Overview on strategies and adaptation to climate change in North America

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Flood hazard

Design floods for High Potential Impact Classification dams

- Typically, in the order of 10,000-year annualized return period event, or Probable Maximum Flood (PMF)

- These are extremely large floods and their estimates come with high uncertainty *(there are many contributors to this uncertainty with changing climate being one of them)*

- A reasonable measure of uncertainty associated with estimating extreme floods could be obtained from analyzing uncertainty of Probable Maximum Precipitation (PMP), which is the main component/input of most extreme floods

Uncertainty in PMP

Background

- Due to its definition as physical upper limit, the concept of Probable Maximum Precipitation (PMP) is often believed to provide absolute safety with no probability of exceedance:
  - Zero hydrometeorological risk - Not true!
  - Theoretical PMP cannot be computed directly
  - Operational PMP estimates are developed through stepwise procedures that require significant degree of subjective professional judgment
- Operational PMP estimates are lower than the theoretical upper limit by some variable amount that depends on:
  - Available storm data
  - Chosen methodology
  - Analyst’s approach to deriving the estimate

Consequently…

The exceedance probability of a PMP is greater than zero and could be relatively high in some cases.

Variables influencing PMP estimate

- The overall weather conditions producing the precipitation for general and local storms
- Available atmospheric moisture for given location and time-of-year
- Temporal and spatial variation of atmospheric moisture during storm activity
- Method for in-place moisture maximization
- Estimation of “storm center” and precipitation magnitude at storm center
- Storm efficiency in the controlling storm relative to maximum storm efficiency
- Horizontal transposition of moisture for controlling storms
- Path of the storm through the location(s) of interest
- Positioning of the transposed storm over the watershed of interest
- Freezing level over the basin
- Modelling method (e.g., Storm Separation Method, Isopercental, others)
- Methods employed in developing temporal and spatial distributions of PMP

PMP estimates are highly uncertain

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Uncertainty analysis for Probable Maximum Precipitation estimates

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A R T I C L E   I N F O

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S U M M A R Y

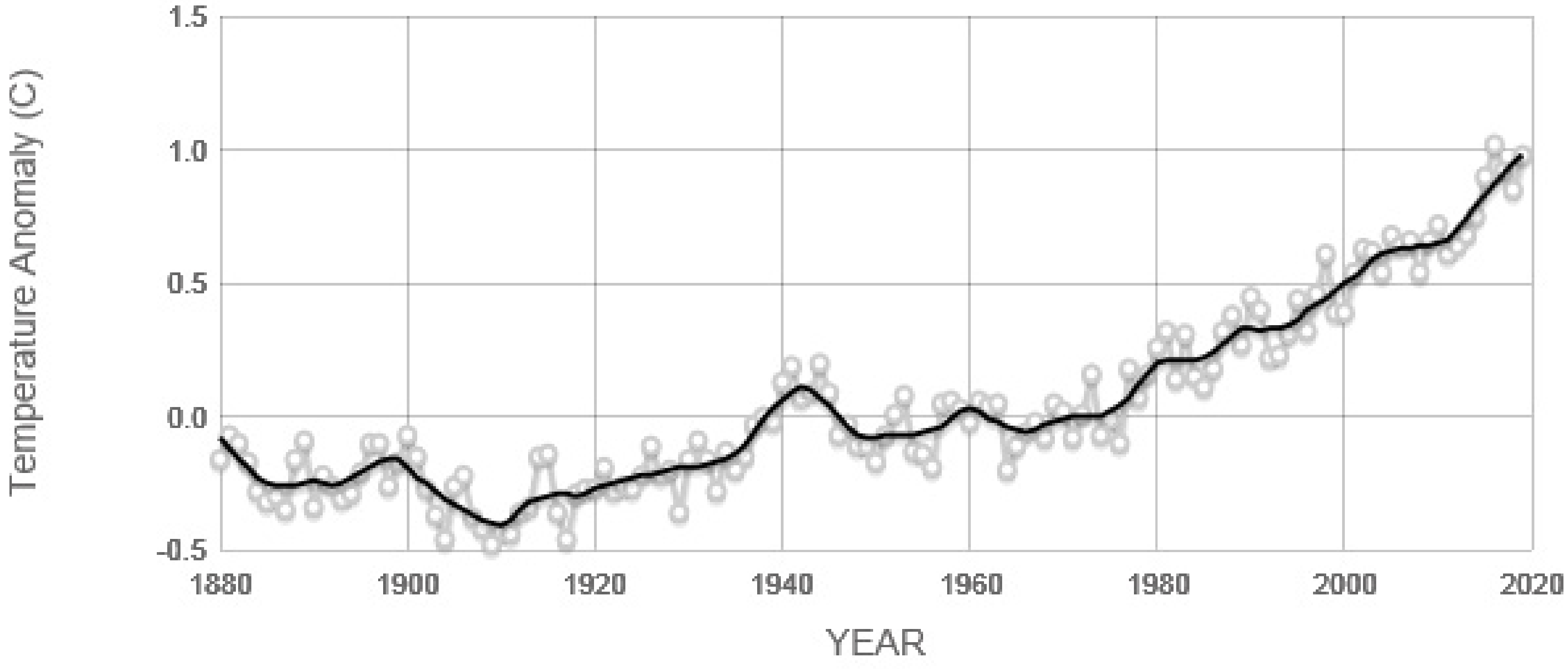
An analysis of uncertainty associated with Probable Maximum Precipitation (PMP) estimates is presented. The focus of the study is firmly on PMP estimates derived through meteorological analyses and not on statistically derived PMPs. Theoretical PMP cannot be computed directly and operational PMP estimates are developed through a stepwise procedure using a significant degree of subjective professional judgment. This paper presents a methodology for portraying the uncertain nature of PMP estimation by analyzing individual steps within the PMP derivation procedure whereby for each parameter requiring judgment, a set of possible values is specified and accompanied by expected probabilities. The resulting range of possible PMP values can be compared with the previously derived operational single-value PMP, providing measures of the conservatism and variability of the original estimate. To our knowledge, this is the first uncertainty analysis conducted for a PMP derived through meteorological analyses. The methodology was tested on the La Joie Dam watershed in British Columbia. The results indicate that the commonly used single-value PMP estimate could be more than 40% higher when possible changes in various meteorological variables used to derive the PMP are considered. The findings of this study imply that PMP estimates should always be characterized as a range of values recognizing the significant uncertainties involved in PMP estimation. In fact, we do not know at this time whether precipitation is actually upper-bounded, and if precipitation is upper-bounded, how closely PMP estimates approach the theoretical limit.

It is reasonable to conclude…

- There is high uncertainty in PMP estimation using standard hydrometeorological practices
- PMP, often reported as a single number, is best characterized as a range of values
- Could climate change effect be contained within this (already large) uncertainty?
- In fact, we do not know whether precipitation is actually upper-bounded, and if it is, how closely PMP estimates approach the upper limit

Climate change implications

Change in global temperature relative to 1951-1980 average temperature

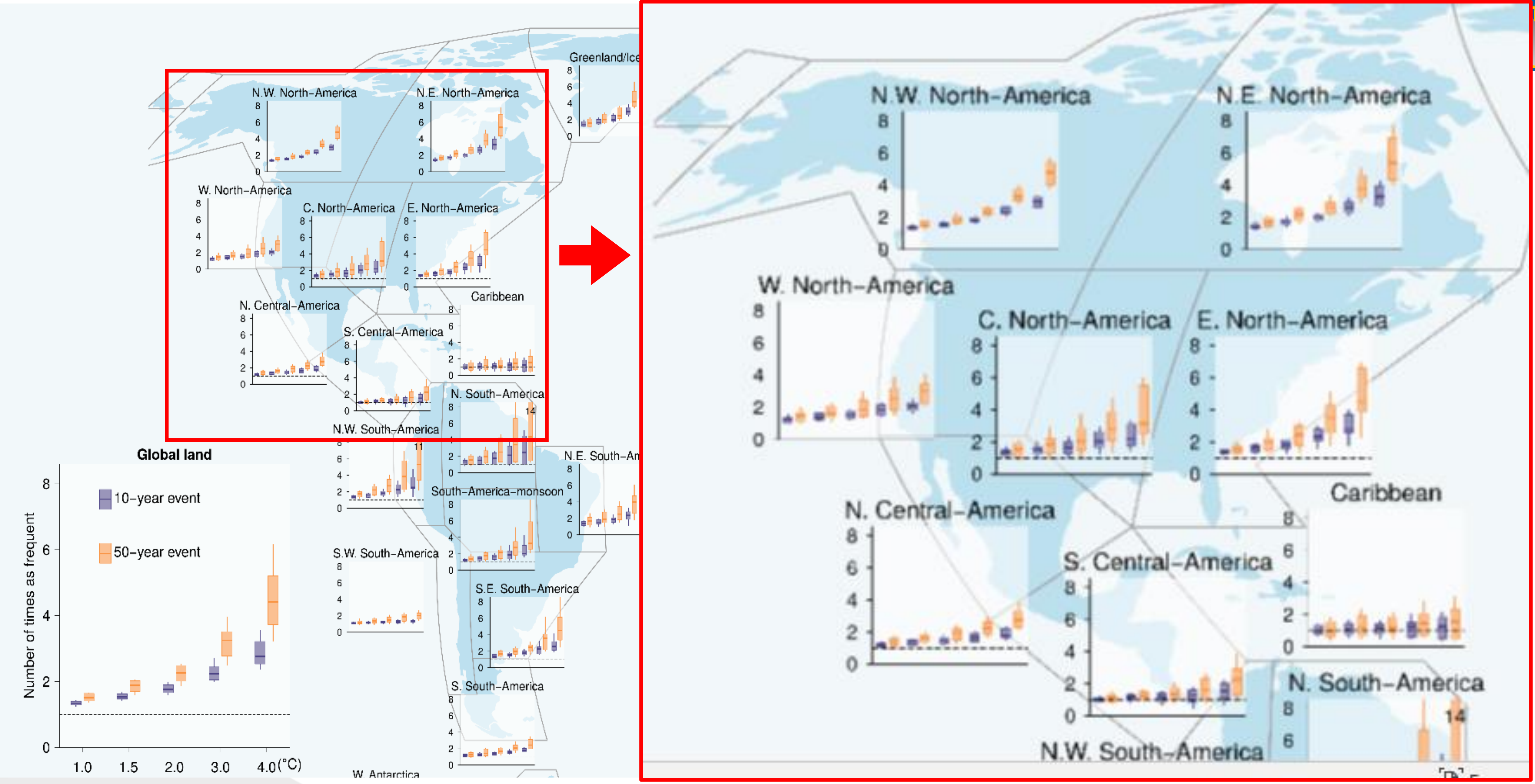


Source: climate.nasa.gov

Climate change and PMP

- Brings additional component of uncertainty to the PMP estimation process
- It’s nearly certain that it will be warmer, and the future will have higher atmospheric moisture content and higher levels of moisture transport into storms – some argue that will lead to increases in PMP
- It could also be argued that atmospheric mechanism (i.e., combination of various factors/inputs) leading to the extreme PMP storm is so unlikely and unique that it could occur at any point in time, regardless of any change in climate
- If, for example, a 100-year storm becomes a 25-year storm, would this affect the entire frequency distribution including its upper tail where extreme events are (i.e., would 10,000-year storms be affected)?
- And do we currently even have sufficient data to reliably determine the effects on such rare quantiles?

Projected changes in the frequency of 10-yr and 50-yr precipitation under 1, 1.5, 2, 3, and 4°C global warming relative to the 1951-1990 baseline *(Chapter 11, IPCC AR6 WGI report, Aug 2021)*

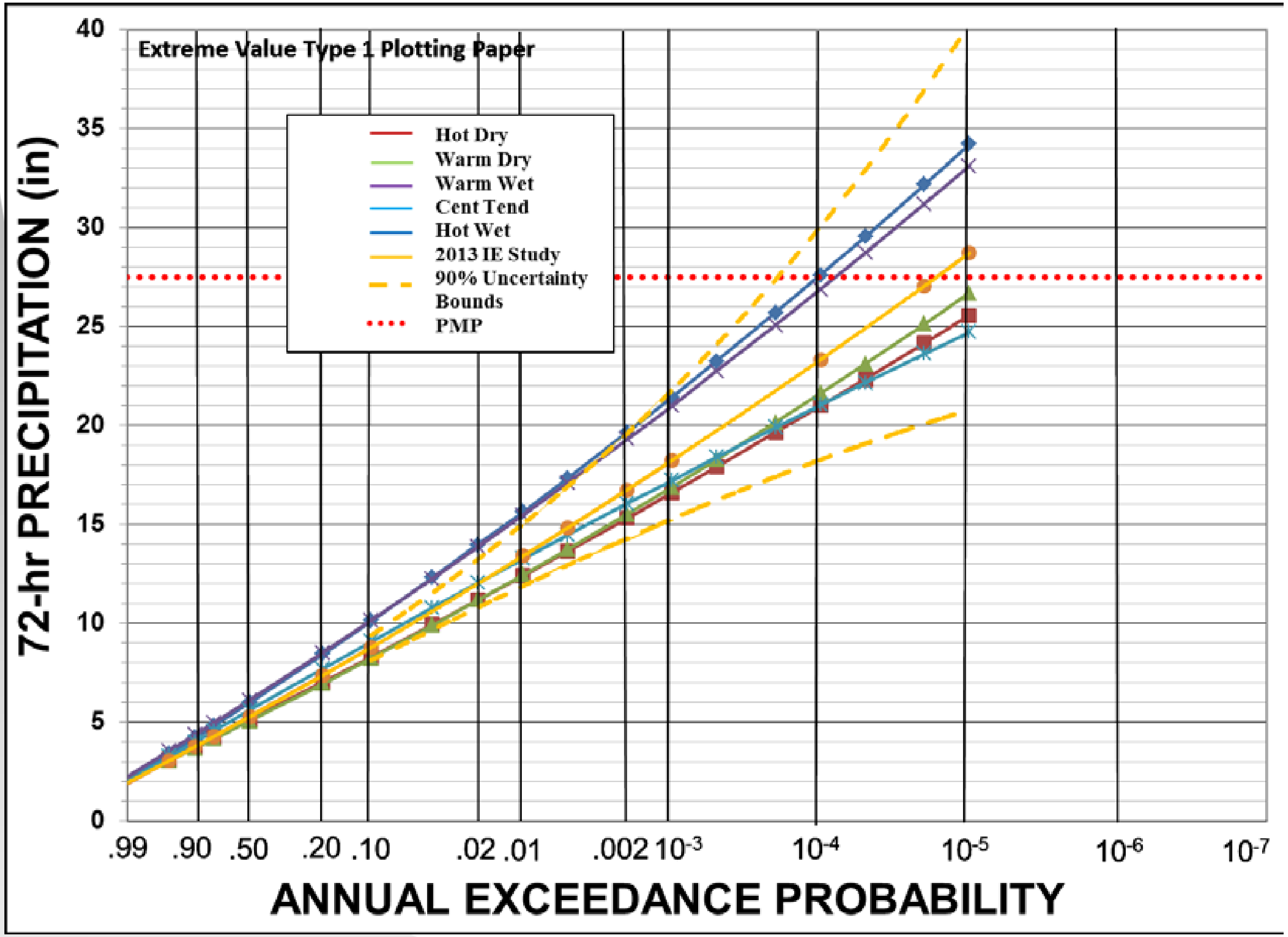


Formal guidance?

- There is a lot of ongoing research, but currently no clear and specific way to address the issue of climate change as it affects extreme floods used in dam safety applications (i.e., PMP, PMF, 10,000-yr flood)
- As the scientific understanding of climate change effects on extreme precipitation/floods is growing, some dam owners, regulators and professional associations are trying to adapt/modify the existing practices for extreme (design) flood estimation and their application in risk assessment

Attempts to address climate change in flood hazard applications

USBR pilot study 2014 (Friant Dam, CA)



- Comparison with the precipitation-frequency relationship and 90% uncertainty bounds from the 2013 flood frequency study.
- All climate change scenarios are within 90% uncertainty range of the original study.

USBR Best Practices (July 2019)

From “Hydrologic Hazard Analysis” (Chapter B-1):

- *“Uncertainty estimates for hydrologic hazard curves may include relevant climate change information, as appropriate. This is an active area of research in flood hydrology, and* ***guidance on specific methods and applications is not yet available.*** *Reclamation has completed several pilot projects on the use of climate information in dam safety hydrologic hazard studies.”*

- *“Current Reclamation policy is to consider climate change information as part of adaptation, resilience, and infrastructure reliability in planning studies, including dam safety.”*

US Army Corps of Engineers

DESIGN RECOMMENDATIONS | PROJECT MANAGEMENT - O & M | FEDERAL FACILITY CRITERIA | CONTINUING EDUCATION | ADDITIONAL RESOURCES

DEPARTMENT OF DEFENSE / ENGINEERING AND CONSTRUCTION BULLETINS (ECB) / USACE ECB 2018-14 GUIDANCE FOR INCORPORATING CLIMATE CHANGE IMPACTS TO INLAND HYDROLOGY IN CIVIL WORKS STUDIES, DESIGNS, AND PROJECTS -- CATEGORY: GUIDANCE

USACE ECB 2018-14 Guidance For Incorporating Climate Change Impacts To Inland Hydrology In Civil Works Studies, Designs, And Projects -- Category: Guidance

Date: 09-10-2018

Change / Revision Date: 09-10-2020

Status: Active

This Engineering and Construction Bulletin (ECB) reissues and updates the policy in ECB 2016-25 (reference a), Guidance for Incorporating Climate Change Impacts to Inland Hydrology in Civil Works Studies, Designs, and Projects. This ECB is effective immediately and applies to all hydrologic analyses supporting planning and engineering decisions having an extended decision time frame (i.e., not for short-term water management decisions). It provides guidance for incorporating climate change information in hydrologic analyses in accordance with the USACE overarching climate preparedness and resilience policy and ER 1105-2-101 (reference l) . This policy requires consideration of climate change in all current and future studies to reduce vulnerabilities and enhance the resilience of communities. Hence, consideration of climate change should occur early enough in the SMART planning process to inform plan formulation, evaluation, and selection of the tentatively selected plan.

Related Links

- Non-Government Standards (Limited Access)
- Military Standards: ASSIST database
- Corrosion Prevention & Control (CPC) Source
- Tri-Services Building Technology Vendor Portal
- Tri-Services Sustainability Program

Click an agency logo below for

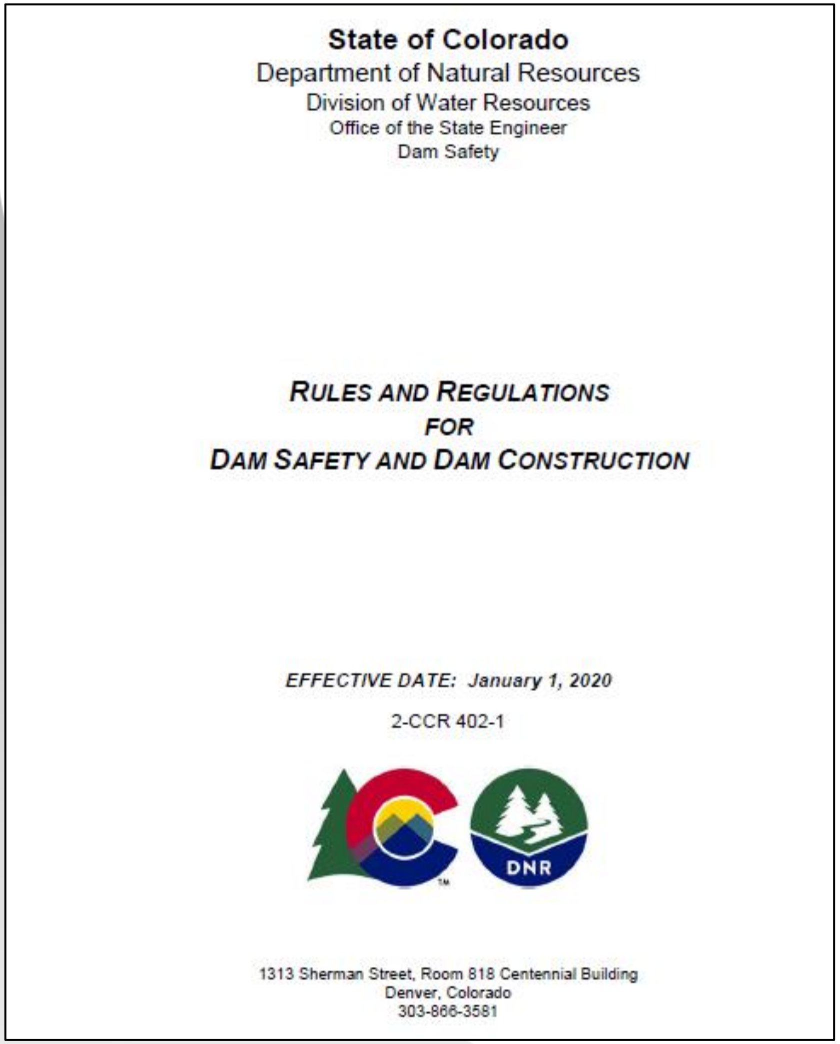
US Army Corps of Engineers

- *"The objective of this ECB is to enhance USACE climate preparedness and resilience by incorporating relevant information about observed and expected climate change impacts in hydrologic analyses for planned, new, and existing USACE projects."*

- *"The qualitative analysis required by this ECB should focus on those aspects of climate and hydrology relevant to the project's problems, opportunities, and alternatives, and include consideration of both past (observed) changes as well as projected, future (modeled) changes."*

- ***"At the time of issuance of this ECB (September 2020), the qualitative analysis is not expected to alter the numerical results of the calculations made for the other, non-climate aspects of the required hydrologic analyses."***

State of Colorado



State of Colorado
Department of Natural Resources
Division of Water Resources
Office of the State Engineer
Dam Safety

RULES AND REGULATIONS
FOR
DAM SAFETY AND DAM CONSTRUCTION

EFFECTIVE DATE: January 1, 2020

2-CCR 402-1

DNR

1313 Sherman Street, Room 818 Centennial Building
Denver, Colorado
303-866-3581

- Colorado-New Mexico regional Precipitation Study (2018) was an example of “what if” scenario when potential effects of changing climate on future extreme precipitation was evaluated.

- The updated Colorado dam safety guidance (Section 7.2.4) contains “Atmospheric Moisture Factor”:

  “All rainfall depth estimates calculated by means acceptable to the State Engineer ***shall be multiplied by a factor of 1.07*** *prior to calculating runoff to account for expected increases in temperature and associated increases in atmospheric moisture availability over the 50-year period 2020 to 2070.”*

Recall the Clausius–Clapeyron relation, according to which the water-holding capacity of the atmosphere increases by about 7% for every 1 °C (~2 °F) increase in air temperature

US National Academies of Science, Engineering, and Medicine – PMP Modernization Project

- The current approach to the PMP estimation is outdated
- The study committee was established earlier this year
- The aim of the study is to consider approaches for estimating PMP in a changing climate, with the end goal of recommending an updated approach, appropriate for decision-maker needs that incorporates the impacts of climate change and the characterization of uncertainty
- The Committee will make recommendations for the development of an updated approach that can serve as a US national standard for estimating probable maximum precipitation in a changing climate

Canada

- Engineering profession regulatory body in the province of British Columbia has released new practice guidelines on dam hydrologic loading indicating:

  "… all types of climate data – historic, current, and projected future – should be considered, and risk-informed approaches or other well-supported methods should be used to address climate change impacts on analyses" (EGBC, 2022)

- In March 2023, Canadian Standards Association (CSA) has assembled a technical committee charged with developing and drafting the first Canadian standard on climate change vulnerability assessment of dams ***(CSA S910.1*** *Climate Change Vulnerability Assessment of Dams in Canada).* The standard is expected to be published next year.

Climate projections from GCMs and RCMs

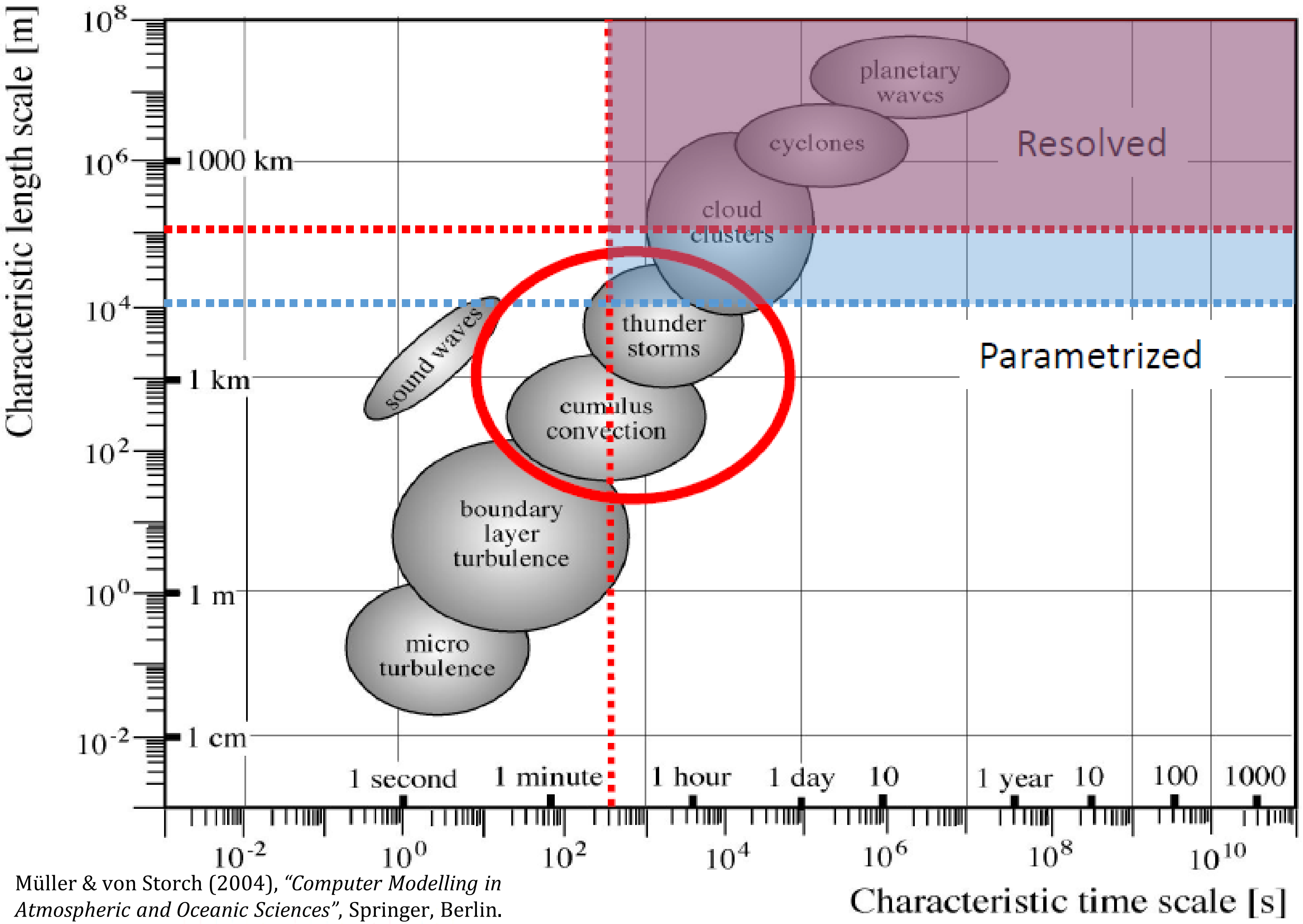
- GCM (General Circulation Models) - physically-based models that attempt to consistently simulate the behavior and interactions among the atmosphere, land surface and oceans at a global scale

- RCM (Regional Climate Models) - similar to GCMs but have higher resolution and smaller modelling domains (i.e., downscaling from GCMs). They produce their own bias in addition to inheriting bias from GCM boundary conditions, RCM projections are commonly further bias corrected and downscaled.

- Both types of models have highly uncertain precipitation estimates and unknown future skill*****.

- Their projections are not recommended for hydrologic watershed modelling and flood-frequency estimation because the simulation periods are too short, and the small number of realizations does not allow a correct representation of the range of GCM internal variability

Climate models resolution



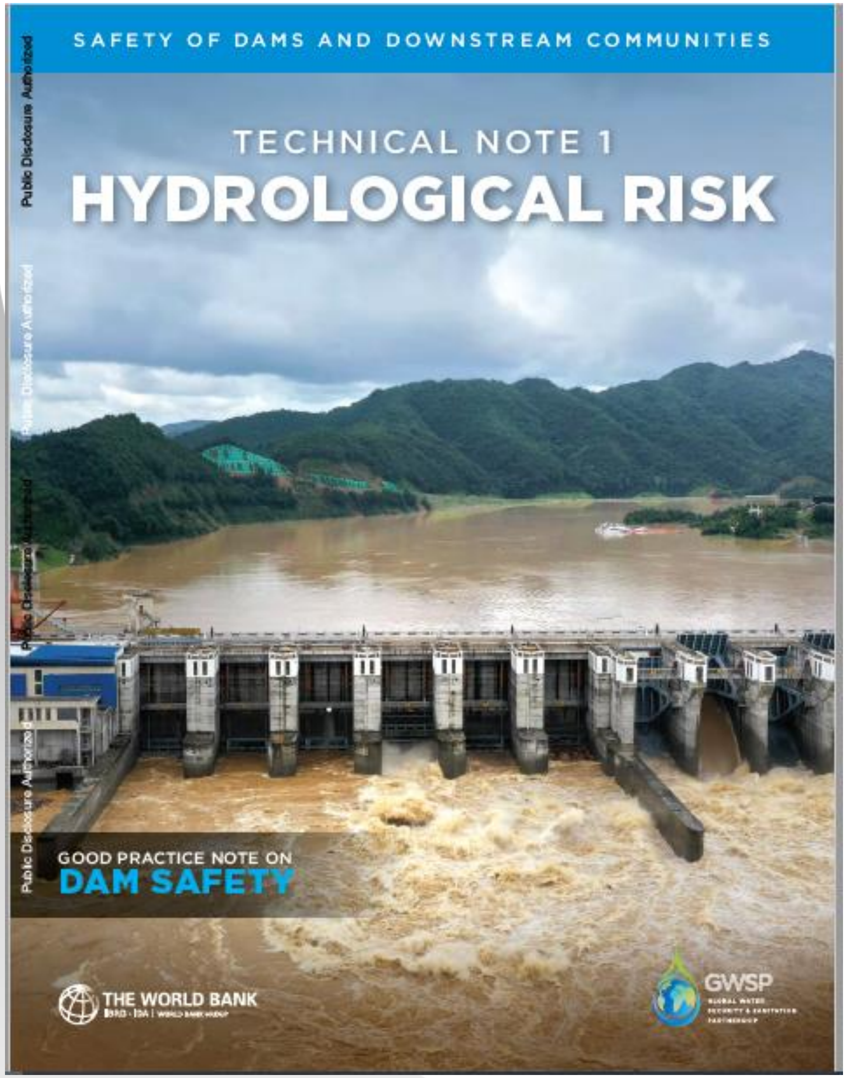
Müller & von Storch (2004), *"Computer Modelling in Atmospheric and Oceanic Sciences"*, Springer, Berlin.

(GCMs) CMIP5: ~100 - 350 km

(RCMs) CORDEX: ~10 - 100 km

Spatial & temporal resolution is a major limiting factor!

The World Bank 2021

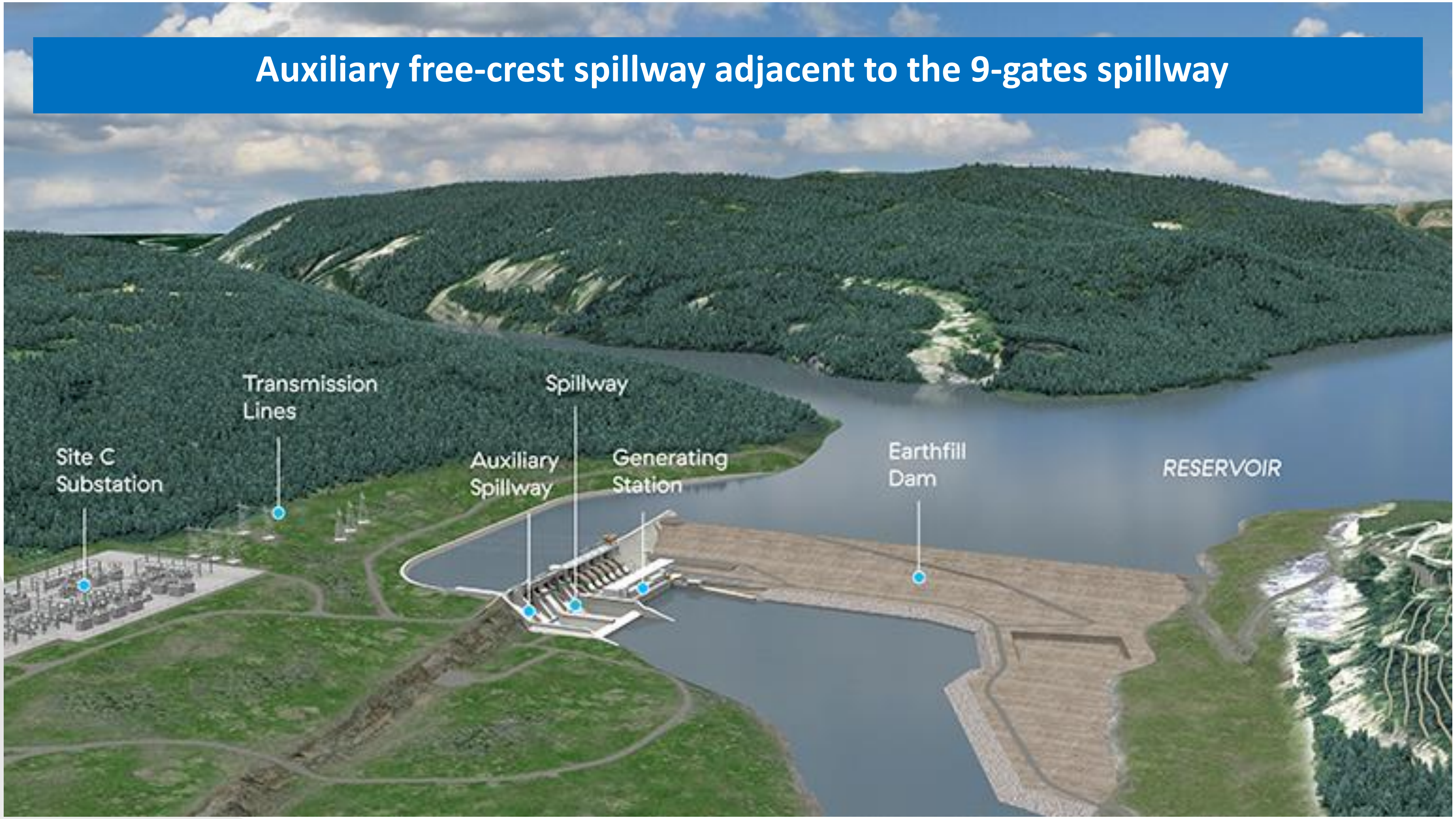


- *"At present there is insufficient command of the climate change modeling and the modeling of its effects on hydrology and water resources to make any attempts to quantify these aspects of hydrological risk."*

- *"However, what is also emerging … is the postulate to characterize general direction of the changes and to use such information to use the principles of adaptive design and adaptive management in the face of uncertainty."*

Adaptive design example

Site C Dam (BC Hydro, Canada)



Site C Dam (BC Hydro, Canada)

August 2022

Site C Dam (BC Hydro, Canada)

Site C auxiliary free-crest spillway covers both climate change related and non-climate change related risks.

- An example of climate change related risk:

  The extreme flood that spillway must pass is higher than the design flood due to climate change effects

- Non-climate change related risks:
  - Flow imbalance from upstream reservoirs
  - Failure of Site C spillway gates

Incorporating climate change in the Cheakamus Dam PMF update

Recalling an earlier slide…

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And also…

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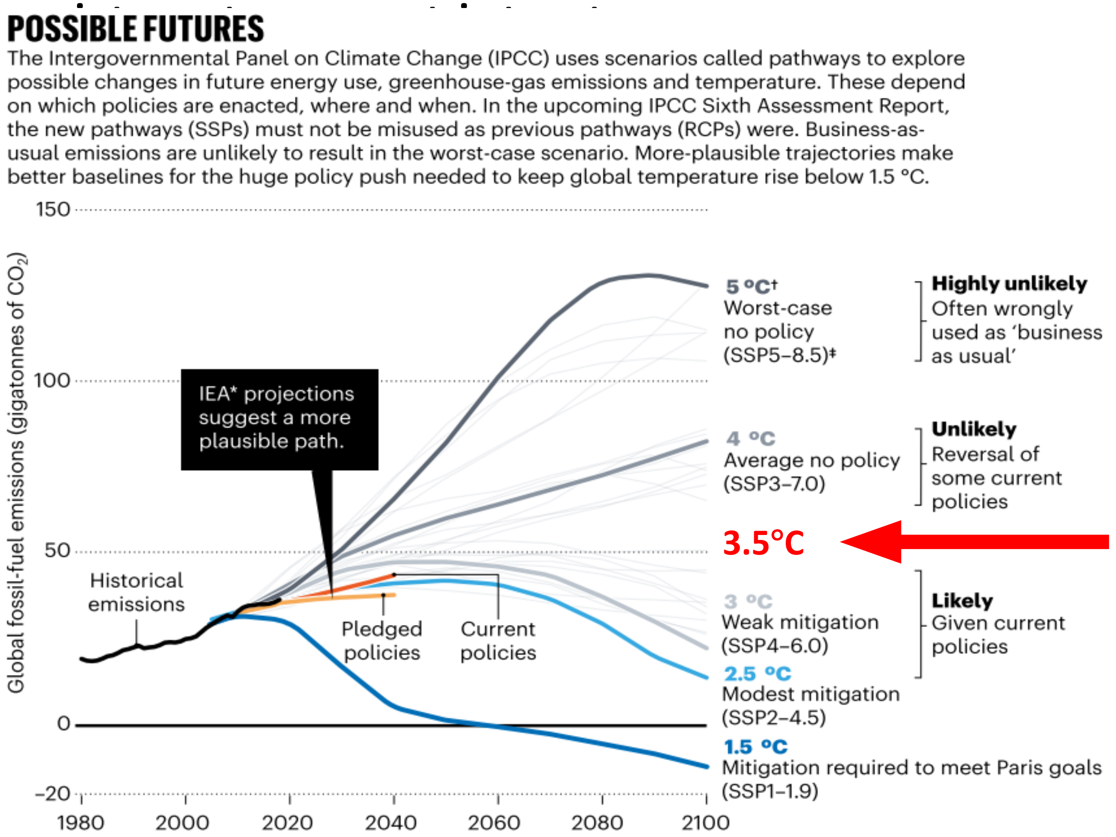
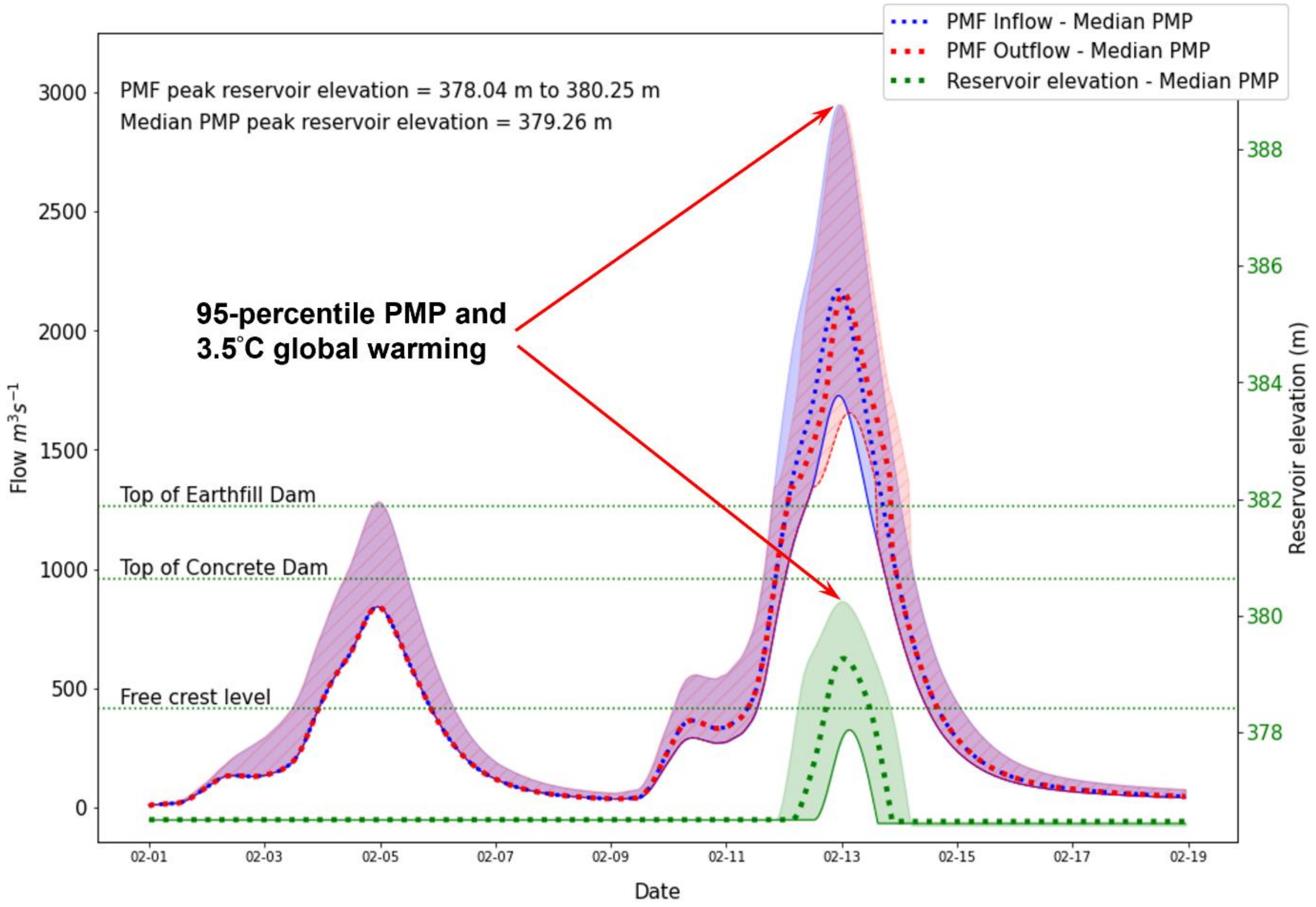


- The expected change in mean temperatures corresponding to 3.5°C global temperature increase is about 5.2°C for the Cheakamus Dam location according to the latest report from National Building Code of Canada (Cannon, Jeong, Zhang & Zwiers, 2020. *"Climate-resilient building and core public infrastructure: An assessment of the impact of climate change on climatic design data in Canada."* Environment and Climate Change Canada.)

- Climate model projections were not relied upon for precipitation increases here, because of the generally low confidence in results for precipitation (and extreme precipitation in particular)

- PMP was derived as a probabilistic range (95-percentile used as the upper bound)

Results for Cheakamus Dam PMF



Concluding remarks

- It appears that currently no dam owner or regulator has a structured or scientifically defensible way to describe climate change effects on extreme floods (i.e., dam design floods)
- Climate change effects are likely contained within large uncertainty associated with extreme (design) flood estimates
- Recognize general direction of the effects and large uncertainty, and use adaptive design/management whenever possible

Recommendations/suggestions

- Consider size and/or consequence classification of a dam. It's likely to have a separate guidance on climate change adaptation for small or low consequence dams; these dams were designed to lower criteria and may be impacted differently.

- Determine what climate change data (climate projections) and methodology is the most appropriate for the specific dam/system

- Enhance climate literacy across the workforce ("Climate change 101")

- There are many non-climate change related risks in design, operation and maintenance of dams. Develop the way to prioritize climate and non-climate related risks in decision making process considering available budgets and organizational risk tolerance.

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