BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

FRASER BASIN COUNCIL

ISSUE C-1: FLOOD FORECASTING SERVICES

PROJECT REPORT

FINAL

PROJECT NO.: 0511-008 DATE: April 12, 2021

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April 12, 2021
Project No.: 0511-008

Steve Litke
Fraser Basin Council
470 Granville Street
Vancouver BC V6C 1V5

Dear Mr. Litke,

Re: Issue C-1: Flood Forecasting Services Project Report – FINAL

Please find attached an electronic copy of our above-referenced report dated April 12, 2021. This report provides a project summary for our investigations examining Flood Forecasting Services (Issue C-1) in British Columbia. We appreciate the opportunity to contribute to this initiative.

Yours sincerely,

BGC ENGINEERING INC.
per:

Kris Holm, M.Sc., P.Geo.
Principal Geoscientist

EXECUTIVE SUMMARY

Fraser Basin Council (FBC) is coordinating a series of investigations aimed at developing recommendations to inform flood hazard management program improvements at multiple geographic scales across jurisdictions in British Columbia (BC). This work is being undertaken on behalf of the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) and includes clear-water flooding processes in BC.

FBC retained BGC Engineering Inc. (BGC) to analyze gaps and user assessments related to Flood Forecasting Services (Issue C-1) for both riverine and coastal flood hazards in BC. The purpose of the project was to identify geographical areas, approaches and opportunities intended to strengthen flood forecasting services in BC.

BGC's investigation was based on stakeholder consultation and a review of flood forecasting – related literature and spatial data. BGC reviewed costs for monitoring tools such as installing a hydrometric station for flow monitoring, launching a debris-flow warning system or implementing a flood forecasting system such as a Delft-Flood Early Warning System (FEWS) system, and provided a case example where flood forecasts were relied upon in an emergency. BGC obtained written survey input from 28 individuals and completed eight, one-hour interviews. Those consulted included a broad array of subject matter experts from private industry, municipal emergency response leaders, and governmental employees. The gaps identified are biased towards areas falling within the jurisdiction of those who responded to the user survey and cannot be considered a comprehensive gap analysis.

As part of the scope of work, BGC provided a Class D cost estimate for monitoring tools such as the implementation of Delft-FEWS by a government agency such as the BC River Forecast Centre (RFC). Delft-FEWS is an industry-standard, open data-handling platform to ingest, analyze, and communicate information relating to real-time hazards such as floods. BGC estimates a cost of $60,000 to develop a pilot project for the execution of the CLEVER model (Channel Links Evolution Efficient Routing)[1] used by the BC RFC, and a cost of $400,000 to develop a FEWS system that includes integration of the CLEVER flood forecast model with a 2D HEC-RAS model of the Fraser River, which would also receive forecasted downstream boundary conditions from the BC Storm Surge Model. The MIKE 21 model is used as an example, but the cost estimate could apply to other hydraulic models such as HEC-RAS 2D.

BGC examined a May 2020 case study at Slocan and Salmo rivers in the Regional District of Central Kootenay (RDCK), where the RDCK evacuated about 1,000 homes during their largest ever emergency response effort. The case describes how local government, the Province, and Qualified Professionals (QPs) collaborated to use flood forecast data for emergency response decisions on two rivers using flood forecasts with varying levels of success.

[1] CLEVER is a hybrid lumped watershed and semi-distributed channel routing model (C.Luo, August 16, 2017).

General Conclusions

The main report lists the findings of this investigation, for which BGC provides the following conclusions:

- Authorities responsible for emergency management require not only flood forecasts but also indication of flood hazard extent, intensity, and timing. Understanding flood characteristics is essential for Emergency Operations Center (EOC) Directors to issue informed evacuation orders and deploy resources. Hydraulic models can be deployed, where available, to transform forecasts into predicted hazard extents and characteristics for emergency response decisions.
- While the focus of the current investigation is on flood forecasting, many of the decisions made during an emergency are based on flood monitoring (e.g. gauging stations and field observation). Quantitative systems exist in BC for hydrotechnical hazard management on linear infrastructure (e.g., pipelines), where flow monitoring is tied to Trigger Action Response Plan (TARP) protocols, including automated flood alerts. Developing TARP requires hazard analysis to develop protocols in advance of an emergency. Once in place, it may fulfill the practical needs of emergency managers responsible for locations where flood forecasting is difficult, such as small watersheds with rapid hydrograph responses to precipitation and snowmelt.
- Emergency managers and operations and maintenance staff at diking districts and local governments, emphasized reliance on qualitative judgement to make “flood forecasts”. While judgement will always form an important component of uncertain decision making, such approaches are vulnerable to the loss of institutional knowledge when staff retire, and to errors when flood scenarios occur that are outside the historical record or local experience. Objectives to address these issues should include protocols for flood forecasting that capture experiential knowledge before it is lost, and communication tools that illustrate how extreme events will extend beyond the experience of even the most seasoned practitioners and require scientifically rigorous methods to estimate.
- Provincial flood forecasting services are not applicable to steep creeks. Hydroclimatic, debris-flow warning systems have been developed for select creeks or areas within BC for different clients and should be reviewed for provincial scale application. They require recalibration for different regions and creek types. In BGC’s experience, the setup cost for a debris-flow system that uses publicly available weather data and provides automated email notifications can range from <$50,000 to >$100,000 depending on the location, previous work, and the elements at risk (e.g. a road compared to populated area).
- BGC notes the following factors that would need to be addressed as part of the incorporation of hydraulic flood models into a FEWS system potentially managed by the Province of BC:
    - Flood management, including the preparation of detailed floodplain maps (and associated hydraulic models), is currently the responsibility of local government.
    - Many separately developed hydraulic models exist for BC rivers, for example as developed by QPs in the private sector to prepare flood hazard maps.

  - Flood modelling results based on flood forecasts are currently the responsibility of Qualified Professionals undertaking the work.
- Within the existing division of local and Provincial government responsibilities for flood management, a network of flood models could be connected to the CLEVER model forecasts via data services. The maintenance of the models themselves would remain the responsibility of local government, most likely via contracting of QPs. Copies of these models would be housed in the provincially operated FEWS system and model forecast results could be managed and disseminated within this system.
- Through the public sector organization BC Hydro and Power Authority, the Province of BC has already invested in the implementation and ongoing operations and maintenance of a FEWS system in BC, albeit one that is not publicly accessible.

Specific Recommendations

- Hydrometric gauge data are considered a critical component of a majority of the user's flood management planning efforts. Building on the user feedback in this report, improve flow and snow gauge coverage in small watersheds. Key focus areas are listed in the main report. In BGC's experience, a hydrometric gauge station costs approximately $30,000 to install and $20,000 per year to maintain.
- Provide resources to the RFC for areas such as the following:
  - Information technology (IT) resources for improvements to infrastructure (e.g., equipment and technological resources needed to develop and maintain flood forecast systems)
  - Staff resources for data interpretation supporting EOC staff during flood events.
  - Implementation of ensemble modelling to improve the types of uncertainty that can be considered in RFC forecasts via the CLEVER model.
  - Incorporation of weather inputs including gridded snow data and ensemble forecasts.
  - Implementation of a FEWS system to couple flood forecasts to hydraulic models to use for inundation forecasting.
- Develop a plan to use hydraulic models and expert knowledge in their use for floodplain mapping, in association with flood forecast data, to aid emergency response.
- Provide resources to EOC during flood emergencies, including Geomatics (GIS) staff to assist with data products and QPs to assist in their analysis and interpretation.
- Utilize the substantial FEWS experience that has been developed within BC Hydro to ensure success with the deployment of future provincial FEWS systems.
- Provide training courses to government users in the interpretation of flood forecast data.
- Provide long-term funding and resources to maintain and upgrade the BC Storm Surge Model.

GLOSSARY

Term	Definition
AEP	Annual Exceedance Probability. Chance that a flood magnitude is exceeded in any year. For example, a flood with a 0.5% AEP has a 1 in 200 chance of being exceeded in any year.
AHPS	Advanced Hydrologic Prediction Service
ALR	Agricultural Land Reserve
BC	British Columbia
BGC	BGC Engineering Inc.
Clear-water floods	Riverine and lake flooding resulting from inundation due to an excess of clear-water discharge in a watercourse or body of water such that land outside the natural or artificial banks which is not normally under water is submerged. While called “clear-water floods”, such floods still transport sediment, but at a lower concentration by volume than debris floods or debris flows.
CLEVER	Channel Links Evolution Efficient Routing flood forecasting model
COFFEE	COastal Fall Flood Ensemble Estimation
Consequence	In relation to risk analysis, the outcome or result of a hazard being realized. Consequence is a product of vulnerability (V) and a measure of the elements at risk (E).
Delft-FEWS	Delft Flood Early Warning System
DFO	Department of Fisheries and Oceans
ECCC	Environment and Climate Change Canada
Elements at Risk	Assets exposed to potential consequences of geohazard events.
EPA	Emergency Program Act
FBC	Fraser Basin Council
Flood Maps	Delineation of flood lines and elevations on a base map, typically taking the form of flood lines on a map that show the area that will be covered by water, or the elevation that water would reach during a flood event. For more complex scenarios, the data shown on the maps may also include flow velocities, depth, other hazard parameters, and vulnerabilities.
Flood Setback	The required minimum distance from the natural boundary of a watercourse or waterbody to maintain a floodway and allow for potential erosion.
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations and Rural Development
IOD	Inspector of Dikes
MOE	BC Ministry of Environment and Climate Change Strategy
NOHRSC	National Operational Hydrologic Remote Sensing Center
NWP	Numerical Weather Prediction
NWRFC	Northwest River Forecast Center
QP	Qualified Professionals
RFC	BC River Forecast Center

Term	Definition
Steep-creek	Rapid flow of water and debris in a steep channel, often associated with avulsions and strong bank erosion. The term steep creek is a collective term for debris flows and debris floods.
SNODAS	SNOw Data Assimilation System
SSFS	BC Storm Surge Forecasting Service
TARP	Trigger Action Response Plan
WARNS	Water and Routing Numeric System
WSC	Water Survey of Canada

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LIMITATIONS

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1.0 PREAMBLE

Fraser Basin Council (FBC) retained BGC Engineering Inc. (BGC) to conduct a gap analysis and user assessments related to flood forecasting services for both riverine and coastal flood hazards in British Columbia (BC). The scope of work outlined in BGC's November 27, 2020 proposal was authorized by FBC based on a contract dated December 4, 2020. The work represents "Issue C-1" of a broader investigation coordinated by FBC to support flood strategy development in BC. The following is text provided by FBC and included here as context for the larger project:

> *Many communities in BC are working to better manage their river and coastal flood risks through a wide range of flood management activities. But current approaches to managing flooding are not always efficient, coordinated, equitable, or cost-effective.*
>
> *The **Investigations in Support of Flood Strategy Development in British Columbia** is a province-wide initiative aimed at developing a comprehensive understanding of current challenges and opportunities relating to flood management across BC. The focus is primarily on riverine, coastal, and ice jam floods, although other types of flooding are recognized where appropriate. This initiative recognizes that flood management is a multi-faceted, ongoing process requiring the coordination of many organizations, agencies, and orders of government and linked with broader processes, including climate change adaptation and disaster risk reduction, among others.*
>
> *The BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (MFLNRORD) retained FBC to manage and coordinate research and engagement across a broad range of flood management issues relating to governance, hazard and risk management, forecasting, and emergency response and recovery. Consulting teams were retained to undertake research and technical analysis with input from experts, practitioners, and stakeholders from all four orders of government, the private sector, and other organizations. Each investigation produced recommendations to inform flood management program improvements at multiple scales and across many jurisdictions. Investigations were undertaken across 11 interrelated issues under 4 themes:*

	Theme A – Governance	
A-1	***Flood Risk Governance***	*Review current governance and delivery of flood management activities in BC involving all four orders of government and non-government entities, identify challenges, and recommend changes to improve coordination, collaboration, and overall effectiveness.*

	Theme B – Flood Hazard and Risk Management	
B-1	***Impacts of Climate Change***	*Investigate the state of climate change information and new and existing tools that can support authorities in integrating climate change impacts in flood management.*

Theme B – Flood Hazard and Risk Management		
B-2	***Flood Hazard Information***	*Examine the state of flood mapping and dike deficiency information and recommend ways to fill current gaps in flood mapping and manage and maintain information about flood hazards and dike deficiencies.*
B-3	***Flood Risk Assessment***	*Explore approaches to completing flood risk assessments at various scales, methods for prioritizing risk reduction actions, and standards- versus risk-based approach to flood management.*
B-4	***Flood Planning***	*Examine the ability of local authorities to undertake integrated flood management planning and opportunities to improve capacity.*
B-5	***Structural Flood Management Approaches***	*Assess the potential for improvements to dike management, improve the capacity of diking authorities, and implement innovative structural flood risk reduction measures.*
B-6	***Non-Structural Flood Management Approaches***	*Investigate current and alternative approaches to managing development in floodplains and opportunities for implementing non-structural flood risk reduction actions.*

Theme C – Flood Forecasting, Emergency Response and Recovery		
C-1	***Flood Forecasting Services***	*Identify gaps and opportunities for improvement in the province's flood forecasting services.*
C-2	***Emergency Response***	*Investigate roles, plans, and capabilities for flood response and opportunities for improving emergency response.*
C-3	***Flood Recovery***	*Examine approaches that would support recovery efforts and help reduce future flood risk.*

Theme D – Resources and Funding		
D-1	***Resources and Funding***	*Investigate resource and funding needs associated with actions to strengthen flood management and evidence in support of proactive flood mitigation.*

2.0 BACKGROUND

2.1. Project Description

The development of flood forecasting and early warning systems are essential elements for flood hazard reduction and risk mitigation. A gap analysis and assessments with key producers and users of flood forecasting information was undertaken by BGC to help identify geographical areas, approaches, and opportunities to strengthen flood forecasting services in BC.

The project scope focused on two investigations:

- Investigation C-1.1: investigate the current capacity, coverage, value, and gaps in flood forecasting services
- Investigation C-1.2: visualize where flood forecasting gaps exist and estimate costs for improvement to end users.

Specific tasks for Investigation C-1.1 included:

- Document end user needs and expectations of flood forecasting data, and how end users of forecasts find value in current flood forecasting services
- Identify regions, watersheds, and watercourses that are challenging for forecasting or where flow forecasting services may not be adequately meeting the needs of the end users
- Document the reasons for the gaps and challenges, including how user perceptions of modelling and uncertainties may affect these reasons
- Provide a case study representing situations under which user needs may or may not be met, considering geographic, technical, jurisdictional, and operational factors
- Identify gaps in coastal storm surge forecasting.

Specific tasks for Investigation C-1.2 included:

- Produce maps and / or other products to visualize gaps in the current system
- Analyze and evaluate opportunities and provide guidance and recommendations for filling the forecasting gaps identified
- Provide costs (Class D ±50% estimate) and resources required to improve areas where gaps exist between current forecasting services and the needs of end users, including the costs to install a hydrometric station for flow monitoring, implement a debris-flow warning system or upgrade to a Delft-FEWS (Delft Flood Early Warning System) platform to facilitate a potential cost-benefit analysis.

The report herein provides the results of these investigations, which are summarized in the following sections:

- Section 3.0 provides applicable policies, legislation and guidance
- Section 4.0 summarizes the methodology used for consultation with end users and producers of flood forecasting information
- Section 5.0 provides the key findings for the two investigations

- Section 6.0 provides a case study example from a recent application of flood forecasting information in an emergency situation
- Section 7.0 provides a summary of the resources required to implement additional tools for flood forecasting such as the Delft-FEWS platform
- Sections **Error! Reference source not found.** and 10.0 provides conclusions and recommendations to strengthen flood forecasting services in BC.

2.2. Project Team

The project was undertaken by a multi-disciplinary team of specialists with flood monitoring, flood hazard assessment and mapping experience in riverine and coastal settings. Appendix A provides a summary of the main BGC contributors to the investigations. Additional BGC subject matter specialists, technical and administrative staff also provided project support.

2.3. Flood Forecasting Services in BC

Flood forecasting is a key service for managing and preparing for extreme flood events. At its most effective, flood forecasts can minimize the potential impacts from damaging flood events, particularly for those areas most susceptible to flood-related losses, such as communities settled in valley bottoms and where linear infrastructure and transportation corridors traverse floodplains. To predict flooding, hydrometric data along with observed and forecasted weather, and information on the watershed, are applied to a hydrologic model to estimate flow rates or water levels for a point in time that can vary from a few hours to several days (Jain et al., 2018; Wu et al., 2020). A wide range of techniques and approaches are used for flood forecasting in response to the large diversity in hydro-climatic and geographic conditions across Canada; however, the responsibility for executing forecasting services occur at a provincial level (Zahmatkesh et al., 2019).

Riverine flood forecasting services in BC are primarily provided by the MFLNRORD River Forecast Center (RFC). The RFC analyzes hydrometric data (e.g., snow pillow, meteorological and streamflow data), provides information on current and forecasted streamflow (e.g., discharge and water levels) to the public and in the case of extreme floods or droughts, issues flood watch and flood warning alerts and supports provincial emergency management efforts. The RFC uses several hydrometric and climate products as inputs to flood forecasting models, including:

- Observed hydrometric data provided by the Water Survey of Canada (WSC).
- Observed meteorological data from climate stations managed by Environment and Climate Change Canada (ECCC), and several provincial ministries.
- Forecast data from ECCC's Numerical Weather Prediction (NWP) product.

BC users or "consumers" of flood forecasting information rely on the forecasts provided by the RFC and attempt to apply forecasts at a local level as part of emergency management decision making. BC Hydro and Power Authority (BC Hydro), which is a Public Sector, BC Crown Corporation, also operates flood forecasting services that are not generally accessible outside that organization[2]. Coastal flood forecasting is conducted by the BC Storm Surge Forecasting Service (SSFS), which provides 6-day total water level forecasts categorized by low, medium and high risk of extreme water levels above annual tides for a section of the southern BC coast (Drawing 01). The SSFS model was initially developed by BC Ministry of Environment (MOE) and Department of Fisheries and Oceans (DFO) but is currently operated by a sole practitioner Qualified Professional, with funding currently administrated through FBC.

RFC uses the CLEVER (Channel Links Evolution Efficient Routing)[3] model to produce a 10-day flow forecast for riverine flooding at specific locations in the Province (Drawing 01). The RFC provides a 5-day flow forecast for select coastal storm dominated watersheds along the BC coast including the south, central and northwest coastline and Vancouver Island to predict riverine flooding using the COFFEE (COastal Fall Flood Ensemble Estimation) model during the autumn-winter storm season using NWP data. The RFC also operates two different forecast models for the Fraser River including a routing model which takes measured streamflows from the headwaters of the Fraser River and routes the flow to Hope and Mission, BC, and a numerical watershed model based on 10-day weather forecast called the WARNS (Water and Routing Numeric System) forecast model. A MIKE 11 hydrodynamic model was also developed to predict 10-day water levels for the lower Fraser River between Hope, BC to the Burrard Inlet. It is operated by MFLNRORD's Flood Safety Section and provides 10-day water level forecasts during high flow periods (e.g., during spring freshet).

Table 2-1 summarizes the models used by the RFC and SSFS to produce flood forecast products. In general, these models rely heavily on preliminary data collected in near real-time that can change once the data is verified by other public agencies such as WSC and ECCC.

Table 2-1. Summary of publicly available flood forecasting services currently available in BC.

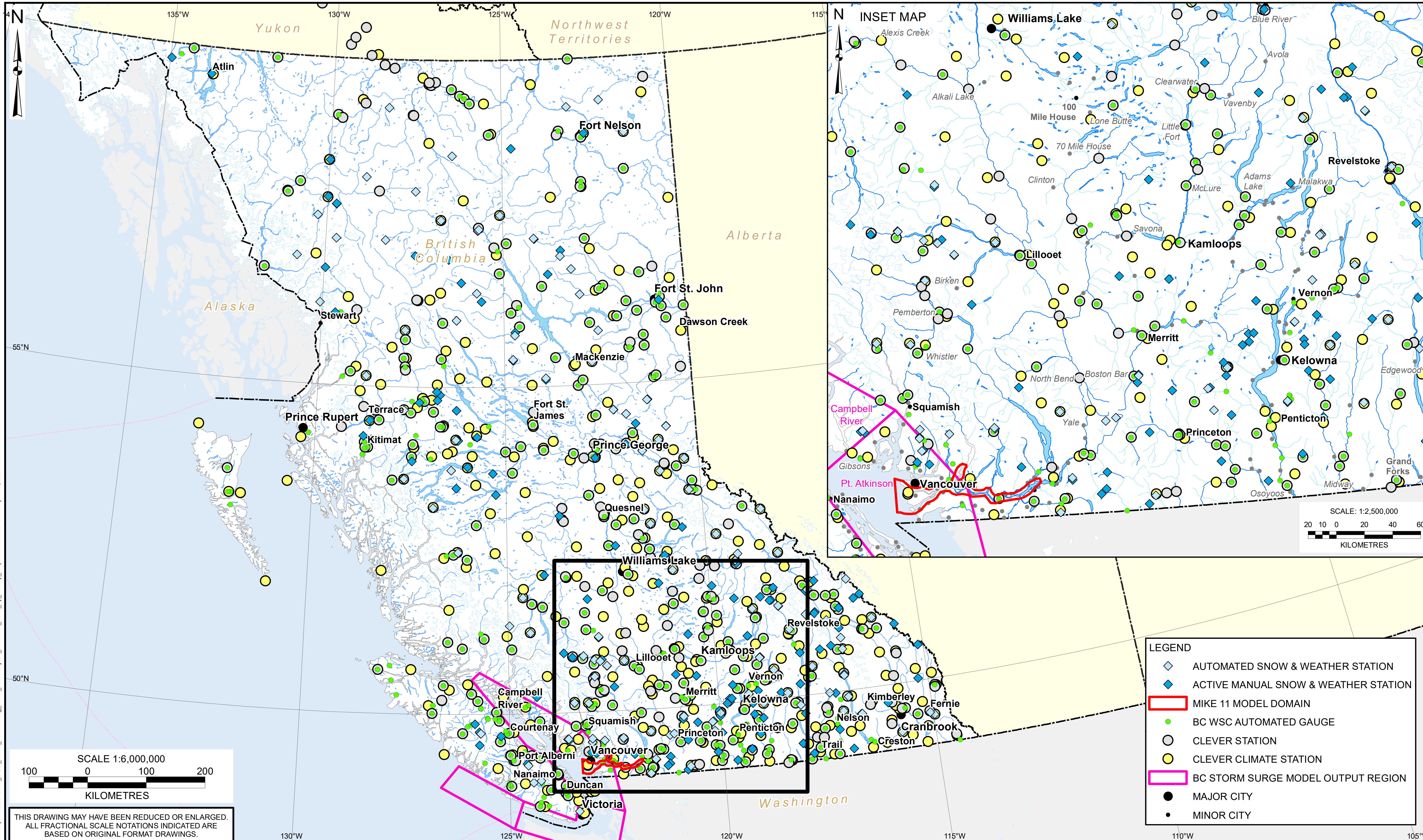
Provider	Model (Forecast)	Primary Data Inputs	Processes
BC River Forecast Center (RFC)	CLEVER (10-day)	Snowpack, streamflow, climate	Riverine
	COFFEE (5-day)	Snowpack, streamflow, climate	Riverine
	WARNS (10-day)[4]	Snowpack, streamflow, climate	Riverine
MFLNRORD Flood Safety Section	MIKE 11 (10-day)	Streamflow (including forecasted), Water levels	Riverine
BC Storm Surge Forecasting Service (SSFS)	Predictive ocean model (6-day)	Climate	Oceanic and Coastal

2 BC Hydro uses the Delft-FEWS system (Deltares) an open data handling platform for developing hydrological flood models and forecasting and warning systems.

3 CLEVER is a hybrid lumped watershed and semi-distributed channel routing model developed by the River Forecast Center, BC MFLNRO (C.Luo, August 16, 2017).

4 CLEVER/WARNS forecasts and flows are used to drive water level forecast (boundary conditions).

Riverine flood forecasting in BC is particularly challenging due to the topographic and climatic diversity in the Province. Climate and streamflow observation points are limited in numbers and locations when compared to this diversity. The topographic and climatic diversity may not be adequately represented in climate or flood forecasting models. Flooding can also be triggered from other mechanisms such as ice or large woody debris jams, undersized watercourse crossings, structural encroachments into flood-prone areas, channel encroachment due to bank erosion, wind- or landslide-generated waves, failure of engineered structures or, landslide, glacial, moraine or beaver dam outbreak floods. Generally, these additional mechanisms are not considered in regional flood forecasts.



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "FLOOD FORECASTING SERVICES", AND DATED APRIL 2021.
3. BASE TOPOGRAPHIC DATA BASED ON CANADA NSF PROVIDED BY NRCAN, DATED 2006.
4. COORDINATE SYSTEM IS NAD 1983 BC ENVIRONMENT ALBERS. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.
7. THE MAP SHOWS DATA THAT RESPONDENTS STATED THEY WERE USING; THEREFORE, IT DOES NOT SHOW AN EXHAUSTIVE SET OF STATION LOCATIONS.

SCALE: 1:6,000,000	CLIENT: FRASER BASIN COUNCIL	PROJECT: FLOOD FORECASTING SERVICES	
DATE: APR 2021		TITLE: DATASETS USED BY SURVEY RESPONDENTS	
DRAWN: MIB		PROJECT No.: 0511008	DWG No: 01
REVIEW: RS			
APPROVED: KH			

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3.0 APPLICABLE POLICIES, LEGISLATION AND GUIDANCE

This section provides a high-level summary of flood-related policies, legislation, and professional practice guidelines in BC. It is provided as general reference about areas of governance and regulation relevant to flood forecasting services and flood management in general and is not exhaustive.

3.1. Emergency Program Act

The Emergency Program Act (EPA) and the associated regulations provide the legislative framework for the management of disasters and emergencies in BC, including decisions based on flood forecasts. The EPA is currently being modernized[5] to incorporate international best practices, including the United Nations (UN) Sendai Framework for Disaster Risk Reduction (Sendai Framework); the UN Declaration on the Rights of Indigenous Peoples (the Declaration); and principles that guide the Province's relationship with Indigenous Peoples.

3.2. Land Title Act

Jurisdiction over land development in BC is established by the *Land Title Act [RSBC 1996]* Section 77, which defines approving officers as those appointed by:

- The municipal government for land located within a municipality.
- Lieutenant Governor in Council may appoint the regional district to appoint an officer for rural land of the regional district, otherwise the approving officer is located within the Ministry of Transportation (*Transportation Act*). Currently no regional districts hold this authority[6].
- Treaty First Nations for Treaty First Nation Land.

Additionally, the Agricultural Land Commission has a degree of jurisdiction over land designated as Agricultural Land Reserve (ALR). Some Improvement Districts (e.g., Diking District) have land development-related bylaws that must be considered. Aboriginal reserve lands are managed separately under the federal Indian Act.

The Land Title Act is indirectly relevant for flood forecasting in that it pertains to the same geographic areas where flood hazard is relevant to land regulation. The Land Title Act [RSBC 1996] Section 86 (1)(c) provides considerations that would allow the approving officer to refuse approval of the subdivision plan, including:

- (iv) "the land has inadequate drainage installations"
- (v) "the land is subject, or could reasonably be expected to be subject, to flooding, erosion, land slip or avalanche"
- (ix) "the subdivision is unsuited to the configuration of the land being subdivided or to the use intended".

[5] **https://engage.gov.bc.ca/govtogetherbc/consultation/emergency-program-act-modernization/**.
[6] **http://www.th.gov.bc.ca/DA/L3_min_trans.asp** accessed April 14, 2020.

Section 86 (1)(d) states:

"if the approving officer considers that the land is, or could reasonably be expected to be, subject to flooding, erosion, land slip or avalanche, the approving officer may require, as a condition of consent to an application for subdivision approval, that the subdivider do either or both of the following:

(i) provide the approving officer with a report certified by a professional engineer or geoscientist experienced in geotechnical engineering that the land may be used safely for the use intended;

(ii) enter into one or more covenants under section 219 in respect of any of the parcels that are being created by the subdivision."

With respect to local government bylaws, Section 87 allows the approving officer to refuse approval of the subdivision plan if it does not meet applicable requirements contained in the Local Government Act as well as "all applicable municipal, regional district and improvement district bylaws regulating the subdivision of land and zoning".

3.3. Local Government Act

As with the *Land Title Act*, sections of the *Local Government Act* are indirectly relevant for flood forecasting in that they pertain to land regulation in flood-prone areas. Specifically, Section 524 of the *Local Government Act* permits a local government to designate, by bylaw, land as a floodplain[7], and for that floodplain, they may specify the flood level and in Section 524(3)(b), "the setback from a watercourse, body of water or dike of any landfill or structural support required to elevate a floor system or pad above the flood level". Section 524(5) allows the local government to make different provisions for things such as different areas of a floodplain, different zones, different types of geological or hydrological features.

Section 488(1) of the *Local Government Act* permits a local government to designate a Development Permit Area (DPA), by way of the Official Community Plan (OCP), for one or more purposes including (b) "protection of development from hazardous conditions". To support the designation, the OCP must describe (Section 488(2)):

- The special conditions or objectives that justify the designation.
- The guidelines for how proposed development in that area can address the special conditions or objectives. These guidelines can be specified in the OCP or in an accompanying zoning bylaw.

Hazardous conditions are defined in more detail in Section 491(2), where a development permit may do one or more of the following:

"(a) specify areas of land that may be subject to flooding, mud flows, torrents of debris, erosion, land slip, rock falls, subsidence, tsunami, avalanche or wildfire, or to another hazard if this other hazard is specified under section 488 (1) (b), as areas that must remain free of development, except in accordance with any conditions contained in the permit;

[7] Provincial bylaws use the spelling "flood plain", while conventional spelling is "floodplain". Both spellings are used interchangeably in this document.

(b) require, in an area that the permit designates as containing unstable soil or water which is subject to degradation, that no septic tank, drainage and deposit fields or irrigation or water systems be constructed;

(c) in relation to wildfire hazard, include requirements respecting the character of the development, including landscaping, and the siting, form, exterior design and finish of buildings and other structures;

(d) in relation to wildfire hazard, establish restrictions on the type and placement of trees and other vegetation in proximity to the development."

Within a DPA, any proposed subdivision, building improvement (i.e., adding to or altering an existing building) or new building construction requires a development permit be issued from the local government (Section 489). The Board may grant or refuse a permit on a case-by-case basis depending on whether the guidelines listed for that DPA in an OCP/zoning bylaw have been satisfied.

3.4. Dike Maintenance Act

Dikes in the Province are governed under the Dike Maintenance Act [1996] and the Drainage, Ditch and Dike Act [1996]. These Acts do not provide detail on dike design parameters but outline the responsibilities and powers of the Inspector of Dikes (IOD). These include the approval of construction for new dikes or changes to existing dikes; the establishment of flood protection standards and dike design criteria; monitoring of the management of flood protection works by local diking authorities, and orders to address critical dike safety issues.

3.5. Professional Practice Guidelines

Multiple provincial, federal, and international guidelines relate to flood forecasting. Those relevant within BC include:

- Flood Mapping in BC, Professional Practice Guidelines, Engineers and Geoscientists BC (EGBC, January 2017)
- Legislated Flood Assessments in a Changing Climate in BC, Version 2.1, Professional Practice Guidelines (EGBC, August 28, 2018)
- Landslide Assessments in a Changing Climate in BC, Professional Practice Guidelines (EGBC, updated Draft issue anticipated Spring 2021)
- Federal Floodplain Mapping Guidelines Series (multiple guidelines) (NRCAN, 2021)
- Guidance for Selection of Qualified Professionals and Preparation of Flood Hazard Assessment Reports, MFLNRO and Rural Development (MFLNRO, n.d.).

4.0 METHODOLOGY

BGC's research and consultation process included the following elements:

1. Conducting a literature review of publicly available reports, documentation and papers related to flood forecasting services.
2. Compiling samples of flood forecasting products.
3. Identifying and categorizing flood forecasting product users.
4. Developing an online survey submitted to a broad group of users of flood forecasting information to solicit user experience feedback.
5. Interviewing a subset of producers and users of flood forecasting information in BC through one-on-one web-based meetings.
6. Conducting a cost analysis for other monitoring resources such as installing a hydrometric station for flow monitoring, implementing a debris-flow warning system or implementation of the Delft-FEWS platform from collaboration with Deltares.

BGC conducted user assessments with both producers of flood forecasting information such as RFC and SFSS, and consumers of forecasting information such as local or regional emergency planners that apply forecasts for decision making purposes, often in near real-time. Drawing 02 provides a summary of the geographical distribution of survey respondents.

The consultation process sought to provide information on the state of flood forecasting in the province, identify what kinds of data products are being used, what the current challenges were, and what kind of data and products are needed to improve flood hazard information availability, accuracy, relevance. A list of participants was developed that included both producers and users (or consumers) of flood forecasting information. Contacts were obtained from BGC's personal and professional network and specific recommendations from the FBC. The list included subject matter experts from private industry, municipal emergency response leaders, and governmental employees. BGC conducted investigations using email, telephone or online platforms due to Covid-19 restrictions. The consultation process took the form of both interviews and written surveys.

The questions included in the phone interviews varied but were generally based on the following:

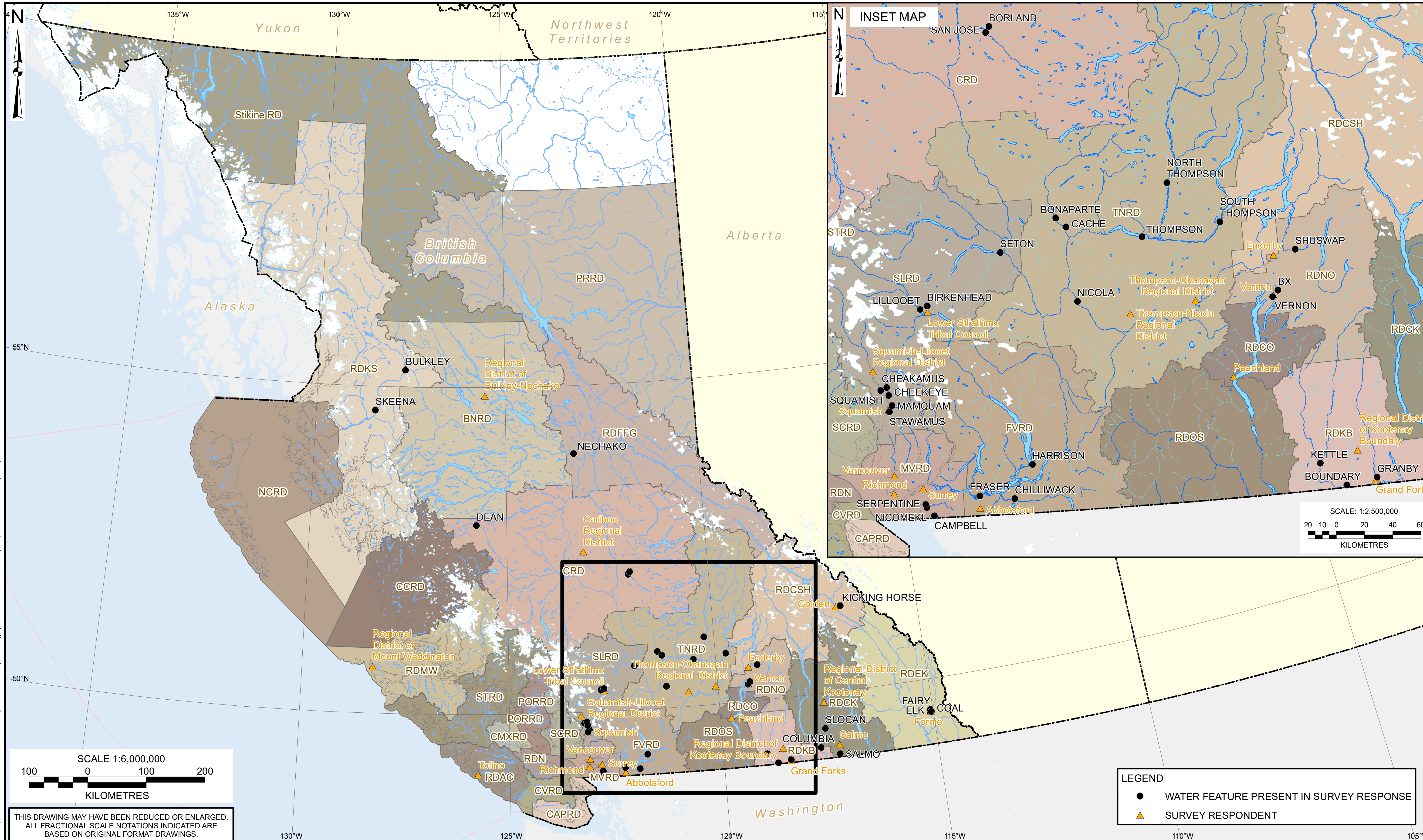
1. What do you see as the key challenges (e.g., technical, social, political, or financial) for advancing flood forecasting services across BC?
2. Where do you see the geographical gaps in coverage in the Province?
3. How is climate change or sea level rise (if relevant) considered?
4. A focus of the review is considering the cost of implementing the Delft-FEWS platform. Is this a platform that your organization has considered implementing? What are the pros and cons in your opinion?
5. How would you improve the communication of flood forecasting information?

A total of 58 individuals were sent a web-based written survey to capture the experience of users of flood forecasting information in the Province. These contacts were also obtained from BGC's personal and professional network, specific recommendations from the FBC, and from past FBC survey correspondents. The list included individuals with a varied professional background related to flood forecasting in BC including roles with government and non-government agencies throughout the Province. BGC received a total of 28 responses (48%).

The questions included in the written survey included the following:

1. Which regions (or rivers) do you operate in and what are your responsibilities with respect to flood hazards?
2. What are the largest challenges you face with respect to flood forecasting in your region?
3. What is the most useful type of flood forecasting data available to you and how do you use it?
4. What sort of flood forecasting information have you previously needed but not had access to? If possible, please briefly describe the situation and whether the information simply didn't exist or if you were limited by other factors (expertise, funding, time, etc.).
5. What has your experience with uncertainty in flood hazard or flood forecasting data been? Does uncertainty affect how you use or perceive the data?

Section 5.0 provides further details on the geographic distribution of responders, including visualization of and comments on limitations of the research and consultation processes.



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DATE: APR 2021		TITLE: GEOGRAPHICAL DISTRIBUTION OF SURVEY RESPONDENTS	
DRAWN: MIB			
REVIEW: RS	BGC	PROJECT No.: 0511008	DWG No: 02
APPROVED: KH			

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5.0 KEY FINDINGS FROM CONSULTATION AND RESEARCH

The following sections summarize the key findings from the gap analysis and user assessments conducted by BGC for both investigations.

5.1. C-1.1 Investigate current capacity, coverage, value, and gaps in flood forecasting services

The following sections provide a summary of the general user feedback from written surveys including a synthesis of flood forecasting information used to direct emergency management activities, and suggestions for improved data products or services.

5.1.1. Forecasting Services or Products Used

Users reported reliance on several sources of data and information for communication, planning and decision making related to flood forecasting. The following sections provide a summary of the data products or services reported.

5.1.1.1. Hydrometric Gauge Data

The most cited data product used in flood forecasting efforts was hydrometric gauge data. Typically, this was WSC gauge data, but in some cases, gauge data maintained by local authorities or other entities like dam operators to monitor flood situations in real time was used to inform emergency management actions. Hydrometric gauge data is considered a critical component of a majority of the user's flood management planning efforts. Drawing 01 displays data sources used by written survey respondents.

5.1.1.2. CLEVER Model

Several users reported their reliance on forecasts from RFC's CLEVER model. Responses were mixed with respect to degree of use and satisfaction with results. Some users, typically those with greater in-house expertise, reported satisfaction with the model outputs considering the challenges in making such a data product. The following quote from a survey responder captures this sentiment:

> *"I appreciate that the CLEVER data has been improved to provide upper and lower bounds plus an average. This is helpful in communicating the uncertainty to the public. I appreciate uncertainty being addressed - this helps rather than hinders my communications. Beyond that, I recognize that there are real limitations to flood forecasting due to the [number] of variables. I've found CLEVER to be a reasonably good predictor, within its limits."*

Generally, users reported experiences with forecasts related to:

- Inaccuracy (often with an overestimation in flowrate, or in the timing of the peak flow)
- Slow dissemination of flood alerts resulting in mistiming of emergency actions
- Challenges in integrating forecasts with flood hazard maps
- Or difficulties obtaining forecasts that are locally relevant.

More than one user reported challenges in mobilizing emergency action after a flood warning due to public desensitization for such alerts. There was also a perception that Provincial priorities for flood forecasts appeared to center on the Fraser River with less focus on smaller watersheds, particularly in northern communities. Certain respondents mentioned that direct communication with the RFC was useful when a flood event was occurring.

5.1.1.3. Snow Pillow Data

Numerous users reported using snow pillow information to generate an intuition about the amount of snow that would be contributing to the spring freshet. This information would typically be compared against historical data and local experience to put snowpack estimates in perspective although it is unclear how snow pillow data is used by stakeholders. One response mentioned the use of visual helicopter-based inspections for developing snowpack information. Users from Grand Forks, BC reported using the Northwest River Forecast Center (NWRFC) data from the US (United States) because the snow pillow data from the RFC did not provide sufficient detail.

5.1.1.4. Additional Services

Respondents noted their reliance on US services such as the Advanced Hydrologic Prediction Service (AHPS) from the NWRFC and the National Operational Hydrologic Remote Sensing Center (NOHRSC) for jurisdictions near the Canada-US border. In these regions users observed occasional inconsistency between RFC and NWRFC forecasts.

Some respondents reported that the BC SSFS, although useful, did not issue alerts beyond their display on the website, which could sometimes be missed. The use of this model was specific to those communities with a coastal flood risk such as Squamish, Tofino, Richmond, Surrey, and Vancouver.

Some smaller communities mentioned the use of and reliance on separate hydrologic dashboards produced by larger communities, such as those offered by Chilliwack and Kelowna. This suggests that dashboards may be an effective way to convey flood forecast data. One user reported that limitations of the web user experience for the BC SSFS led to increased work to respond to specific data requests.

One respondent cited use of the provincial MIKE 11 model covering the lower Fraser River.

5.1.1.5. Historical Floodplain Mapping

Certain respondents mentioned the use of floodplain maps generated from historical studies. In some cases, respondents identified challenges with respect to reconciling flood maps that were not made in a consistent way, citing fragmented funding scopes as the cause for this incongruency between maps across regions. BGC notes that user comments about flood forecasting reflect user needs and expectations, which may not correspond to the services currently provided by the RFC or BC SSFS. For example, determining flood hazard and associated risk to a community is not a forecasting service that RFC or BC SSFS provides.

5.1.1.6. Other Forecast Considerations

No users mentioned ECCC weather forecasts or data products, or the use of local weather stations. Given the importance of hydroclimatic triggers for flooding and the reliance of weather observation data within modelled watersheds for flood forecasts, BGC believes this may reflect the nature of the survey questions listed in Section 4.0. It may be that respondents did not identify their use of meteorological forecasts as being related to the flood forecasting services reviewed in this report. In addition, no users mentioned hydrogeomorphic processes such as bank erosion. Given the importance of bank erosion as a damage mechanism during floods, this may also reflect the nature of the survey questions and user expectations of what should be included in a flood forecast.

5.1.2. Forecasting Information Needs

Often agencies do not have the resources to apply new scientific developments, adopt new models, or regularly update their systems. Users emphasized the difficulty local governments face in the interpretation of flood forecast information for decision making as indicated in the following quote from a survey responder:

> *"Not all Local Governments can absorb costs for employing hydrologists on staff. The Province needs to understand that local government staff are not subject matter experts and that by not providing needed information, people that do not have education in these fields are attempting to extrapolate and decipher the often-fragmented information. The data interpretation and assumption from non-subject matter experts is then what Local Governments are left with to issue Evacuation Alerts and Orders to provide public and first responder life safety."*

The most prevalent need that emerged from the survey was to expand the hydrometric monitoring network and improve snowpack/snow pillow information. Many users reported that the critical locations in their jurisdictions were on smaller rivers or creeks that are currently ungauged. There was limited information available for these locations and these smaller rivers and creeks tended to be the most unpredictable and destructive in a flood event.

It should be emphasized that this was one of the most common sentiments among respondents. In at least one case, the need for gauges on small tributary rivers of the Bulkley and Nechako Rivers garnered strong local support but was rejected by the provincial and federal governments on the basis that it did not meet federal priorities such as fish habitat. Often, users had to employ unreliable data proxies (e.g., data from adjacent watersheds) or were limited to exclusively reactive measures.

To either supplement or replace river gauge data, some users reported using dam operations data. Some users expressed a need for better dissemination practices for dam operations data to help supplement gauge data. This would improve timing and availability of data and could take on the form of a centralized database accessible via an online portal.

5.1.3. Gap Analysis

The following sections provide a summary of geographical, technical, and operational gaps identified from BGC's literature review and user assessments.

5.1.3.1. Geographic (Jurisdictional) Gap Analysis

The gap analysis was informed primarily from responses received during engagement with users and producers of flood forecasting data. As a result, the gaps identified are biased towards areas falling within the jurisdiction of those who responded and cannot be considered a comprehensive gap analysis. The distribution of respondents and location of rivers and creeks represented in survey are shown in Drawing 02.

A commonly shared perception among respondents was that areas outside of the Fraser River were poorly represented in the available information (numerical models, flow gauges, snow gauges), and for certain data types or locations, the users expressed a lack of support. One user expressed concern over the need for smaller communities within the lower Fraser River watershed to fund their own gauging networks and modelling systems on small budgets. That the BC SSFS does not currently have a long-term funding source was emphasized by several respondents.

Geographic gaps were dominated by reported insufficient coverage of the river and snow gauge networks. These gaps related primarily to information gaps on small, ungauged rivers and creeks, which many users identified as the most concerning hazard in their jurisdiction. The gaps identified from the analysis of survey and interview responses were categorized into the following classes:

1. Insufficient flow gauge data.
2. Insufficient snow gauge data.
3. Insufficient CLEVER model accuracy.
4. Emerging hazards.

These geographic gaps and associated categories are visualized in Drawing 03.

5.1.3.2. Technical Gap Analysis

This section summarizes gaps identified by users. BGC notes that when describing gaps, users did not typically distinguish between local and provincial government responsibilities for flood management. As such, the gaps include those related to flood hazard and risk management planning, which is the responsibility of local government.

The analysis of survey data found that outside the lower Fraser River, there is little information and effectively no framework for how available data translates to flood hazard (specifically flood extent, timing, and intensity). For example, although a community may have a nearby gauge, and perhaps even a somewhat accurate flow forecast, the predicted flood extent and elevation is unknown and hinders evacuation decision making. This represents a gap in the translation of flow to flood hazard. Additionally, when flood mapping studies are available, it was noted that flood maps can originate from different sources such as government or qualified professionals (QPs), and are sometimes challenging to reconcile with one another or with the specific flood return period that is represented by the inundation map. This is a gap of concern to Regional District governments that must consider large areas with multiple flood hazard maps.

Technical gaps are also present in the mechanics of the forecasting tools available. The RFC identifies that one of the largest stumbling blocks is snowpack data, especially in small watersheds. Additionally, there is limited ability to anticipate and consider the impact of river ice in flood forecasting models.

The data-driven modelling employed by the RFC also has limitations under changing environmental conditions, notably climate change. As the hydrosphere is affected by a changing climate the response of rivers will change accordingly (BC MOE, 2016). Some respondents believe that the increase in hazard level posed by smaller rivers and creeks is related to climate change. Changes in land use and land cover presents another environmental change that is reported by the RFC as contributing to potentially poor model performance in some areas. Data-driven models may not explicitly incorporate land use changes, and so changes such as large-scale deforestation can affect the hydrology in a way that may contribute to poor flood forecasting results. Furthermore, there is an understanding that flood behavior is changing under the influence of climate change and these changes may not be ingrained in the presently available flood map data, making land-use planners apprehensive to trust the prescribed set-back distances. Planners report that this puts more onus on developers to demonstrate safe set back distances under the future conditions of a changing climate.

A limitation of many of the flood forecasting approaches is that they provide a deterministic forecast; that is, a single forecast scenario for future conditions without quantifying the uncertainty in the forecast that comes from making a probabilistic forecast. The RFC only uses point weather forecasts and does not provide ensembles[8]. The main barrier to implementing improvement in these areas is internal resources. Additional internal resources are required to implement these technical improvements and increase accuracy overall. The inclusion of ensembles will also augment the type of uncertainty addressed in the RFC forecasts. Currently the uncertainty associated with historical error, whereas the inclusion of ensemble uncertainty will address uncertainty due to the uncertainty of the inputs.

Even when model output is available with reasonable accuracy, the use of flood forecast data can be limited by a user's technical knowledge. In some jurisdictions, a lack of local knowledge and training posed a problem for translating model output into actionable insight. Specifically, some communities are finding it hard to translate what is currently offered into effective action internally or acquire funds to hire capacity or a QP, while those that do not have this problem have in-house expertise and internal capacity to responded to flood emergencies. There are some specific

[8] An ensemble is a group of different model simulations. In this context it represents a group of models with different input data that collectively are used assess uncertainty in the modelling effort.

instances where information like raster data cannot be processed by local communities due to a lack of training, software or in-house capacity.

A specific technical gap exists with respect to reconciling coastal and fluvial flooding at the Fraser River-Georgia Strait estuarine interface. The BC Storm Surge model domain extent ends at the mouth of the Fraser River. The Fraser River MIKE 11 and MIKE 21 models also ends at mouth of the river. These models are not coupled, and so interactions between storm surge, tide, and high flows on the Fraser River are not captured. An increase in sea level due to tide and storm surge at the mouth of the Fraser River will decrease the hydraulic gradient along the river and increase water levels, but the operational output of the BC Storm Surge model is not currently coupled to upstream water levels and potential flooding. Having these two models decoupled leaves a gap in flood forecasting along the Fraser River. Changes in the coincidence of these two phenomena under a changing climate should be investigated.

5.1.3.3. Operational Gap Analysis (Uncertainty)

Operational gaps are defined here as gaps that are not related to the absence of data in a specific location or technical limitations of the science or assumptions in the data. Operational gaps are those that have to do with dissemination of information or the communication of uncertainty.

With respect to inland flood forecasting tools, which are effectively limited to the CLEVER model, there are a handful of operational limitations identified. The first has to do with timing of the peak flow. This is a critical piece of information that many emergency managers rely on, and yet its timing can be quite uncertain or volatile in certain situations. Managers want to avoid a situation where they see a forecast, anticipate the timing of the peak flood, and then send the evacuation order or emergency response resources, only to see the evacuation take place or resources arrive while the flow is decreasing. This type of problem is further described in the case study (Section 6.0).

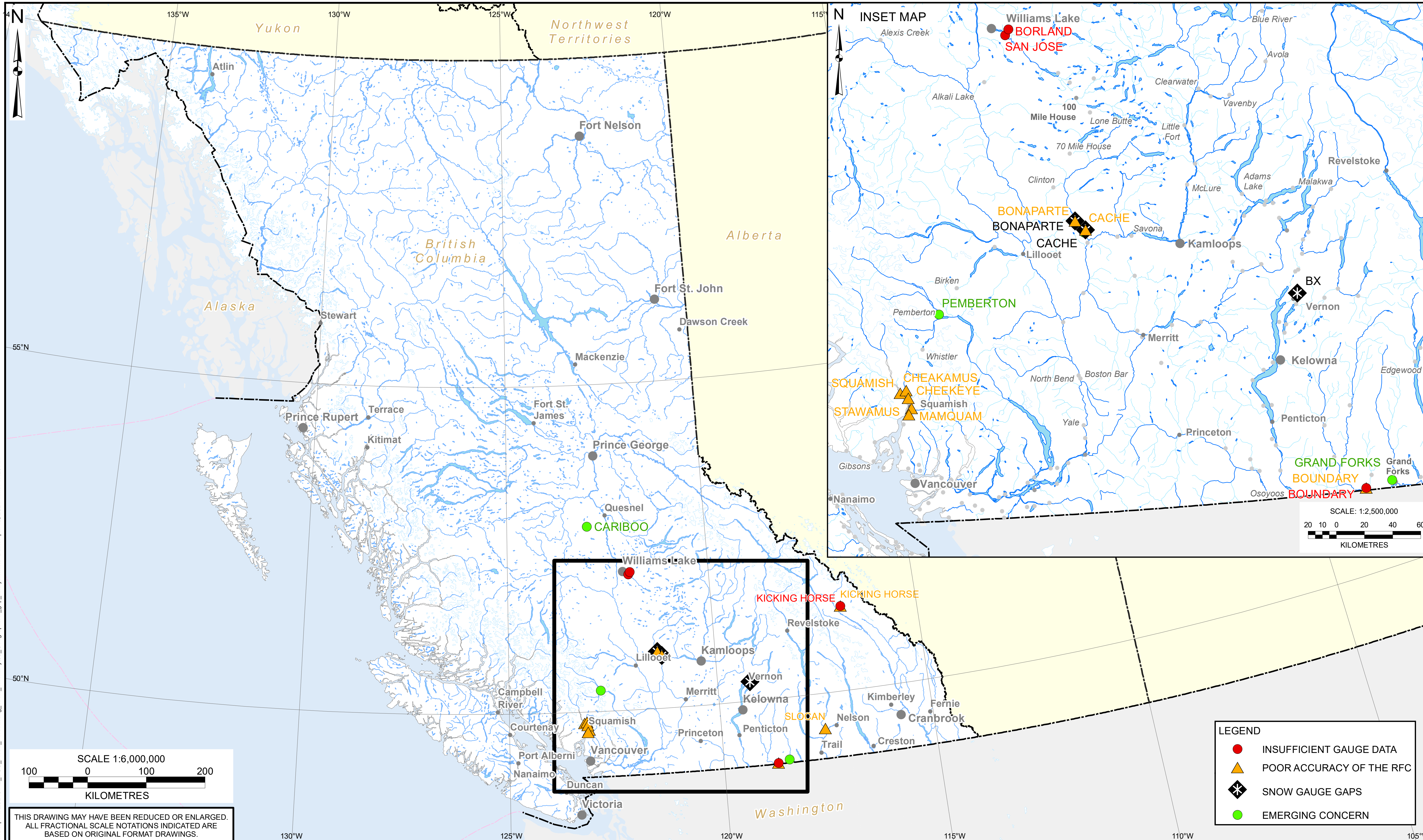
Some respondents describe challenges in dealing with drastic short-term changes in the CLEVER forecast. The following excerpt captures this sentiment:

> *"During a flood event, (for example this year in Williams Lake), it would be useful to be able to get better understanding of uncertainty in a forecast from the modeller. Often, the forecast can change drastically, but the end user doesn't know why this has happened, and whether we should expect it to keep happening as more forecasts are released."*

This phenomenon, described as 'yo-yo-ing' by one respondent, hinders use of and confidence in the model, highlighting a greater need to communicate what is contributing to changes between forecasts. One respondent mentioned that knowledge of the input (e.g., precipitation return period) communicated to them during direct contact with the RFC was useful in putting the forecast uncertainty in context. With this knowledge, they were able to realize that the probability of realizing the upper bound of the forecasted flow was surprisingly quite high. Overall, users would appreciate knowing what contributes to model uncertainty and changes in the forecast from one forecast to the next.

Coastal communities such as Tofino described day-to-day operational needs for timely, accurate storm surge forecasts and monitoring to manage public safety along the coastline. The only product available to serve this need is the BC Storm Surge model (although Tofino was a relatively recent expansion of the model to the coastal community), which has substantial operational limitations. Public communication of model output was reported as a gap; users would like to see the inclusion of storm surge information in ECCC reports, web products, and alerts, in a format that can be readily understood by the public. This is not possible unless ECCC becomes more involved in its development and operation. Additionally, interactivity with the website is a gap, the system is quite outdated and can only deliver information in pdf form.

Finally, an operational gap faced by forecasters is capacity and information-technology (IT) expertise. In the case of the BC Storm Surge model, the entire system is run off the laptop computer of the sole contributor. Funding is obtained through a variety of mechanisms and is uncertain from year to year. To ensure long-term sustainability of a system that many users rely on, budget certainty and governmental support is needed. Currently, the annual operational costs for SSFS operations from October through March are $40,000 and does not include the costs for any system upgrades, expansions or enhancements. Adoption of new technologies at the RFC is also limited by IT support. The implementation of FEWS systems has been a point of interest for the group, but any work towards this goal has been hindered by a lack of governmental IT support. Without additional IT support, flood forecasting system architecture is limited by the knowledge of in-house staff.



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CLIENT:
FRASER BASIN COUNCIL

PROJECT:
FLOOD FORECASTING SERVICES

TITLE:
GEOGRAPHICAL GAP ANALYSIS

PROJECT No.: 0511008
DWG No: 03

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5.2. C-1.2 Visualize where flood forecasting gaps exist and estimate costs for improvement to end users

Results of the gap analysis and user assessments are summarized visually in Drawing 03 to communicate the regions, watersheds, and watercourses that are identified as challenging for forecasting and/or flow forecasting services by end users. BGC used discussions with Deltares, a Dutch national water resources research institute, to provide a summary of the resources required to implement the industry standard software for operational flow forecasting, Delft-FEWS as summarized in Section 7.0.

5.3. Summary of Investigation: Key Findings

Table 5-1 lists key findings and potential actions that could be undertaken to address feedback. The findings should not be considered as an exhaustive representation of flood forecasting opinions in BC. However, they still provided a useful range of feedback to inform about the state of flood forecasting in the province, what kinds of data products are being used, what the current challenges are, and what kind of data and products are needed to improve flood hazard information availability, accuracy, and relevance.

Table 5-1. Summary of key findings from user assessments and potential actions.

Category	Key Finding	Comments / Potential Action
Flow and climate data gaps	• Insufficient flow and snow gauge coverage, especially on watercourses in smaller watersheds (e.g., less than 30 km^2). This data limitations impacts the ability of emergency responders to make local predictions and inform actions during flood emergencies. • These data gaps were the most common limitation identified from the user surveys. • Locations with limited coverage include but are not limited to: Cache Creek, Bonaparte River, BX Creek, Kicking Horse watershed, Borland Creek, San Jose River and Boundary River	• Improve flow and snow gauge coverage in smaller watersheds that have experienced past damaging floods or are in high-consequence areas of the Province.
	• Gridded flow forecasts or forecasts at more key locations, including smaller watercourses, would better inform the timing of flood response including the allocation of equipment and staff resources.	• Increase the scale of RFC flood forecasts beyond output at specific Water Survey of Canada (WSC) gauges.
Communication	• Users rely on short-term or real-time flow and snow gauges to make qualitative “forecasts” of flood risk. Experience is used to estimate how long it would take for a flood wave observed at an upstream gauge to reach downstream locations.	• Provide stakeholder training related to the application of monitoring versus forecasting data products and tools.
	• Flood forecast data products often need to be interpreted to be applied and can be difficult to interpret for non-technical staff. Users generally do not feel they have adequate training in the use and interpretation of flood forecast data. • Forecasts that are provided in simple and clear terms are especially important during an emergency.	• Continue to provide access to RFC staff to aid in data translation and interpretation. This was seen as beneficial by several users and should continue to be supported and potentially expanded. • Provide training courses to users to help with interpretation and application of flood forecasts.
	• Geomatics professionals are needed within the Emergency Operations Center (EOC) teams to effectively incorporate digital information into a format that supports decision making.	• Ensure the presence of a geomatics staff person in EOCs to assist in the incorporation and use of data products by EOC staff.
	• The involvement of subject matter specialists such as Qualified Professionals (QPs) is needed by EOCs to assist with the interpretation and analyses of flood forecast information.	• Involve QPs in EOCs to assist in the analysis and application of flood forecast data.
	• Users familiar with Alberta flood forecasting services felt the Province of Alberta is doing a good job of developing and communicating flood forecast information.	• Complete review of capacity, methods and tools for flood forecasting in Alberta for potential application to BC.
	• Local governments and residents near the U.S. border rely on transboundary forecast data (i.e. from Washington State USGS) for decision making.	• RFC could provide guidance on where and when transboundary forecast data (i.e. from Washington State USGS) may supplement or supersede RFC forecasts for decision making by local governments and the public when the data is inconsistent.
	• The issue of river forecasts has implications for those potentially in harms way, including mental, physical, and financial impacts (for residents, businesses, organizations and local governments) even when direct flood impact does not occur. Disclaimers attached to forecasts are easily overlooked.	• Consider issuing simplified RFC updates for public consumption and more detailed forecasts for emergency managers and QPs.
Hazard analyses	• Users noted that flood forecasts help indicate potential flooding but cannot provide any information on where the water is likely to go (extent) or its characteristics (depth, velocity). Understanding flood characteristics is essential for EOC Directors to make informed decisions.	• Identify the connection between regional or detailed floodplain mapping for planning and regulation, and how the hydraulic models developed for such purposes can be deployed for emergency response. • Develop a process to operationally couple flood forecasts to hydraulic models. An example of this would be to implement the CLEVER model as a Delft-FEWS system. In this system the CLEVER model output would be connected to numerous hydraulic models covering specific regions of interest. The hydraulic models would be developed by external consultants and the FEWS system would be hosted and operated by the Province. The system would be run operationally and would provide forecasted flood extents across various regions. The system forecasts would be open to emergency managers much like the CLEVER model currently is and if needed, QPs could be called in during flood events to help interpret model output in specific cases.
Model uncertainty - riverine	• The inclusion of upper and lower estimates in the CLEVER model output in 2020 was seen as a valuable addition.	• The inclusion of ensemble modelling will improve the types of uncertainty that can be incorporated into forecasts. Accounting for future climate change scenarios and land use changes would be beneficial.

Category	Key Finding	Comments / Potential Action
	• Improving the timing of the peak flow and accuracy of the forecast overall of the CLEVER model forecast would go a long way in increasing confidence in the model output. Locations where accuracy was reported as a concern includes but is not limited to: o Cache Creek o Bonaparte River o Squamish River o Mamquam River o Cheakamus River o Stawamus River o Cheekeye River o Boundary River o Cariboo River o Slocan River o Peace River o Granby River o Grand Forks River o Nicola Lake o Elk River upstream of Fernie o Kettle River o Granby River o Hatzic Valley and Hatzic Lake	• Locations identified where accuracy is a concern reflect the geographic distribution and responsibilities of survey respondents. Improvement of flood forecasting in these areas will require systematic gap analysis for forecast input data (e.g. gauges) and an implementation plan and resources for their installation and incorporation into the CLEVER model.
Model uncertainty - coastal	• Locations where accuracy was reported as a concern includes but is not limited to: o Tofino (detailed forecasting needs for beach users) o Howe Sound at Squamish	• Improvement of flood forecasting in these areas will require systematic gap analysis for forecast input data (e.g. gauges) and an implementation plan and resources for their installation and incorporation into the BC Storm Surge Model.
Funding and Resources	• Any initiative to improve the architecture of forecasting services within government must be accompanied by Information Technology (IT) support. Notwithstanding minor updates, neither the RFC nor BC Storm Surge Model will be able to implement changes without additional assistance.	• Provide IT resources to the RFC for upcoming improvements to infrastructure.
	• Multiple users advocated for reliable, long-term provincial funding and staff support for the BC Storm Surge Model, and upgrades to the user interface.	• The current system is run by an individual contractor on a personal computer without redundancies to maintain function during an emergency. Improvements would be related to inclusion in a more official system managed by the government and improved interactivity.
	• Generally, there are biases in the survey/interview responses regarding geographic gaps but less so in the technical gaps. A geographic prioritization for funding allocation must be done in conjunction with a grid-based gap analysis and weighted quantitative prioritization.	• Riverine flood risk prioritization has been completed across substantial portions of BC, including rural and less populated areas (e.g. Holm et al., 2019). This work can form the basis to identify high priority flood hazard areas that also coincide with gaps in flood forecasting services.
Technical gaps	• The RFC generally does not use spatial data in their forecasts (i.e. precipitation). Additionally, the model only ingests a single weather forecast.	• Invest in improving the RFC model's implementation of weather inputs to include gridded snow data and ensemble forecasts.
	• The BC Storm Surge Model is a gridded model that only has output at tide gauge stations.	• The technical capabilities of the BC Storm Surge Model should be upgraded. Invest in improving resolution and providing output along the entire model domain. The model could be improved to incorporate modern gridded forecast products and data assimilation techniques to reduce predicted model bias.
	• There is no system that captures the interaction between the Georgia Strait and the Fraser River. This leaves gaps with respect to coincident high flows, sea level rise, storm surge and waves.	• A 2D Fraser River model should be developed and implemented in the FEWS system. The downstream open water boundary should be coupled operationally to the output of the BC Storm Surge Model.

6.0 CASE STUDY

6.1. Introduction

This section examines a May 2020 emergency response case study for Slocan and Salmo River in the Regional District of Central Kootenay (RDCK). BGC has chosen this case example for the following reasons:

- RDCK's 2020 flooding required a major emergency response effort (largest ever for the District) and relied heavily on flood forecast information for decision making.
- Flood forecasts for Salmo and Slocan rivers, which were a focus of emergency response, had different levels of success and thus provide a useful comparison.
- The case example provides insight into ways that local government, the Province, and Qualified Professionals (QPs), can collaborate during an emergency to improve how flood forecast data is used to support emergency response.
- BGC provided technical services to the RDCK EOC during the emergency response and can provide a perspective of a QP advising a local government. Their EOC Director was also included in the list of those interviewed for this project.

During the period of May 30 - June 1, 2020 a storm system passed through the region encompassed by the Regional District of Central Kootenay (RDCK). The combination of extreme heat and snowmelt, thunderstorms and precipitation resulted in elevated flood hazard throughout the region. Between May 29 and June 1, 2020, an unprecedented District-wide evacuation alert was issued and about 1000 homes were evacuated. Drawing 04 shows the location of the case study.

Table 6-1 lists RDCK evacuation decisions tied to flood forecasts and additional flood modelling over the May 29 to June 2 period. Section 6.2 compares forecasted and observed discharges during the event, highlighting the implications of differences between forecasted and observed discharges for decision making.

Table 6-1. Overview of major RDCK evacuation decisions tied to RFC flood forecasts.

Date	Forecast Actions	RDCK Actions
May 29, 2020	RFC issues a high streamflow advisory for an area encompassing the entire RDCK.	RDCK Emergency Operations Centre (EOC) issues Evacuation Alert for all homes adjacent to, or near waterbodies throughout the entire RDCK, including all communities and municipalities except the City of Castlegar and the City of Nelson.

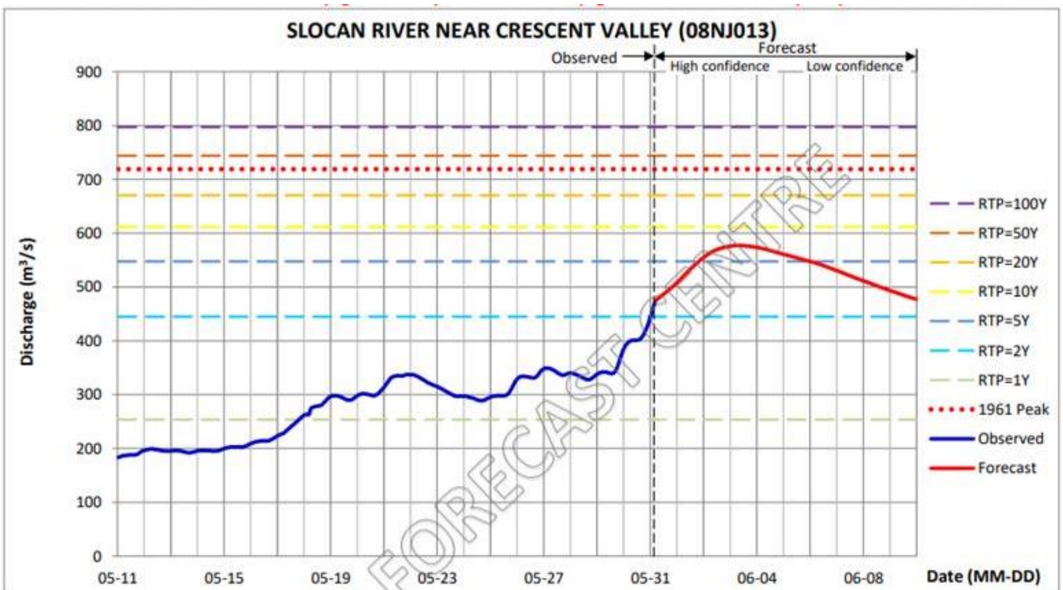
Date	Forecast Actions	RDCK Actions
May 30, 2020	RFC issues a Flood Watch for the Slocan River, Salmo River and surrounding tributaries. Environment Canada issues a Special Weather Statement for Arrow Lakes – Slocan Lake, Kootenay Lake, and West Kootenay, forecasting thunderstorm development, winds gusting upwards of 100km/hour, significant precipitation in the range of 30mm-100mm Saturday May 30 through Sunday May 31. Flood inundation modelling developed to estimate hazard extents based on forecasted flows.	RDCK declares a State of Local Emergency for all eleven Electoral areas (A, B, C, D, E, F, G, H, I, J, K) within the RDCK. RDCK issues an evacuation order for Crawford Creek (Crawford Bay) in Electoral Area A.
May 31, 2020	RDCK and external consultant continue to monitor RFC forecasts. Flood inundation modelling updated to estimate hazard extents based on forecasted flows.	RDCK issues an evacuation order for Duhamel Creek (North Shore) in Electoral area F, Broadwater Road (Columbia River) in Electoral area J, Salmo/Ymir in Electoral Area G, and the entire Slocan River drainage region in Electoral Area H and I including the Village of Slocan, Lemon Creek, Perry's, Appledale, Winlaw, Lebahdo, Vallican, Passmore, Slocan Park, Crescent Valley and Shoreacres.
June 1, 2020	RDCK and external consultant continue to monitor RFC forecasts.	RDCK rescinds the evacuation order for the Slocan River drainage region in Electoral Area H and I, including the Village of Slocan, as well as Crawford Creek (Crawford Bay) in Electoral Area A, Duhamel Creek (Nelson) in Electoral Area F, Salmo/Ymir in Electoral Area G, and Broadwater Road (Columbia River) in Electoral area J.
June 2, 2020	RDCK and external consultant continue to monitor RFC forecasts.	RDCK removes the evacuation alert for the entire region with the exception of Crawford Creek (Crawford Bay) in Electoral Area A, Duhamel Creek (Nelson) in electoral Area F, Broadwater Rd. (Robson) in electoral Area J, Salmo/Ymir in electoral Area G, and the Slocan River drainage region in Electoral Areas H and I.

6.2. Forecasted and Observed Discharges

The RFC provides daily 10-day forecasts of discharges at specific Water Survey of Canada (WSC) gauges along rivers and creeks across BC. For the flood response for the Slocan and Salmo rivers, the forecasts at the following locations were used:

- Slocan River – CLEVER forecast provided at WSC gauge: 08NJ013 SLOCAN RIVER NEAR CRESCENT VALLEY)
- Salmo River – CLEVER forecast provided at WSC gauge: 08NE074 - SALMO RIVER NEAR SALMO).

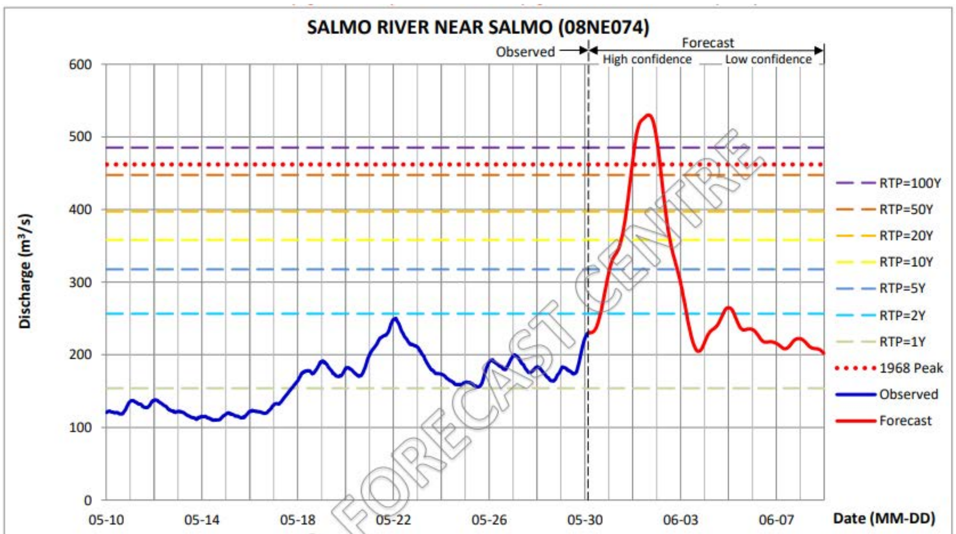
Examples of the BCRFC CLEVER forecasts for the Slocan and Salmo rivers are presented in Figure 6-1 and Figure 6-2. The RFC also provides the forecasts as hydrographs in CSV format. The EOC and BGC reviewed the forecasts for the two rivers after every release. The forecasted and observed flows were compared to the previous days flows to determine the variability and uncertainty in the forecasted flows.



Reading at 05 AM (m^3/s)	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
Sun 2020-05-31	Sun 2020-05-31	Mon 2020-06-01	Tue 2020-06-02	Wed 2020-06-03	Thu 2020-06-04	Fri 2020-06-05	Sat 2020-06-06	Sun 2020-06-07	Mon 2020-06-08	Tue 2020-06-09
	507.1	554.0	575.7	577.1	573.5	560.6	547.2	530.2	511.1	493.1
474.4	**491.2**	**532.3**	**568.1**	**576.1**	**567.7**	**554.2**	**539.5**	**520.9**	**502.4**	**485.0**
	476.1	509.0	555.5	573.9	561.1	547.8	531.0	511.8	493.8	477.4

Color Scheme for Return Periods:	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	1961 Peak (m^3/s)
	253.5	445.1	547.5	611.3	670.3	744.0	797.3	719.0

Figure 6-1. BCRFC CLEVER 10-day forecast for 08JE013 – Slocan River Near Crescent Valley for May 31, 2020.



Reading at 05 AM (m^3/s) Sat 2020-05-30	Forecast Daily Discharge (m^3/s)	Sat 2020-05-30	Sun 2020-05-31	Mon 2020-06-01	Tue 2020-06-02	Wed 2020-06-03	Thu 2020-06-04	Fri 2020-06-05	Sat 2020-06-06	Sun 2020-06-07	Mon 2020-06-08
	MAX	310.0	461.3	530.3	493.2	296.0	264.8	264.8	234.5	222.3	221.9
230.3	AVERAGE	258.4	370.2	515.9	381.9	233.3	242.3	244.4	221.8	214.7	211.4
	MIN	230.4	316.1	472.4	302.2	204.9	218.5	234.4	216.1	208.3	202.1

	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	1968 Peak
Color Scheme for Return Periods:	154.0	256.5	317.7	358.3	397.2	447.6	485.3	462.0

(m^3/s)

Figure 6-2. BCRFC CLEVER 10-day forecast for 08NE078 – Salmo River Near Salmo for May 30, 2020.

6.2.1. Slocan River Observed and Forecasted Flows

Plots of the observed and the forecasted discharges for the Slocan River at the WSC gauge 08NJ013 are shown in Figure 6-3 along with the approximate return periods based on analysis of historical peak discharges. The forecasts between May 27 and June 1 predicted the peak discharge to occur between June 2 and 4 with a long recession and the peak discharges varying between the 5-year and 10-year floods (Table 6-2). The actual peak discharge on the Slocan River occurred on Sunday May 31 at 8:00 pm and the discharge of 636 m^3/s was approximately equal to the 10-year flood. The peak then proceeded to recede faster than the forecasted flows. The team continued to monitor forecasts for the Slocan River after the flood peak passed on May 31 as there was concern over the possibility of a second higher peak. Data on the current and historical snowpack within the watershed were also reviewed to determine the likelihood of this occurring.

Table 6-2. Summary of the BCRFC Clever Forecasts and observed peak discharges in the Slocan River at the gauge 08NJ013.

Forecast	Peak Discharge (m^3/s) and Return Period[1]	Time of Peak
May 27	578 (5-yr)	Thursday June 4
May 28	551 (5-yr)	Wednesday June 3
May 29	518 (5-yr)	Thursday June 4
May 30	638 (10-yr)	Wednesday June 3
May 31	576 (5-yr)	Wednesday June 3
June 1	650 (10-yr)	Tuesday June 2
June 3	457 (2-yr)	Wednesday June 3
Observed	636 (10-yr)	Sunday May 31 at 8:00pm

Note:

1. Return period based on analysis of historical discharge data collected at the 08NJ013 streamflow gauge.

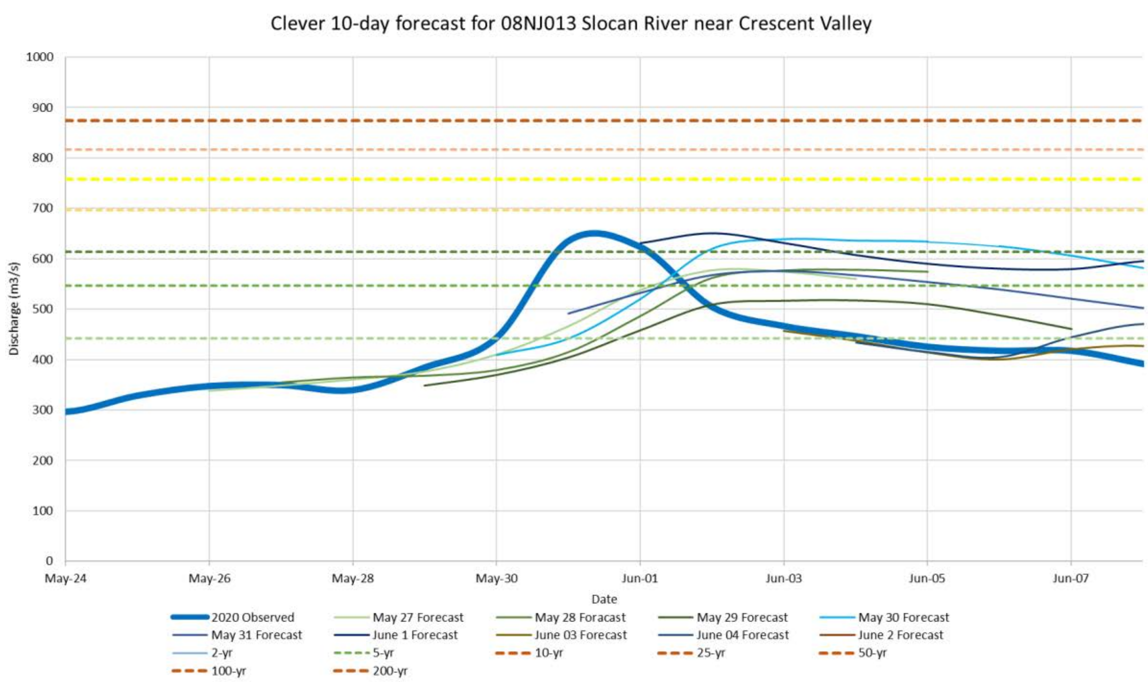


Figure 6-3. BCRFC CLEVER Forecasts for May 30 to June 3 and observed discharges for the Slocan River.

6.2.2. Salmo River Observed and Forecasted Flows

Plots of the observed and forecasted discharges for the Salmo River at the gauge 08NE074 are shown in Figure 6-4 along with the flood quantiles. The forecasts for the Salmo River predicted the flood peak to occur on Monday June 1 between 9:00 am and 4:00 pm with the peak discharges varied between the 25- and 500-year floods (Table 6-3). The observed peak discharge occurred on Sunday May 31 at 7:00 pm. The discharge of 486 m^3/s was approximately equal to the 100-year flood but receded faster than the forecasted discharges.

Table 6-3. Summary of the BCRFC CLEVER Forecasts and observed peak discharges in the Salmo River at the gauge 08NE074.

Forecast	Peak Discharge (m^3/s) and Return Period based on Historical Peak Discharges	Time of Peak
Saturday May 30	530 (> 500-yr)	Monday June 1 at 4:00 pm
Sunday May 31	392 (25-yr)	Monday June 1 at 9:00 am
Sunday May 31 (Revised)	469 (200-yr)	Monday June 1 at 1:00 pm
Observed	486 (200-yr)	Sunday May 31 at 7:00 pm

Note:

1. Return period based on analysis of historical discharge data collected at the 08NE047 streamflow gauge.

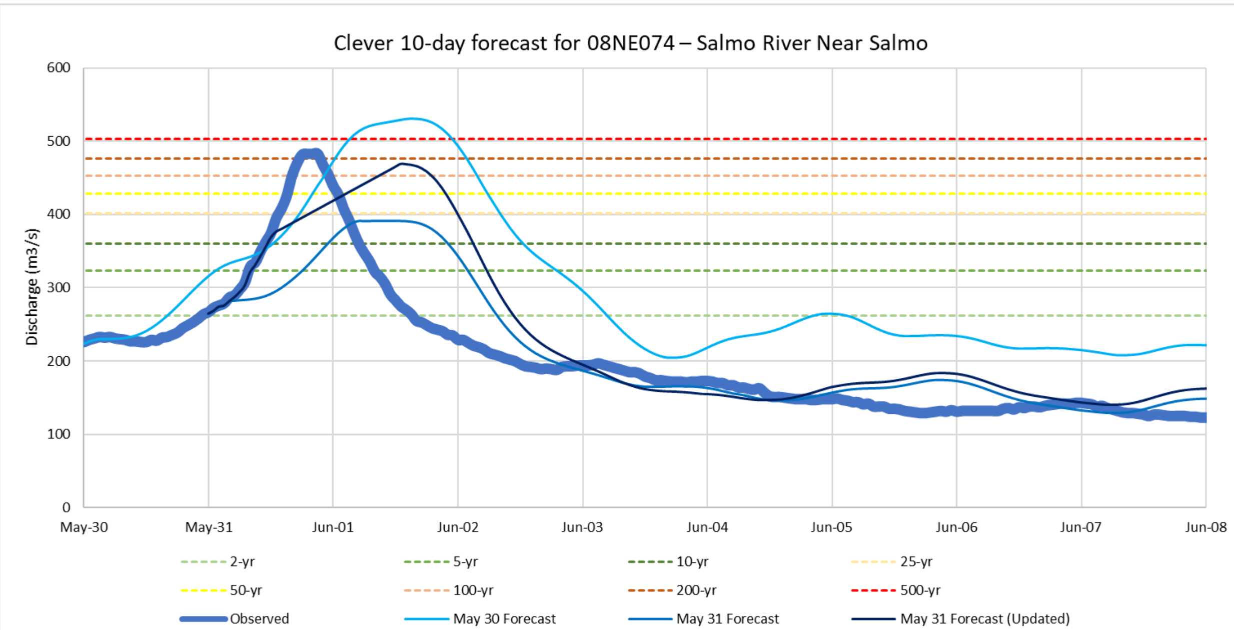


Figure 6-4. BCRFC CLEVER Forecasts for May 30 to May 31 and observed discharges for the Salmo River.

6.3. Hydraulic Modelling of Forecasted and Observed Discharges

The flooding extents, depth and velocities based on the forecasted discharges from the RFC were determined using hydraulic modeling. Through May 30-31, BGC staff provided updated versions of hazard mapping based on the latest forecasted flows and provided guidance on the use of hazard maps informing emergency response.

BGC ran the simulations based on the forecasted peak discharges from the RFC using HEC-RAS hydraulic models developed by BGC for detailed flood hazard mapping on Slocan and Salmo rivers. BGC made simplifications to the computational mesh to reduce run times and ran the models on the fastest computers available on Amazon Web Services (AWS) EC2 Cloud Compute service (z1d.12xlarge – 48 CPUs with 384 GiB memory).

6.3.1.1. Slocan River

BGC set up and began running the Slocan River model using the BCRFC May 28 forecasted peak discharge of 577 m^3/s which was estimated between a 2-year to 20-year return period flood event (Table 6-4). It was noted over the weekend that the observed peak discharge was exceeding the forecasted peak discharge. On May 30, the BGRFC forecasted a peak of 638 m^3/s for June 3. As there was no time to update the inflows to the hydraulic model and produce results within a realistic timeframe, BGC recommended RDCK reference existing flood hazard maps at the nearest comparable flood magnitude. Through June 2, BGC continued to investigate the possibility of a secondary flood, at which point further flooding was determined to be unlikely.

Table 6-4. Historical and climate change adjusted flood quantiles for the Slocan River near Crescent Valley (08NJ013).

Scenario Return Period (years)	Annual Exceedance Probability (AEP)	Historical (m^3/s)	Climate Change Adjusted (m^3/s)
2	0.5	450	540
20	0.05	685	825
50	0.02	770	920
200	0.005	885	1060
500	0.002	960	1150

Note: Flood quantiles are rounded to the nearest 5 m^3/s.

6.3.1.2. Salmo River

BGC ran the Salmo River HEC-RAS model using the RFC May 30 forecasted peak discharge of 530 m^3/s and the results were provided to RDCK on Sunday May 31. On Sunday May 31, BGC ran the model based on the RFC May 31 forecasted peak discharge of 391 m^3/s. BGC also recommended that RDCK use the climate change - adjusted 20-year flood hazard mapping (BGC March 31, 2020) which was based on a peak discharge of 480 m^3/s (Table 6-5). BGC continued to monitor observed and forecasted flows on Salmo River through June 2. However, further modelling for the Salmo River was not performed as the river peaked on Sunday evening and subsequent forecasts indicated that further flooding was unlikely.

Table 6-5. Historical and climate change adjusted flood quantiles for the Salmo River near Salmo (08NE074).

Scenario Return Period (years)	Annual Exceedance Probability	Historical (m^3/s)	Climate Change Adjusted (m^3/s)
2	0.5	260	315
20	0.05	400	480
50	0.02	440	530
200	0.005	505	605
500	0.002	545	655

Note: Flood quantiles are rounded to the nearest 5 m^3/s.

6.4. Discussion

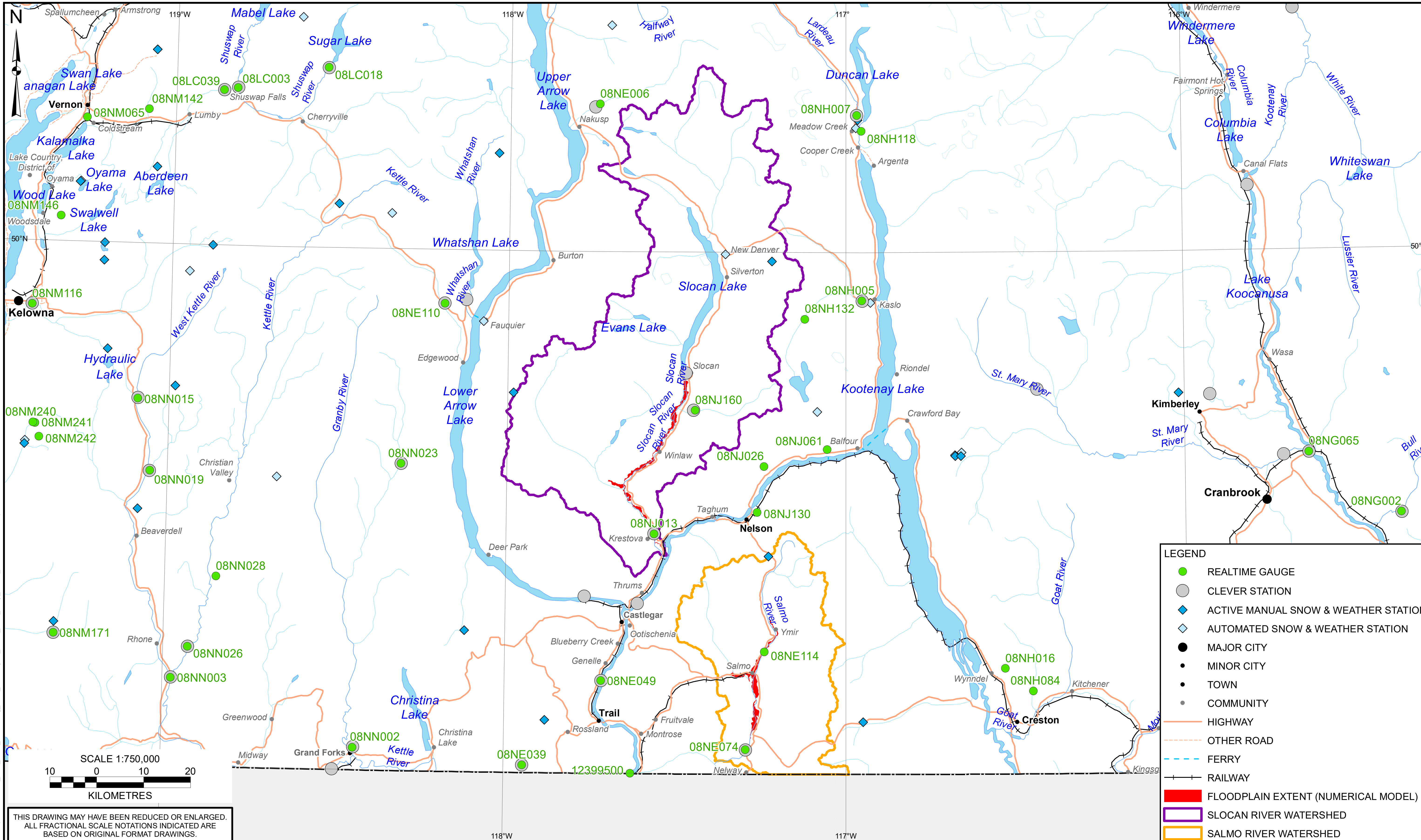
Responding to flood events in near real-time with short forecast windows is challenging due to the short timeframe to act. For this case example, the short timeframe was compounded by substantial uncertainty in the flood forecasts for both Slocan and Salmo rivers, and the challenge to complete hydraulic modelling in time to supplement forecast data in real-time emergency response. These experiences would be consistent with the application of hydraulic models during most flood emergencies. The following is feedback from the RDCK EOC Team related to flood forecasting, via discussion with EOC Director Chris Johnson:

- EOC Team based their decisions to issue evacuation alerts and ultimately orders based on discussions with, and products delivered by the RFC and supported by on-the-spot analyses provided by partner agency qualified professionals (QPs).
- Decisions were made more difficult (delay and wait for better data, or act conservatively) because the data were rapidly changing.
- EOC team felt the forecast hydrographs were questionable and needed to communicate with RFC to determine how confident the EOC team should be in the forecasts.
- EOC team additionally looked at SNOw Data Assimilation System (SNODAS) snowpack data and used judgement and local QPs to predict how an above average snowpack and above average warm weather might affect flooding over the coming days, and implications for response measures.
- EOC team capacity for GIS work was limited as the GIS staff were already committed to other aspects of emergency management.
- EOC team would like more granular flow forecasts at more locations, including smaller tributaries. The current flood forecasts provide timing for a given area on a stream, which makes determining timing outside of those areas difficult, resulting in additional difficulties in allocating equipment and staff resources.
- EOC team benefits from direct communication with the RFC and appreciates their responsiveness. Talking with the RFC helps staff get a better feeling for how confident the RFC is in their forecasts.
- Flood forecasts are of no help for steep creeks prone to debris floods or debris flows, where the EOC team was “flying blind” in this and any other comparable emergency.

- To effectively receive technical information in a small local government EOC it is critical to have access to QPs that are willing to provide on-the-spot interpretation of the information to turn it into actionable intelligence.

BGC also comments from the perspective of a QP relying on flood forecast data to support local government in an emergency response effort.

- Flood forecasts indicate potential flooding but cannot provide any information on where the water is likely to go (extent) or its characteristics (depth, velocity). They also provide no information on the location or extent of secondary geomorphic hazards such as bank erosion or landslide dams. Bank erosion is often the dominant damage mechanism for elements at risk near steep banks in non-cohesive sediments, and can exceed several tens of metres in extreme cases.
- Understanding flood characteristics is essential for EOC Directors to issue informed evacuation orders. Ideally, hydraulic models can be deployed where available to turn flood forecasts into predicted hazard extents and characteristics for emergency response decisions. While ‘on the fly’ hydraulic modelling can be developed during an emergency, it is much more efficient if these are already in place. All the emergency hydraulic modelling that supported the May 30-31 emergency response was made possible because detailed hydraulic models were already developed.
- EOC teams require geomatics specialists with sufficient capacity to quickly incorporate geospatial data provided by QPs or the Province during an emergency and develop derivative products for decisions (e.g., to query flood extents to develop contact lists for evacuation orders).
- In the absence of re-running hydraulic models for forecasted flows, forecast discharges can be compared to the nearest comparable scenario on existing flood hazard maps. If this is done, flood hazard characteristics (e.g., discharge) should be used, rather than the return period or Annual Exceedance Probability (AEP) specified for the flood hazard map, which may have been adjusted for climate change.
- To support decisions resulting from flood forecasting and emergency hydraulic modelling, “Quick Action Tables” would be helpful to develop in advance that tie anticipated scenarios to emergency response decisions and protocols.
- Forecasts at additional locations along the Slocan and Salmo rivers would have improved hydraulic modelling of forecasted flows and contributed to more informed decision making by the EOC. For example, it would have reduced the EOC response effort on the Slocan River by reducing the size of area evacuated and support measures put in place.
- Hydraulic modeling involves selecting model parameters to optimize model resolution, accuracy, and run time. Different parameters may apply for modelling under an emergency response than would be selected for planning scenarios (e.g., to prioritize speed over level-of-detail, or prepare results important in an emergency, such as arrival times). These details need to be considered to ensure that hazard modelling results are used as intended. As a specific recommendation, hydraulic models should be able to run efficiently to perform unsteady flood simulations, which can produce information regarding flood arrival times and more accurate flood mapping during emergencies.



NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "FLOOD FORECASTING SERVICES", AND DATED APRIL 2021.
3. BASE TOPOGRAPHIC DATA BASED ON CANADA NSF PROVIDED BY NRCAN, DATED 2006.
4. COORDINATE SYSTEM IS NAD 1983 BC ENVIRONMENT ALBERS. VERTICAL DATUM IS UNKNOWN.
5. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

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APPROVED:	KH

CLIENT:
FRASER BASIN COUNCIL

BGC

PROJECT:
FLOOD FORECASTING SERVICES

TITLE:
RDCK CASE STUDY – SLOCAN AND SALMO RIVERS

PROJECT No.:	DWG No:
0511008	04

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7.0 CLASS "D" ESTIMATES FOR INVESTIGATIONS WITH POTENTIAL COSTS

The following sections provide high-level costs estimates to implement additional monitoring tools such as installing a hydrometric station for flow monitoring, launching a debris-flow warning system or implementing a flood forecasting system. The cost estimation focuses on the potential implementation of an industry standard software for operational flow forecasting called Delft-FEWS, with a focus on a pilot study to link the CLEVER model with the Delft-FEWS platform. BGC collaborated with Deltares, an international applied water resources research institute based in the Netherlands, to provide the estimated costs included in this section.

The preliminary cost estimates presented in this report will be compiled, reviewed, and potentially refined together with those from the other projects in this initiative as part of Issue D-1: Resources and Funding. For more information, refer to the D-1 report.

7.1. Hydrometric Gauge Data

As indicated in Section 4.0, a key data product for end users is hydrometric gauge data provided by WSC or maintained by a local authority. A challenge with these data is the lack of coverage across the Province, especially on watercourses in smaller watersheds (e.g., less than 30 km^2). These data limitations impact the ability of emergency responders to make local predictions and inform actions during flood emergencies. A potential option to improve the coverage of local hydrometric data may be installing a gauge station on key watercourses or engaging WSC to convert a seasonal gauge to a year-round monitoring gauge. In BGC's experience, a hydrometric gauge station costs approximately $30,000 to install and $20,000 per year to maintain, depending on the quality of data required.

7.2. Debris-flow Warning System

Hydroclimatic-based, debris-flow warning systems have been developed for select creeks or areas within BC for different clients and should be reviewed for provincial scale application. They require recalibration for different regions. A service that BGC implemented for a debris-flow creek in southern BC used forecasted and hindcast rainfall at 1-hour, 6-hour and 24-hour durations linked to an evacuation criterion to provide notifications. In BGC's experience, the setup cost for a debris-flow system that uses publicly available weather data and provides automated email notifications can range from <$50,000 to >$100,000 depending on the location, previous work, and the elements at risk (e.g. a road compared to populated area).

7.3. Delft-FEWS Platform

The development of flood forecasting and early warning systems is an essential element in national and regional strategies for flood hazard reduction and risk mitigation. The challenges in flood forecasting are both technical and institutional. Institutional challenges related to a consistent national approach are rooted in the Canadian constitution, which stipulates that oversight of flooding is the responsibility of provincial governments, who may in turn stipulate that

local governments take responsibility for flood management, who may then rely on QPs to undertake and take responsibility for the work.
The technical challenge is the translation of available data with national coverage to actionable information in the local context, generally through the use of local modelling and methods. Operational flood forecasters generally have a challenging mandate for acquisition and processing of data, running a potential cascade of models and generating the output for decision making. The adoption of new tools by forecasters is limited by constant work effort of an operational system, staff capacity and costs.

A possible solution to these technical challenges would involve the implementation of industry standard software for operational flow forecasting, Delft-FEWS. Delft-FEWS is an open data-handling platform primarily used in many flood forecasting and warning systems, and water management efforts. It offers a streamlined way to obtain, model, visualize, and communicate information relating to real-time hazards such as floods. Each implementation of the FEWS platform is custom designed for the user via the inclusion of pre-existing or custom-made plugins and adapters for a wide array of data feeds and model types.

Globally, the Delft-FEWS platform has become an industry standard software for operational flow forecasting. Currently, the provincial governments of Alberta, Saskatchewan, Manitoba, Quebec, and New Brunswick use, or are developing Delft-FEWS to support their 24/7 operational flood warning services. A pre-operational pilot system using the same software is currently under development in the Northwest Territories. Additionally, the software is in use by reservoir operators (BC Hydro, Manitoba Hydro, Ontario Power Generation) across Canada to host their operational hydrological forecasting services. Municipal users of Delft-FEWS in Canada include the City of Calgary and the Toronto and Region Conservation Authority.

FEWS systems are typically implemented as pilots before a full-scale deployment is launched. The first step involved in establishing a successful pilot system is defining what the specifications of the system are. This depends on the scale of the system, the objectives of the system, and the breadth of the envisioned user base. These specifications are extremely important but are not defined for the scope of this project. As a result, assumptions about these specifications must be made to arrive at a cost estimate.

The assumptions made for the class D estimate of a FEWS system are as follows:

1. The FEWS model will encapsulate an existing data product or model and there will be no new product created to serve the FEWS platform.
2. The scale of the system should be as large as possible as to serve the largest population possible within BC.
3. The cost estimate includes setup and implementation costs of the software and assumes the internal costs for ongoing operations and maintenance of the software will be borne by a single lead organization such as the Province (e.g., staff and administrative salaries and resources, facility, and hardware).

With these three assumptions under consideration, there are two options foreseen for a pilot FEWS system. The first is a FEWS system that runs the CLEVER model operationally. The second is a FEWS system that runs either the Fraser River MIKE 11 or MIKE 21 model operationally. A pros and cons list for each of these options is shown in Table 7-1. As CLEVER is a hydrologic model and Mike 21 is a hydraulic model, BGC notes their implementation would have different outcomes (Table 7-1 and the discussion in this section are not intended to compare the functions of CLEVER and MIKE 21). Moreover, the MIKE 21 model is used as an example but the cost estimate could apply to other hydraulic models such as HEC-RAS 2D.

Table 7-1. A comparison of the pros and cons of implementing the MIKE 21 model versus the CLEVER model in a FEWS system.

MIKE 21		CLEVER	
Pro	**Con**	**Pro**	**Con**
The model covers an important corridor of the province.	MIKE 21 has a licensing fee.	The input data is somewhat well formatted and there are clear paths for what data ingestion to add.	An operational system is essentially already in place.
Output is available along the entire model domain.	The model only covers a small region of the province.	The CLEVER model has wide geographic coverage.	Output is only available as point locations.
The model can be coupled to storm surge model.	There is a higher barrier to scaling the system with model growth	Low barrier to scaling with model growth.	There is a higher expected cost of FEWS implementation due to more complicated inputs.
The cost of FEWS implementation is lower due to fewer and simpler inputs.		The model been used operationally and has recognition among end-users.	Will not offer new information if simply turned into a FEWS system.
Implementation will offer new information about coincident effect of storm surge and river flow.		The model provides flows, which could be coupled to smaller hydraulic models upon future scaleup of FEWS system.	The model is not built using a standard framework, and so custom adapters would have to be built.
MIKE 21 FEWS adapters already exist.			

With consideration of the pros and cons listed in Table 7-1, BGC's cost estimate assumes implementation of a FEWS system using the CLEVER model. The main factors for this selection are that this model is already supported by the government for operational use and there is strong scale-up potential for the inclusion of additional models coupled to the output of the CLEVER model. Note that at the pilot stage the difference in price between both options is minimal but this difference will grow upon full implementation.

The second step in defining a pilot FEWS system would be identifying the data sources that should be ingested and the models that should be run. BGC understands that the CLEVER model is currently managed by code contained within Microsoft Excel Macros, and the pilot project would need to evaluate what additional software development may be required to connect FEWS to CLEVER. The CLEVER model should be able to be initiated by Delft FEWS, for example by calling the macros from the command line. This has been achieved numerous times in past projects. If not immediately possible for the CLEVER model, a little bit of work is needed to expose the Macros. This is a very standard part of projects and is an important collaborative step to facilitate integration of models in FEWS via adapters[9].

Improving the efficiency of the workflow required to run the CLEVER model is an objective that was expressed by the FBC and a transformation of CLEVER to a FEWS system would serve this objective. It is possible to make a FEWS system that simply reads in output from the CLEVER model and displays it. However, this is not the recommended approach and does not fully utilize the capabilities of FEWS. Additionally, the CLEVER model is not currently configured to provide data to a FEWS system even exclusively for visualization purposes.

The third step would be to develop an initial pilot system with the following functionality:

1. Collecting data that is needed to run the CLEVER model, such as precipitation data.
2. Processing this data to format it for use by the CLEVER model.
3. Allow user interaction with the CLEVER model parameters via the FEWS interface. Calibration could also be run.
4. Running the CLEVER model based on calibrated parameters.
5. Visualizing the output of the CLEVER model.

An example of what the data flow for the pilot FEWS system encapsulating the CLEVER model would look like is shown in Figure 7-1.

9 https://publicwiki.deltares.nl/display/FEWSDOC/15+Connect+external+modules+with+a+model+adapter

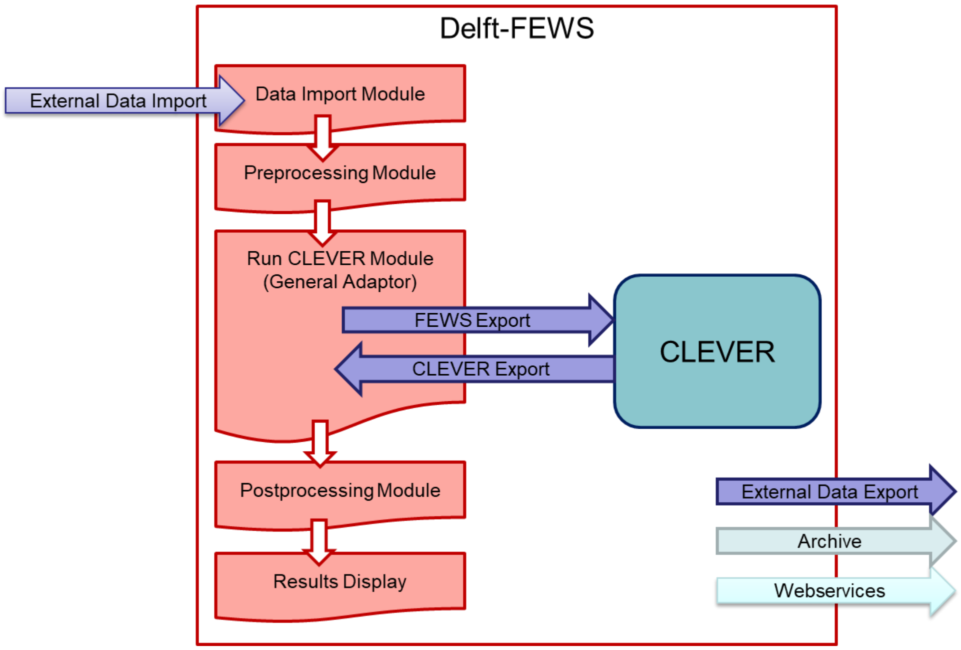

Figure 7-1. A schematic showing the data pipeline for a FEWS pilot study built on the CLEVER model.

A discussion with Dave Casson from Deltares produced a class D cost estimate for such a system of $60,000. This would include the following components:

- Development of a pilot scale system for at least one basin with multiple gauges in the CLEVER model.
- Development of the automated import and export routines for all inputs and outputs required for a CLEVER model run.
- Development of customized graphical user interface.
- Implementation of FEWS modifiers to actuate model settings from within FEWS.
- Implementation of a model verification and data archiving system.
- Delivery of training for the system and interaction with Deltares.

Note that FEWS has no licensing cost. FEWS configurations are free and open source. The FEWS source code is free but not open source. The fourth step would be to develop the full FEWS system. What this system looks like is unknown at this time as it will be informed by the decisions that arise after this report is published. However, BGC can provide an estimate based on a hypothetical system. One possible system configuration involves using the CLEVER model as the foundational framework on top of which numerical models are coupled and run. The two models most readily available for inclusion in the full system are the BC Storm Surge model and the Fraser River MIKE 21[10] model. The full system could integrate the flows of the CLEVER model

[10] It is proposed that the MIKE 21 model be incorporated in the FEWS system since it provides greater spatial detail as compared to MIKE 11. However, if run times are prohibitive for use in an operational forecasting system and the system owner does not want to invest in computing resources required to parallelize model runs, MIKE 11 should be used instead. The choice does not affect the class D estimate.

with the hydraulics of the MIKE 21 model, which would also receive forecasted downstream boundary conditions from the BC Storm Surge Model. Both the BC Storm Surge Model and the MIKE 21 model would provide water level output across their modelled domains. The role of FEWS in this forecasting system is demonstrated in Figure 7-2. In the proposed system, the model in the BC SSFS, the MIKE 21 model, and the CLEVER model are all represented by the "external model" unit, whereas all other functions are provided by the FEWS system.

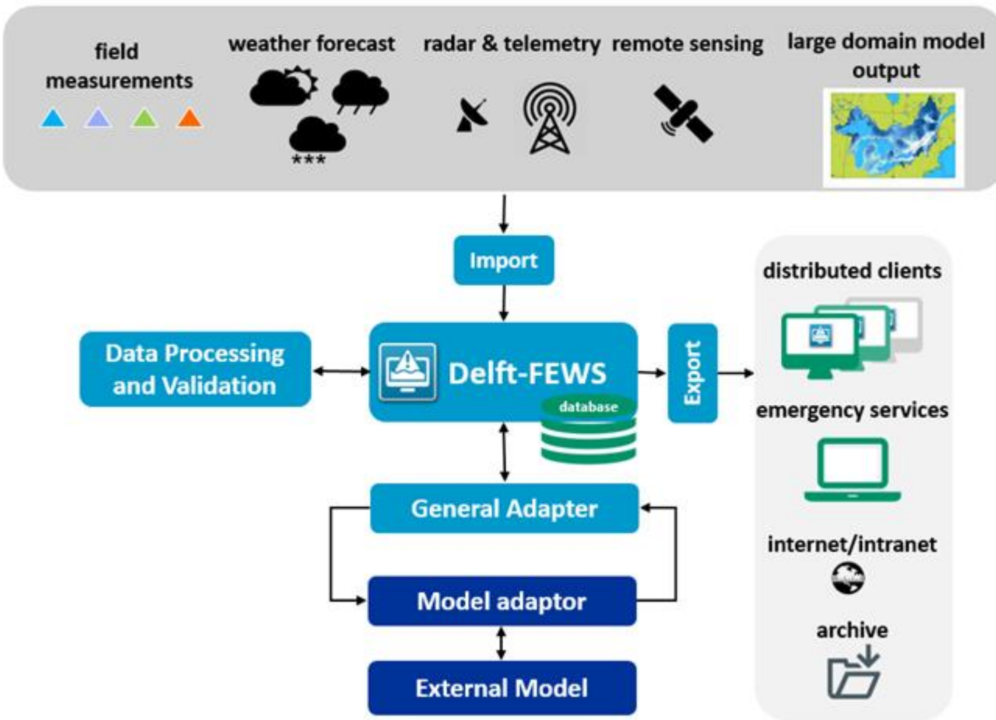

Figure 7-2. A schematic demonstrating the relationships between data, models, and the FEWS system in typical situations.

A discussion with Dave Casson about the costs associated with a system of this scale resulted in a class D cost estimate of $400,000. The main tasks for the implementation of this system would be as follows:

- Implementation phase
    - Expand system geographic coverage of the FEWS implementation of the CLEVER model.
    - Integrate more data feeds within the data management system.
    - Expand the system to integrate the models not integrated thus far (i.e. the model in the SSFS and the MIKE 21 model).
    - Upgraded user interface.
    - Trainings on the configuration of the system.
- Commissioning phase
    - Commission the system and conduct testing
- Operational monitoring phase

- Monitor the system to ensure desired performance.
- Implement an improved archiving and a verification system.

This class D estimate includes a training component and one year of technical support that can be extended at additional cost. In practice, operational users tend to purchase a support and maintenance contract which provides system support and software upgrades.

Following development of a FEWS system, additional numerical models could potentially be integrated within a consistent framework, with additional effort. One example of this would be the HEC-RAS models developed for the RDCK, which could be coupled to the CLEVER output within the FEWS system and run operationally. Section **Error! Reference source not found.** notes challenges that may exist with the addition of other numerical models given the current division of government responsibilities for flood management and identifies possible alternatives.

8.0 SUMMARY

BGC completed a gap analysis and user assessment related to the provision of riverine and coastal flood forecasting services by the Province of British Columbia. The purpose of the project was to identify geographical areas, approaches, and opportunities to strengthen flood forecasting services in BC. Flood forecasting services must be relevant across a broad range of geographic scales and levels of detail, from provincial scale emergency management to operations centers for individual communities. In particular, flood forecasting must be relevant to the determination of flood hazard, including the extent, intensity (velocity and depth), and timing.

BGC's investigation included a literature and spatial data review, stakeholder consultation via online survey and interviews, review of costs for monitoring tools such as installing a hydrometric station for flow monitoring, launching a debris-flow warning system or implementing a flood forecasting system such as a Delft- Flood Early Warning System (FEWS) system, and a case example where flood forecasts were relied upon in an emergency. In total, BGC obtained written survey input from 28 individuals and completed eight, one-hour interviews. Those consulted included a broad array of subject matter experts from private industry, municipal emergency response leaders, and governmental employees.

BGC examined a May 2020 case study at Slocan and Salmo River in the Regional District of Central Kootenay (RDCK), where the RDCK evacuated about 1,000 homes during their largest ever emergency response effort. The case example includes flood forecasts with contrasting levels of success on two rivers, and describes lessons learned as a local government, the Province, and Qualified Professionals (QPs) worked together to use flood forecast data for emergency response decisions.

BGC estimated a cost of $60,000 to develop a pilot project for the execution of the CLEVER model within Delft-FEWS. Development of a full FEWS system could use the CLEVER model as the foundational framework to which additional numerical models are coupled and run, such as the BC Storm Surge model and the Fraser River MIKE 21 model. A perceived benefit of this type of system is that as additional local models are developed across the province, they could be integrated in the FEWS system and connected to the CLEVER model forecasts within a consistent framework. One example of this would be the HEC-RAS models developed for the RDCK, which could be coupled to the CLEVER output within the FEWS system and run operationally. It should be noted that BC Hydro currently operates an advanced full-scale FEWS system for operational forecasting and has cultivated substantial in-house knowledge on the implementation of these systems.

9.0 CONCLUSIONS

Table 5-1 listed the main findings of this investigation based on user inputs. BGC provides the following broad conclusions:

- Emergency managers and operations and maintenance staff at diking districts and local governments, make qualitative “flood forecasts” based on experience. For example, staff may have an intuitive grasp of flood timing on the larger river systems based on gauges upstream, and of connections between snowpack observations and stream flows during spring freshet. While judgement will always form an important component of uncertain decision making, such approaches are vulnerable to the loss of institutional knowledge when staff retire, and to errors when flood scenarios occur that are outside the historical record. Objectives to address these issues should include protocols for flood forecasting that capture experiential knowledge before it is lost, and communication tools that illustrate how extreme events will extend beyond the experience of even the most seasoned practitioners and require scientifically rigorous methods to estimate.
- While the focus of the current investigation is on flood forecasting, many of the decisions made during an emergency are based on flood monitoring (e.g., gauging stations and field observation). BGC’s questions to users about forecasts often led to responses about real time monitoring. Quantitative systems exist in British Columbia for hydrotechnical hazard management on pipelines, for example, where flow monitoring is tied to Trigger Action Response Plan (TARP) protocols, including automated flood alerts. Developing TARP requires sufficient hazard analysis to develop protocols in advance of an emergency. Once in place, it may fulfill the practical needs of emergency managers responsible for locations where flood forecasting is difficult, such as small watersheds with rapid hydrograph responses to precipitation and snowmelt.
- Provincial flood forecasting services are not applicable to steep creeks and cannot provide meaningful guidance for the management of debris flow or debris flood/flash flood emergencies. While outside the scope of this investigation, hydroclimatic-based, debris flow warning systems have been developed within British Columbia and should be reviewed for provincial scale application. In BGC’s experience, the setup cost for a debris-flow system that uses publicly available weather data and provides automated email notifications can range from <$50,000 to >$100,000 depending on the location, previous work, and the elements at risk (e.g. a road compared to populated area).
- Authorities responsible for emergency management at both rivers and coastlines require not only flood forecasts but also indication of flood hazard extent, intensity, and timing. Understanding flood characteristics is essential for EOC Directors to issue informed evacuation orders and area closures. Ideally, hydraulic models can be deployed where available to turn flood forecasts into predicted hazard extents and characteristics for emergency response decisions.
- BGC notes the following factors that would need to be addressed as part of the incorporation of hydraulic flood models into a FEWS system potentially managed by the Province of BC:
    - Flood management, including the preparation of detailed floodplain maps (and associated hydraulic models), is currently the responsibility of local government.
    - Many separately developed hydraulic models exist for BC rivers, for example as developed by QPs in the private sector to prepare flood hazard maps.

    - Flood modelling results based on flood forecasts are currently the responsibility of Qualified Professionals undertaking the work.
- Through the public sector organization BC Hydro and Power Authority, the Province of BC has already invested in the development and ongoing operation of a FEWS system in BC, albeit one that does not provide public-facing services. It has been the experience of BC Hydro that the successful implementation of FEWS systems requires the cultivation of in-house expertise to complete maintenance and upgrades. These types of systems require cooperation between IT teams and scientific teams, and it is imperative that the institution that hosts these systems provisions for the development of in-house technical knowledge of FEWS development. Close collaboration with Deltares early in the system development would be helpful.

Within the existing division of local and Provincial government responsibilities for flood management, a network of flood models could potentially be connected to the CLEVER model forecasts via data services. The maintenance of the models themselves would remain the responsibility of local government, most likely via contracting of QPs. Copies of these models would be housed in the provincially operated FEWS system and model forecast results could be managed and disseminated within this system. Additional work is required beyond the scope of this investigation to determine what this would look like in practice. The cost to develop this approach would depend on the number and complexity of models included.

10.0 RECOMMENDATIONS

BGC provides the following recommendations, which will require prioritization by the Province:

- Hydrometric gauge data is considered a critical component of a majority of the user's flood management planning efforts. Building on the user feedback in this report, improve flow and snow gauge coverage in small watersheds. In BGC's experience, a hydrometric gauge station costs approximately $30,000 to install and $20,000 per year to maintain, depending on requirements (depending on requirements, real time stage recorders may be installed at lower cost). Key areas needing improvements in flow and snow gauge coverage include but are not limited to the following:
    - Cache Creek.
    - Bonaparte River.
    - BX Creek.
    - Kicking Horse Watershed.
    - Borland Creek.
    - San Jose River.
    - Boundary Watershed.
- Provide provincial resources to the RFC for areas such as the following:
    - IT resources for upcoming improvements to infrastructure.
    - Staff resources for data interpretation supporting EOC staff during flood events.
    - Implementation of ensemble modelling to improve the types of uncertainty that can be considered in BCRFC forecasts via the CLEVER model.
    - Incorporation of weather inputs including gridded snow data and ensemble forecasts.
    - Implementation of a FEWS system to operationally couple flood forecasts to hydraulic models, including a 2D Fraser River model in the FEWS system. The downstream open water boundary should be coupled operationally to the output of the BC Storm Surge Model.
- Develop a plan to use hydraulic models and expert knowledge developed for floodplain mapping, in association with flood forecast data, to aid emergency response.
- Provide resources to EOC during flood emergencies that include the following:
    - Geomatics (GIS) staff person to assist in the incorporation and use of data products.
    - QPs to assist in the analysis and application of flood forecast data.
- Utilize the substantial FEWS experience that has been developed within BC Hydro to ensure success with the deployment of future provincial FEWS systems. Where possible, explore opportunities to leverage the existing FEWS system operated by BC Hydro for broader information sharing.
- Provide training courses to local government users in the interpretation of flood forecast data.
- Provide long-term funding and resources to maintain and upgrade the BC Storm Surge Model system, for areas such as the following:

- Improve resolution and output provided along the entire model domain.
- Incorporation of modern gridded forecast products and a review of data assimilation techniques.

- Following development of a FEWS system for the Fraser River, consider integrating additional riverine hydraulic flood models. One example of this would be the HEC-RAS models developed for the RDCK, which could be coupled to the CLEVER output within the FEWS system and run operationally.

11.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

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per:

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APPENDIX A
PROJECT TEAM MEMBERS

Team Member	Designations	Title	Project Role
Kris Holm	M.Sc., P.Geo.	Principal Geoscientist	Project manager
Matthias Jakob	Ph.D., P.Geo.	Principal Geoscientist	Project review
Rob Millar	Ph.D., P.Eng., P.Geo.	Principal Hydrotechnical Engineer	Project review
Elisa Scordo	M.Sc., P.Geo., P.Ag.	Senior Hydrologist	Project lead
Rudy Schueder	M.A.Sc., EIT	Data Scientist, Engineer	Technical support
Matthew Buchanan	B.Sc., GISP	GIS Analyst	Geomatics support
Lynn Forrest	-	Library Researcher	Research support

APPENDIX B
COMPLETE LIST OF INVESTIGATIONS

Investigations in Support of Flood Strategy Development in BC

List of All Investigations

Theme A. Governance

Issue	Investigation
A-1 Flood Risk Governance	1. Identify the flood management services provided by each order of government in BC.
	2. Investigate the roles of non-government entities in flood management in BC.
	3. Identify challenges, gaps and limitations with current service delivery.
	4. Identify opportunities for improving collaboration and coordination within and across authorities and adjusting non-government entities' roles that would address challenges and improve efficiency and effectiveness.
	5. Recommend changes to support improved collaboration and coordination in flood management, including an analysis of benefits and costs/limitations for each recommendation.
	6. Investigate alternative options for distributing and integrating flood management responsibilities among authorities, including an analysis of benefits and costs/limitations for each option.

Theme B. Flood Hazard and Risk Management

Issue	Investigation
B-1 Impacts of Climate Change	1. Investigate the state of climate change science in relation to BC flood hazards and identify gaps and limitations in provincial legislation, plans, guidelines and guidebooks related to flood hazard management in a changing climate.
	2. Identify current sources of information and models used by experts in the province to predict future climate impacts and investigate opportunities for improved predictive modeling.
	3. Investigate the capacity of responsible authorities and other professionals and practitioners in the province to integrate climate change impacts and scenarios to inform flood planning and management.
	4. Investigate the legislative, policy, and regulatory tools available to responsible authorities in all levels of government for integrating climate change impacts in flood planning and management.

Issue	Investigation
B-2 Flood Hazard Information	1. Investigate the current state of flood mapping in the province, including gaps and limitations. Recommend an approach to improve the spatial coverage, quality, utility and accessibility of flood hazard maps and other flood hazard information.
	2. Investigate the approximate level of effort to prepare flood hazard mapping to address current gaps for existing communities and future areas of development (including floodplain maps and channel migration assessments).
	3. Investigate the current state of knowledge related to dike deficiencies and recommend an approach to improve the quality, consistency, review, utility and accessibility of this information.
	4. Investigate the status of LiDAR standards for flood mapping and develop recommendations to improve standards if applicable.
B-3 Flood Risk Assessment	1. Evaluate and compare the benefits and costs/limitations of taking a risk-based approach to flood management versus a standards-based approach.
	2. Investigate the effort required to develop and maintain a province-wide asset inventory and/or exposure dataset covering flood prone areas.
	3. Investigate approaches to completing a province-wide flood risk assessment, addressing effort required, level of detail, types of flood risk, current and future scenarios, scale, and any information required and data gaps.
	4. Investigate the level of effort to develop a coarse local-scale flood risk map based on available flood hazard map(s).
	5. Determine the effort required to undertake a local-scale comprehensive flood risk assessment for multiple types of flood hazards (e.g. riverine, coastal).and for varying degrees of available data on flood hazard, exposure, vulnerability and risk.
	6. Investigate methods for valuing the benefits and costs/limitations of flood risk reduction actions in a holistic and consistent manner and develop a framework for project prioritization that could be applied or adapted across the province to reduce flood risk.
B-4 Flood Planning	1. Investigate the ability of responsible authorities in the province to develop adaptation plans and strategies for flood management.
	2. Investigate opportunities to improve the knowledge and capacity of local authorities with regard to climate change adaptation and the benefits of proactive flood risk reduction.
	3. Investigate the potential content of a provincial guideline to support the development of local Integrated Flood Management Plans.
	4. Investigate the level of effort for a local authority to complete an Integrated Flood Management Plan and the possible role of the province in reviewing and/or approving these plans.

Issue	Investigation
B-5 Structural Flood Management Approaches	1. Investigate opportunities to incentivize or require diking authorities to maintain flood protection infrastructure and plan for future conditions such as changing flood hazards.
	2. Investigate opportunities to improve the knowledge and capacity of local diking authorities with regard to dike maintenance.
	3. Investigate opportunities to improve coordination amongst diking authorities under non-emergency conditions.
	4. Investigate impediments to and opportunities for implementing innovative structural flood risk reduction measures, including the role of incentives and regulation.
B-6 Non-Structural Flood Management Approaches	1. Investigate past and current approaches to land use and development decisions in floodplains by local and provincial authorities.
	2. Investigate alternatives to the current approach to managing development in floodplains, including returning regulatory authority for development approvals in municipal floodplains to the Province, and provide an analysis of the benefits and costs/limitations of both local and provincial authority.
	3. Investigate impediments to and opportunities for implementing available non-structural flood risk reduction actions, including the role of incentives and regulation.
	4. Investigate the nature of an educational campaign for regional, local and First Nations governments to raise awareness of flood risk and possible risk reduction options.

Theme C. Flood Forecasting, Emergency Response and Recovery

Issue	Investigation
C-1 Flood Forecasting Services	1. Investigate current capacity, coverage, value, and gaps in flood forecasting services.
	2. Visualize where flood forecasting gaps exist and estimate costs for improvement to end users.
C-2 Emergency Response	1. Investigate the future direction of the Federal government related to a National Flood Risk Strategy and the future of Disaster Financial Assistance Arrangements
	2. Investigate the Province’s expanding role in providing flood response to First Nations.
	3. Investigate the status of local authority flood response plans and recommend an approach to manage, update and improve this information.

Issue	Investigation
	4. Investigate flood response capabilities considering different flood hazards and different regions of the province.
	5. Investigate opportunities for improved organizational planning for emergency response in all levels of government.
C-3 Flood Recovery	1. Investigate the current status of coverage of existing overland flood insurance available to home-owners.
	2. Investigate the concept of "build back better" and impediments to implementation.

Theme D. Resources and Funding

Issue	Investigation
D-1 Resources and Funding	1. Investigate resource and funding needs associated with implementing recommendations to strengthen flood management in BC.
	2. Investigate evidence in support of investment in proactive flood planning and mitigation activities.