CHAPTER 6 FLOODPLAIN MAPPING & APPLICATIONS

6.1 Chapter Synopsis

Okanagan Valley lake and riverine floodplain maps were derived from the river and lake modelling described in previous chapters. Floodplain maps have been prepared that include flood inundation level and extent for mid-century flood events, riverine velocity and depth, as well as design FCLs that incorporate freeboard. These maps have been provided as GIS layers (Table 6-2) as well the FCL maps that accompany this report. The maps have been compared to previous Okanagan Valley flood mapping.

The goal of floodplain mapping is to reduce the risk of floods through improving understanding of the hazard and allowing First Nations, governments, organizations and individuals to plan for potential floods and reduce their risk. Flood risk reduction approaches are summarized in section 6.5, including structural mitigation and non-structural. As part of the educational component of non-structural mitigation, an interactive and informative online website was developed to provide public access to flood hazard information.

Following the development of a sophisticated understanding of the flood hazard in the Okanagan region gained through this project, First Nations, governments, and residents have an opportunity to further develop their comprehensive flood mitigation strategies.

6.1.1 Limitations on Floodplain Mapping Component of this Study

- The design flow magnitudes are projected to increase over time as a result of climate change. The design flood events applied for the lake and riverine reaches are based on a modified operational regime of the flow control structures at the outlet of the lakes. If the operational regimes of these structures are not modified to adapt to the increasing flow regime, then flood levels and extents will be greater than those illustrated in the maps.
- The maps delineate FCL extents under the design flood event. Mapping of the Okanagan River, Skaha Lake, Vaseux Lake, Ellison Lake, and Osoyoos Lake is based on the 200-year mid-century (2041-2070) design event. Mapping of Okanagan Lake and Wood / Kalamalka lakes is based on the flood of record (2017) adjusted to mid-century for climate change. Tributaries are not included in mapping.
- The mapped FCL includes a freeboard allowance of 0.6 metres, which has been added to the calculated flood water level to account for local variations in water level and uncertainty in the design event estimates. The inundation maps do not include freeboard, and hence should only be considered with an understanding of the uncertainty in their results.
- The FCLs shown on all lake maps include an allowance for wind setup (except Ellison) and wave runup based on co-occurrence of the seasonal 200-year wind event. The wind and wave effects extend 40 m shoreward to delineate the expected limit of wave effects. Beyond this limit the FCL is based on inundation of the flood event without wave effects. Shorelines FCLs take precedence over lake inundation FCLs. Wave effects have been calculated based on generalized shoreline profile and roughness for each shoreline reach. Site specific runup analysis by a Qualified Professional may be warranted to refine the generalized wave effects should the shoreline slope be significantly different than the

generalized profile used for that reach (Table 4-7). Site-specific analysis could increase or decrease the FCL by as much as a metre.

- Underlying hydraulic analysis assumes channel and shoreline geometry is stationary. Erosion, deposition, degradation, aggradation, and local blockages may occur during a flood event to sufficiently alter actual observed flood levels and extents. Obstructions, such as log-jams, local storm water inflows or other land drainage, groundwater, or tributary flows may cause flood levels to exceed those indicated on the maps.
- The Okanagan floodplain is subject to persistent ponding due to poor drainage. Persistent ponding is not covered by the flood inundation mapping.
- The majority of the Okanagan River is diked; breaching of the dike was not modelled. Isolated areas below the FCL (as projected perpendicular to flow from the channel), such as those landward of the dikes, are mapped as inundated. This delineation accounts for potential failure and breaching of the dike, seepage through, or inflows trapped behind the separating dike or embankment. This approach is consistent with BC floodplain mapping guidelines.
- Filtering was used to remove isolated areas smaller than 100 m^2. Holes in the inundation extent with areas less than 100 m^2 were also removed. Isolated areas larger than 100 m^2 were retained for mapping if they were within 40 metres of direct inundation or within 40 metres of other retained polygons.
- Okanagan Dam breach and dam overtopping were not modelled. On the right bank of the Okanagan River from the Okanagan Dam downstream to the Highway 97 bridge, inundation mapping is based on modelling of design lake level overflowing to the river downstream; along the left bank downstream of Okanagan Dam inundation mapping is based on river modelling, as Okanagan Lake level overtopping along the left bank is limited to a localized area adjacent to the dam. Overflow at this site was not simulated.
- The accuracy of the selected design floods is limited by the reliability and temporal and spatial extent of water level, flow, and climatic data, as well as the operations of the lake outflow structures. The accuracy of floodplain levels and extents is limited by the accuracy of the design flood flow, the hydraulic model, and the digital surface representation of local topography, which is bare-earth (no buildings or structures). Localized areas above or below the FCL maybe generalized by the inundation mapping. Therefore, floodplain maps should be considered an administrative tool that indicates flood elevations and floodplain boundaries for a designated flood. A Qualified Professional is to be consulted for site-specific engineering analysis.
- Industry best practices were followed to generate the floodplain maps. However, actual flood levels and extents may vary from those shown. Residual flood risk beyond that mapped exists for flood events more extreme than the design events. OBWB and NHC do not assume any liability for variations of flood levels and extents from that shown.

6.2 Floodplain Mapping

Floodplain mapping for the Okanagan Basin covers from Okanagan Lake to the US border including Wood-Kalamalka, Ellison, Skaha, Vaseux, and Osoyoos Lake as well as the Okanagan River from Okanagan Lake to Osoyoos Lake. The mapping was developed from: hydrologic routing of flow through the lakes, river hydraulic modelling, and lake wave modelling. The results from the calculated water surface profiles were mapped on 116 sheets at 1:5,000 scale (maps of the FCL are included with this report). The flood mapping is based on the design flood scenario and includes FCLs for the river and the lakes with freeboard added to the simulated water level, as discussed in the next subsection. The floodplain maps are accompanied by an index map which includes detailed map notes.

The floodplain maps are designed according to mapping standards presented in NHC (2020b).

6.2.1 Coordinate System and Datum

The following has been used for the Okanagan Valley flood mapping:

- Coordinate system: UTM Zone 11. Coordinates in metres.
- Horizontal datum: NAD 83 (CSRS).
- Vertical datum: Geodetic – CGVD2013.

The horizontal datum for BC is NAD83. For the most accurate positioning, the CSRS realization of NAD 83 is used.

CGVD2013 is a new vertical datum for Canada, gradually being adopted across the country.[1] The Province of BC is developing a transition plan and tools to support migration to CGVD2013.[2] CGVD2013 will replace the older CGVD28 HTv2.0_2002 vertical datum. Conversion between the two datums can be done with spot heights inputted into NRCan's online tool GPS-H[3], or through development of an in-house conversion grid.

Changes in the elevations between the two vertical datums for representative locations in the Okanagan Valley are shown below in Figure 6-1 and Table 6-1. Values were calculated using the NRCan GPS-H tool. Differences range from 0.190 m to 0.332 m.

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[1] Natural Resources Canada (2017). Height Reference System Modernization, https://www.nrcan.gc.ca/earth-sciences/geomatics/geodetic-reference-systems/9054

[2] Government of British Columbia. Vertical (Height) Reference System, https://www2.gov.bc.ca/gov/content/data/geographic-data-services/georeferencing/vertical-reference-system

[3] Natural Resources Canada (2019). GPS-H, http://webapp.geod.nrcan.gc.ca/geod/tools-outils/gpsh.php?locale=en

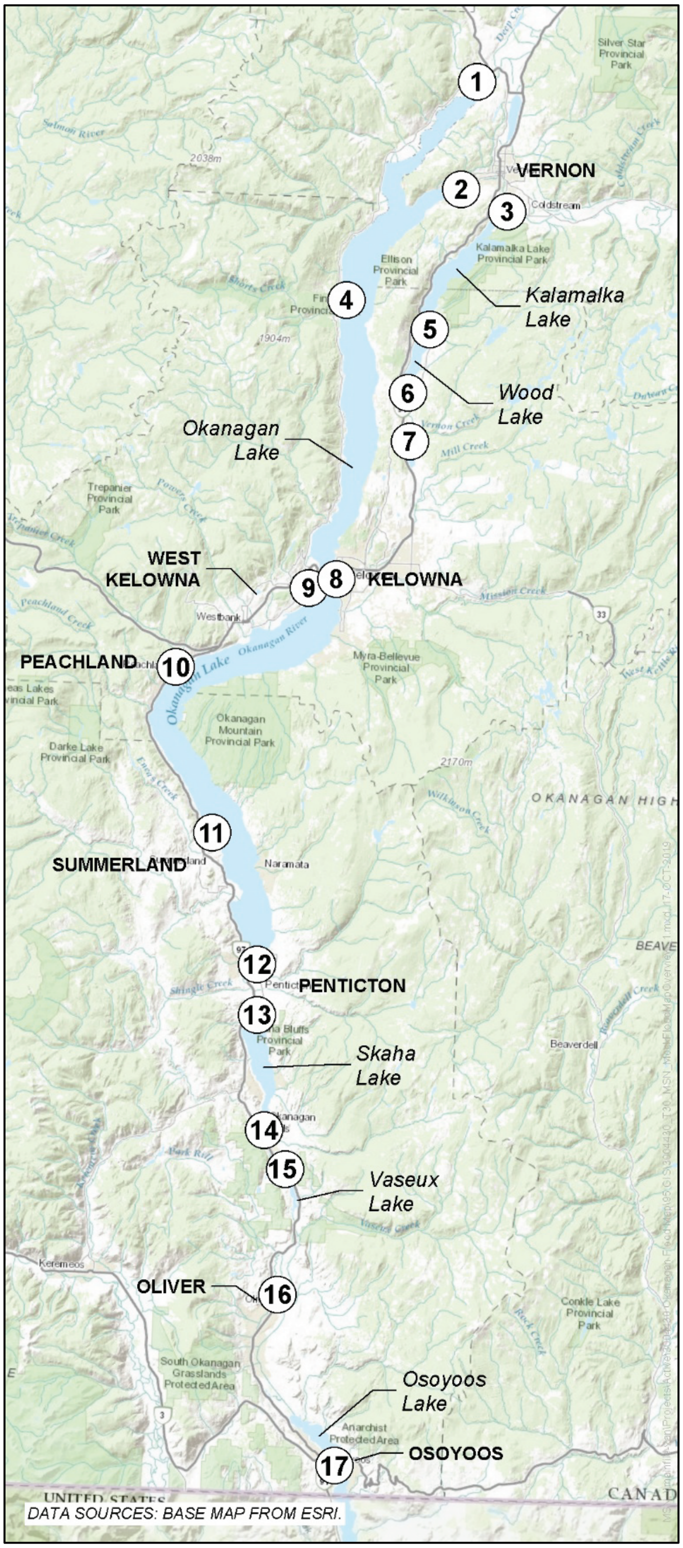


Figure 6-1 Representative points for vertical datum comparison.

Table 6-1 Changes in elevation between vertical datums at representative locations[1].

ID	Location	Latitude	Longitude	Elevation (m, CGVD28 HTv2.0)	Elevation (m, CGVD2013)	Difference in Elevation (m)[2]
1	north end Okanagan Lake	50° 20' 57" N	119° 18' 43" W	343.229	343.561	0.332
2	Vernon Regional Airport	50° 14' 47" N	119° 19' 49" W	345.859	346.157	0.298
3	north end Kalamalka Lake (Coldstream)	50° 13' 35" N	119° 15' 41" W	393.259	393.551	0.292
4	Fintry, west shore Okanagan Lake	50° 8' 16" N	119° 29' 40" W	344.973	345.279	0.306
5	Oyama, south end Kalamalka Lake	50° 6' 43" N	119° 22' 14" W	412.775	413.046	0.271
6	south end Wood Lake	50° 3' 3" N	119° 23' 57" W	394.027	394.295	0.269
7	north end Ellison Lake (Duck Lake Reserve)	50° 0' 18" N	119° 23' 40" W	427.924	428.188	0.264
8	Kelowna, east shore Okanagan Lake	49° 52' 18" N	119° 29' 45" W	343.478	343.722	0.244
9	West Kelowna, west shore Okanagan Lake	49° 51' 45" N	119° 32' 12" W	369.042	369.259	0.217
10	Peachland, west shore Okanagan Lake	49° 46' 58" N	119° 43' 38" W	344.470	344.687	0.217
11	Crescent Beach, west shore Okanagan Lake (Summerland)	49° 37' 35" N	119° 39' 55" W	344.533	344.723	0.190
12	Penticton, south end Okanagan Lake	49° 30' 11" N	119° 35' 37" W	344.275	344.486	0.211
13	Penticton, north end Skaha Lake	49° 27' 17" N	119° 35' 27" W	339.125	339.365	0.240
14	south end Skaha Lake	49° 20' 43" N	119° 34' 29" W	343.872	344.150	0.278
15	north end Vaseux Lake	49° 18' 32" N	119° 32' 31" W	333.043	333.322	0.279
16	Oliver	49° 11' 23" N	119° 32' 48" W	296.284	296.581	0.297
17	Osoyoos	49° 1' 42" N	119° 27' 22" W	280.231	280.468	0.238

[1] Data in this table is provided as an example only. These data points should not be used to transform elevations. Refer to conversion tools such as NRCan's GPS-H tool.

[2] Changes are from CGVD28 HTv2.0_2002 to CGDV2013.

6.2.2 Development

For riverine flood extents, the simulated water level at each cross section from the model was used to generate a water surface. The surface was linearly interpolated along the thalweg between sections and assumed to have a constant level projecting across the floodplain from the thalweg perpendicular to the flow path. The surface was mapped over the DEM. The projected flood inundation extends past dikes and roads to account for potential breach or seepage through or under the embankments (Figure 6-2).

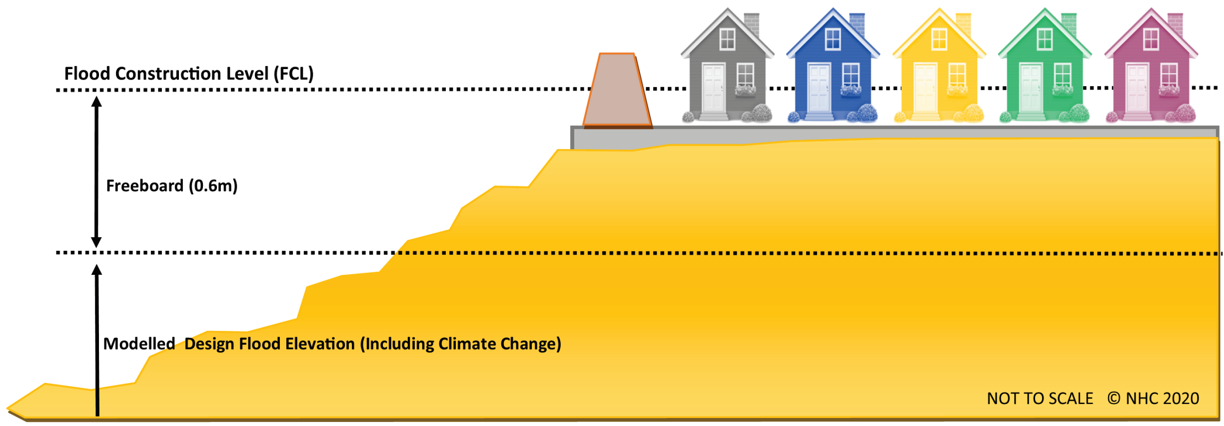


Figure 6-2 Flood construction level schematic for rivers.

FCL is 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. For riverine FCLs this is the upstream extent of the building or space. Where the building or space is located between isolines, two options exist for determining the applicable FCL:

- Option 1: the FCL is taken as the value represented by the next upstream isoline, or
- Option 2: the FCL is calculated through linear interpolation between the 2 isolines in which upstream face of the building or space is located.

An example is presented below based on the building and mapped isolines shown in Figure 6-3:

- The highlighted FCL line has an elevation of 317.20 m, with the downstream FCL (shown as a black line) having an elevation of 317.00 m. The distance between these lines is 28 m, and the upstream side of the building is 7 m downstream from the 317.20 FCL isoline.
- The FCL for the labelled building using Option 1 is 317.20 m and using Option 2 it is 317.15 m (through interpolation of the FCL using a 0.20 m drop over 28 m).

Figure 6-3 Example of river FCL line calculation.

Flooding from the lakes is identified in the mapping through characterization of two hazards – lake inundation and wave effects. Lake inundation is developed through modelling of the flood elevation for each lake, called the 'still-water' level. On top of this still-water level, wind-setup (increase in water level due to the effect of the wind displacing the water in a direction due to shear), and freeboard were added. This elevation (determined for each lake) was projected on the DEM surface to identify the flood extents. The FCLs for the lake inundation zones are comprised of the modelled still-water level, wind setup and freeboard.

Along the shorelines of the lake, additional flooding is expected due to the effects of waves. To show this hazard, a wave effect zone (area which may be impacted by waves) was developed through the following steps:

- The generalized shoreline (where the lake edge typically meets the land) was used as the lakeward edge of the wave effect zone.
- To characterize the waves, a wave model was run to determine wave heights and calculate runup. The model was run twice, for wind events from both the north and the south, and the maximum values were used.
- A wave height line was developed where waves are equal to 0.3 metres in height (a wave height which causes damage based on FEMA guidelines).
- The wave height line was offset 40 metres inland to define the landward edge of the wave effect zone. The line was then smoothed and reviewed to ensure appropriate representation of likely wave effects on the shoreline.

- To determine the height of the FCL, estimated wave runup was added to the lake inundation FCL elevation. See FCL components in Figure 6-4.

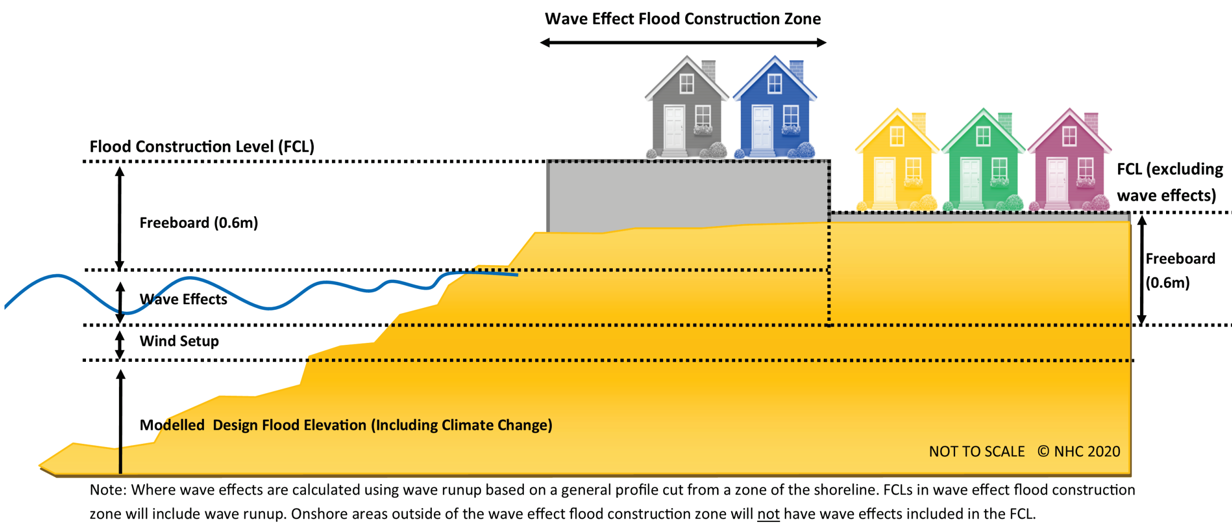


Figure 6-4 Flood construction level schematic for lakes.

Freeboard Requirements

Freeboard is added to provide a safety factor to account for local variations in water level (such as standing waves, super-elevation at the outside of river bends, and local turbulence) and uncertainty in the flood level analysis. Historically in BC, the minimum freeboard allowance applied has been the greater of 0.3 m above the instantaneous (peak) flood event or 0.6 m above the daily flood event. For some rivers, freeboard should be increased to 1 m or more, to address greater uncertainty in the assessment or concerns regarding sediment deposition, debris blockages or ice jams (MWLAP, 2004).

In recent years, a minimum freeboard of 0.6 m has been frequently used with an instantaneous event[1], as suggested in recent provincial guidelines for sea dikes (MOE, 2011) and as discussed in the EGBC professional practice guideline for floodplain mapping (APEGBC, 2017). Considering the uncertainty of climate change on future flood flows, a minimum freeboard allowance of 0.6 m is recommended.

OBWB and local governmental bodies may wish to define a higher level of protection for certain infrastructure or facilities, such as dikes, major transportation routes, hospitals, emergency response centers, communications centers, residences for the elderly, or schools.

[1] A brief set of examples of use of a minimum of 0.6 m freeboard above the instantaneous flood flow within BC include flood hazard study and mapping in Prince George, the lower Fraser River, Maple Ridge, Squamish, Pemberton, and North Vancouver (KWL, 2014, 2017; NHC, 2008b, 2014, 2016, 2018).

6.2.3 Explanation of Layers

Table 6-2 summarizes layers shown on the floodplain maps, as well as additional flood mapping GIS layers described in the following sections.

Table 6-2 Summary of floodplain mapping and GIS layers; climate change is mid-century (2041-2070) except where noted as end of century (2071-2100).

Description LAKE	Includes Climate Change	Includes Freeboard	Includes FCL	Extent Polygon	Depth Raster	Velocity Point
FCL shoreline zone	Y	N	Y – on map	Y – on map	N	N
inundation extent – design with freeboard (FCL)	Y	Y	Y – on map	Y – on map	Y	N
inundation extent – design without freeboard	Y	N	N	Y – on map	Y	N
20-year ARI extent	Y	N	N	Y	Y	N
100-year ARI extent	Y	N	N	Y	Y	N
200-year ARI extent	Y	N	N	Y	Y	N
500-year ARI extent	Y (end-of-century)	N	N	Y	Y	N
RIVER - INUNDATION EXTENTS						
river cross sections	Y	Y – where indicated	N.A.	N.A.	N.A.	N.A.
inundation extent – design with freeboard (FCL) and FCL river isoline	Y	Y	Y – on map	Y – on map	Y	N
inundation extent – design without freeboard	Y	N	N	Y – on map	Y	N
20-year ARI extent	Y	N	N	Y	Y	N
100-year ARI extent	Y	N	N	Y	Y	N
500-year ARI event	Y (end-of-century	N	N	Y	Y	N
RIVER – HAZARD						
hazard data - design flood	Y	N	N	N	Y	Y
2017 WATER EXTENTS						
2017 flood edge of water	N.A.	N.A.	N.A.	Y	N.A.	N.A.

6.2.4 Comparison to Previous Flood Mapping

The most recent previous floodplain mapping, 1991, was based on 1D modelling of the Okanagan River from Osoyoos Lake to Okanagan Lake. Direct comparison with the historic maps is challenging due to differences in vertical survey datum. However a spot comparison of FCL between the 1991 maps (roughly converted to CGVD2013) and the current maps suggests an increase in FCL on the order of 0.7 m along Okanagan Lake (Vernon, Kelowna, Peachland, Penticton); this increases to a 1 to 1.2 m increase in FCL through Penticton and Osoyoos Lake, and then reduces to a 0.1 to 0.4 increase in FCL downstream of Okanagan Falls to the USA boarder. Since most of the floodplain is confined by relatively steep slopes, particularly along Okanagan Lake, Skaha Lake, and Osoyoos Lake, the increase in FCL generally only translates to a relatively small increase in extent (typically <100 m but up to 300 m further beyond the source water body).

Several factors have led to the increase in the design flood. These are:

- Design event – for the Okanagan Lake and Wood-Kalamalka Lake, the flood of record (2017 flood) has been selected as the design event. This event has a magnitude similar to the 500-year event. In comparison the past mapping was based on a 200-year event. On Okanagan Lake, the difference between the previous 200-year event and the new 500-year event (both with freeboard) is 0.7 m.
- Design flow – the design inflow has increased for all events (such as the 200-year and the 500-year event). An additional 30 years of flow and climate data has been used to develop the design flow estimates. The current 200-year design flood in Okanagan River output from Okanagan Dam is 56% greater than that used in 1991.
- Design levels – the design levels have increased for both 200-year and 500-year events. This is due to a number of reasons: 1) an additional 30 years of records have been collected; 2) the effect of regulation on the system has been accounted for in the production of design levels and flows through the combined hydrology/reservoir operations models; and 3) the impact of a changing climate (either changes that have already happened or those expected to happen in the future) on inflow timing and volume have been accounted for through ensemble climate simulations, <u>including application of a modified version of the current operational regime of the lake outflow structures</u>. The ensemble climate simulations provided the ability to account for the fact that data collected prior to the 1991 report may no longer be representative of the present-day conditions.
- Freeboard – the current maps have been prepared with a freeboard of 0.6 m. The previous maps which used a variable freeboard that ranged from 0.6 m to 0.8 m. The variable freeboard was to account for wind and wave effects along the lake shoreline in addition to study uncertainties (Ministry of Environment, Lands and Parks Water Management Division, 1992). In contrast, the current study incorporated wind and wave effects directly in the calculated design water level.
- Climate change – the design event for the current maps has been increased to account for climate change to the middle of the current century.

- Shoreline effects – the current lake floodplain maps include an allowance for the calculated wind and wave effects, including wind setup (<0.1 m) and wave runup (as much as 2.7 m), which the previous maps did not include.

In addition to these changes, the 1991 maps are presented in CGVD28 datum instead of CGVD2013 datum. The difference between the datums varies across the study area; with data from the CGVD28 datum increased by 0.2 to 0.3 m to be converted into the CGVD2013 datum. Additional variability in conversion likely exists across the study area dependent on the approach used in preparation of the historic map. The magnitude or extent of this additional variation is unknown and would require extensive discovery and survey of the historic benchmarks to define.

The following tables (Table 6-3 and Table 6-4) provide a comparison of the FCL's presented in the 1991 maps and the current maps.

Table 6-3 Comparison of proposed vs. previous lake level FCLs.

Location of Comparison Point	Previous FCL (CGVD28)	Previous FCL (CGVD2013)	Recommended FCL (excluding wave effects) (CGVD2013)	Approximate increase
Kelowna Hospital	343.66	343.90	344.56	0.66
Peachland	343.66	343.89	344.56	0.67
Okanagan Falls	339.20	339.47	340.63	1.16
Osoyoos	280.70	280.93	281.01	0.08

Table 6-4 Comparison of proposed vs. previous river FCLs.

Location of Comparison Point	Previous FCL (CGVD28)	Previous FCL (CGVD2013)	Recommended FCL (CGVD2013)	Approximate increase
Upstream of Hwy 97 North Bridge in Penticton	341.30	341.52	342.60	1.08
Upstream of Skaha Lake	339.25	339.49	340.70	1.21
Upstream of Vaseux Lake	329.60	329.88	329.90	0.02
Upstream Hwy 97 Bridge in Oliver	307.50	307.79	308.00	0.21
North end of Tuc-El-Nuit Lake	299.00	299.29	299.67	0.38
Upstream of Osoyoos Lake at Road 22 Bridge	280.70	280.95	281.35	0.40

6.3 Additional Flood Mapping Scenarios

In addition to the design flood scenarios shown on the floodplain maps, GIS layers were generated for several other flood scenarios. All flood layers are summarized in Table 6-2.

6.3.1 Development

Riverine and lake flood layers for the 20-year, 100-year, 200-year, and 500-year ARI events were mapped using the approach described above in section 6.3.1. All scenarios include either mid-century or end-of-century climate change effects as noted in Table 6-2. Results were generated without inclusion of freeboard. FCL values and lake wave effect zones were not created for these additional flood scenarios.

As indicated in Table 6-2, layers provided include:

- inundation extent polygons; and
- depth rasters.

6.4 Flood Hazard Layers

River hazard has been mapped using depths and velocities output from the model. This information is most effectively presented by overlaying velocity vectors (arrows indicating direction and magnitude) on top of depth rasters. This will give users an idea of how deep the water is and how fast the water is moving. This is a departure from example approaches presented in guidelines (APEGBC, 2017), which suggest using a composite hazard value derived as a function of depth and velocity. Hazard mapping layers are created without using freeboard.

Since the dikes mostly contain the flood flows for the Okanagan River, and breaching was not included in this study, it was determined that the best approach to approximate flow velocity on the floodplain was to simulate the river as if the dikes were not in place. Three simulations were performed to track floodwaters and understand flood velocities across the floodplain based on Appendix C of FEMA (2013): i) the left dike was removed, ii) the right dike was removed, and iii) both dikes were removed. The largest resulting velocities and depths from these scenarios were used to develop the hazard maps. Due to the simplistic approach used (Appendix C of FEMA, 2013), however, the depth and velocity hazards near the main channel may be underestimated.

Depths are provided as a raster GIS layer with elevations in metres. Depth categories can be presented as recommended in Table 6-5. These categories were adapted from a Japanese national standard (EXCIMAP, 2007), have been applied by NHC for numerous other projects across BC, and are presented in the provincial flood mapping guidelines (APEGBC 2017). Velocity arrows show the magnitude and direction of water movement.

Table 6-5 Depth layer categories.[1]

Depth (m)	Description	Example
< 0.1	most buildings are expected to be dry; underground infrastructure and basements may be flooded	
0.1 – 0.3	water may enter buildings at grade, but most are expected to be dry; walking in moving water or driving is potentially dangerous; underground infrastructure and basement may be flooded	
0.3 – 0.5	Water may enter ground floor of buildings; walking in moving or still water or driving is dangerous; underground infrastructure and basements may be flooded	
0.5 – 1.0	water on ground floor; underground infrastructure and basements flooded; electricity failed; vehicles are commonly carried off roadways	
1.0 – 2.0	ground floor flooded; residents and workers evacuate	
> 2.0	first floor and often higher levels covered by water; residents and workers evacuate	

1. Categories and colours adapted from EXCIMAP (2007) and Flood Control Division, River Bureau, Ministry of Land, Infrastructure and Transport (MLIT) (2005).

An example of the flood hazard outputs is shown for the reach of the Okanagan River south of Vaseux Lake in Figure 6-5. In the second image, the green and yellow areas circled in red on the left bank (east side of the dike) show the calculated depth hazard.

The current study does not include dike break analysis. Typically, such analysis is expected to result in lower flood levels for areas protected by dikes. This example location illustrates how flood levels could potentially be identified as more severe following a dike breach analysis. A breach of the upstream left bank dike at this sample location could result in greater depth and velocity across this area, particularly if floodwaters from the upstream breach were trapped behind the dikes.

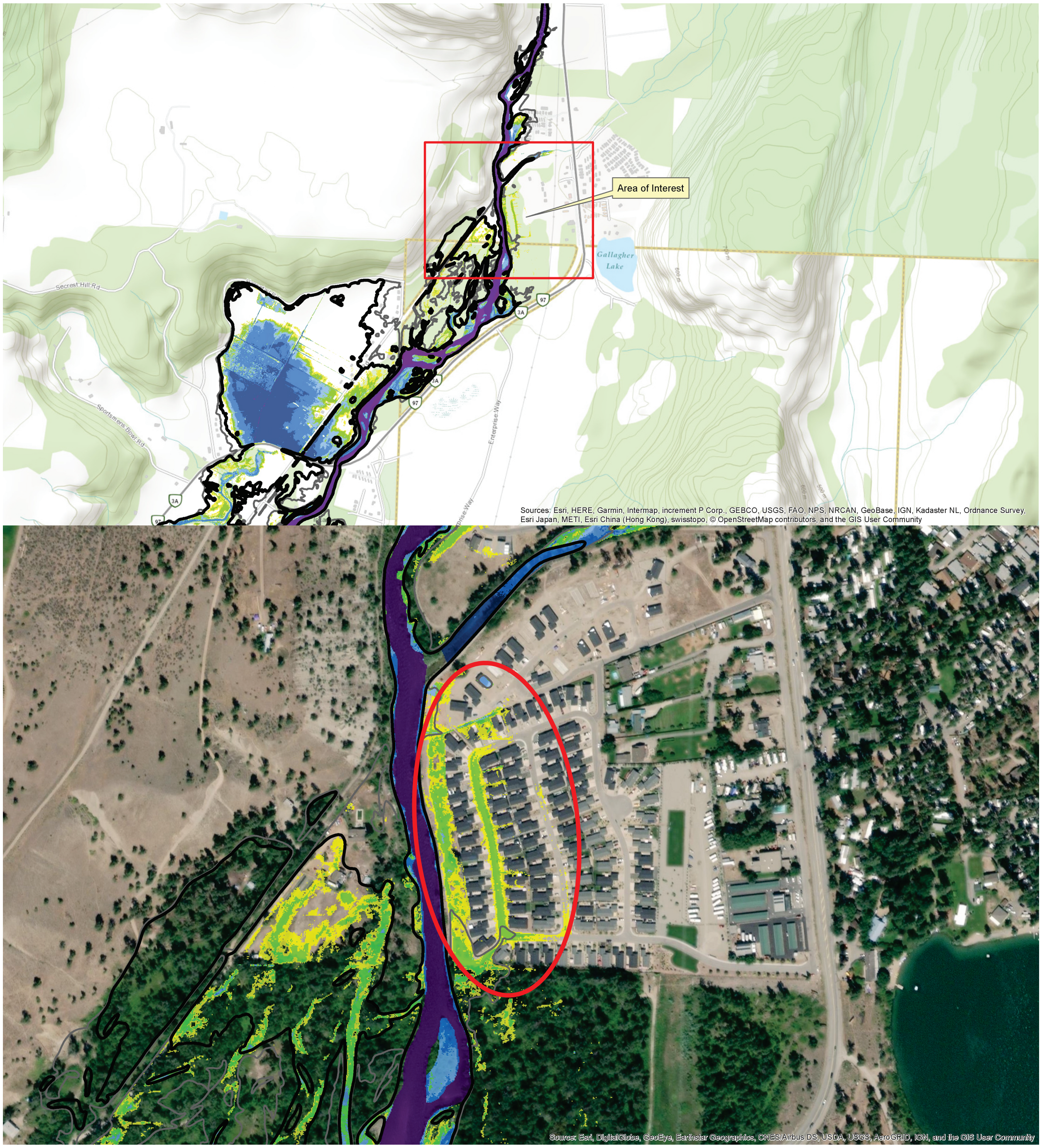


Figure 6-5 Example of flood hazard depth mapping. Top image shows area of interest, bottom image showing detail: coloured hatching (as defined in Table 6-5) illustrate depth hazard category, and black lines delineate flood inundation extent (no freeboard), with grey lines delineating the FCL extent.

6.5 Application to Flood Risk Reduction

The purpose of floodplain mapping is to reduce the risk of floods through improving understanding of the hazard and allowing First Nations, governments, organizations, and individuals to plan for potential floods and reduce their risk.

In 2015, the United Nations developed the Sendai Framework for Disaster Risk Reduction, an international document adopted by 185 United Nations member states including Canada. In 2018, BC adopted the Sendai Framework, and updated the provincial Emergency Program Act (EPA) to align with the framework.

As explained by BC's EPA modernization discussion paper, "The Sendai Framework marks a shift from focusing on emergency preparedness and response to recognizing that risk identification and mitigation are key to managing hazards and reducing the impact of events. It aims for substantial reduction of disaster risk and losses in lives, livelihoods and health and in the economic, physical, social, cultural and environmental assets of persons, businesses, communities and countries and calls for all of society to share responsibility for reducing disaster risk (Government of British Columbia, 2019)." The Sendai Framework specifies four priorities for action:

- Understanding disaster risk;
- Strengthening disaster risk governance to manage disaster risk;
- Investing in disaster risk reduction for resilience; and
- Enhancing disaster preparedness for effective response and to "build back better" in recovery, rehabilitation, and reconstruction.

The flood mapping of the Okanagan mainstem contributes to the first priority, understanding disaster risk, through improving understanding of the hazard. The flood mapping provides primary information needed to work on the other priorities for action. The application of the floodplain mapping to the other priorities for action within the BC regulatory framework and typical practice is explained in the following sections.

There are two main goals in flood risk reduction best practice (AIDR, 2017):

- Managing flood risk – improving community resilience to flooding and limiting flood risk growth; and
- Maintaining the flood function of the floodplain – ensuring the floodplain can perform its natural functions of flow conveyance and storage through measures such as:
  - maintenance or improvement of the capability of the floodplain to perform its natural function of conveying and storing floodwater (AIDR, 2017)
  - plan for land uses compatible with the flood function of the specific area of the floodplain (AIDR, 2017)
  - maintenance of the capability of the floodplain to support floodplain ecosystems dependent on inundation (AIDR, 2017)

- floodplain and catchment management practices that are ecologically sustainable (AIDR, 2017)

The remainder of this section discusses techniques towards the goal of managing flood risk. Maintaining the flood function of the floodplain should be considered in development of an implementation plan for any measure designed to manage flood risk.

Selection of appropriate flood risk treatments should be based on the risk faced by the area. Risk is based on a combination of likelihood and consequence. The consequences of flooding are determined by studying the hazard (extent of flooding, depth and velocity of water, length of warning, duration of flooding), exposure (what is inundated or affected by the flood), and vulnerability (consequence of exposure). There are several guidelines available for risk assessment in Canada and internationally. In BC, EGBC provides professional practice guidelines for flood risk assessment including:

- Legislated Flood Assessments in a Changing Climate in BC (EGBC, 2018)
- Flood Mapping in BC (APEGBC, 2017)

Nationally, Natural Resources Canada is developing the Federal Flood Mapping Guidelines Series. The Flood Risk Assessment procedures for this guideline series are currently under development by NHC.

In addition to the Sendai Framework, several international examples can be consulted to inform flood risk assessment in Canada including:

- United Kingdom, Framework and Tools for Local Flood Risk Assessment (United Kingdom Department for Environment Food and Rural Affairs, 2014)
- Managing the Floodplain - A Guide to Best Practice in Flood Risk Management in Australia Handbook 7 (AIDR, 2017)

Flood risk information is typically used to inform policy direction and guide flood mitigation planning. Flood risk is dynamic and therefore the approach to floodplain management should also respond to changing climate and development conditions, using an approach such as the Dynamic Adaptive Policy Pathways (DAPP)[1] approach.

A flood risk assessment, which includes considerations of flood hazard, exposure, and vulnerability for multiple categories of receptors is recommended as a next step to support flood risk reduction in the Okanagan valley.

The following subsections illustrate some general examples of mitigation measures that flood risk assessment can be used to identify and inform the prioritization of.

[1] Dynamic Adaptive Policy Pathways (DAPP) is adaptive planning involving continued review and revision of a plan as it is implemented and conditions continue to change, for example as climate change impacts are better understood (https://www.deltares.nl/en/adaptive-pathways/, accessed 31 March 2020).

6.5.1 Structural Mitigation

Structural mitigation aims to reduce the flood hazard. Structural mitigation of floods and control of rivers and lakes has been done extensively in the Okanagan valley through dams, dikes, dredging and channelization. The following sections describe structural mitigation measures and their typical use in BC. With the increases in flooding anticipated due to climate change, existing structural mitigation measures will not provide the same level of protection as they have historically. As such, it is important to consider upgrades to existing structural mitigation measures or use of non-structural mitigation measures as discussed in section 6.5.2.

Flood Barriers

Typical flood barriers include permanent dikes and temporary structures.

Permanent dikes have been used extensively to provide protection from high water as a barrier to hold back ponding or flowing water. Dikes are generally most suited to address flooding of dense communities where the tax base is sufficient to fund both construction and ongoing maintenance. Dikes are often seen as a desirable form of flood protection as they can block water, sediment, and debris from entering a community, protecting it from frequent flood events, however there are many drawbacks:

- High cost expenses include acquiring the land, constructing the dike, monitoring the dike, and maintaining the dike.
- Dikes can limit habitat potential by restricting riparian habitat and acting as a barrier between terrestrial and aquatic habitat, limit space for the river to migrate and store sediment and debris.

- When a dike encroaches on the floodway, it has the potential to increase local velocities, increase water levels, and decrease in-channel storage (which can increase downstream flow).
- Dikes block flow from the flood source (i.e. the Okanagan mainstem), but also prevent outflow from local stormwater, tributaries, and groundwater. Suitable drainage must be provided and maintained for groundwater and channels that flow through dikes. Groundwater can pool behind dikes as it seeps through from the river and beneath dikes and is then unable to drain into the channel.
- Dike breaches through overtopping, surface erosion, internal erosion (piping), or seismic destabilization can be more hazardous and consequential than the flood events that the dikes protect against. Dike failure typically causes significant velocity and depth of flow behind the dike. Dikes can also increase water levels within a diked floodplain if there is an upstream dike breach.

Inset 6-1 Temporary flood barrier in the City of Kelowna, photo courtesy of City of Kelowna - Michael Hintringer

Some of the adverse environmental aspects and costs can be reduced if dikes are setback from the river floodway and erosion protection is set back from the active channel.

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 and planning should include consideration of the foundation and procurement of the temporary structure. These systems were used in the 2017 floods in the Okanagan and include sandbags and inflatable flood walls. 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.

Flow Conveyance Improvements

Flow conveyance improvements have been made extensively along the Okanagan River including straightening, widening, dredging and clearing the original, meandering channel. Improving conveyance with these techniques reduces the flood elevation within a given area and immediately upstream. Dredging of accumulated sediment and removal of debris is often done where channel gradients decrease from sediment accumulation. Overtime, sediment can accumulate within channels, effectively constricting flows and causing flood levels to be higher as sedimentation reduces the cross section for water to flow. Dredging and debris removal are an effective strategy to maintain conveyance at culverts and bridges and along channels, however, there are environmental impacts associated with dredging. Dredging causes habitat and vegetation disturbance in streams, often removing the vital components of aquatic habitat.

Diverting water around a community through diversion channels is also possible. Large scale diversion of flow is typically only suitable when protecting a large community and where there is room to route flood flows (such as the Red River floodway around Winnipeg). In the Okanagan valley, the large lakes and surrounding development occupy much of the space where diversion could be considered.

Flow conveyance improvements can be implemented with a focus on naturalization. Dikes can be set back, and relic channels can be restored to increase conveyance. Reconnecting and rewatering oxbows which were removed from the river channel through straightening can improve flow conveyance and have significant habitat value.

Flood Flow Reduction

Upstream storage can be used to attenuate flood flows. There are numerous dams on the Okanagan River with sizable reservoirs (lakes) which are operated for the purpose of flood reduction as well as many other priorities. Dam operation can mitigate downstream flooding by prolonging and subsequently reducing the peak flow downstream. In order to also reduce upstream flooding (i.e. lake shoreline flooding) the operator may need to lower lake levels in anticipation of high inflows. Operation of the Okanagan mainstem dams will continue to change as the understanding of climate change evolves and other agreements related to the operation of the dam are updated. Due to the uncertainty in the timing and magnitude of future flows expected with climate change, dam operators will be increasingly challenged in determining when to lower upstream lake levels. The uncertainty is expected to result in the dams being less effective for flood mitigation in the future. The addition of dams on substantial tributaries could provide further flood mitigation; however, the scale of available storage is expected to limit their effectiveness. Furthermore, there are large financial, environmental, and societal costs as well as increased risks (such as potential for dam failure) associated with development of new dams, suggesting that such opportunities unlikely to be feasible.

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. However, the scale of flooding along the Okanagan River is not expected to be substantially impacted by such approaches.

Erosion Protection

Erosion protection is typically the armouring of banks 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 dikes, homes, and other infrastructure located near fast flowing water. See Inset 6-2 for a photo of erosion threatening the stability of a road.

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.

Inset 6-2 Erosion resulting from the 2018 freshet, photo courtesy of the RDOS.

Riprap spurs (also referred to as groynes) and bendway weirs can be used in conjunction or as an alternative to linear bank armouring. These structures extend rock roughly perpendicular to the bank instead of parallel to the bank. When working properly, these structures reduce the velocity along the bank and can direct flow towards the centre or opposite bank. Often these structures require similar or more rock than linear bank armouring, however effective redirection of flow can limit the length of bank armouring required and potentially reduced maintenance along the bank. Furthermore, such structures create variable hydraulic conditions and can incorporate large wood debris and planting; all of which is often seen as beneficial to aquatic habitat and can therefore support permit acquisition.

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

Monitoring and Maintenance

Many of the tributary flood conditions may be exasperated by blockage of crossings. Monitoring and subsequent removal of debris and sediment from these culverts and their entrances should be done routinely throughout the high flow season to ensure flow is not further restricted at these locations. In addition, any dikes or other flood protection infrastructure should be inspected annually and maintained as needed. Operation, maintenance, and surveillance documents should exist for key flood mitigation infrastructure to help guide this process.

6.5.2 Non-structural Mitigation

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

Land-Use Management

The province provides guidelines to help local governments develop and implement land-use management plans and make development decisions for flood hazard areas (FLNRORD, 2018). Development decisions may include limiting land use and density within certain hazard zones and or requiring site specific hazard assessment and mitigation measures for development within hazard zones (i.e. EGBC, 2018). Part 14 of the *Local Government Act* (Land Title Act 1996) provides local governments with several land-use management tools to promote flood safety. For example, the Act empowers local authorities to establish development permit areas, designate certain lands as floodplains through bylaws, enact zones to promote safe developments in floodplains, and implement measures such as setback from the rivers edge and preventing disturbance of riparian vegetation.

Any development within the floodplain should only be done following a site-specific flood hazard assessment conducted by a registered professional following the EGBC guidelines for such assessments (2018). Assessments may be waived by regulators if the flood risk and any mitigation measures are well known; for example, development within an existing community, behind a regulated dike, with current floodplain mapping. Specific land-use management measures include zoning, development permit areas, setbacks and relocation or managed retreat. There is some overlap in implementation of these techniques, and they can be implemented in conjunction with each other.

Zoning – Some communities have allowed limited development within the floodplain for specific land use (i.e. agriculture and recreation) or on pre-existing lots that otherwise would not be buildable. Such allowances should be reviewed and only approved if deemed safe for use and do not transfer flood risk to other properties. Covenants and occasionally other communications (such as signage, or warnings in lease agreements) are typically a condition of such developments to ensure future landowners and users are aware of the risk. Evacuation planning for humans, animals, and potentially goods of value and potentially damaged by floodwaters should be considered prior to development.

Development Permit Areas – Development permits areas are another land use management tool to ensure that specific requirements are met within hazard areas. They can specify conditions such as flood construction levels and requirement for a property-specific hazard assessment. These can be used in conjunction with zoning.

Setbacks from Waterways – Typically, mitigation measures include set back 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.

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. On going 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.

Flood Proofing Individual Assets

This often includes constructing or raising buildings to the FCL but can also include waterproofing of the portion of structures located below the FCL. 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. Elevation of habitable areas is an effective mitigation measure regardless of the presence of dikes to account for the potential for dikes to fail as well as any groundwater seepage or stormwater inflows that may raise water levels on the landside of the dike.

Community resilience can be increased in the following general ways:

- Raising valuables above the FCL;
- Developing plans for the continuation of business operations in the case of flooding;
- Anchoring potential floating assets (e.g. propane tanks);
- Storing or protecting contaminants up to the FCL; and
- Planning exits, posting warning signs, developing closure plans, etc.

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 requires robust scientific understanding; accurate, detailed measurements of snowfall and precipitation; robust weather forecasting; and clear dam operation rules. Flood warning must be clear, consistent and informative.

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 ERP in identifying areas at risk to flooding 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 emergency response plans (ERP) 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).

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.

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 (NRC/PSC, 2018). Despite preparation of the floodplain map, distribution and education should shortly follow. 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 (NRC/PSC, 2018). Despite preparation of the floodplain map, distribution and education should shortly follow.

The Project ArcGIS Hub is intended to serve as a key source of information about the potential flood hazard in the Okanagan. This page includes information digestible by a wide audience about the flood hazard and resources for preparation and risk reduction (see section 6.5.3).

With a datum shift and an expanded flood plain defined due to changes in modelling and climate change, community conversations are needed as people that may have once considered themselves safe from a flood may now be within the floodplain and should be made aware of the risk.

Inset 6-3 Sandbagging competition in Skagit County.

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

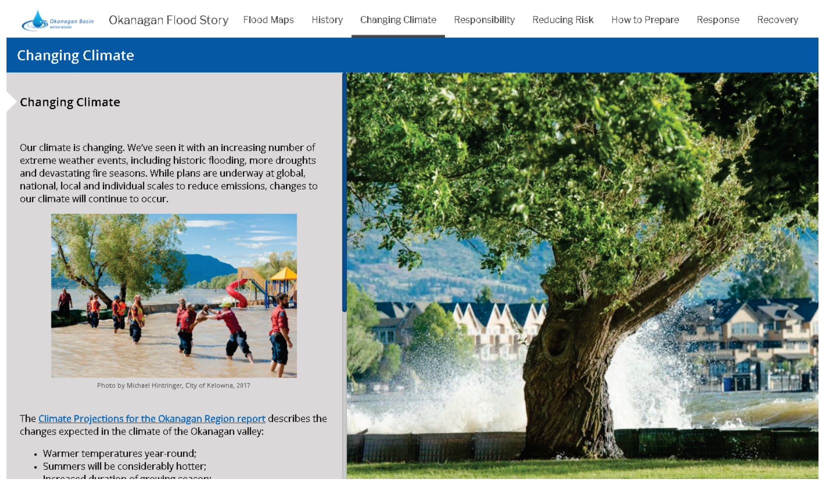
- Presenting the new flood mapping and updated understanding of current and future flood hazard (i.e. floodplain FCL, depth, velocity, or hazard maps);
- How to prepare for and be aware of the timing and seasonality of floods;
- Where to find sources for information on floods and flood preparedness;
- Community resources with respect to flooding (such as information from Okanagan Basin Water Board, BC Flood Forecast Centre, local government websites);

- Where to find real time forecasts of water level, water flow, and what it means; and
- Local evacuation routes, notifications, procedures and high ground.

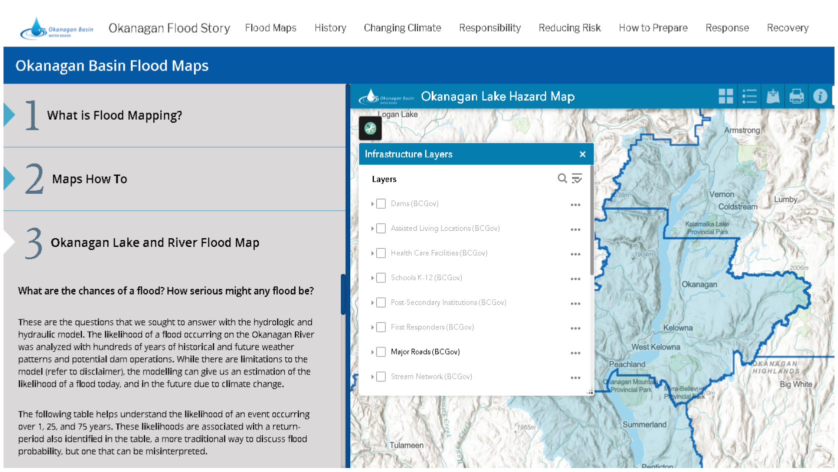
Community outreach can take the form of websites, handouts, news articles, community meetings, and poster and booth presentations at community events (i.e. county fair). Some diking districts hold spring sandbag competitions to build awareness of the upcoming flood season (i.e. Inset 6-3, courtesy Skagit County).

6.5.3 Project Website

To share the potential flood hazard information with the public, an interactive and informative online website was developed. The website is hosted on ArcGIS Hub, and contains a narrative of the flooding within the Okanagan valley. The purpose of the website is to inform the public about the potential flood hazard in context with the local environment and provide the public with comprehensive resources to reduce their flood risk. The information is intended to be non-technical and provide resources with more information. Images of the website are provided in Inset 6-4 and Inset 6-5. The website includes the following pages:



Inset 6-4 Okanagan Flood Story website changing climate webpage.



Inset 6-5 Okanagan Flood Story website flood map webpage.

- Landing page – an introduction to flooding in the Okanagan and an overview of the website as well as a disclaimer about the use of the flood mapping which must be accepted
- Flood Maps – a custom explanatory video introduces flood mapping concepts, the mainstem flood maps are presented, related creek flood hazard information is provided, and freshet aerial photos are provided from the 2017 flood

- History – dates and photos of major floods and mitigation efforts in the Okanagan valley are presented in a geographical timeline
- Changing Climate – expected changes to the local climate and the impacts of these changes on flooding are identified
- Responsibility – division of flood responsibility between property owners, local governments, and First Nations, provincial and federal governments are identified
- Reducing Risk – strategies for reducing flood risk for homeowners and communities are identified
- How to Prepare – resources about preparing for a flood are provided through links to government websites
- Response – resources about flood response, flood warnings and advisory notifications and emergency alerts and orders are provided through links to government websites and maps
- Recovery – resources about recovering from a flood are provided through links to government websites

The website was developed with assistance, information and input from a variety of local governments and is intended as a resource for residents from many local jurisdictions. The development of the website and flood mapping included a half day workshop with First Nation and local government representatives. In the workshop, information was collected about local priorities for information, suggested flood mapping look and feel, and interest in ARIs.

6.6 Conclusions, Recommendations, and Future Work

Recommendations for future work include:

- Share the flood hazard with local communities through in-person workshops and discussions to ensure the information is available and accessible. These workshops help inform the community about the understanding of the hazard developed to date, identify what matters to the community and stakeholders, and educate people on the issues and options, as well as identify and build momentum for next steps.
- Evaluate and optimize the operating regime for flow control structures along the Okanagan River to maximize the effectiveness of flood control with consideration of the other environmental, cultural, agricultural, and recreational requirements on the lakes and rivers.
- Develop of a comprehensive risk reduction plan. This plan should take a risk-based approach to flood mitigation, include stakeholder priorities, be developed for the short, medium and long term, include consideration of climate change, and strive for consistency between jurisdictions. The key steps in this plan are:
  - Assess existing structural and non-structural flood mitigation measures;
  - Conduct a flood risk assessment to identify areas of high risk and in greatest need of further flood mitigation, and help prioritize mitigation measures; and,

- Identify structural and non-structural risk mitigation measures and develop an actionable plan to implement the measures.

- Re-evaluate and maintain studies associated with the plan including floodplain mapping, risk assessment, and mitigation planning to reflect changes in risk related to hazard likelihood or consequence. Flood hazard maps should be reviewed at least every 10 years and updated if there are changes to conditions such as the design event, channel geometry, new flood hazards, dike construction, or floodplain development, as recommended by EGBC (APEGBC, 2017).