Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Emergency Management BC

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BULLETIN 2020-4-PMP

British Columbia Extreme Flood Project

MetStorm Reports Used for Determining the Probable Maximum Precipitation Guidelines

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.

The Province thanks the advisory committee for their provision of technical support and review. The committee consisted of Angela Duren, US Army Corps of Engineers; Edgar Watt, Professor Emeritus, Queen's University; and Zoran Micovic, BC Hydro. The Province also thanks the consulting firms who assembled a skilled team to respond to a complex task over a relatively short time frame and provided additional out of scope material to improve the final product. The project would not have been possible without the support of Scott Morgan, Jesal Shah, and Ted White of the WMB. Assistance was also provided by several staff within FLNRORD and other provincial ministries, as well as all those who responded to the project request for information. Funding for the project was provided by Emergency Management BC and the Public Safety Canada National Disaster Mitigation Program.

Robert K McLean, M.Sc, P.Eng.

FLNRORD Senior Dam Safety Engineer and Project Manager

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PROBABLE MAXIMUM PRECIPITATION GUIDELINES FOR BRITISH COLUMBIA

BULLETIN 2020-4-PMP

METSTORM REPORTS

Prepared by:

DTN
3030 S. College Ave. Unit 207
Fort Collins, CO 80525

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ABBREVIATIONS AND ACRONYMS

The following abbreviations and acronyms are used in the MetStorm Reports.

AEP	Annual Exceedance Probability
BCHydro	BC Hydro: Electric Services Company
CAPE	Convective Available Potential Energy
CSB	Canadian Storm Books
COOP	Cooperative Observer Network
DAD	Depth-Area-Duration
EC-Vol	Environment Canada Volunteer Observer
EC-DNR	Environment Canada – Department of Natural Resources
FQPE	Final Quantitative Precipitation Estimate
GHCN	Global Historical Climatology Network
GIS	Geographic Information System
in.	inch(es)
IPMF	In-Place Maximization Factor
km	kilometer(s)
MAPE	Mean Absolute Percentage Error
mb	millibar(s)
mm	millimeter(s)
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NWS	National Weather Service
PCIC	Pacific Climate Impacts Consortium
PMP	Probable Maximum Precipitation
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RAWS	Remote Automated Weather Stations
SST	Sea Surface Temperature
WBAN	Weather Bureau Army Navy (airport observations)
WMO	World Meteorological Organization

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1 PURPOSE

This report accompanies Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report. The purpose of this report is to provide hydrologists and engineers with storm reconstruction background information (MetStorm Reports) for each storm considered in the PMP analysis. Guidance for the access, interpretation, and usage of the storm precipitation grids is provided in the Bulletin 2020-5-PMP/RPFA: MetPortal User's Guide – Probable Maximum Precipitation and Regional Precipitation-Frequency Analysis for British Columbia.

Section 2 of this report is a table that lists all the storms considered in the PMP analysis. Section 3 describes the elements of a MetStorm Report. The MetStorm Reports for each analyzed storm are available for download on the MetPortal.

2 STORMS USED TO DETERMINE PMP

A total of 44 storms were considered in the PMP analysis for British Columbia (Table 1). The MetStorm Reports for all these storms are available for download on the MetPortal.

Table 1: Storms considered in the PMP analysis.

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
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

Storm Number	Storm Name	Storm Date
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

3 ELEMENTS OF A METSTORM REPORT

A MetStorm Report is a document that contains all the background information associated with a storm reconstruction using MetStorm®. Overall, the intention of a Storm Report is to inform users of the data inputs, and limitations thereof, that underpin a MetStorm analysis. The MetStorm Reports include:

- A pertinent data table with the storm name and storm number, date, general location, storm analyst, version of MetStorm, and pertinent notes;
- Brief storm discussion (Section 3.1);
- Notable storm reports (Section 3.2);
- Basemap (Section 3.3);
- Data sources (Section 3.4);
- In-Place Maximization Factor (IPMF) analysis (Section 3.5);
- Error statistics (Section 0);
- Confidence in results (Section 3.7);
- Multiple storm centers (Section 0); and
- Transposition limits (Section 3.9).

3.1 Storm Discussion

The MetStorm Reports begin with a summary of the synoptic conditions that generated the storm event. This includes an overview of the moisture conditions and locations of low pressure centers, troughs, and other synoptic features. Weather maps may be provided to illustrate the atmospheric conditions during the event.

3.2 Notable Storm Reports

This is an optional section, and its inclusion is dependent upon the availability of historical records associated with the storm event. Here, the source of historical records is provided, and important figures from the record may be reproduced, including isohyetal maps and mass curves. A discussion of the veracity of the historical record may also be presented.

3.3 Basemap

Basemaps are independent grids of spatially distributed weather or climate variables that are used to govern the spatial patterns of the hourly precipitation, particularly in areas where radar is either not available or of poor quality. The basemap provides a stable and spatially consistent reflection of how the precipitation may fall over a region. For MetStorm analyses over complex terrain, climatological basemaps, such as mean monthly precipitation or precipitation-frequency grids, are often used given they resolve inherent orographic enhancement and micro-climates. Climatological basemaps in flat terrain, however, are not as effective given the weak precipitation gradients; therefore, in these cases, basemaps are often developed from pre-existing (hand-drawn) isohyetal patterns, independently-created radar-estimated storm totals, the summation of daily precipitation grids or individual monthly (e.g., March 2013) PRISM precipitation grids available online. In this section, the source and basemap used in the analysis will be given, and an explanation for the basemap selection will be provided. The quality of the basemap may be discussed.

3.4 Data Sources

MetStorm analyses are driven by a wide variety of precipitation gauge (station) data and other rainfall reports. In this section, the sources of these station data or other reports are provided and the quantity of each type of precipitation station used in the analysis is given. The station types are as follows:

- Hourly: stations that report precipitation on an hourly basis. These stations dictate both the hourly breakdown of precipitation in their immediate vicinity and the calculated storm total precipitation at their location.
- Hourly timer: stations that report precipitation on an hourly basis, but the precipitation magnitudes are not factored into the storm magnitude at their location. These are generally stations that are closely located to daily or auxiliary stations with greater precipitation totals (it is common for hourly stations to slightly under report precipitation magnitude compared to daily stations due to factors such as wind under-catch).
- Daily: stations that report precipitation once per day, at a standardized time.
- Auxiliary: stations that report precipitation at an irregular time period, such as the storm period or for a defined portion of the storm. These stations are generally from the public or previous storm analyses.

In some cases, anecdotal information from independent storm reports provide ranges of precipitation over a particular area without specific geographic coordinates (e.g., up to 400-mm in the mountains east of Vancouver). For these cases, estimated virtual stations are added to the analysis to anchor precipitation in these locations without true stations.

Additionally, the source of each precipitation station used in the analysis is listed. A list of the most common station data sources is found in Table 2. If applicable, other sources used in a MetStorm analysis are listed in the individual MetStorm report.

Lastly, data quality concerns and limitations relevant to the storm magnitude are discussed in this section.

Table 2: Station data sources.

Abbreviation	Description
BCASWS	BC Data Catalogue (BC Automated Snow and Weather Stations)
BCHydro	BC Hydro: Electric Services Company
CoCoRaHS	Community Collaborative Rain, Hail & Snow network
COOP	Cooperative Observer network
ECCC	Environment and Climate Change Canada
EC-Vol	Environment Canada Volunteer observer
EC-DNR	Environment Canada – Department of Natural Resources
GHCN	Global Historical Climatology Network
NADP	National Atmospheric Deposition Program
NCDC	National Climatic Data Center
NCEI	National Centers for Environment Information
NWS	National Weather Service
PCIC	Pacific Climate Impacts Consortium
PRISM	Parameter-elevation Regressions on Independent Slopes Model
RAWS	Remote Automated Weather Stations
Snotel	Snowpack Telemetry
USACE	US Army Corps of Engineers
USBR	United States Bureau of Reclamation
USGS	U.S. Geological Survey
WBAN	Weather Bureau Army Navy (airport observations)

3.5 In-Place Maximization Factor Analysis

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).

This section presents the calculations to determine the IPMF, a ratio of the moisture associated with the climatological maximum to the observed moisture associated with the storm. A moisture maximized storm assumes the same atmospheric dynamics and precipitation timing as the observed storm but scales the precipitation upwards.

The steps associated with moisture maximization may be summarized as follows. Note that if an IPMF was calculated and approved during a prior study, then the IPMF value from that study was adopted here. The study from which it was adopted is cited.

1. The coordinates and elevation of the storm center are determined, where the storm center is the location where the greatest amount of total storm precipitation occurred. This information is provided in a table of pertinent IPMF summary information. Also supplied in this table is the onset

and duration of the maximum precipitation period and direction and speed of the storm moisture inflow vector.

2. A back-trajectory analysis, which shows the path of the air parcels at the storm center from the onset of the maximum precipitation period backward for a specified length of time. A figure is shown depicting the back-trajectory analysis.
   - For post-1948 events, the HYSPLIT model is used to determine the back-trajectory analysis (Stein et al., 2015; Rolph, 2017).
   - For pre-1948 events, the back-trajectory is estimated from reanalysis weather maps.

3. The back-trajectory analysis is used to determine the storm representative dewpoint location, a point location that is outside of the storm precipitation at a distance that allows for the greatest moisture available to be processed by the storm (Cudworth, 1989). The storm representative dewpoint location is labeled on the back-trajectory figure.

4. At this location, the observed moisture associated with the storm, reported as dewpoint temperature, is found. The storm representative dewpoint temperature is calculated from 20th Century Reanalysis data (Compo et al., 2011). A table is included that provides the latitude, longitude, and elevation of the storm representative dewpoint location and the storm representative dewpoint temperature, reduced adiabatically from the elevation at the storm representative dewpoint location to 1000-mb at zero height. If the storm representative dewpoint location was over the ocean, then the reduction in elevation was near zero.

5. Another table of pertinent information is provided, which includes the climatological maximum dewpoint temperature (progressed 15-days into the warm season) at the storm representative dewpoint location. This is found from 100-year monthly maximum 12-hour average dewpoint temperature maps (may be found in Bulletin 2020-3-PMP: Probable Maximum Precipitation Guidelines for British Columbia – Technical Report). The climatological maximum dewpoint temperature is also reduced adiabatically from the elevation at the storm representative dewpoint location to 1000-mb at zero height.

6. The table also includes the reduced storm representative dewpoint temperature and reduced climatological maximum dewpoint temperature converted to precipitable water at 1000-mb and precipitable water at the elevation of the storm center location. Total precipitable water is the total atmospheric water vapor "contained in a column of unit cross section extending all of the way from the earth's surface to the 'top' of the atmosphere" (American Meteorological Society, 2020). This extra step translates the dewpoint temperature information at the storm representative dewpoint location to the storm center location.

7. The IPMF is also included in the table. This is calculated as the ratio of the climatological maximum precipitable water divided by the observed precipitable water (Equation 1).
   - If the resulting IPMF if greater than 1.50, then the IPMF is set to 1.50, as it is generally assumed that changing atmospheric moisture content by more than 50% would have the effect of significantly altering atmospheric dynamics.

$$IPMF = \frac{PW_{Td_{max}}}{PW_{Td_{obs}}}$$

Equation 1: IPMF, where $PW_{Td_{max}}$ *is the precipitable water for the maximum average dewpoint temperature from monthly climatology, and* $PW_{Td_{obs}}$ *is the precipitable water for the storm representative dewpoint temperature.*

3.6 Error Statistics

To evaluate the performance of the spatial interpolation technique used to derive and interpolate total storm precipitation values in MetStorm, a jackknife cross-validation technique is used. This method of validation resamples the data to understand how the results vary with and without a specific station included in the analysis. The cross-validation results reflect the accuracy of the derivation and interpolation procedure. Typically, every station is subject to the jackknife cross validation test, unless a prohibitively large number of stations were used in the analysis (multiple thousands).

The output from the jackknife cross-validation is summarized into mean bias and mean absolute percentage error (MAPE) statistics. The mean bias represents the average difference in the total storm value between the MetStorm analysis and the observed data. A positive bias signifies that the MetStorm analysis was estimating higher magnitudes than the observed values of precipitation, and a negative bias means the MetStorm analysis was estimating lower than the observed data. MAPE (Equation 2) represents how well MetStorm predicted the total storm precipitation at each station location (as a percentage of the observed value) in the station's absence. MAPE is a common measure of an analysis's predictability and functions best when there are no extremes in the data, otherwise small values amplify the percentages and distort the MAPE.

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{O_t - M_t}{O_t}\right|$$

Equation 2: MAPE, where O_t is observed precipitation, M_t is MetStorm Precipitation, t is an individual station, and n is the number of stations.

Both the mean bias and MAPE error statistics are summarized in a table in this section.

In addition to the jackknife error statistics, the quality of a MetStorm analysis can be assessed by comparing the observed gauge data to the analyzed MetStorm precipitation values. This assessment is summarized in this section in a gauge-versus-FQPE (final quantitative precipitation estimate) scatterplot. The figure includes a correlation between the observed gauge data (i.e., the 'ground truth') and the co-located MetStorm gridded values with a best fit line (which can be compared to a "perfect" 1:1 line). Correlations are expected to be quite high, often in excess of 0.9 and usually approaching one. However, the inclusion of a number of stations whose reporting periods do not cover the entire analysis time period (e.g., local storm reports covering just a couple of days out of a 4-day event) results in a number of stations being infilled, which has the effect of lowering the correlation and skewing the best fit line. Such cases are discussed in the 'Confidence in Results' section when relevant.

3.7 Confidence in Results

In this section, a brief discussion of the factors that affect the overall confidence in the quality and reliability of the analysis is offered. This could include concerns about a storm report, stations with limited temporal coverage, and uncertainty about precipitation timing. Additionally, comparisons to any prior notable historical storm report(s) will be included.

3.8 Multiple Storm Centers

Some storms are quite large in spatial extent and have more than one storm center. If a storm is divided into multiple storm centers (i.e., storm center zones), the rationale for the division will be included in this section. A map that shows the boundaries of each storm center will also be shown. Conversely, a brief statement will be included here if multiple storm centers are not necessary.

Each storm center zone is addressed individually and given a name based on the location of the point of maximum total precipitation. Several graphical outputs from MetStorm are shown for each storm center, including:

- the total storm precipitation map for the area of the storm center,
- the mass curve plot (which displays both incremental and total precipitation for the storm period),
- the depth-area-duration (DAD) plot, and
- a figure showing the time-series of the 1000-mb temperature and freezing level height for the duration of the storm at the point of maximum total precipitation.

Additionally, maps illustrating the 24-, 48-, 72-, and 96-hour total maximum precipitation are shown for each storm center zone. Moreover, maps of the associated annual exceedance probability (AEP) for the total maximum precipitation at each duration of interest are provided. These maps were created using the regional precipitation-frequency statistics calculated from the coincident study, Bulletin 2020-2-RPFA: Regional-Precipitation Frequency Analysis for British Columbia – Technical Report. These figures are relevant because they show the storm spatial pattern, magnitude of precipitation, and spatial distribution of AEP values.

Lastly, a table with the coordinates for the locations of maximum precipitation and rarest precipitation for each duration of interest is provided. At times, these two points have the same coordinates; however, precipitation that is less than the magnitude of the point maximum precipitation can have a rarer AEP due to the climatology and/or topography of its location. The location with the rarest precipitation for each duration of interest is needed for the transposition process.

3.9 Transposition Limits

For transposition, each storm center zone is treated independently. As such, each storm center zone has its own transposition region, an area where a storm could have theoretically occurred and is climatologically and topographically similar to the area where the storm originally occurred. In this section, the rationale for the storm center zone's transposition limits is discussed, and a map of the transposition region is provided.

For all storm centers, an initial assessment of the transposition region was found based on elevation. The area in the corresponding Project Macro Region that was within +/-300-m of the elevation of the storm center zone was identified. Using this initial area, the storm transposition region was refined for areas of upslope flow, where mountain barriers did not block the flow of moisture, and there was potential for enhancement to the storm's moisture. Areas in neighboring Project Macro Regions were then considered for inclusion in the storm transposition region. Lastly, using meteorological judgement of weather patterns, moisture sources, and geographic barriers, the borders of the storm transposition regions were smoothed and broadened to ensure that the entirety of British Columbia was covered.

REFERENCES

American Meteorological Society, cited 2020: Precipitable water. Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Precipitable_water].

Compo, G.P., J.S. Whitaker, P.D. Sardeshmukh, N. Matsui, R.J. Allan, X. Yin, B.E. Gleason, R.S. Vose, G. Rutledge, P. Bessemoulin, S. Brönnimann, M. Brunet, R.I. Crouthamel, A.N. Grant, P.Y. Groisman, P.D. Jones, M. Kruk, A.C. Kruger, G.J. Marshall, M. Maugeri, H.Y. Mok, Ø. Nordli, T.F. Ross, R.M. Trigo, X.L. Wang, S.D. Woodruff, and S.J. Worley, 2011: The Twentieth Century Reanalysis Project. Quarterly J. Roy. Meteorol. Soc., 137, 1-28. DOI: 10.1002/qj.776 Free and Open Access.

Cudworth, A.G., Jr., 1989: Flood Hydrology Manual, United States Government Printing Office, Denver, CO.

Melone, A.M., 1985: Flood Producing Mechanisms in Coastal British Columbia, Canadian Water Resources Journal, 10:3, 46-64, doi: 10.4296/cwrj1003046.

Rolph, G., A. Stein, and B. Stunder, 2017: Real-time environmental applications and display system: READY. Environmental Modelling & Software, **95**, 210-228,
https://doi.org/10.1016/j.envsoft.2017.06.025
http://www.sciencedirect.com/science/article/pii/S1364815217302360

Septer, D., 2007: Flooding and Landslide Event Northern British Columbia 1820-2006, published by the B.C. Ministry of Environment.

Stein, A.F., R.R. Draxler, G.D. Rolph, B.J.B. Stunder, M.D. Cohen, and F. Ngan, 2015: NOAA's HYSPLIT atmospheric transport and dispersion modeling system, Bull. Amer. Meteor. Soc., **96**, 2059-2077, http://dx.doi.org/10.1175/BAMS-D-14-00110.1

World Meteorological Organization (WMO), 2009: Manual for Estimation of Probable Maximum Precipitation, Operational Hydrology Report No 1045, WMO, Geneva, 259 pp.