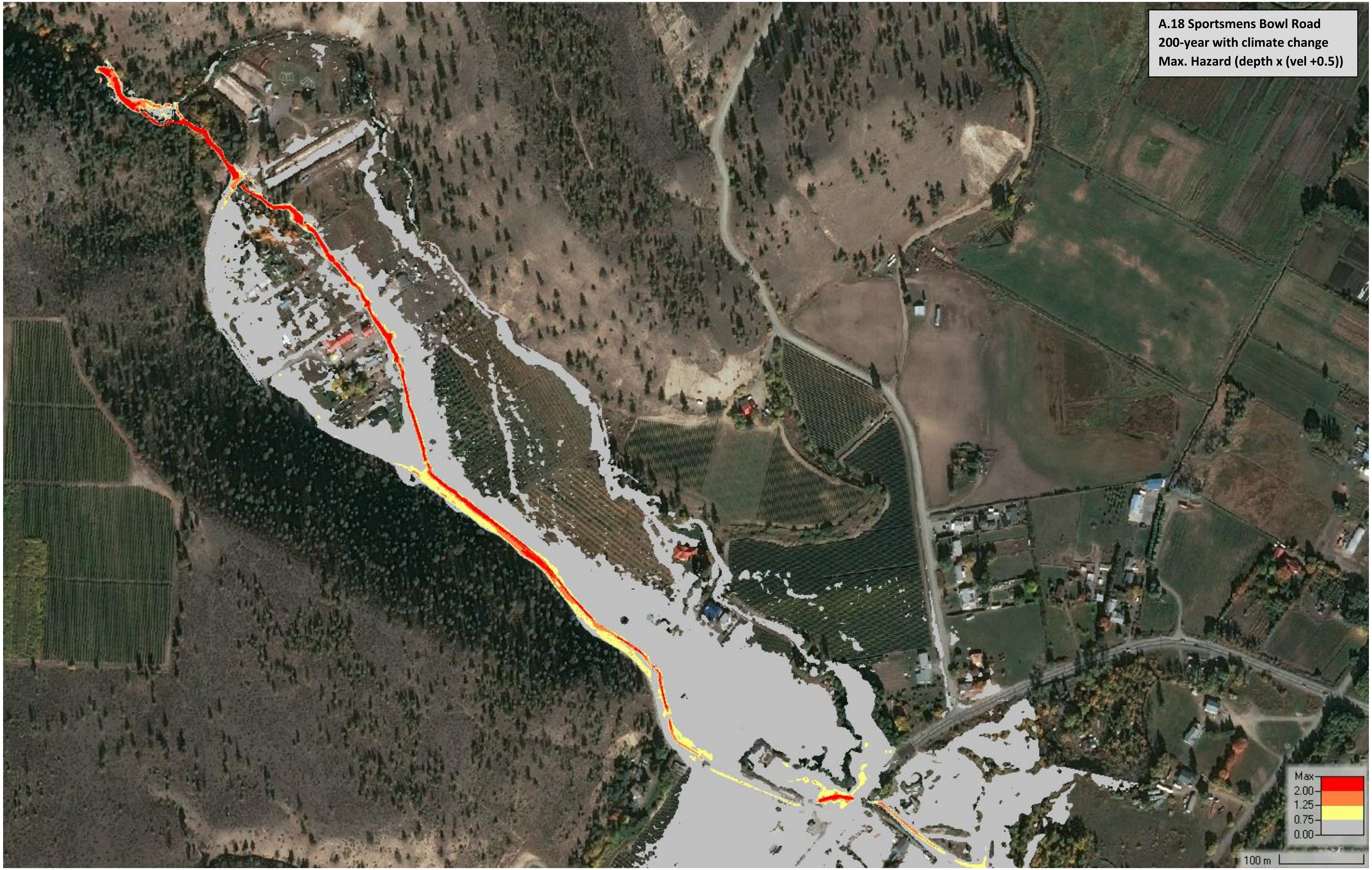

A.14 Sportsmens Bowl Road
50-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000



A.15 Sportsmens Bowl Road
100-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000


A.16 Sportsmens Bowl Road
200-year with climate change
Max. Velocity (m/s)
Max
1.000
0.500
0.250
0.000

A.17 Willowbrook
200-year with climate change
Max. Hazard (depth x (vel +0.5))
Max
2.00
1.25
0.75
0.00
200 m


A.18 Sportsmens Bowl Road
200-year with climate change
Max. Hazard (depth x (vel +0.5))
Max
2.00
1.25
0.75
0.00
100 m

APPENDIX B
FLOOD EXPOSURE RESULTS


Twin Lakes
Twin Lakes Rd
Eastview Rd
Sagewood Lane
White Lake Rd
Grand Oro Rd
Sportsmen
Secrest Hill Rd
Test Orchard Rd
Horsetail Rd
Sportsmens Bowl Rd
Willowbrook
Green Lake Rd
Jones Way
Myers Rd
Carr Cres
Johnson Cres
Willowbrook Rd
Orofino Creek Rd
private driveway
Goldtau Rd
Lillian Rd
Legend
Study Area
200-year flood depth (m)
3
0
Flood Impacts
Buildings (depth m)
0.0 - 0.0
0 - 0.3
0.3 - 0.5
0.5 - 1
Roads (m inundated)
0 - 100
100 - 200
Power Poles (depth m)
0 - 0.1
0.1 - 3.0
0
100
200 m
RDOS
Flood Impact Map
200-year
2021-04-02T11:32:19.016, RDOS - impacts.qgz, 594x841mm