British Columbia Extreme Flood Project

MetPortal User's Guide – Probable Maximum Precipitation and Regional Precipitation-Frequency Analysis

PREFACE AND ACKNOWLEDGEMENTS

The British Columbia Extreme Flood Project was initiated by the Water Management Branch (WMB), Dam Safety Section, of the British Columbia Ministry of Forests, Lands, Natural Resource Operations & Rural Development (FLNRORD), the regulator of BC water dams. A large challenge hydrologists face when estimating the magnitude of extreme flood events is access to sufficient data and guidance on what regional data can be utilized in the catchment area of interest. Estimation of the magnitude of an extreme flood is a substantial task with multiple approaches available. When the design is for an engineered structure, a Professional Registrant of Engineers and Geoscientists BC requires specialized education and work experience. Standardization of relevant information is useful to a Professional Registrant as it reduces the level of effort, allows for a wider area of data to be considered in the analysis, provides a standardized approach for comparison with other studies, and provides an initial estimate to verify more detailed project-specific analyses.

It is recognized that there is considerable uncertainty with estimating the magnitude of floods and that decisions must be made involving considerable infrastructure dollars and public safety risk. The goals of the project were to supplement observed hydrology and hydrometeorological data in BC and improve the quality and confidence in baseline data pertaining to the magnitude and uncertainty of extreme flood events to support the design of hydrotechnical structures, such as: dams, spillways, dikes and river crossings (bridges and culverts). The guidance provided in the project documents is mostly limited to the use of the products developed as part of the current study.

The project is being released as a series of 5 technical bulletins, data portals, and GIS information. The bulletins and associated products have been developed and quality controlled by the consulting firms in consultation with the project technical advisors, who also proved technical support and review. The bulletins have not undergone detailed external review to date and do not provide all information or guidance necessary to complete a hydrotechnical study. It is anticipated these bulletins will be utilized by Professional Registrants who design dams and by qualified hydrologists tasked with calculating the magnitude of floods in BC. The uncertainties of climate cycles and climate change, the occurrence of future low probability events, and changes in land cover characteristics requires that the study be periodically updated, and that the Professional Registrant exercise judgement based on the information available for the specific analysis being completed.

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Putting Weather into Perspective®

PROBABLE MAXIMUM PRECIPITATION AND REGIONAL PRECIPITAITON-FREQUENCY ANALYSIS FOR BRITISH COLUMBIA

BULLETIN 2020-5-PMP/RPFA

METPORTAL USER'S GUIDE

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ABBREVIATIONS AND ACRONYMS

AEP	Annual Exceedance Probability
AMS	Annual Maximum Series
ARI	Average Recurrence Interval
CDA	Canadian Dam Association
CDF	Cumulative Distribution Function
DAD	Dept-Area-Duration
DDST	Database of Daily Storm Types
DSS	Dam Safety Section
ESTP	Enhanced Storm Transposition Procedure
EIRL	Equivalent Independent Record Length
FLNRORD	Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
GEV	Generalized Extreme Value
GIS	Geographic Information System
HMR	Hydrometeorological Report
ICOLD	International Commission on Large Dams
IDF	Inflow Design Flood
IPMF	In-Place Maximization Factor
km	kilometer(s)
MLC	Mid-Latitude Cyclone
PF	Precipitation-Frequency
PMF	Probable Maximum Flood
PMP	Probable Maximum Precipitation
PMS	Probable Maximum Storm
RPFA	Regional Precipitation-Frequency Analysis
SWT	Schaefer-Wallis-Taylor

U.S.	United States
User's Guide	Reference to this document
WMO	World Meteorological Organization

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1. INTRODUCTION

This MetPortal User's Guide – Probable Maximum Precipitation and Regional Precipitation-Frequency Analysis document (hereafter, User's Guide) and the accompanying web-interface, MetPortal®, provide:

- Probable Maximum Precipitation (PMP) estimates for synoptic-scale storms at the 24-, 48-, 72-, and 96-hour durations at key watershed area sizes ranging from 10- to 10,000-km^2 for a series of transposition points across British Columbia;

- Probable Maximum Storms (PMSs), the storm spatial and temporal patterns that produced the PMP at a key watershed area size and duration of interest at each of the transposition points to convert the PMP estimates into input for a hydrologic model;

- Point precipitation-frequency estimates for the 24-, 48-, 72-, and 96-hour durations at annual exceedance probabilities (AEPs) ranging from 1:2 to 1:1,000,000 (average recurrence intervals from 2-year to one million-years) with uncertainty bounds across British Columbia; and

- Scalable temporal storm patterns to translate a point precipitation magnitude at a duration of interest and AEP into input for flood modeling.

Guidance for the interpretation and usage of these products are provided in this User's Guide. For the full account of the technical analysis that produced the data, please refer to Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

1.1. Authorization

This project, the contents herein, and the products provided by MetPortal® were funded by the Public Service Canada National Disaster Mitigation Program and Emergency Management British Columbia. The British Columbia Ministry of Forests, Lands, Natural Resource Operations and Rural Development (FLNRORD) provided in-kind funding to manage the project. All procedures, methodologies, and results were approved by a Technical Advisory Committee and the FLNRORD.

1.2. Purpose

The purpose of this study is to improve the information available for dam and spillway design, evaluate spillway adequacy for existing structures, and to provide data to protect other critical infrastructure. The hydrometeorological products created for this study may also increase the efficiency, improve the quality, and lower the cost of hydrotechnical studies. The study results may be used as guidance or input for deterministic and/or risk-informed analyses of extreme flood events. However, if more refined PMP estimates beyond the scope of this study are needed, a site-specific PMP study is recommended. In particular, a site-specific study may be needed if a duration or area size not approximated by those provided is required; or if the site of interest is remote and not represented by the available storm transposition points.

1.3. Regulation

Dams in British Columbia are regulated by different ministries dependent on the type of dam. The regulatory authorities require a defensible hydrotechnical study, which includes design information for the flow capacity of the dam's spillway system in compliance with the Canadian Dam Association (CDA) guidelines for Inflow Design Flood (IDF) analysis. The

various regulatory groups expect hydrotechnical consultants to utilize the findings of this study when preparing IDF studies on behalf of dam owners in British Columbia.

The Dam Safety Section (DSS) of the FLNRORD Water Management Branch has completed several guidelines for dam owners and consultants, however, the Province has limited staff and technical knowledge to prepare the wide variety of guidance documents required to safely divert and store water. Thus, the Province utilizes guidance from other organizations, including the CDA; Engineers and Geosciences BC; International Commission on Large Dams (ICOLD); and various dam safety organizations in the United States. Despite the numerous flood guidelines developed by these organizations, inconsistencies with deterministic methods utilized by consultants to estimate the magnitude of floods in British Columbia have been observed by the DSS.

The IDF method of designing a spillway is a deterministic approach. The CDA recognizes that continued development of a risk-informed approach to sizing a spillway capacity using probabilistic methods is required. It is anticipated that this study will assist with the development of a risk-informed approach, as well as aid in current deterministic methods.

The CDA Guidelines recommend a 5-tier dam failure consequence classification system which is based on the downstream impact of a possible dam breach. The CDA Guidelines indicate that the IDF method should be used to size the capacity of a spillway. Depending on the consequence classification of the dam, the 1-in-100-year flood through the PMF may be used to size the capacity of the spillway. Regional precipitation-frequency estimates at various return periods can be implemented in a rainfall-runoff model to determine the corresponding flood event. Please refer to the CDA Guidelines for more detailed information (Canadian Dam Association, 2013).

1.4.   Definitions

1.4.1.   PMP

According to the WMO Manual on Estimation of PMP (2009), the definition of Probable Maximum Precipitation (PMP) is "the greatest depth of precipitation for a given duration meteorologically possible for a design watershed or a given storm area at a particular location at a particular time of year, with no allowance for long-term climatic trends." The caveat in the WMO Manual states that "the current knowledge of storm mechanisms and their precipitation-producing efficiency remains insufficient to allow precise evaluation of limiting values of extreme precipitation. PMP estimates, therefore, must still be considered approximations." This is applicable here.

1.4.2.   PMS

The Probable Maximum Storm (PMS) is the storm that produced the greatest volume of precipitation for a key watershed area size and duration of interest. This is an important feature for engineering and hydrology efforts because the spatial and temporal patterns from the storm that produced the PMP can be download via the MetPortal and input into a hydrologic model.

1.4.3.   PMF

According to the WMO Manual on Estimation of PMP (2009), the definition of Probable Maximum Flood (PMF) is "the theoretical maximum flood that poses extremely serious threats to the flood control of a given project in a design watershed. Such a flood could plausibly occur in a locality at a particular time of year under current meteorological conditions."

1.4.4.   PF

A precipitation-frequency (PF) estimate is the best-estimate of a precipitation depth, at a particular point or area, for a defined duration that has a probability of occurrence in any given year. The probability of occurrence is provided in terms of an annual exceedance probability (AEP) or average recurrence interval (ARI). PF estimates are sometimes referred to as design precipitation, given they inform hydrologic models to evaluate the design, operation, and safety of hydraulic structures, ranging from drains and culverts to bridges and large dams.

1.5.   Linking Hydrology and Meteorology

Translating PMP estimates and/or PF estimates into meaningful input for a hydrologic model requires cooperation and coordination between meteorologists and hydrologists/engineers. Although an ongoing dialogue between meteorologists and hydrologists/engineers during the flood modeling phase for a design watershed would be ideal, this User's Guide aims to provide the meteorological elements of the conversation. As such, this User's Guide provides insight into the processes and methodologies used to calculate the PMP and PF estimates, but more importantly, for the use and application of the results in a hydrologic model. The accompanying web-interface, MetPortal, provides the hydrometeorological products.

This User's Guide assumes that users possess basic knowledge of hydrometeorology.

1.6.   Scope of Study

The entire province of British Columbia is considered in this study, along with adjacent portions of Alaska, Yukon, Northwest Territories, Alberta, Washington, Oregon, Idaho, Montana, northern California, northern Nevada, northern Utah, and western Wyoming (Figure 1). Since the Project Domain is topographically and climatologically diverse, it is sub-divided into four Project Macro Regions (also shown in Figure 1) - the Coastal, Interior Mountain, Interior Lowland, and a so-called Hybrid which is a mixture of terrain types and climate zones to the northeast with sparse precipitation gauge coverage to warrant further delineation.

For the PMP analysis, a series of transposition points was established across British Columbia (Figure 2). At these transposition points, the hydrometeorological products created from the PMP analysis, including the spatial and temporal pattern for the PMS and the PMP estimates, may be downloaded. The density of the transposition points coincides with the density of dams and mines in the Province; areas of higher density transposition points occur in areas where there is a higher density of dams and/or mines.

Figure 1: Project Domain and Project Macro Regions.
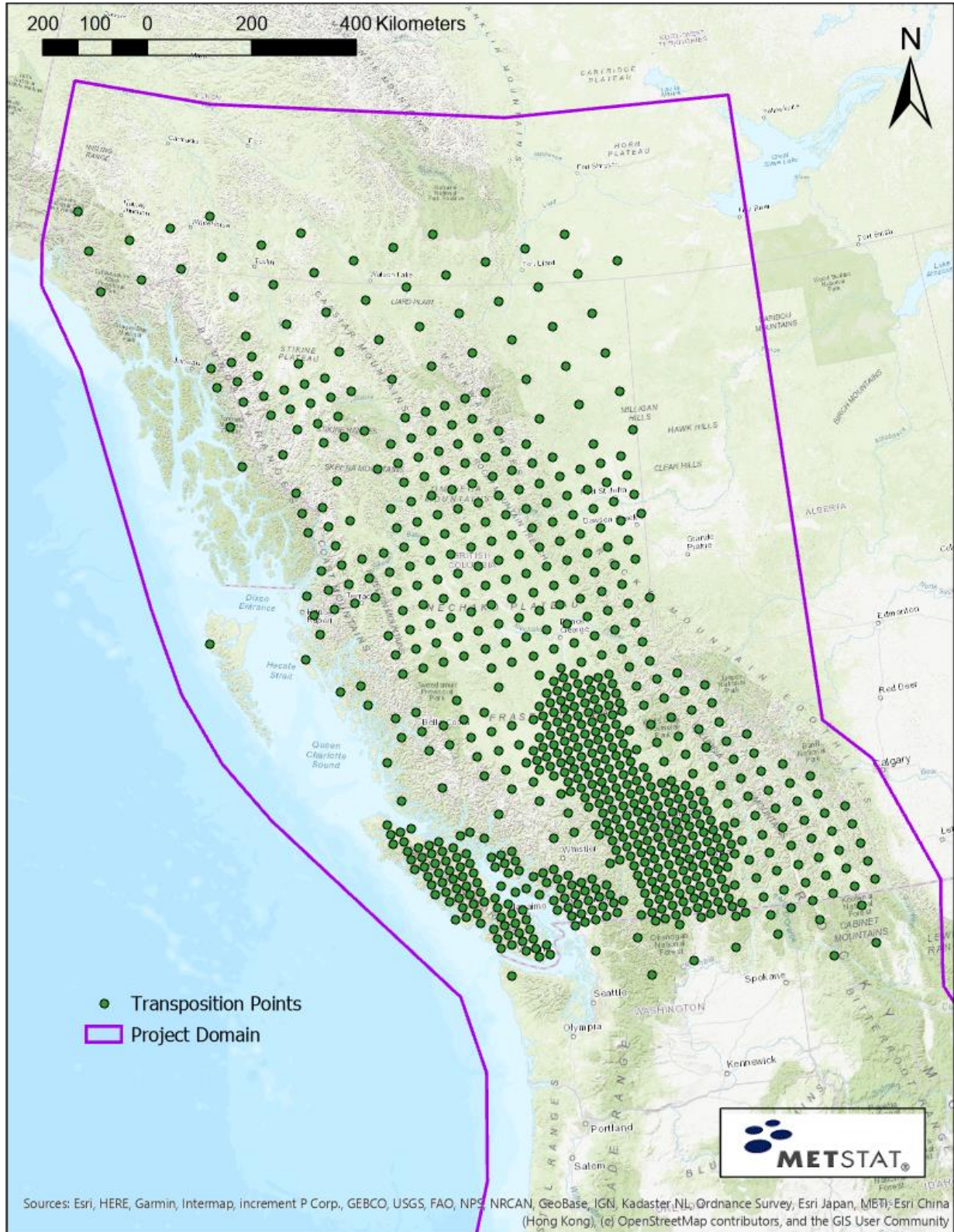
Figure 2: Series of transposition points where the PMP hydrometeorological products may be downloaded.

Focus is placed on the mid-latitude cyclone (MLC) storm type since this is the chief mechanism by which precipitation is generated at the high latitudes of the Project Domain. MLCs are synoptic-scale, low pressure systems with cyclonic circulations. The spatial pattern of precipitation from an MLC occurs over broad areas and is relatively smooth and spatially coherent across the storm system. MLCs and associated frontal systems can produce precipitation for several days over very large areas. This storm type includes atmospheric river events, precipitation associated with the Aleutian Low, low pressure systems, and cold fronts.

Key watershed area sizes for each Project Macro Region were selected so that the PMP estimates and PMS spatial and temporal patterns were applicable to the majority of dams. Also, there were insufficient long duration storms to adequately compute PMP at the 72-hour and 96-hour durations for some Macro Regions.

Four durations were of interest in this study: 24-, 48-, 72-, and 96-hours. At these specific durations:

- The PMP and PMS were determined at select key watershed area sizes (Table 1) for the series of transposition points in Figure 2, and

- Point PF estimates were calculated at AEPs ranging from 1:2 to 1:1,000,000 with uncertainty bounds for all points in British Columbia.

The key watershed area sizes differ between the four Project Macro Regions as prescribed by the general characteristics of watersheds and available storm data found within that Project Macro Region.

Table 1: Key watershed area sizes by duration and Project Macro Region.

Duration	Coastal Region	Lowland Interior Region	Interior Mountains Region	Hybrid Region
24-hour	10-km^2 100-km^2	10-km^2 100-km^2	10-km^2 100-km^2	10-km^2 100-km^2
48-hour	10-km^2 100-km^2 1,000-km^2	10-km^2 100-km^2 1,000-km^2	10-km^2 100-km^2 1,000-km^2 10,000-km^2	10-km^2 100-km^2 1,000-km^2
72-hour	10-km^2 100-km^2 1,000-km^2	10-km^2 100-km^2 1,000-km^2		
96-hour	100-km^2 1,000-km^2			

1.7.   Revisions

This User's Guide and the MetPortal may be subject to periodic revisions to reflect bug changes, clarifications, and/or new tool functionality.

1.8.   Organization of this User's Guide

Information pertaining to the technical methodologies used to calculate the PMP and the PMS may be found in Chapter 2. Chapter 3 explains how to access and apply the PMP hydrometeorological information from MetPortal, and Chapter 4 shows an example PMP case study.

The technical methodologies used to generate the point PF estimates may be found in Chapter 5. Chapter 6 explains how to use MetPortal to access the PF hydrometeorological information, and Chapter 7 shows an example PF case study.

2.   TECHNICAL METHODOLOGY TO CALCULATE PMP ESTIMATES

To determine the PMP estimates for the 24-, 48-, 72-, and 96-hour durations at key watershed area sizes ranging from 10- to 10,000-km^2 for British Columbia, the Storm Transposition Model (a.k.a. Transposition Method or Transposition Model) was used. In this method, significant storms were adjusted for differences in topography, distance from moisture source, and storm efficiency between the area of occurrence and the target location; then transposed to the target location, where the target location was within meteorologically and climatologically similar areas as that of the in-place location (WMO, 2009). The storms were transposed using the Enhanced Storm Transposition Procedure (ESTP).

The Storm Transposition Model differs from the Generalized Method (a.k.a. Generalized Estimation) used in most U.S. Hydrometeorological Reports (HMRs; Corrigan, et al., 1999; Hansen, et al., 1994; Hansen et al., 1988; Hansen et al., 1977) which separate storms into orographic and convergence components (WMO, 2009). The current state-of-the-science is to consider the storms intact as opposed to separating the storm into these components or decomposing the storm into depth-area-duration (DAD) tables that oversimplify and largely lose the spatial and temporal characteristics.

The primary steps to calculate the PMP estimates are as follows (WMO, 2009; Wang, 2004):

1.   Analysis of a significant storm event

2.   Moisture maximization

3.   Transposition

4.   Envelopment

5.   PMP estimation.

Each of these steps is discussed briefly in the ensuing sections. Methods similar to those prescribed in the U.S. HMRs, Canadian Dam Association (CDA) Guidelines, International Commission on Large Dams (ICOLD), and those employed in recent site-specific, regional, and statewide storm-based PMP studies conducted by federal, state, and local governmental

agencies and private consultants were considered to complete these steps. Additionally, novel approaches were also incorporated to advance the current state-of-the-science.

For the full account of the technical analysis, please refer to Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

2.1. Significant Storm Event

A storm search was conducted to identify significant storm events that could have the potential to control PMP after being maximized and transposed at the 24-, 48-, 72-, and 96-hour durations and key watershed area sizes (Table 1) for any location within the province of British Columbia. The definition of a significant storm event is a storm that could result in a flood that poses "serious threats to flood control in the design watershed" (WMO, 2009).

From the storm search, the most significant storms that could control PMP were identified. In total, 44 storms were selected (Figure 3; Table 2). Some storms were quite large in spatial extent and had more than one storm center. There was a total of 82 distinct storm center zones within the 44 storms.
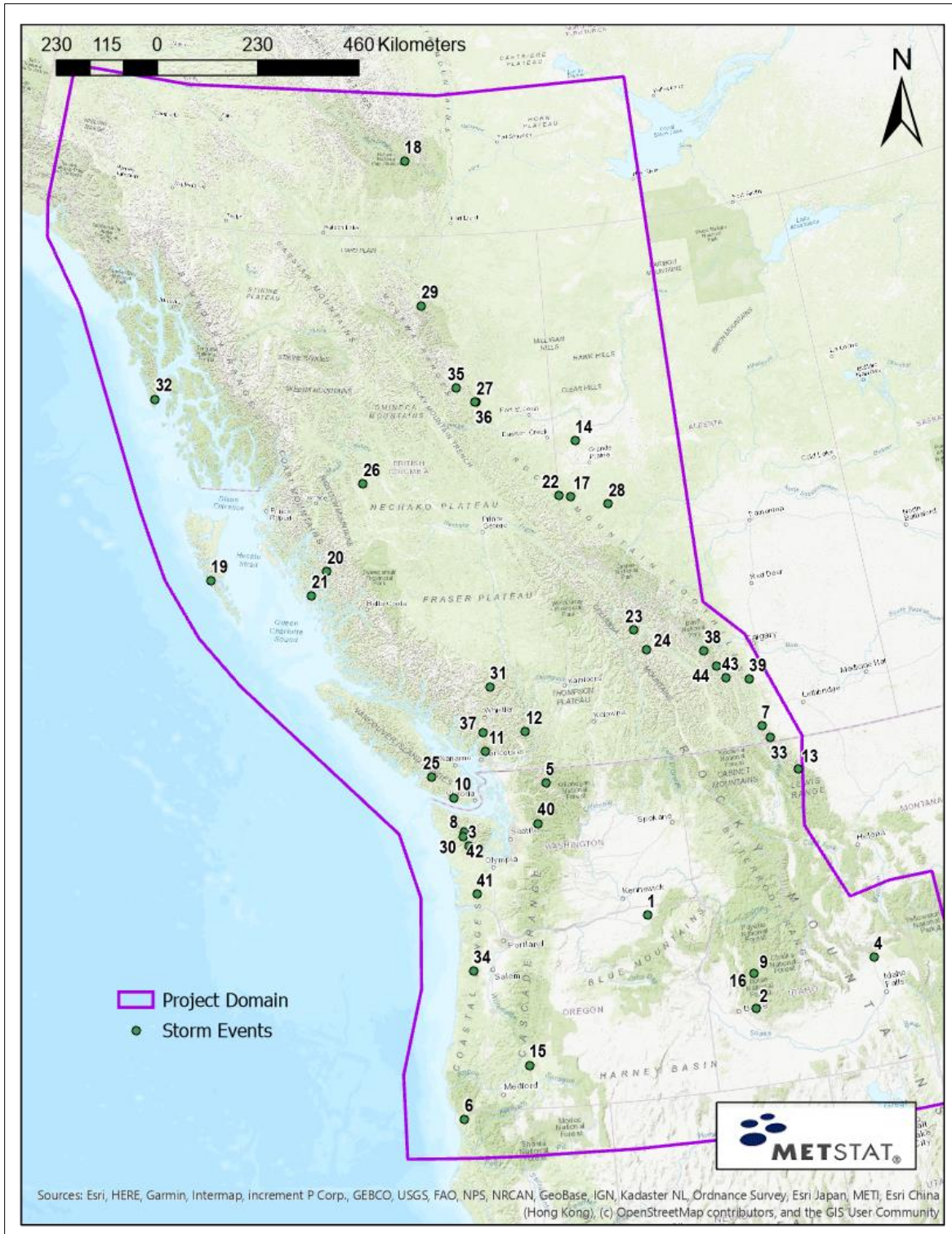
Figure 3: Significant storm events analyzed to determine PMP in British Columbia.

Table 2: Significant storm events analyzed to determine PMP in British Columbia.

Storm Number	Storm Name	Storm Date
1	Weston, Oregon	May 1906
2	Rattlesnake, Idaho	November 1909
3	Olympic Peninsula, Washington	January 1935
4	Dubois, Idaho	June 1944
5	Northern Cascades, Washington (East Side)	February 1949
6	Northwestern California and Oregon	October 1950
7	Beaver Mines, Alberta	April 1951
8	Olympic National Park, Washington	November 1955
9	Deadwood Dam, Idaho	December 1955
10	Jordan River Diversion, British Columbia	December 1956
11	Seymour Falls, British Columbia	January 1961
12	Lytton, British Columbia	October 1963
13	Gibson Dam, Montana	June 1964a
14	White Mountain, Alberta	June 1964b
15	Coastal Range, Oregon	December 1964a
16	Deadwood Dam, Idaho	December 1964b
17	Nose Mountain, Alberta	June 1972
18	Nahanni Karst/Quiet Lake, Yukon	July 1972
19	Sewell Inlet, British Columbia	February 1975
20	Ocean Falls, British Columbia	November 1975
21	Sewell Inlet, British Columbia	October 1978
22	Nose Mountain Lo, Alberta	July 1982
23	Glacier National Park, Montana and Fidelity, British Columbia	July 1983

Storm Number	Storm Name	Storm Date
24	Sonata Mountain, British Columbia	August 1984
25	Taseko River at Outlet, British Columbia	October 1984
26	Smithers, British Columbia	June 1986
27	Christina Falls, British Columbia	July 1986
28	West Valemount, British Columbia	July 1987
29	Summit Lake, British Columbia	July 1988
30	Olympic National Forest	November 1990
31	Lillooe, British Columbia	August 1991
32	Little Port Walter, Alaska	November 1993
33	Spionkop Creek, Alberta	June 1995
34	Gifford Pinchot National Forest, Washington	February 1996
35	Mount Laurier, British Columbia	August 2001
36	Wonowon, British Columbia	June 2003
37	Squamish, British Columbia	October 2003
38	Stahl Peak, Montana	August 2004
39	Calgary, Alberta	June 2005
40	Mt. Baker - Snoqualmie National Forest, Washington	November 2006
41	Pacific County, Washington	November 2007
42	Aberdeen, Washington	January 2009
43	Driftwood River, Washington	June 2012
44	Calgary, Alberta	June 2013

The storms were subsequently subject to a detailed storm precipitation analysis using MetStorm®, a state-of-the-science Geographic Information System (GIS) based analysis software that produces gridded precipitation at 1-hour intervals over a specified domain at a resolution of approximately 1-km^2. MetStorm is not a stand-alone software system, but a system

operated exclusively by expert storm analysts to produce consistent, quality-controlled storm reconstructions (Hendricks et al., 2015; Laro and Parzybok, 2015; MetStat, 2015; Parzybok et al., 2015).

All the information associated with a storm reconstruction using MetStorm is contained in a MetStorm Report. MetStorm Reports include:

- A pertinent data table with the storm name, date, general location, storm analyst, version of MetStorm, and pertinent notes;

- Brief synoptic discussion;

- Notable storm reports;

- Basemap;

- Data sources;

- In-Place Maximization Factor (IPMF) analysis;

- Error statistics;

- Confidence in results;

- Multiple storm center discussion; and

- Transposition limits.

Overall, the intention of a MetStorm Report is to inform users of the data inputs, and limitations thereof, that underpin a MetStorm analysis.

The MetStorm Reports for each of the 44 storms analyzed in the PMP study are available for download via the MetPortal. Please refer to Bulletin 2020-4-PMP: MetStorm Reports Used for Determining the Probable Maximum Precipitation Guidelines for an explanation of the figures and tables found within the individual MetStorm Reports.

2.2.   **Moisture Maximization**

Storm analyses used in PMP studies undergo a moisture maximization process because it is theoretically possible for the storm to have produced more rainfall than what was observed. The process by which the storm's rainfall is increased to its potential maximum is called moisture maximization and is completed by applying an in-place maximization factor (IPMF).

The IPMF for each of the storms is provided in its individual MetStorm Report. Please refer to Bulletin 2020-4-PMP: MetStorm Reports Used for Determining the Probable Maximum Precipitation Guidelines for an explanation of the figures and tables found within the individual MetStorm Reports. For the full account of the technical analysis, please refer to Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

2.3.   Transposition

All storm center zones were treated separately for transposition, so there were 82 distinct storm transposition regions for the 44 storms. A storm transposition region is an area where a storm could have theoretically occurred and is climatologically and topographically similar to the area where the storm originally occurred. A map of the storm transposition region (or limits) for each storm center zone is provided in the MetStorm Report for that storm (Bulletin 2020-4-PMP: MetStorm Reports Used for Determining the Probable Maximum Precipitation Guidelines).

The storm center zones were transposed to all transposition points that were located within the storm's respective storm transposition region using the Enhanced Storm Transposition Procedure (ESTP). The ESTP leveraged the hourly precipitation grids from the MetStorm analyses (after the IPMF was applied) and from regional PF statistics (Bulletin 2020-2-RPFA: Regional Precipitation-Frequency Analysis for British Columbia – Technical Report) to objectively move the storms to the new locations. The ESTP accounted for changes in topography, distance from moisture source, and storm efficiency between the area of occurrence and the target location without applying adjustment factors, all while maintaining a realistic precipitation pattern. It was able to accomplish this because inherent in the regional PF statistics are the orographic and moisture characteristics at both locations. For the full account of storm transposition, please refer to Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

2.4.   PMP and PMS Estimates

After the storms center zones were transposed, the greatest volume of precipitation for each of the combinations of key watershed area sizes and durations listed in Table 1 was determined at the transposition points in their respective Macro Region. The volume calculations were constrained to a square box with the transposition point at the centroid and with an area equal to the key watershed area size of interest (e.g. a volume representing a 100-km^2 watershed area size would be calculated from a 10km by 10km box, centered around a transposition point). The value of the greatest volume of precipitation for that specific combination was the PMP, and the storm center zone that produced that volume of precipitation was the PMS.

Fundamentally, this methodology allowed for the PMP and PMS to be directly defined from the storm spatial and temporal patterns. This is an important feature for engineering and hydrology efforts because the spatial and temporal patterns from the literal storm that produced the PMP at a key watershed area size and duration of interest (i.e., the PMS) could be input into a hydrologic model. The hourly grids of precipitation for the PMS for each combination of key watershed area size and duration of interest are available for download via the MetPortal. In addition, the data corresponding to the secondary maximum storm, defined as the second highest precipitation depth for a given area size once maximized and transposed to the selected transposition point, are also provided for download; additional storms are available upon request.

3.   ACCESSSING PMP ESTIMATES FROM THE METPORTAL

The purpose of this section is two-fold:
1.   To provide instructions on using and navigating the MetPortal; and
2.   To interpret, use, and understand the data provided by this tool.

3.1.   MetPortal PMP Interface Overview

To access the MetPortal PMP Interface:

1. Use this URL: < https://dtn-metportal.shinyapps.io/bc_region/ >.

2. Once the map of British Columbia appears, click on the 'Click Here to Begin' button.

3. Select the 'Probable Maximum Precipitation' tab in the upper left-hand corner.

A webpage in the likeness of Figure 4 will appear. Figure 4 provides an overview of the elements found on the MetPortal PMP interface.
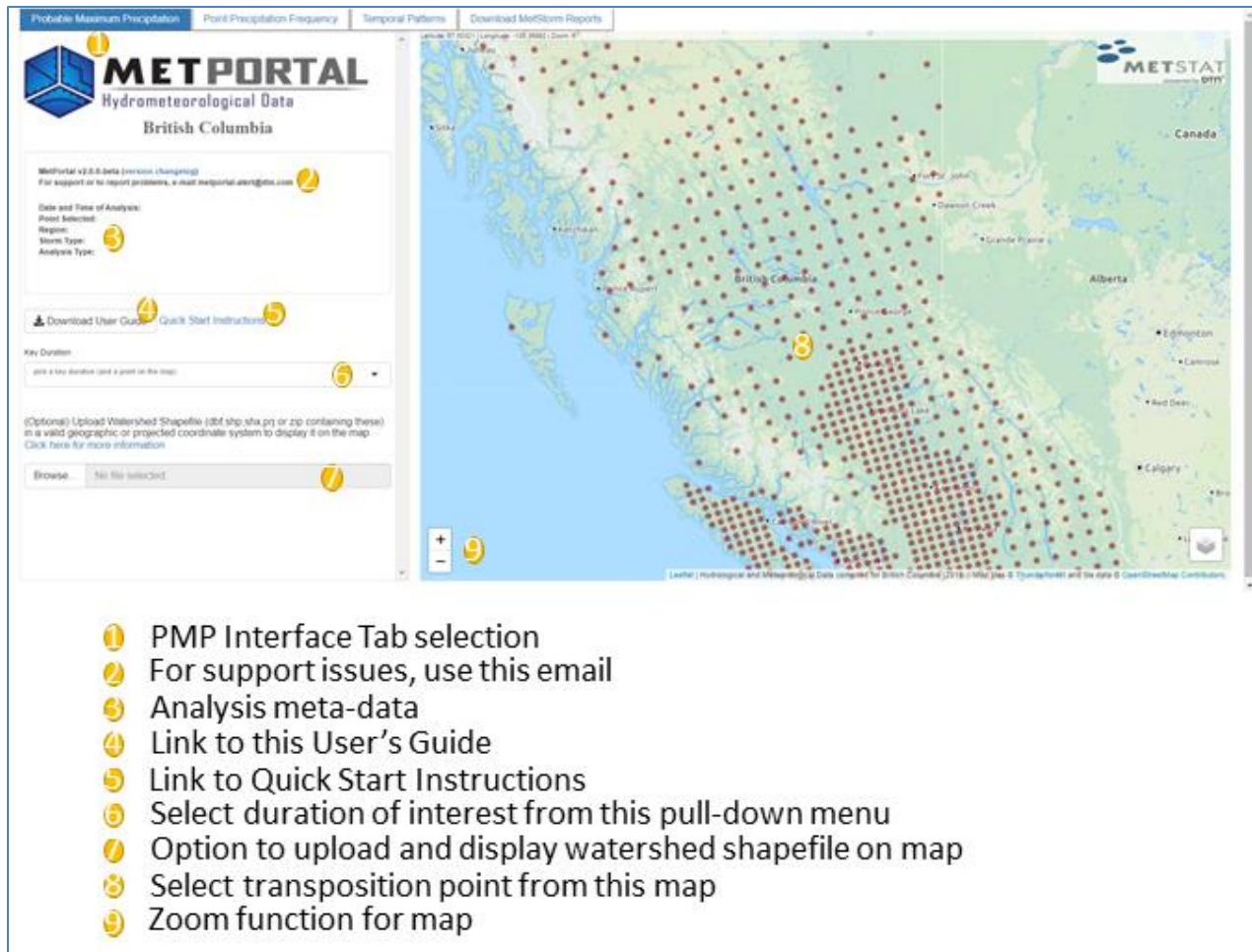
Figure 4: MetPortal Probable Maximum Precipitation Interface Overview.

Element 1:   Select this tab to access the PMP interface. The other tabs will navigate to the Point PF Interface (Section 6), Temporal Patterns for PF estimates (Section 6.6), or the MetStorm Reports (Section 3.4.2).

Element 2:   To report any issues with the function of the interface, email metportal-alert@dtn.com.

Element 3:   Once you select a transposition point and key duration, these meta-data will automatically populate to record the date and time of the analysis, the point selected, the Macro Region, the Storm Type (for this project, mid-latitude cyclones or MLC), and analysis type (here, Probable Maximum Precipitation).

Element 4:   Select this link to download this User's Guide.

Element 5:   Select this link to view Quick Start Instructions which lists a few steps to start accessing the PMP data.

Element 6:   (Optional) Upload a GIS shapefile of a watershed for display purposes on the map.

Element 7:   Select an appropriate storm duration for the watershed of interest. Available durations include 24-hour,
                    48-hour, 72-hour, and 96-hour.

Element 8:   Select a transposition point most relevant to the watershed of interest.

Element 9:   Use the zoom function to increase the scale of the map. The scroll wheel of a computer mouse can also be
used.

3.2.   Obtain PMP Estimates for a Design Watershed

The following information is for accessing the PMP estimates in the MetPortal. It is considered general guidance and should not be solely relied upon for understanding, interpreting, or applying the data in a PMP/PMF analysis. Hydrologists/engineers should consult guidance from the CDA regarding requirements for their specific circumstance.

3.2.1.   Obtain PMP Estimates Using the Transposition Points

Once a Key Duration (24-hour, 48-hour, 72-hour, or 96-hour) is selected from the drop-down menu (Figure 4, Element 7) and a transposition point has been clicked (Figure 4, Element 8), the PMP estimates for the set of area sizes (from Table 1: Key watershed area sizes by duration and Project Macro Region.) will populate in a table on the left side panel below the selected criteria (e.g., Element 10 in Figure 5). Additionally, the PMP may be adjusted to provide a Seasonally Adjusted Depth in the table, although the default is all-season. See Section 3.3 for more information on Seasonality. The table also provides the MetStorm ID number which indicates the date of the PMS as part of the ID (the form of YYYYMMDD10); the 10 (or 20 or 30) at the end denotes which storm center from multiple-centered storms has been transposed to this transposition point; the default is 10 for storms with a single storm center.

Tables provide PMP information for the PMS and also for the Secondary Storm, defined as the second highest precipitation depth for a given area size once maximized and transposed to the selected transposition point (Element 11 in Figure 5). The Secondary Storm is provided as an alternative realization of the spatio-temporal characteristics of an extreme, near-PMP event. Alternative temporal patterns may produce different hydrologic results, such as greater peak flows, despite smaller precipitation depths at the selected duration.
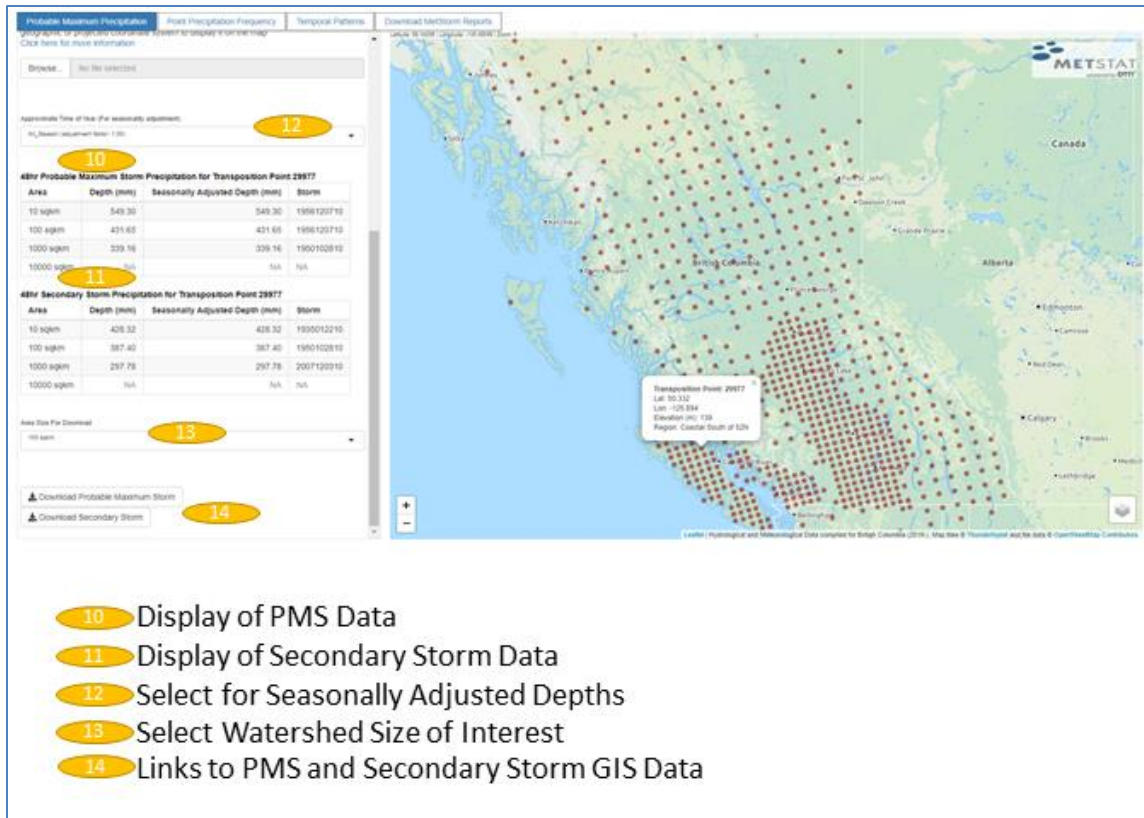
Figure 5: Example of PMP estimates for a selected Transposition Point for the 72-hour duration.

Element 10:   Display table of PMP and Seasonally Adjusted Depth (Section 3.3) values for selected Transposition Point for available area sizes in that Macro Region. MetStorm ID for the controlling PMP storm is also provided.

Element 11:   Display table of PMP values for Secondary Storm for selected Transposition Point.

Element 12:   Select time of year for Seasonally Adjusted PMP Depths (Section 3.3).

Element 13:   Select watershed area size for determining PMS and Secondary Storm. Area sizes vary depending upon Macro Region and duration selected, but can include 10 km^2, 100 km^2, 1,000 km^2, and 10,000 km^2.

Element 14:   Select to download the GIS data for the PMS or Secondary Storm.

3.2.2. Obtain PMP Estimates Using a Design Watershed Shapefile

The function to upload a shapefile of the design watershed (Element 6, Figure 4) is beneficial to help identify the transposition points that are within or nearest to the design watershed. It is important to understand the MetPortal will not calculate a PMP estimate for an uploaded shapefile, but rather display it on the map for reference.

3.2.2.1 Upload a Design Watershed Shapefile

To display a design watershed of interest, a GIS polygon shapefile (dbf, shp, shx, and prj; or alternatively as a zipped file containing these files with the same name) of the watershed layer can be uploaded (Element 6, Figure 4). The shapefile should be in a valid geographic coordinate system and will be re-projected as necessary by MetPortal. This is optional and not necessary to select a transposition point. The function of the shapefile is for display purposes only.

3.2.2.2 Identify Transposition Points

It is possible that there is more than one transposition point within or near a design watershed depending upon its size (e.g., Figure 6). These can be identified once the watershed shapefile is uploaded and displayed on the map. PMP data for each transposition point can be downloaded (Section 3.4) for further review and use in modeling. If no transposition points occur with the watershed of interest, the nearest or most relevant transposition point may be used.
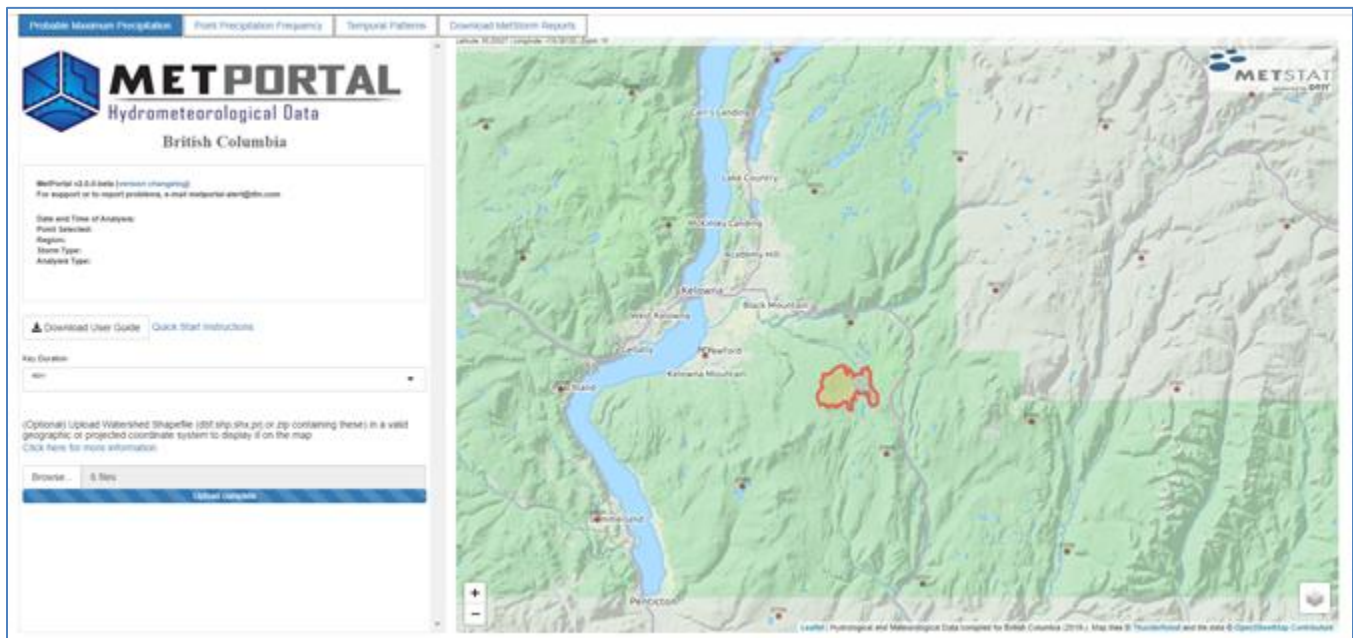
Figure 6: Display of example watershed (McCulloch Reservoir Catchment) and transposition points.

3.3. Seasonality of PMS and PMP Estimates

The PMP values at every transposition point for each combination of key watershed area size and duration of interest were all-season values (or 100%) PMP. This is the most conservative estimate of PMP for a location. However, if a PMP is needed for a particular month of the year, the PMP values may be adjusted using seasonality factors. There are also times of the year when PMP is not expected to occur (for instance, wintertime in the Interior Mountains).

Seasonality factors are percentages of PMP that were developed for each Macro Region because each Macro Region had distinct seasonality characteristics. Additionally, the Coastal Macro Region was found to have distinct characteristics between the northern latitudes and southern latitudes. It is divided into Coastal North and Coastal South along the latitude 52º N. For the technical analysis to determine the seasonality factors, please refer to Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

By default, All-Season (i.e., 100%) PMP is selected and is displayed as the PMP Depth and (initially) in the Seasonally Adjusted Depth in the output tables in the interface (Elements 10 and 11, Figure 5). Seasonality factors (Table 3) can be applied by selecting an approximate time of year from the drop-down list that is displayed just above the PMP tables once a duration and transposition point are selected (Element 12, Figure 5). Time of year can be selected from twice monthly increments on the 1st and 15th of each month. This will apply the appropriate percentage (factor) of PMP to estimates in the Seasonally Adjusted Depth column of the output tables. The seasons where PMP is not expected to occur are indicated as out-of-season.

Table 3: Percent PMP seasonality factors. -99% designates out-of-season.

	Coastal North	Coastal South	Lowland Interior	Interior Mountains	Hybrid
Jan. 1	100%	100%	100%	-99%	-99%
Jan. 15	100%	100%	100%	-99%	-99%
Feb. 1	100%	100%	100%	-99%	-99%
Feb. 15	95%	100%	100%	-99%	-99%
Mar. 1	85%	95%	100%	-99%	-99%
Mar. 15	80%	85%	85%	-99%	-99%
Apr. 1	75%	80%	75%	60%	-99%
Apr. 15	-99%	75%	80%	75%	-99%
May 1	-99%	-99%	100%	85%	70%
May 15	-99%	-99%	100%	100%	75%
June 1	-99%	-99%	100%	100%	100%
June 15	60%	-99%	100%	100%	100%
July 1	65%	60%	100%	100%	100%
July 15	70%	65%	100%	100%	100%
Aug. 1	75%	70%	100%	85%	100%
Aug. 15	80%	75%	100%	85%	100%
Sept. 1	95%	80%	90%	85%	95%
Sept. 15	100%	95%	85%	90%	90%
Oct. 1	100%	100%	85%	95%	95%
Oct. 15	100%	100%	90%	95%	100%
Nov. 1	100%	100%	100%	-99%	-99%
Nov. 15	100%	100%	100%	-99%	-99%
Dec. 1	100%	100%	100%	-99%	-99%
Dec. 15	100%	100%	100%	-99%	-99%

3.4.   Download PMS Information

Once a transposition point and duration have been selected, GIS data for the PMP storm (aka, PMS) and the Secondary Storm may be downloaded by next selecting the area size of interest from a drop-down menu (Element 13. Figure 5). Links will download a "tarball" of files that contain the necessary GIS data associated with the PMS or Secondary Storm for the given point/duration/area-size.

3.4.1. Files found in Tarball

Tar is a format to deliver an archive of files (aka, tarball) without compression and the files must be extracted. To accomplish this in LINUX, the *tar* command is commonly used with options *-xvf* and the tarball name (-x extracts files from an archive; -v verbosely lists files processed; -f uses archive file name).

In Windows, commercial and freely available software, such as 7-Zip, provide a graphical user interface (GUI) to unpack a tarball. To use 7-Zip, first navigate to the tarball in Windows Explorer. Then, right click on the file to access 7-Zip to open the file using 7-Zip's "Open archive" function. This will open the 7-Zip GUI and show the name of the tarball which is a directory of files (Figure 7, left). Double-click this directory and it will list all of the files within the archive which can then be extracted by clicking the "Extract" button at the top of the interface (Figure 7, right).

The downloaded files are named based on the selected transposition point, duration, area size, and/or MetStorm ID number. For example, in the file names listed below, the selected transposition point was 8853; the duration was 48-hour; the area size was 100 km^2; and the MetStorm ID number was 2006110610. The set of five files found within the tarball are:

PMP_point8853_48hr_100km_precipgrids.tar: An archive of hourly ASCII grids that must also be unpacked. Each grid within the tarball represents the spatial patterns of precipitation (in mm) of each hour of the storm named with an incremented hour - e.g., ppt_2006110610_48-hr_0001_8853_metric.asc, ppt_2006110610_48-hr_0002_8853_metric.asc, ppt_2006110610_48-hr_0003_8853_metric.asc, etc. Also includes the storm total grid. All of the grids are in a latitude/longitude geographic coordinate system; see README for more details. It should be noted that due to the vast computational exercise of transposing the hourly storm grids to the great number of transposition points, a few grid cells, particularly on the periphery of storms, may be less than zero; in these instances, these values should be set to zero or cropped from the template.

2006110610_8853_48hr_summary.txt: Summary file containing storm metadata information of the transposed storm analysis including MetStorm ID number, storm begin/end dates, duration of storm analysis, transposition point ID and coordinates, Macro Region, key duration for which the storm is PMP, In-Place maximization Factor (IPMF), key area size and PMP depth (mm).

frzlvl_template_2006110610_metric.txt: Comma-separated freezing level and 1000-mb temperature hourly time series data for the duration of the storm used for modeling rain/snow events. Reference values for the freezing level and 1000-mb temperature time series are found at the top of the file; these reference values should be applied to the off sets found for each hour of the time series to produce the actual hourly freezing level heights and 1000-mb temperatures.

zltemp_scaled_2006110610.png: Freezing level and 1000-mb temperature time series graphic (Figure 8).

README: Text file that provides the naming convention and tarball contents, pertinent metadata for the storm precipitation grids, citation information, disclaimer, date of the MetStorm analysis, and contact information.
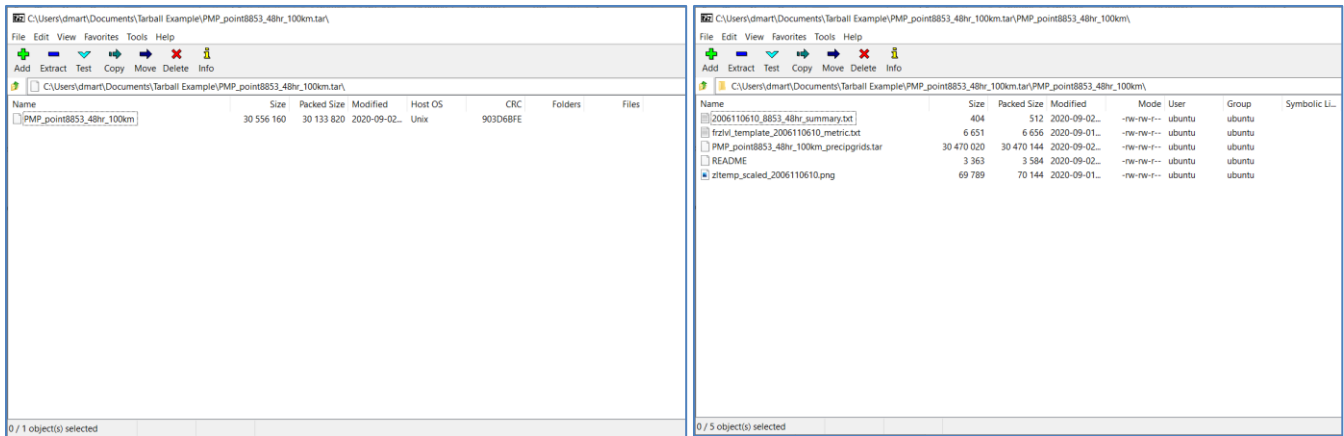
Figure 7: Example of extracting files from a tarball using 7-Zip.
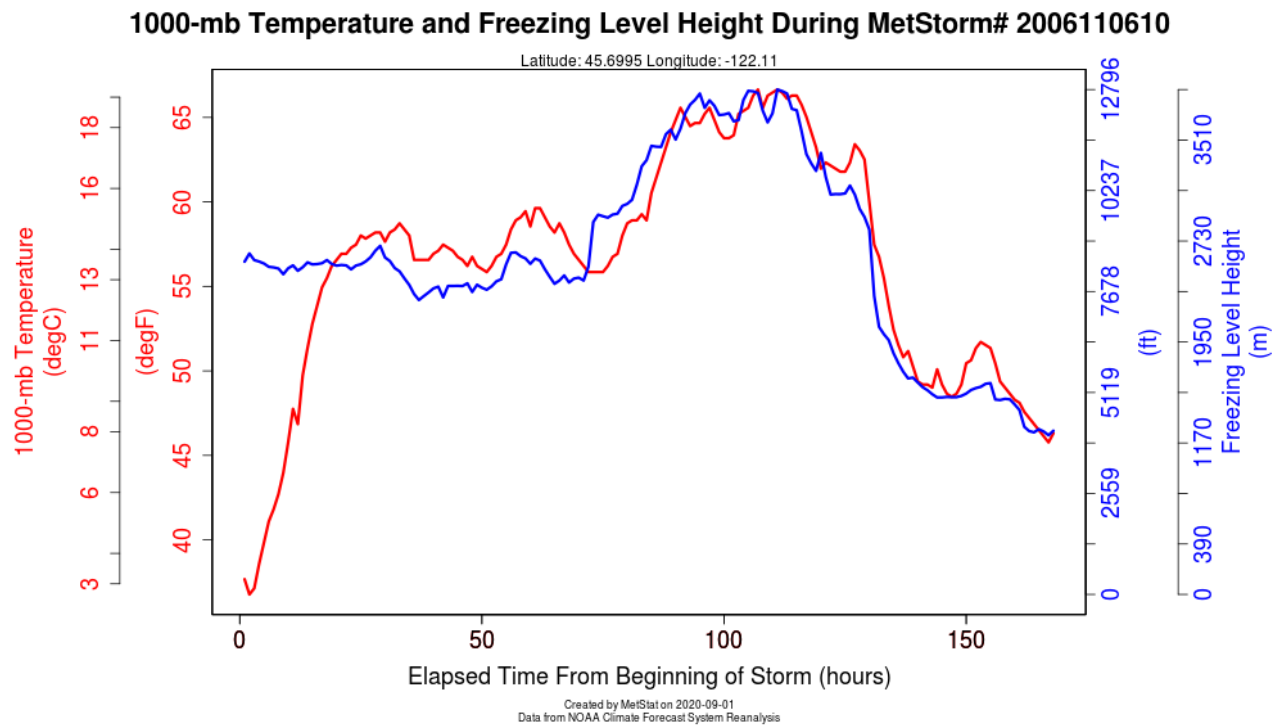
Figure 8: Graphic showing the freezing level and 1000-mb temperature time series throughout a selected storm.

3.4.2.   Access MetStorm Reports

The MetStorm Reports for each of the 44 analyzed storms are available on the "Download MetStorm Reports" tab of MetPortal. To download a report, choose a report in the "Select Storm Report to Download" dropdown menu and click "Download Selected Report". Section 2.1 of this User's Guide briefly describes the contents of a MetStorm Report. Please

refer to Bulletin 2020-4-PMP: MetStorm Reports Used for Determining the Probable Maximum Precipitation Guidelines for a full explanation of the figures and tables found within the individual MetStorm Reports.

3.5.   Uncertainty of PMS and PMP Estimates

PMP estimates are historically presented as a single value for a given location, duration, and storm type. However, uncertainties exist in the deterministic process of estimating PMP due to several factors including: the limited sample of extreme storms that have occurred in a given region; limitations in the available data for measured precipitation and for the meteorological conditions that produced the observed extreme storms; and imperfect understanding of the possible range of meteorological factors that can produce extreme storms. In addition, policy decisions and judgments have been made over time in the procedures for estimating PMP which often result in use of rare, but not upper bound, conditions for computing PMP. This situation results in a range of plausible PMP magnitudes, where the PMP value estimated by current procedures is typically smaller than the median value of plausible PMP magnitudes.

An uncertainty analysis (Micovic et al., 2015) was conducted for each of the four Macro Regions to consider various sources of uncertainty in estimating PMP. The uncertainty analysis considered uncertainties associated with inputs to PMP computation including: dewpoint data as an indicator of atmospheric moisture; vertical saturation of the atmosphere; horizontal transposition of storms; storm centering; storm efficiency; and storm spatial analysis using MetStorm software. Stochastic simulations were conducted emulating the PMP estimation procedure which considered 5,000 combinations of input values from the six sources of uncertainty listed above. These simulations allowed development of estimates of the 5th, median and 95th percentiles for plausible PMP estimates. A complete description of the uncertainty analysis of PMP is contained in Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report.

PMP uncertainty was determined for the 5th, 50th (median), and 95th percentile values. These are displayed as scaling factors for each Macro Region (Table 4). To determine a transposition point's Macro Region, the Macro Region information is displayed in the popup information window when a point is selected, as well as on the left-hand information box after a point and duration are selected (Figure 9). To compute PMP uncertainty, simply multiply the transposition point's PMP estimate by the appropriate value in Table 4 for the Macro Region and uncertainty percentile of interest. Note that the PMP estimate for the transposition point obtained from standard deterministic procedures is typically near the 5th percentile for this project. This situation occurs because there are sizable uncertainties in the inputs/factors used in estimating PMP that could result in plausible PMP values greater than computed by standard procedures.
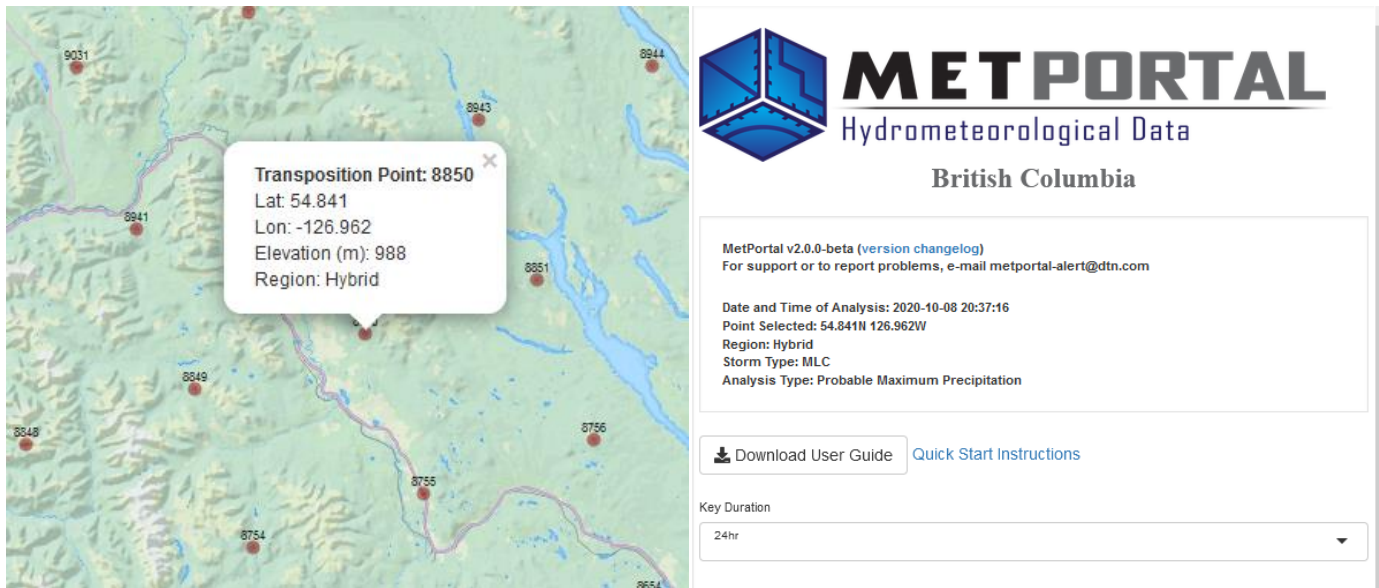
Figure 9. Transposition point 8850, with popup showing the point is in the hybrid region and information table also indicating the transposition point is in the hybrid macro region.

Table 4: Scaling factors for select percentiles for PMP uncertainty for each Project Macro Region.

Project Macro Region	5th Percentile	Median	95th Percentile
Coastal	1.056	1.265	1.528
Lowland Interior	1.027	1.237	1.493
Interior Mountains	1.023	1.236	1.494
Hybrid	1.030	1.332	1.727

3.6. Alternative Watershed Area Sizes

The standard area sizes addressed in this study were 10-km^2, 100-km^2, 1,000-km^2, and 10,000-km^2. Interpolation between the PMP depths for these area sizes (at a given duration and transposition point) can obtain estimated results for an alternative area size. By plotting the PMP depths at a given transposition point for a given duration for each available area size, a trend line can be added and used to estimate depths at intermediate sizes. It is common to use a logarithmic scale for the area size and a linear regression; however, it is up to the user to determine the best interpolation scheme for their selected criteria. However, with interpolation comes increased uncertainty. If greater accuracy is necessary, a site-specific analysis is strongly recommended. Extrapolation to significantly larger area sizes is not recommended; a site-specific analysis would provide better accuracy.

3.7. Alternative Durations

The standard storm durations addressed in this study were 24-, 48-, 72-, and 96-hours. Interpolation between the PMP depths for these durations (at a given area size and transposition point) can obtain results for an alternative duration. By plotting the PMP depths for each available duration at a given transposition point for a given area size, trend line, such as a 2nd order polynomial, can be added and used to estimate depths at intermediate durations. It is up to the user to determine the best interpolation scheme for their selected criteria. However, with interpolation comes increased uncertainty. If greater accuracy

is necessary for a non-standard duration, a site-specific analysis may be recommended. In particular, extrapolation to durations less than 24-hours or greater than 96-hours is not recommended.

PMS, and secondary storm, spatial and temporal information provided are from the storms that produced the PMP, and second highest precipitation depth, at key durations. Interpolation to an alternate duration would not guarantee a one-to-one correspondence to a storm that produced the PMP for that duration. Storms associated with the closest key duration should be inspected and could be used as a proxy.

4.   PMP EXAMPLE CASE STUDY

The following provides an example case study to obtain guidance 48-hour PMP depths for storms that occur in May for Fulton Lake. Fulton Lake sits within Bulkley-Nechako Regional District and ultimately feeds into Babine Lake, located within the Hybrid Macro Region. The catchment for Fulton Lake is approximately 1,400 km^2.

Step 1. Load MetPortal: Go to https://dtn-metportal.shinyapps.io/bc_region/. Click the "Click Here to Begin" button to use the tool; select the "Probable Maximum Precipitation" tab.

Step 2. Select Duration: Select '48hr' from the Key Duration drop-down list.

Step 3. Upload Watershed: Click the "Browse" button and navigate to the appropriate directory. Select the pieces of the watershed shapefile (dbf, shp, shx, prj, at a minimum) (Figure 10). Alternatively, this can be a zipped file.
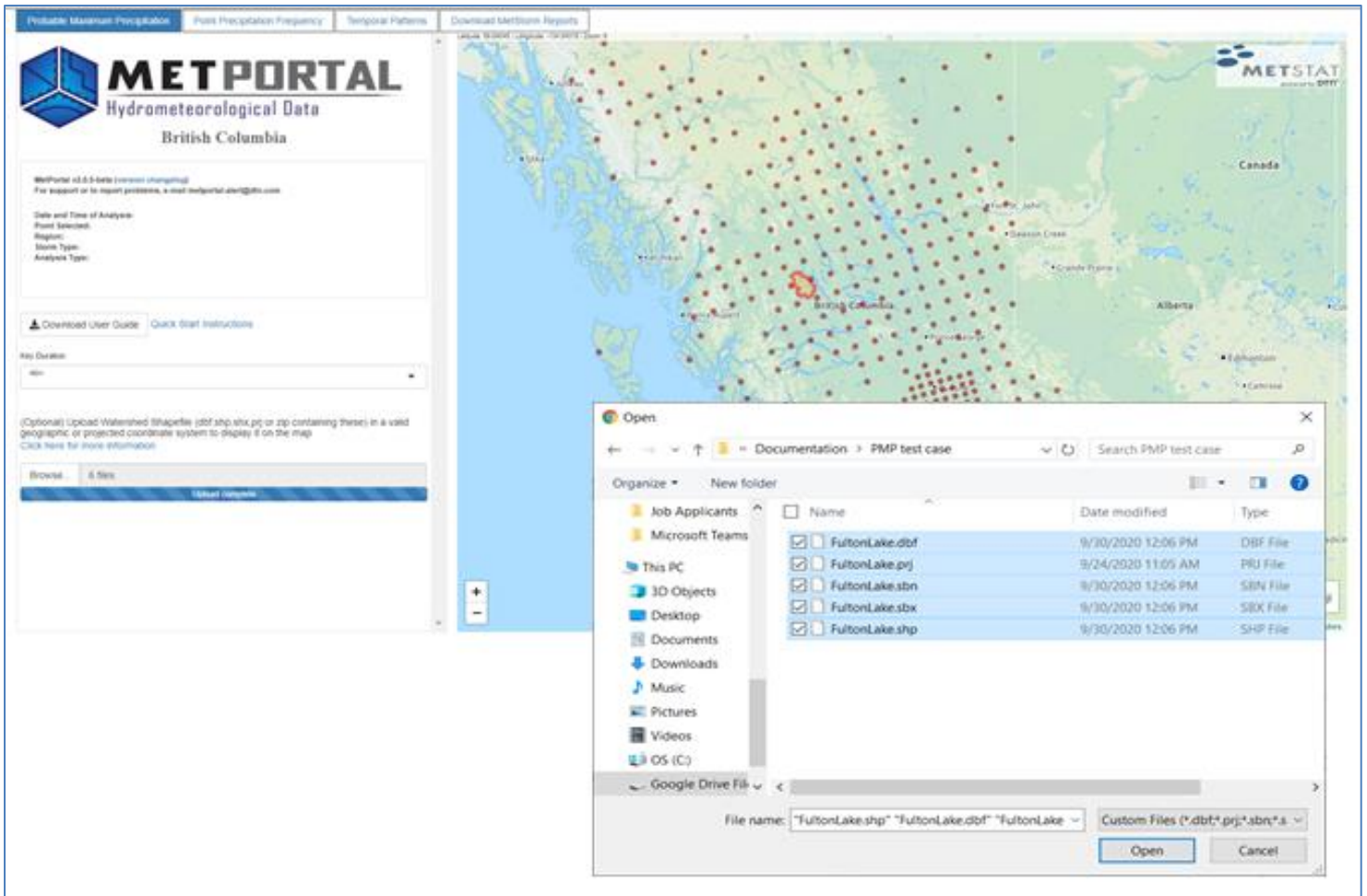
Figure 10: Uploading the shapefile for the Fulton Lake catchment.

Step 4. Select a Transposition Point: There are two potential transposition points near the watershed – 8850 to the west and 8851 to the east. Selecting each in turn (e.g., Figure 11) shows that point 8850 has a depth of 148 mm and point 8851 has a depth of 138 mm for a 1,000 km² watershed, which is closest to the size of Fulton's. Point 8850 provides a more conservative (higher) estimate, as is determined to be the PMP. This estimate can then be used in a deterministic study, or as guidance for consideration of whether a site-specific study is required based on the particular needs of the dam.

Also, at this time, the analysis metadata populates above the input selections showing the latitude and longitude of the transposition point and that the point selected is within the Hybrid (Macro) Region Figure 11.
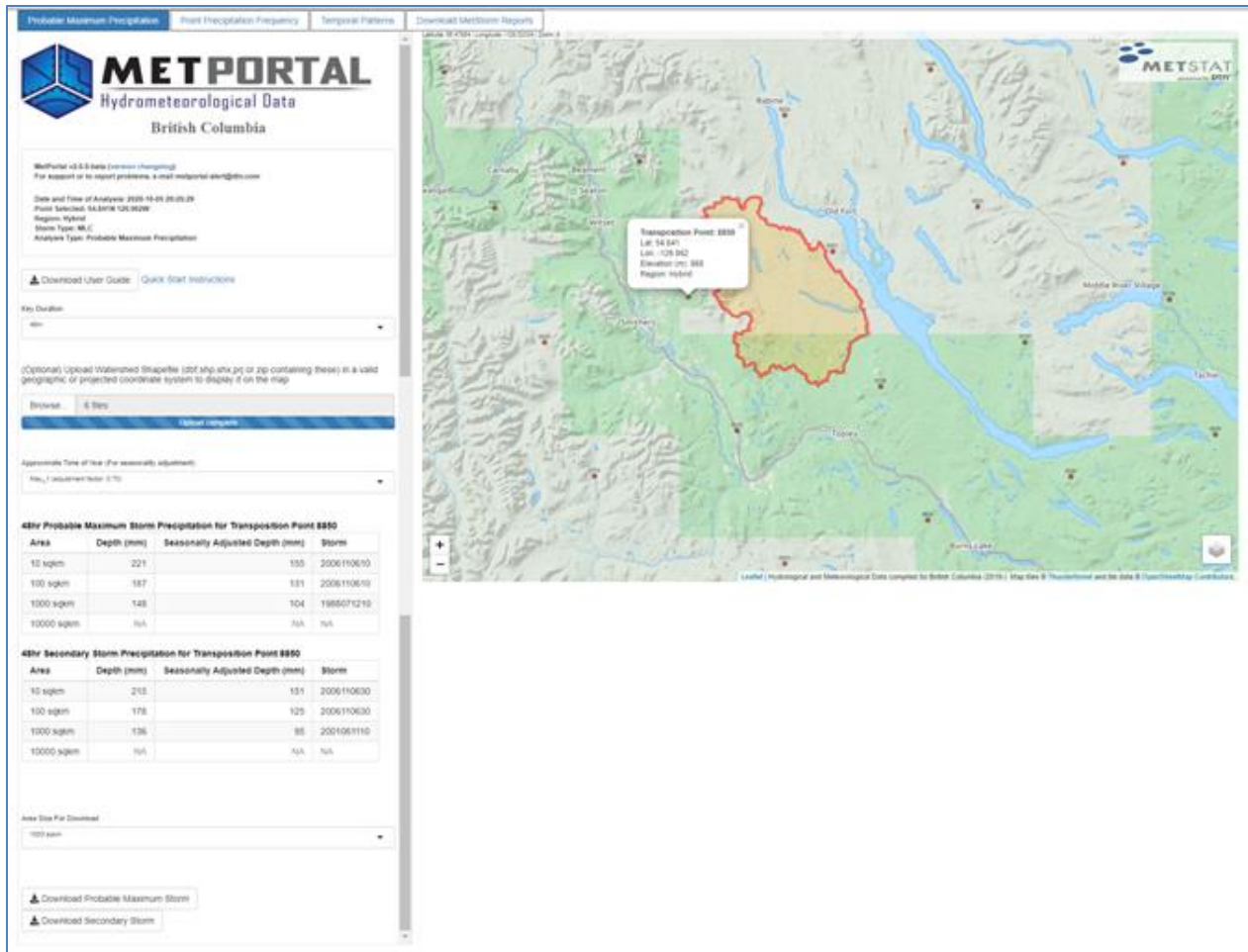
Figure 11: Transposition point 8850 was selected to view PMP depths; May 1 was selected as an approximate time of year to apply a seasonality adjustment; and 1,000 km² was selected as the area size closest to the catchment size.

Step 5. Select a season (optional):   If there is interest in a particular month where storms that occur are less than the all-season PMP, e.g., May in this example, select the "Approximate Time of Year" for the seasonality adjustment. Here, May 1 was selected which has an adjustment factor of 0.70. Therefore the Seasonally Adjusted Depth for the PMS at 1,000 km² is the percentage of PMP a storm at Point 8850 is 104 mm (Figure 11).

Step 6. Download PMS GIS data: To apply the temporal and spatial characteristics of the PMS in hydrologic modelling, click the "Download Probable Maximum Storm" button at the bottom (Figure 11). This provides you with the hourly precipitation grids and temperature template which can be used as input for a hydrologic analysis.

Step 7. Review the MetStorm Report: For further insight into the PMS, navigate to the "Download MetStorm Reports" tab to obtain the MetStorm Report. The PMS MetStorm ID number from the output table was 1988071210 (Figure 11). Select the MetStorm_Report_1988071210.pdf from the drop-down list (Figure 12). Then click the "Download Selected Report" button.

Figure 12: Download MetStorm Reports tab.

Step 8. Consider uncertainty: Table 4 provides a set of factors that can be applied to PMP depths to develop the 5th, median, and 95th percentiles of PMP depths particular to each Macro Region. Using the all-season PMP depth of 148 mm for 1000 km^2 for the catchment for Fulton Lake and the Hybrid Macro Region factors (1.030, 1.332, and 1.727) from Table 4, the 5th, median, and 95th percentiles would be 152 mm, 198 mm, and 256 mm, respectively. These values provide insight into the uncertainty associated with computing a PMP depth given likelihood functions of various factors that can impact PMP estimation.

5.   TECHNICAL METHODOLOGY TO CALCULATE PF ESTIMATES

Regional frequency analysis is a methodology to evaluate datasets comprised of measurements of the same phenomenon observed at multiple sites (here, MLC storm precipitation at the 24-, 48-, 72-, and 96-hour durations, considered separately). The primary goal in a regional frequency analysis is to use the collective statistical information from all measurement sites within a study area to develop magnitude-frequency relationships that can be applied throughout the area. This essentially uses the concept of trading space for time sampling. This approach greatly reduces the sampling variability present at any one site and increases the reliability (i.e., narrows the uncertainty bands) of magnitude-frequency estimates throughout the region, particularly at ungauged locations.

The approach to create the gridded PF estimates used here is the Schaefer-Wallis-Taylor (SWT) climate region method using L-Moments (Schaefer et al., 2018). The SWT climate region method reduces uncertainty in the regional analysis by using storm typing methods and optimizing spatial mapping procedures. Using this method, the point PF estimates were not directly interpolated between gauges but rather developed by creating spatial grids of the statistical parameters through

predictor equations based on continuous base maps (predictor variables) and computing the PF estimate at each grid cell. This state-of-the-practice technique offers considerable benefits, including reduction of uncertainty, improved representation of spatial variability of the L-Moment parameters, and high confidence in extrapolations well beyond 0.001 AEP (1 in 1,000-year ARI).

The SWT climate region method may be subdivided into the following generalized elements:

1. Assemble and quality-check the input annual maxima dataset;

2. Delineate and verify the homogeneous sub-regions using regional L-Moment statistics and homogeneity measures;

3. Analyze the spatial behavior of the precipitation at-site mean and regional L-Moment ratios L-Cv and L-Skewness for use in spatial mapping;

4. Identify the regional probability distribution for computing precipitation AEPs;

5. Compute the Equivalent Independent Record Length (EIRL) to estimate the effective independent size of the regional dataset; and

6. Produce gridded datasets of precipitation for selected AEPs from the median to at least 0.001 AEP.

7. Develop uncertainty bounds for the gridded datasets of precipitation.

Each of these steps is briefly discussed in the following sections. For the full account of the technical analysis, please refer to Bulletin 2020-2-RPFA: Regional Precipitation-Frequency Analysis for British Columbia – Technical Report.

5.1.   Annual Maxima Dataset

Since the focus of this project was a single storm type (MLC), it was necessary to conduct the PF analysis using only input data relating to this storm type. Storm typing procedures provide a methodology in which the MLC storm type and associated data may be identified and extracted from the historical period of record, thus creating an input dataset that is nearly homogeneous with regard to the generating phenomenon (MLC storm type).

The storm typing approach coupled with regional PF analysis is a major advancement over traditional all-storm, all-season PF methods. In the all-storm, all-season methods, the input datasets were comprised of a mixture of storms from various storm types (mixed distributions) leading to a flood-frequency analysis comprised of a mixture of flood events. This posed a problem for hydrologists/engineers since it is difficult to combine storm spatial and temporal patterns from different storm types into a plausible pattern for inflow design flood modeling.

The use of storm typing procedures and a nearly homogeneous dataset results in three notable outcomes: 1) separate PF relationships for different storm types; 2) spatial and temporal patterns specific to the storm type; and 3) greater insight into the statistical characteristics of the various storm types. Thus, the storm typing approach provided the important direct link between a PF relationship and the storm spatial, temporal, and seasonal characteristics of the storm type. Furthermore, due to the knowledge of the statistical characteristics of the storm types, the uncertainty bounds for estimation of extreme AEPs of precipitation can be more rigorously assessed and thus narrowed in extent.

5.1.1.   Point Precipitation Observation Data

Point precipitation observation data measured at the daily time-step were acquired for gauges within the Project Domain from various sources. Focus was placed on the daily time-step since the MLC storm type and the four durations of interest were 24-hours or greater; storm types with sub-daily time-steps were not considered in this study. The primary sources of the daily precipitation data were as follows:

- NOAA's National Center of Environmental Information (NCEI) Global Historical Climatology Network (GHCN)

- Government of Canada's historical daily weather data provided by Environment and Climate Change Canada (ECCC)

- BC Hydro

- British Columbia Ministry of Agriculture

- Agriculture and Rural Development Act Network

- British Columbia Ministry of Environment – Air Quality Network

- British Columbia Ministry of Environment – Automated Snow Pillow Network

- Forest Ecosystems Research Network

- Wildfire Management Branch

- Forest Renewal BC

- Ministry of Transportation and Infrastructure

- Rio Tinto Alcan

The collective period of record was January 1851 to August 2019, a total of 168 years.

5.1.2. Seasonality

The seasonality of the MLC storm type in British Columbia was analyzed to set the dates for the extraction of the precipitation annual maximum series (AMS) at all precipitation gauges within the Project Domain. Even though MLCs may occur during any month of the year, this storm type was more prominent in a set of several months (or "season") in regions within the Project Domain. So that while the terminology indicates 'annual' maxima time-series, the AMS for the MLCs may not extend to a full 12-month period in some of the Project Macro Regions (

Table 5).

Table 5: Seasonality by Project Macro Region (highlighted months are 'in-season').

Region	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Coastal	■	■	■	■			■	■	■	■	■	■
Lowland Interior	■	■	■	■	■	■	■	■	■	■	■	■
Interior Mountains				■	■	■	■	■	■	■		
Hybrid					■	■	■	■	■	■		

An analysis of seasonality also provided a description of the likelihood for storms to occur at various times throughout the year. This information is important when conducting flood analyses because hydrologists/engineers will want to link storm seasonality with soil moisture conditions and reservoir levels.

5.1.3.   Database of Daily Storm Types

After the seasonality was determined, the Database of Daily Storm Types (DDST) was produced by assessing daily meteorological characteristics. The DDST is a listing of the dominant type of storm that produced each rainy day in the period of record across the Project Domain. Specifically, at each precipitation gauge, the DDST provides the dates that the storm type of interest occurred from which precipitation annual maxima values may be selected. The DDST allowed for an MLC AMS to be assembled, which removed the problem of mixed storm distributions and hence reduced the uncertainly in the final estimates.

5.1.4.   Annual Maxima Time-Series

Finally, at each of the daily precipitation gauges in the Project Domain, a listing of the AMS for the MLC storm type for each of the four durations of interest was assembled. In this context, the term "annual maxima" refers to the greatest precipitation observation for the specific storm type (here, MLC) for each duration of interest for the appropriate season (Table 5) at each precipitation gauge.

5.1.5.   Data Quality

The AMS for each precipitation gauge was subject to rigorous quality control protocols to remove invalid data and false annual maxima. Data quality checking was accomplished by examining the completeness of the record for each appropriate season or climatic year and scanning the AMS to identify anomalously small or large precipitation amounts. Large precipitation magnitudes that were not sufficiently corroborated by annual maxima at other nearby gauges were considered by a storm analyst to determine if the observation was accurate. Low precipitation annual maxima for climatic years when data were missing for days, weeks, or months were identified, and subsequently accepted or rejected, using a Bayesian-type approach.

5.2.   Homogeneous Sub-Regions

Homogeneous Sub-Regions are collections of stations that fall within a small range of selected climatic and/or location indices and satisfy statistical homogeneity criteria. To form a candidate Homogeneous Sub-Region, 8-15 stations (more typically, 10-13 stations) were grouped together by considering either the climatic index of mean annual precipitation (mm) or the location index of latitude (decimal degrees). L-Moment heterogeneity measures were used to assess the homogeneity of the candidate Homogeneous Sub-Regions (Hosking and Wallis, 1997). Homogeneous Sub-Regions allow for regional L-Moment statistics to be determined.

5.3.   Regional Behavior

Spatial mapping of the at-site mean, regional L-Cv, and regional L-Skewness for the four durations of interest was accomplished by developing predictor equations which relate the L-Moments to climatic and physiographic variables, such as mean annual precipitation (Schaefer and Barker, 2009; MGS et al., 2015). Once spatially mapped, these statistics were used to develop grids of precipitation magnitudes at various AEPs.

An extensive discussion of the spatial mapping for each of the L-Moment statistics is found in Bulletin 2020-2-RPFA: Regional Precipitation-Frequency Analysis for British Columbia – Technical Report.

5.4.   Regional Probability Distribution

The Generalized Extreme Value (GEV) distribution was identified as the best-fit 3-parameter probability distribution for each of the four Project Macro Regions. This is consistent with experience in analysis of precipitation annual maxima for durations of several days in the U.S. and western Canada where goodness-of-fit tests have shown the best-fit regional probability distribution to be near the GEV distribution (Schaefer and Barker, 1997; Schaefer et al., 2002; Schaefer and Barker, 2005; Schaefer et al., 2007).

The 4-parameter Kappa distribution (Hosking and Wallis, 1997) is a very flexible distribution capable of emulating distributions near the GEV distribution, like the situations seen here, and was selected to describe the point PF relationships.

5.5.   Equivalent Independent Record Length

Equivalent Independent Record Length (EIRL) is a measure of the independent information contained in a regional dataset. When applied to the annual maxima time-series of MLC storms, EIRL provides a measure of the effective record length of the statistical information for the storms contained in the dataset. EIRL is a function of the size of the project area, the typical areal coverage of a storm, the density of precipitation stations, and the station-years of record.

For British Columbia, the MLC storm type has a large areal coverage relative to the density of the station network, so the EIRL is expected to be a relatively small fraction of the station-years of record - 1,312-years or 4.6% for the Coastal Macro Region and only 377-years or 5.7% for the Hybrid Macro Region. This occurs because the large areal coverage of a storm often produces annual maxima at many stations and results in greater correlation (statistical dependence) amongst the gauge records.

5.6.   Gridded Point PF Estimates

Point PF estimates at all point locations in the Project Domain for the four durations of interest were obtained from the spatially mapped L-Moment statistics. Specifically, for each duration, distribution parameters for the 4-parameter Kappa distribution were solved for each grid-cell using grid-cell specific values of at-site mean, regional L-Cv, regional L-Skewness, and regional Hondo (the second shape parameter of the Kappa distribution). This process was repeated for each

grid cell, and the inverse cumulative distribution function (CDF) for the Kappa distribution was used to compute the quantile estimates for selected AEPs.

Isopluvial gridded datasets were generated for the following AEPs and available to view and download from the online MetPortal web-interface:

- 1:10

- 1:20

- 1:50

- 1:100

- 1:200

- 1:500

- 1:1,000

- 1:2,000

- 1:5,000

- 1:10,000

- 1:100,000

- 1:1,000,000

5.7.   Uncertainty of the PF Estimates

The ability to characterize uncertainties in the development of point precipitation-frequency relationships is a major advantage of the SWT climate region method. Aleatoric uncertainties (chance occurrence) are inherent to all aspects of the natural processes of synoptic-scale MLC precipitation. Epistemic uncertainties (knowledge/understanding) exist regarding the meteorological processes and the statistical methods used to characterize those processes. Dimensionless uncertainty bounds were developed by characterizing epistemic uncertainties associated with estimating the at-site mean, regional L-Cv, regional L-Skewness, and the regional probability distribution when developing the point PF relationships. A multivariate Monte Carlo simulation using Latin-hypercube sampling (McKay et al., 1979) was used to characterize uncertainties associated with the L-Moment statistics.

The uncertainty simulations were conducted at the 48-hour duration on groups of climate regions with similar uncertainty. The assumption was made that similar dimensionless uncertainty bounds would be applicable to the other three durations of interest (24-, 72-, and 96-hours).

Uncertainty bounds at the 5th and 95th percentiles for the range of the AEPs 1:10 through $1:10^6$ were developed. It is important to note that the uncertainty bounds varied with AEP.

The uncertainty bounds are included in tabular and graphical format in the online MetPortal® web-interface to view and download.

6.   ACCESSSING PF ESTIMATES FROM THE METPORTAL

The purpose of this section is two-fold:
1. To provide instructions on using and navigating the MetPortal; and
2. To interpret, use, and understand the data provided by this tool.

6.1.   MetPortal PF Interface Overview

To access the MetPortal PF Interface:

1. Use this URL: < https://dtn-metportal.shinyapps.io/bc_region/ >.

2. Once the map of British Columbia appears, click on the 'Click Here to Begin' button.

3. Select the 'Point Precipitation Frequency' tab in the upper left-hand corner.

A webpage in the likeness of Figure 13 will appear. Figure 13 provides an overview of the elements found on the MetPortal Point Precipitation Frequency interface.
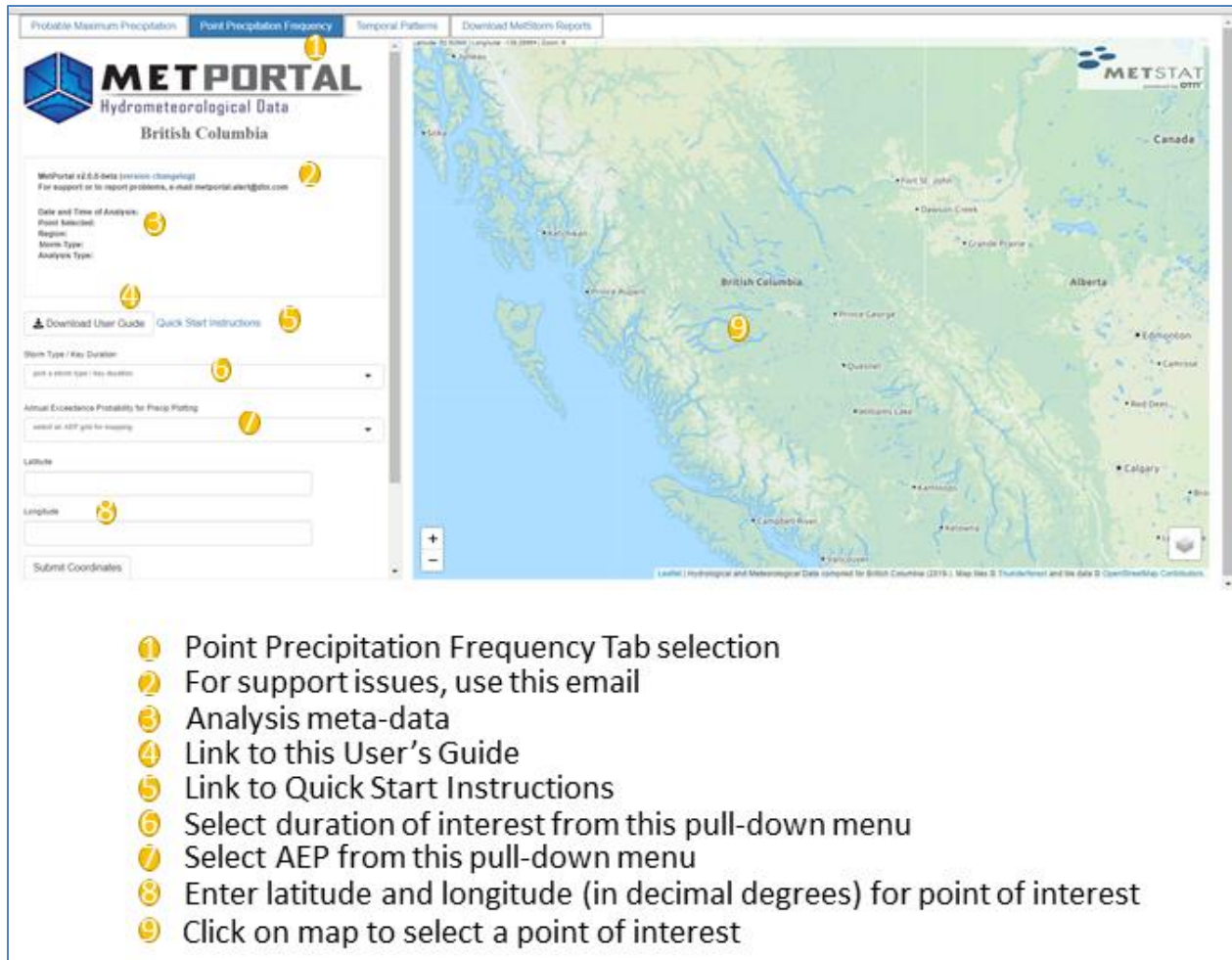
Figure 13: MetPortal Point Precipitation Frequency Interface Overview.

Element 1:   Select this tab to access the PF Interface. The other tabs will navigate to the PMP Interface (Section 3), the Temporal Patterns for PF estimates (Section 6.6) or the MetStorm Reports (Section 3.4.2).

Element 2:   To report any issues with the function of the interface, email metportal-alert@dtn.com.

Element 3:   Once you select a key duration, AEP, and point of interest these meta-data will automatically populate to record the date and time of the analysis, the point selected, the Region name given to the group of climate regions used to compute uncertainty, the Storm Type (for this project, mid-latitude cyclones or MLC), AEP, and analysis type (here, Point Precipitation Frequency).

Element 4:   Select this link to download this User's Guide.

Element 5:   Select this link to view Quick Start Instructions which lists a few steps to start accessing the point PF data.

Element 6:   Select a storm duration of interest. Available durations include 24-hour, 48-hour, 72-hour, and 96-hour.

Element 7:   Select an AEP of interest. Available AEPs are 1:10; 1:20; 1:50; 1:100; 1:200; 1:500; 1:1,000; 1:2,000; 1:5,000; 1:10,000; 1:100,000; and 1:1,000,000. Once selected, an isopluvial map (in mm) for that AEP will display on the map.

Element 8:   Enter the latitude and longitude for the point of interest in decimal degrees if known; if unknown, see Element 9.

Element 9:   Select a location on the map. The zoom function in the lower left of the map or on the mouse scroll bar can increase the scale of the map to facilitate selection. A marker will appear on the map indicating the location selected and the latitude and longitude fields will automatically populate.

6.2.   Obtain Point PF Estimates

The following information is for accessing the PF estimates in the MetPortal. It is considered general guidance and should not be construed as standard-of-practice. Hydrologists/engineers should consult guidance from the CDA regarding requirements for their specific circumstance.

Once a Key Duration and location of interest is selected, a table of precipitation-frequency estimates will populate below the selections (Figure 14). Additionally, the analysis metadata above the selections will populate (Element 3, Figure 13).
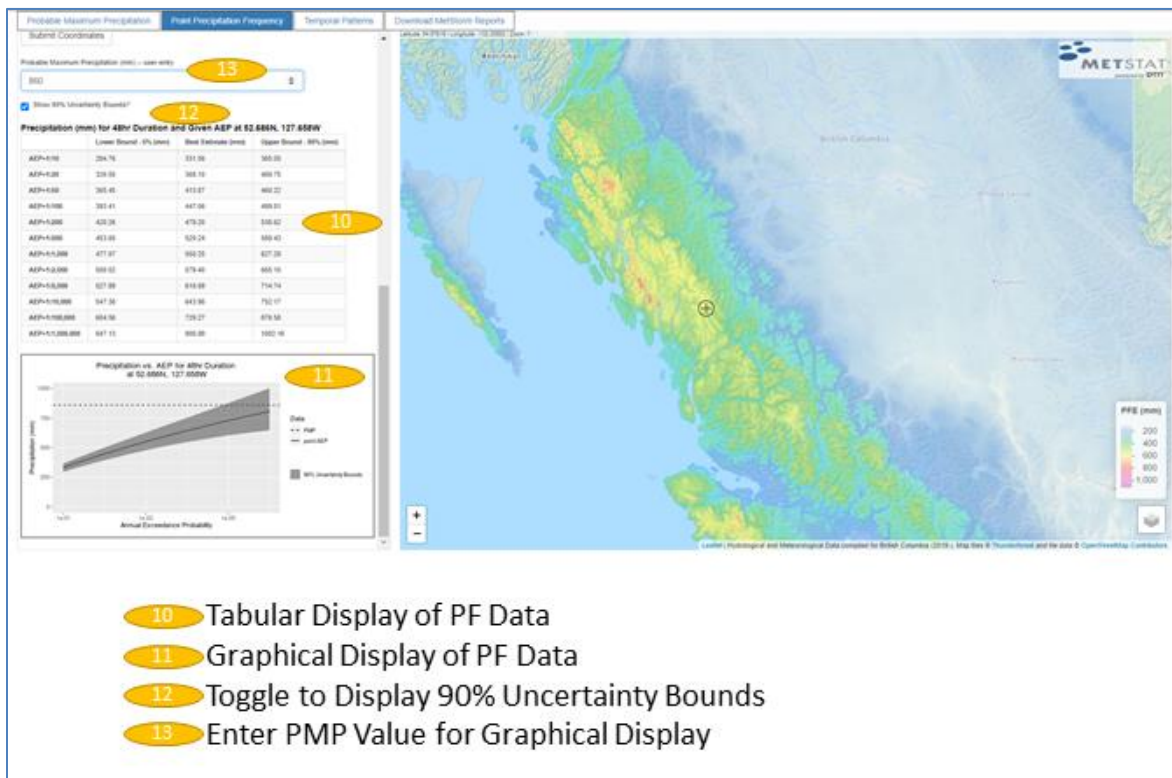

Figure 14: Example of PF estimates for a selected location for the 48-hour Key Duration.

Element 10:   Tabular display table of PF estimates (and their 90% uncertainty bounds) for all available AEPs for the selected point location for the selected Key Duration.

Element 11:   Graphical display PF estimates (and their 90% uncertainty bounds as gray shading) for all available AEPs for the selected point location for the selected Key Duration.

Element 12:   Click this box to toggle the uncertainty bounds on and off. In this example, they are selected and displayed.

Element 13:   Enter a theoretical PMP value in mm to display for information purposes on the graphical display of PF estimates. In this example, a value is entered and displayed in the plot as a horizontal dashed line.

6.3.   Uncertainty of PF Estimates

Uncertainty bounds at the 5th and 95th percentiles for the range of the AEPs 1:10 through 1:10^6 were developed as part of this study (Elements 10 and 11, Figure 14). They were computed using groupings of climate regions with similar uncertainty characteristics. It is important to note that the uncertainty bounds increase in width with increasingly rare AEPs. Element 12 in Figure 14 shows where on MetPortal to toggle the display of the uncertainty bounds.

6.4.   Download PF Information

Once the Key Duration is selected, a button will appear above the selections to download the PF grids for that duration (Figure 15). The data are delivered in a zipped set of files (e.g., *pf_grids_48hr.zip*) - one for each AEP (1:10; 1:20; 1:50; 1:100; 1:200; 1:500; 1:1,000; 1:2,000; 1:5,000; 1:10,000; 1:100,000; and 1:1,000,000) for the selected duration. The format of the grids is GeoTIFF (extension .tif) which is a format for storing georeferenced data that can be easily imported into a GIS software. The zipped files can be opened in Windows Explorer or some similar extracting software such as 7-zip.

Once a location is also selected, a button will appear to download the PF data for the selected Key Duration and location (Figure 15). Two data files are delivered in a zipped set – the display table as a csv and the display graphic as a png. The zipped file is named according to the selected duration, latitude/longitude of the selected location, and date of download (e.g., *pt_pf_data_48hr_52.686N_127.658W_2020-10-1-194439.zip*)
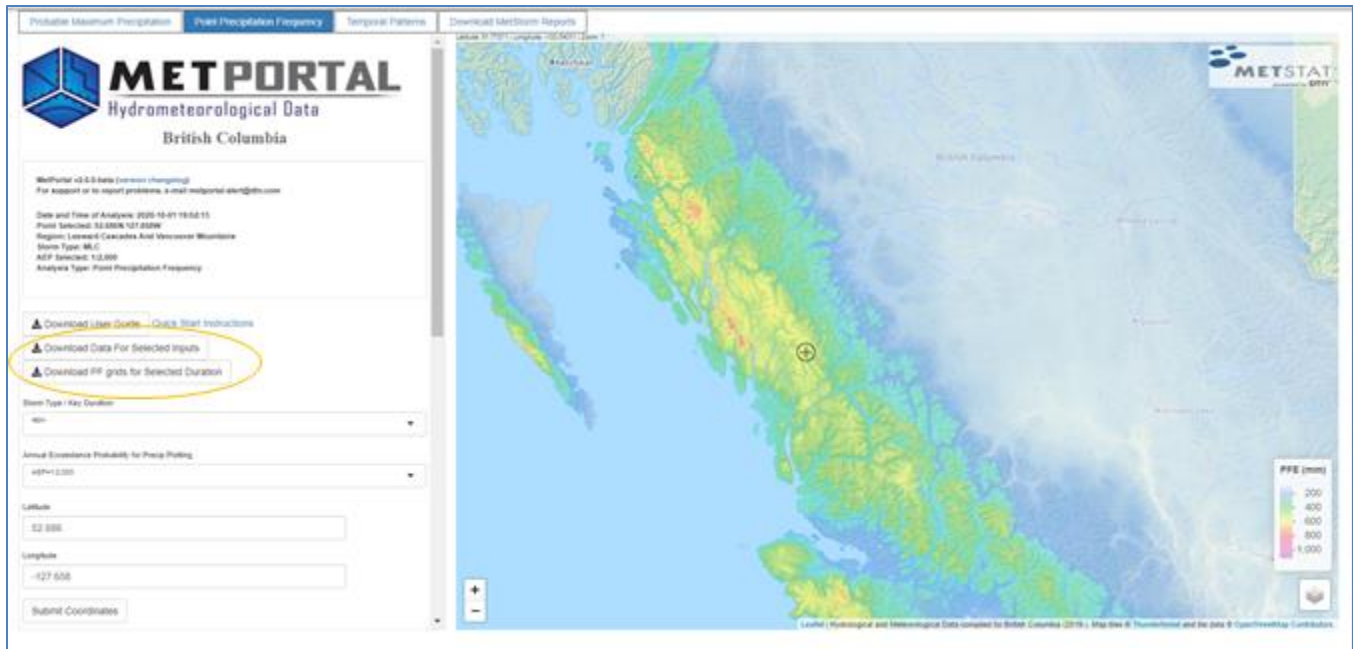
Figure 15: Buttons for downloading precipitation frequency data.

6.5.   Seasonality of PF Estimates

Seasonality is an important component when conducting stochastic flood modeling for setting antecedent conditions, such as temperature, soil moisture, snowpack, and reservoir levels. The seasonality of MLC annual maximum storms are provided in Bulletin 2020-2-RPFA: Regional Precipitation-Frequency Analysis for British Columbia – Technical Report which shows histograms of seasonality for each Macro Region demonstrating the likelihood of occurrence during each month of the year.

6.6.   Temporal Patterns for PF Estimates

Scalable temporal storm patterns are needed in conjunction with point PF relationships to translate a point precipitation magnitude at a duration of interest and AEP into meaningful input for flood modeling. Historical temporal patterns are preferred to synthetic patterns so that the flood model may reflect natural storm behavior. There is great diversity in the shape of historical temporal storm patterns with variability resulting from:

- Single and multi-pulse temporal patterns;
- Timing of the high-intensity pulse: front-loaded, middle-loaded, and back-loaded temporal patterns; and
- Magnitude and sequencing of incremental precipitation.

Each of the components above can affect the shape of the flood hydrograph and the response of the reservoir to the inflow flood. Therefore, it is prudent to examine a suite of scalable temporal storm patterns in evaluating reservoir response and spillway performance for rare to extreme floods. To provide a range of possible flood outcomes, a wide variety of storm temporal patterns for each Project Macro Region were identified from historical storms (Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report). A suite of historical storms was selected to represent each Project Macro Region (Table 6) and provide several realizations of natural storm patterns for flood modeling.

Table 6: Suite of scalable temporal storm patterns for each Project Macro Region.
Storm Number is associated with the yyyy/mm/dd/storm center zone number of the storm.

Project Macro Region	MetStorm Number	Storm Temporal Characteristic
Coastal	1950102820	Backloaded
	1990110920	Frontloaded
	1993112410	Centerloaded
	2007120310	Centerloaded
	2006110610	Backloaded
Lowland Interior	1944062610	Frontloaded
	1949021610	Centerloaded
	1963102120	Backloaded
	1964122220	Centerloaded
Interior Mountains	1955122010	Centerloaded
	1984082610	Frontloaded
	2004082210	Frontloaded
	2005060510	Backloaded
	2012062210	Frontloaded
	2013061710	Centerloaded
Hybrid	1964062810	Frontloaded
	1972072410	Frontloaded
	1986061510	Frontloaded
	1987080120	Backloaded
	2001061110	Centerloaded

6.6.1. Overview of MetPortal Temporal Patterns Tab

Select the 'Temporal Patterns' tab in the upper-left-hand corner to access the MetPortal interface to download storm temporal patterns scaled by a selected AEP (Figure 16). Latitude and longitude coordinates are necessary for the location of interest; based on these coordinates, MetPortal will automatically populate the pull-down menu for selecting a Storm of Interest from the suite of storms appropriate for that Macro Region. After accessing the 'Point Precipitation Frequency' tab, the coordinates for the selected location will automatically populate in the fields of the 'Temporal Patterns' tab which can then be entered by clicking the "Submit Coordinates" button.

The temporal storm patterns are presented as dimensionless temporal mass-curves (hyetographs) scaled by an indexing value. The index value is the point precipitation magnitude for the selected AEP at the duration of interest. To reflect the storm as it occurred, the total storm duration is not limited to the duration of interest (24-, 48-, 72-, or 96-hours), so the total duration may differ from the duration selected.
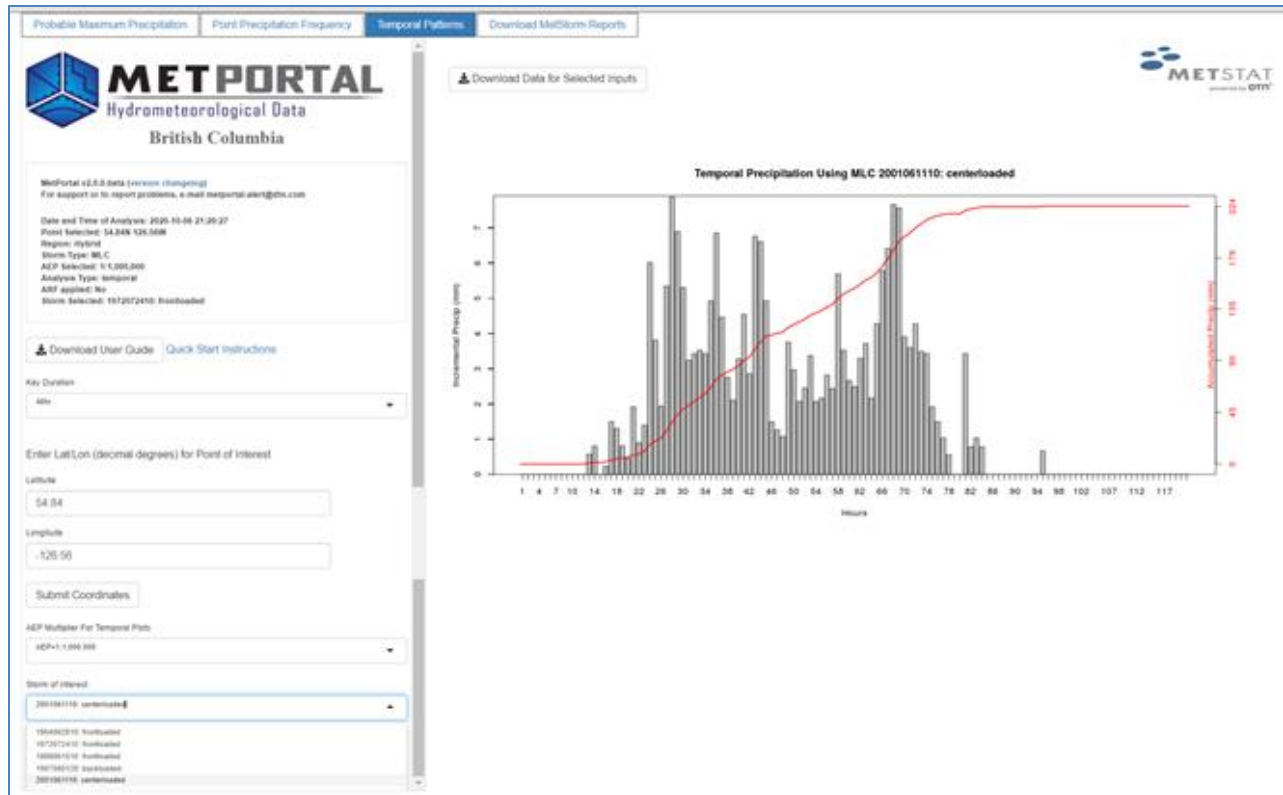
Figure 16: Overview of Temporal Patterns interface.

To obtain temporal patterns, select the Key Duration of interest and submit the latitude and longitude of the point of interest. Once both of these are entered, an AEP multiplier for the temporal plots can be selected and the storm of interest can be selected from separate pull-down lists (Figure 16). A plot of the precipitation temporal pattern for the selected storm of interest will appear. The plot shows the scale for incremental hourly precipitation (mm) on the left y-axis and accumulated precipitation (mm) through time on the right y-axis. The accumulated mass curve of precipitation is shown as a red line summing to the magnitude of the selected AEP for that point.

6.6.2. Download Temporal Patterns

Click the "Download Data for Selected Inputs" button to download a zipped set of two files for the selected storm – the display graphic as a csv and the temporal data as a csv. The csv provides a header with the metadata for the selected inputs, and the incremental and accumulated amounts for each hour of the storm scaled to the selected AEP and unscaled dimensionless factors.

7.   PF EXAMPLE CASE STUDY

The following provides an example case study to obtain precipitation frequency estimates for the 48-hour duration for Fulton Lake watershed. Fulton Lake sits within Bulkley-Nechako Regional District and ultimately feeds into Babine Lake, located within the Hybrid Macro Region. The catchment for Fulton Lake is approximately 1,400 km^2.

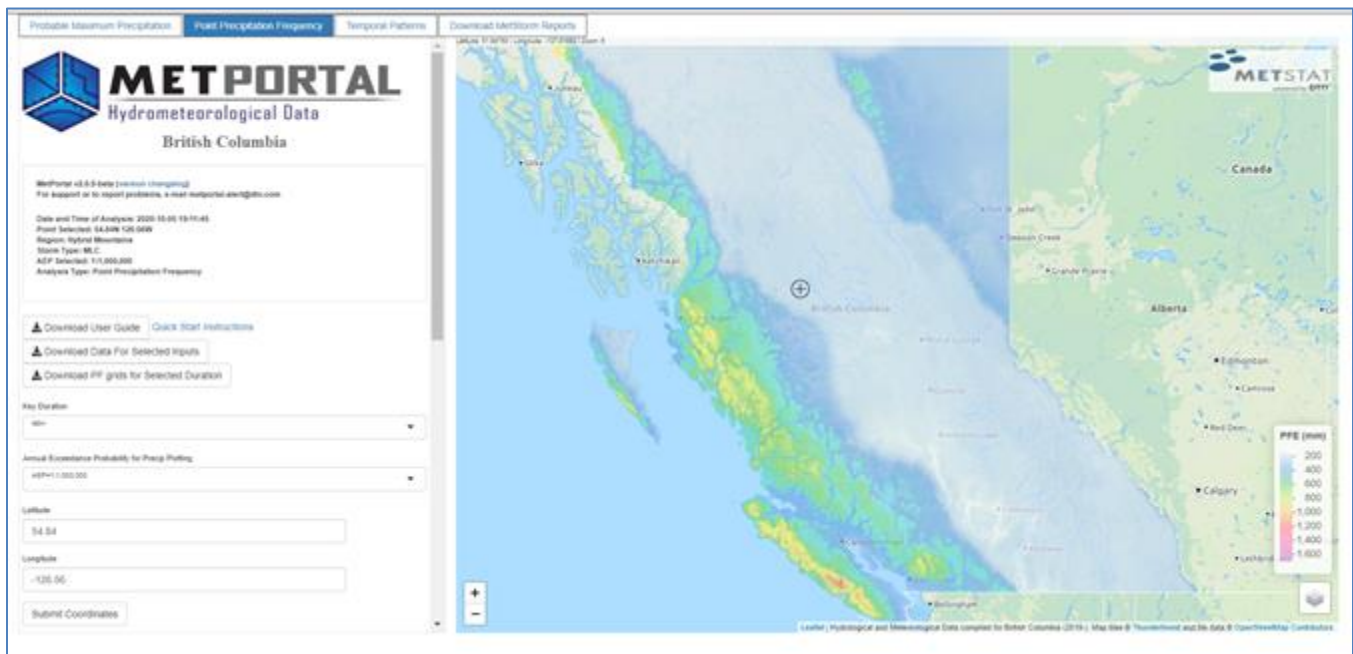|	
Step 1. Load MetPortal:	Go to https://dtn-metportal.shinyapps.io/bc_region/. Click the "Click Here to Begin" button to use the tool; select the "Point Precipitation Frequency" tab.
Step 2. Select Duration:	Select '48hr' from the Key Duration drop-down list (Figure 17).
Step 3. Select an AEP:	For display purposes, select the 1:1,000,000 AEP (Figure 17).

Figure 17: Inputs selected for point precipitation frequency estimates.

Step 3. Input coordinates:	To set a sense of the magnitudes of point precipitation for the set of AEPs within the watershed, enter the coordinates near the center of the watershed (latitude = 54.84, longitude = -126.56) and click "Submit Coordinates." A marker will appear on the map and the point PF estimates will display below (Figure 18).
Step 4. Display uncertainty bounds:	To display (and then download) 90% uncertainty bounds, click the box next to "Show 90% Uncertainty Bounds?". The upper and lower bounds will be displayed in the table and in the plot as a shaded area (Figure 18).
Step 5. Download the Point PF data:	Click the "Download Data for Selected Inputs" above the selections (Figure 17) to obtain a data table of the output for that point and selected duration – here the point is 54.84, -126.56, the duration is 48-hour. Figure 19 shows the downloaded table displayed in MS Excel with the depths rounded to the nearest mm.

Step 6. Compare the PF to PMP: Enter the approximate PMP depth of 148 (Section 4), which is for an area size of 1,000 km², in the "Probable Maximum Precipitation" field and a horizontal line at that depth will appear in the graph (Figure 18). Note that the precipitation-frequency estimates are for a point and not areally-reduced for a 1,000 km² watershed.
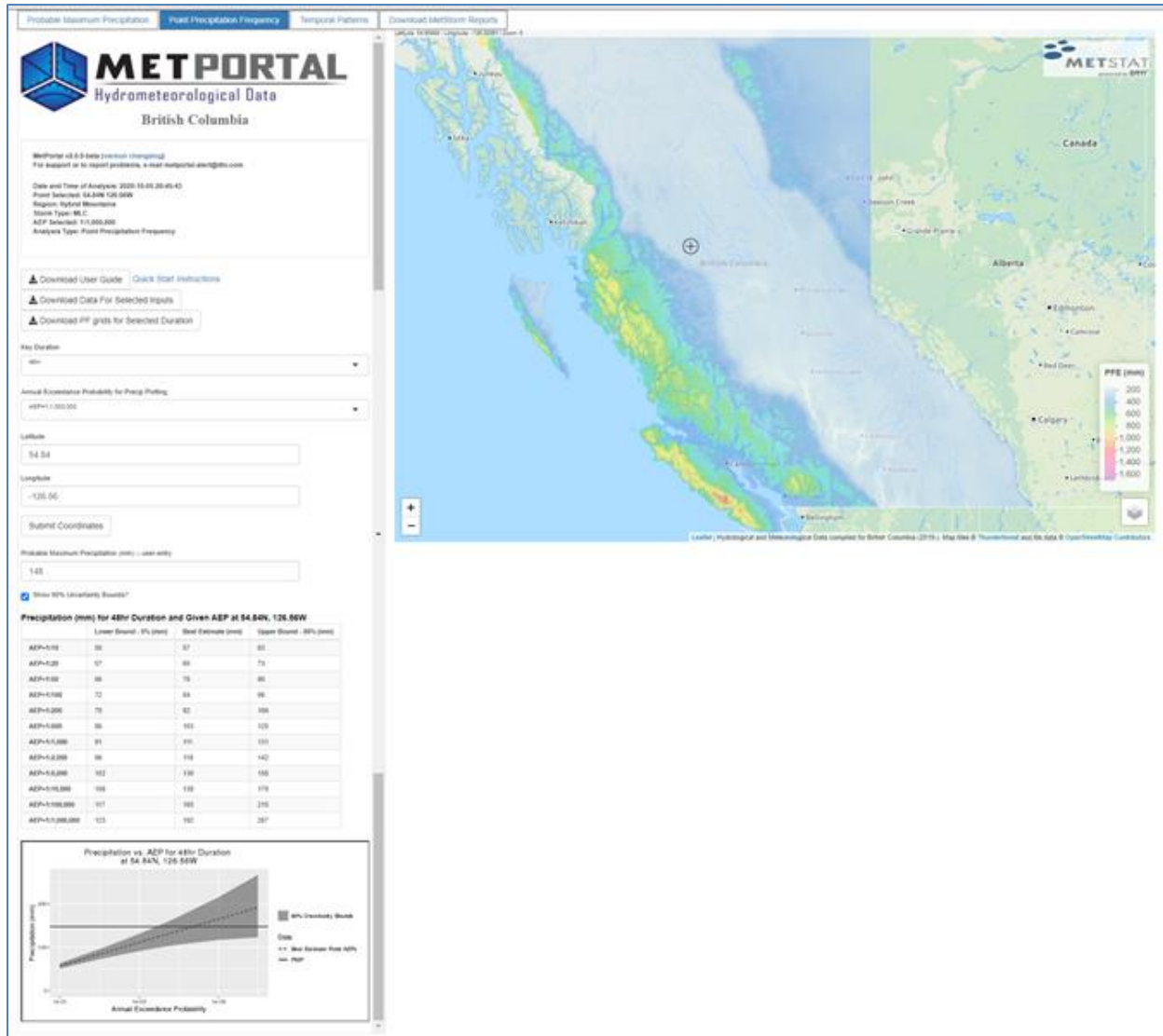

Figure 18: Display of point precipitation frequency estimates.

Figure 19: Precipitation frequency estimates for the point of interest downloaded as a csv opened in MS Excel.

Step 7. For a Watershed, Download PF GIS data: If a location/watershed of interest is larger than 10 km^2, it is necessary to convert the point estimates into an areal estimate. To facilitate an analysis of watershed precipitation-frequency, first, download the point precipitation-frequency grids by clicking "Download PF grids for Selected Duration" above the selections (Figure 17); from here, using a GIS software, compute the watershed average of the point precipitation-frequency estimates within a watershed shapefile. Next, apply an appropriate area reduction factor (ARF) to the watershed average precipitation to convert the point estimates into an areal estimate. It is important to understand the MetPortal does not provide watershed precipitation frequency estimates.

Step 8. Obtain suite of temporal patterns: If temporal patterns are necessary for hydrologic modeling, click on the "Temporal Patterns" tab. Select 48hr, in this example, as the Key Duration and click "Submit Coordinates," noting that the coordinates from the "Point Precipitation Frequency" tab have automatically populated. Select an AEP of interest (here, 1:1,000,000) for the AEP multiplier. Select a storm from the drop-down list – here a frontloaded storm that occurred on June 28th, 1964. Download the temporal data for the selected storm by clicking "Download Data for Selected Inputs" above the display of the temporal plot (Figure 20). The data are delivered in a csv (Figure 21).
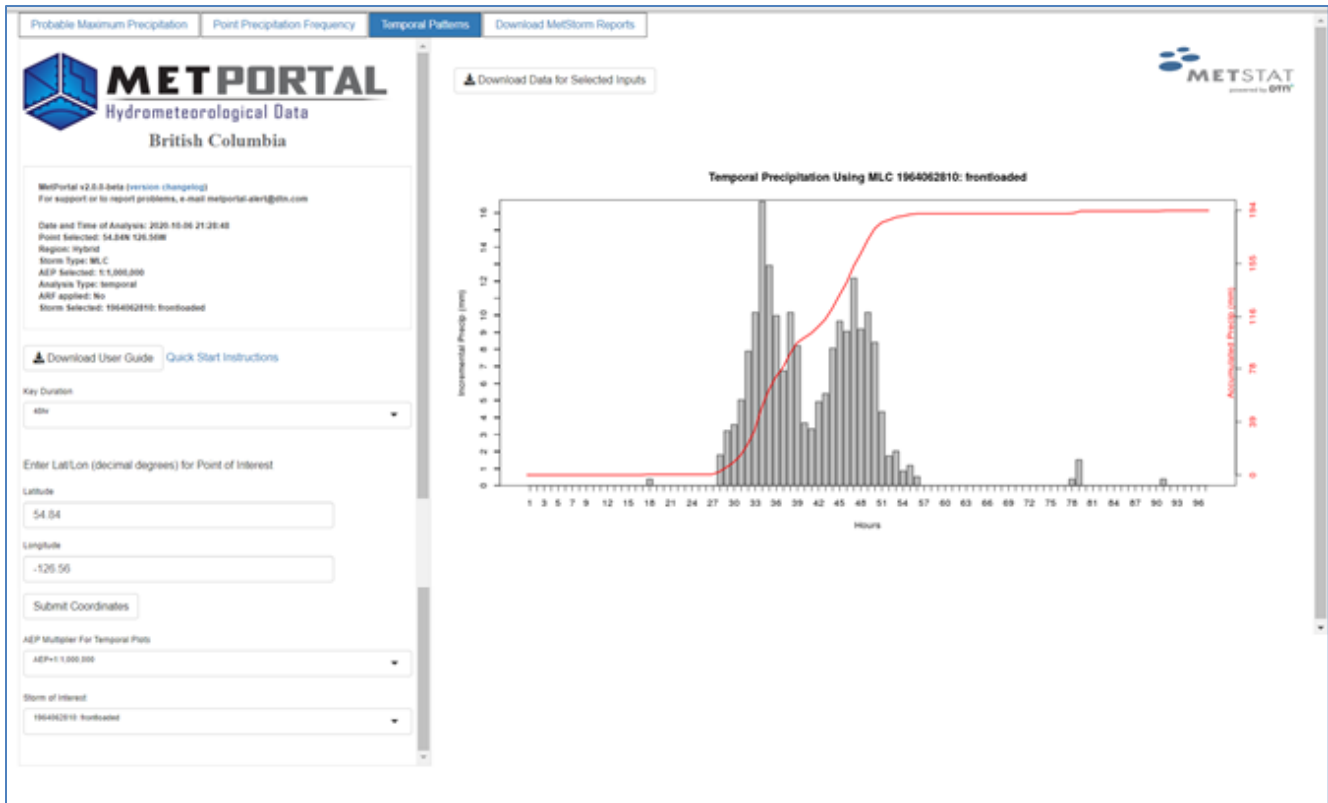
Figure 20: Selecting a temporal pattern for download.

Figure 21: Hourly temporal data for selected storm of interest downloaded as a csv opened in MS Excel.

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