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# TOOLS TO ACCOUNT FOR CLIMATE CHANGE IMPACTS ON SMALL STREAM RESOURCE ROAD CROSSINGS IN BRITISH COLUMBIA

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This report reviews how stream crossing designers can account for the effects of climate change in small, remote watersheds by applying publicly available climate information tools — interactive maps that use or summarize projections of climate models that include historical and projection periods. It identifies five applicable tools for B.C., along with three approaches to using them by referencing applicable professional engineering guidance and climate science developments. To compare tool outputs, the document references a rainfall-regime flood case study location and provides calculations of the variable projections for percent change to a Q100 event. Accounting for climate change on design floods at local scale requires a high level of professional judgment that includes decisions about which climate information tools to incorporate, interpreting their outputs, and considering climate change uncertainties relative to other uncertainties in historical Q100 calculations.

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# 1 CLIMATE TOOLS APPLIED TO RESOURCE ROAD DESIGN

Resource roads in British Columbia (B.C.) often require designs that cross waterflow channels in watersheds with drainage times in the order of 5 to 30 minutes. In mountainous terrain, this equates to flows originating from ~10 to 30 $km^2$ basins. Incorporating design flood hydrology (DFH) methods that account for climate change at this small watershed scale is an emerging practice.

This document presents designers with ways to account for climate change in design flood calculations for small, remote watersheds by using climate information tools, hereafter referred to as climate tools. A climate tool is defined in this report as an interactive graphical user interface with one or more maps that summarize(s) or otherwise use(s) analyzed grid outputs from global climate model (GCM) projections of greenhouse gas and aerosol emissions. Within forest tenure areas, culverts built for service for over three years and bridges built for service for over 15 years must pass a historical 100-year flood (Q100) (B.C. Government, 2022), and designers can use climate tools to adjust this Q100 by assuming that flooding will change in relation to changes in certain climatic variables from GCMs.

## 1.1 Outline of Contents

This document addresses how to account for climate change in small watershed Q100 design floods in B.C. by:

1. reviewing current DFH practices, summarizing the relevant climate projection data, and identifying five climate tools that may inform climate change influences on local scale floods in B.C.;
2. acknowledging the central role of designer professional judgement and referencing professional guidance and climate science developments to identify three approaches for using climate tools;
3. outlining the input choices for climate tools and how to interpret relevant outputs;
4. comparing outputs from climate tools at a coastal climate location with a rainfall-regime Q100 flood
5. discussing developments and limitations of climate tools; and
6. summarizing conclusions.

# 2 CURRENT PRACTICES, MODELS, AND CLIMATE TOOLS

Climate tools and their practices are changing rapidly. Designers must be aware of the latest information when accounting for climate change in design. The most recent version of this document and details about how climate tool calculations were done at the case study location are available at the report's website.

## 2.1 General trends in professional practices, 2018–2022

Professional guidance specific to accounting for climate change in the design of remote, local-scale stream crossings does not exist. In 2018, FPInnovations interviewed water crossing designers in B.C. who were working in the public and private sectors to identify climate change practices for typical small stream resource road crossings. A common practice for smaller crossing designs was to use guidance from an Engineers and Geoscientists B.C. document (Engineers and Geoscientists B.C., 2018). This guidance was first published in 2012 and commissioned by the B.C. Ministry of Forests to support flood risk assessment processes required in rural land development projects. While the document does not reference forestry, it contains general guidance derived by consensus among the group of climate and engineering experts involved in producing the publication. This document, which emerged as the baseline practice within forestry, was interpreted to recommend that when a small watershed has little or no local historical data, a designer can account for climate change by increasing flow estimates by 20%. More specifically, the flooding guidance recommends the 20% increase if an analysis of nearby representative precipitation and stream gauges finds a time trend between storm precipitation and historical flood events. If no trend is found, it recommends using 10% instead. The emergent use of the 20% within forestry is a practical simplification, given that most remote areas of B.C. will have limited historical gauge data that could inform a time trend analysis. The guidance also stipulates that the designer should adjust the percentage to account for possible land use changes that could affect future flows.

A subset of interviewed designers, mostly from the private sector, investigated climate change impacts further by applying publicly available climate tools. To help better understand the use of these tools, they referenced another Engineers and Geoscientists B.C. publication developed for the B.C. Ministry of Transportation and Infrastructure in support of resilience concepts for highways (Engineers and Geoscientists B.C., 2020). This publication reviews a climate risk assessment protocol implementation for highways and in the process references the use of some climate tools for local-scale flooding at a general level.

Between 2020 and 2022, FPInnovations organized and facilitated a series of eight webinars that addressed the topic of climate change on design floods in small, remote watersheds (available at the B.C. Ministry of Forests' Climate Change Adaptation for Resource Roads website). The webinars included live surveys that indicated a growing trend in designers referencing climate tools rather than using the 20% increase approach. The first webinar, presented by FPInnovations, defined the spectrum of climate tools that apply to B.C. road crossings design and how to use them. Subsequent webinars, presented by a variety of speakers, included updates from FPInnovations on climate tool developments. This document synthesizes content presented by FPInnovations during the webinar series and expands upon it, given the developments that have occurred since the eighth webinar in March 2022.

## 2.2 Climate model resolutions and climate index grids for British Columbia

There are several public climate tools for B.C. that are relevant to estimating climate impacts on design floods. All of them reference GCM grids of climate index projections that are downscaled to a higher resolution or left at their original resolution. Downscaling can enhance both spatial and temporal resolution of a grid and can remove possible biases within a region of a GCM by referencing local historical data.

In Canada, two institutes develop, maintain, and disseminate downscaled GCM grids that are part of climate tools. The Pacific Climate Impacts Consortium (PCIC) developed and maintains the finest spatio-temporal resolution climate projection data available for all of Canada: a downscaled daily ~56 $km^2$ grid (1/12 of a degree) that spans 1950–2100. Additionally, the University of British Columbia Centre for Forest Conservation Genetics (CFCG) distributes a desktop software that downscales GCMs and includes versions for three regions, including one for B.C. Its downscaling method outputs monthly grids with a user-defined spatial resolution of any size.

The raw data for original resolution GCM grids and downscaled products from PCIC and CFCG are publicly available. The PCIC website provides download links to their climate projections, which includes the raw downscaled grids for daily maximum temperature, daily minimum temperature, and daily total precipitation. These can be used in numerous ways, including combining them to create additional climate indices of interest that can represent vulnerability-causing climate events, such as extreme flooding. Examples of derivative climate indices include annual maximum consecutive days with no rain, average number of days per year that reach 20°C, and maximum 5-day antecedent rain (mm). The CFCG website has the downscaling software available for download that derives many climate indices relevant to forests. Deriving analogous grids using the PCIC data requires advanced statistical methods to obtain accurate projections; the confidence levels of a resultant grid will vary, depending on the underlying type of statistics it reports. For example, statistical confidence reduces for a climate index when it reports frequencies rather than averages, references precipitation alongside or instead of temperature grids, or requires working with finer temporal resolution data.

## 2.3 Five climate tools that embed climate index grids from climate models

This report focuses on five browser-accessible public climate tools that have information that may help estimate how climate change affects a local-scale Q100 event. Each provides access to GCM grids that make projections for, at least, the entire area of B.C.:

- Plan2Adapt: PCIC daily grids (via derived climate indices)
- ClimateBC_Map: monthly grids (via derived climate indices exported from CFCG desktop software)
- Climate Explorer: PCIC daily grids (via derived climate indices)
- ClimateData.ca: PCIC daily grids (via derived climate indices)
- IDF_CC: PCIC daily grids or GCM grids that are not downscaled

# 3 PROFESSIONAL JUDGMENT OF CLIMATE TOOLS

Currently, there is no consensus among the crossing designers surveyed or in the publications of professional organizations about the use of climate tools for small, remote watershed contexts. The combination of current professional guidance and climate change science amounts to four approaches that can account for climate change in the design of local-scale water crossings in B.C. Three of these use climate tools and the fourth references the Engineers and Geoscientists B.C. (2018) professional guidance for rural development to increase flow by 20% before considering future land use change factors.

## 3.1 Three climate indicators that use climate tools for percent change projections

Three design approaches that use climate tools can be used to estimate how climate change affects a local-scale Q100 event. Each approach uses a different climate indicator that calculates a percent change to adjust an historical IDF curve or other historical information related to a Q100 event:

- a gridded climate indicator approach selects from downscaled GCM-derived precipitation and/or temperature grid(s) based on relationships to local flooding and then interprets the resulting percent changes of this grid(s) to adjust designer-selected historical flooding information;
- an average temperature gridded climate indicator approach (known as temperature scaling) references downscaled temperature GCM grids, then modifies changes of this grid with a formula to calculate a percent change that adjusts an historical IDF curve; and
- a precipitation-based IDF curve climate indicator approach uses IDF_CC to calculate historical and projected IDF curves, then combines them to report a percent change for the historical IDF curve.

These approaches vary in their available documentation and in how much, if any, reference is made to them in professional engineering guidance. The following subsections summarize applicable guidance information and associated climate tools for each approach.

### 3.1.1 Use climate tools showing climate index grids: select climatic grid(s), relate to flooding

Selecting and interpreting gridded climate indicators to account for climate change impacts on local-scale flooding is undocumented; however, interpreting downscaled GCM grids is common within climate risk assessments of other types of climate impacts. As an example, the Public Infrastructure Engineering Vulnerability Committee protocol that informs the highway infrastructure resilient designs document references many climate parameters (indicators) that represent climate events of concern for infrastructure. In applying this protocol, designers can use climate indices to infer a direct or indirect impact on highway infrastructure (Engineers and Geoscientists B.C., 2020). An example of using an extreme temperature grid directly in a stream crossing context would be to consider how it may impact bridge material performance. Conversely, using this or other grids indirectly would consider how changes in snowpack may change stream flow statistics.

The highway infrastructure resilient designs document does not specify how downscaled climate index grids could inform projected changes to a local-scale Q100. Instead, it identifies that PCIC-produced hydrologic grids could be used as a basis for an estimation. This dataset uses daily ~25 km$^2$ grids (1/16 of a degree) calibrated to hydrologic data projections for basins as small as 300 km$^2$ (Schoenberg and Schnorbus, 2021) and requires professional judgement to apply results for smaller watersheds (Engineers and Geoscientists B.C., 2020). It is accessible, however, only by executing a statistical analysis of downloaded raw data, and the analyses have not yet been completed for areas of B.C. outside of the Fraser Basin.

Given the inaccessibility of the hydrologic grid within a climate tool, typical resource road crossing hydrology workflows seeking to account for climate change likely will not be able to reference it. Using gridded climate indicators instead would require that designers (1) select a climate index grid that changes in relation to a Q100 event; (2) interpret how this relationship may change when working with projections beyond the grid's resolution at a small watershed scale; and (3) apply the calculated percent change to adjust a separate historical Q100 design flood calculation. If a designer is not familiar with selecting and interpreting a gridded climate indicator, then involving a climate scientist is best practice, especially if working with extreme climate indices at local scale (Engineers and Geoscientists B.C., 2020). Applying a gridded climate indicator approach to a local-scale watershed having rainfall-regime flooding would be questionable without first consulting a climate scientist, because there are two clear IDF curve adjustment alternatives with documentation. Applying this approach at a snow-influenced flooding regime site is appropriate, however, because climate tools include derivative climate indices relating to snowpack and snowmelt.

Four of the climate tools display downscaled GCM climate index grids and may be useful for future local-scale flooding estimates: Plan2Adapt, ClimateBC_Map, Climate Explorer, and ClimateData.ca. Other than ClimateBC_Map, all these tools display downscaled GCM grid statistics derived from the PCIC daily ~56 km$^2$ data sets. The web version of ClimateBC_Map contains a simpler version of the desktop version's downscaling software and uses monthly 1.6 km$^2$ grids.

### 3.1.2 Use one or more climate tools: apply temperature scaling

A second approach known as temperature scaling is recommended by ClimateData.ca since a mid-2021 update to the website. The temperature scaling approach involves:

1. using projections of the 30-year average of an annual temperature climate index grid to calculate a temperature difference between an historical and a future period;
2. referencing a precipitation station with historical IDF curves that includes sub-hourly information; and
3. calculating $(1.07)^{(\text{temperature difference})}$ and multiplying this percent change output by the historical IDF curve value for the design storm.

ClimateData.ca provides data to support each step, including the daily average grid for step 1 and an interactive map of 500+ stations with IDF curves in Canada for step 2. The exponential formula given for step 3 represents the physical property of warmer air being able to hold more moisture with increasing temperature and, thereby, creating more intense storm precipitation from warmer, wetter air masses (Stull, 2015). While this equation defines a 7% increase in precipitation for each degree warming, some research concludes that this percentage does not work well for all of Canada (Gaur et al. 2018; Schardong et al., 2018). Since ClimateData.ca has IDF curves only at station locations, adjusting IDF curves for locations distant from a station requires the designer to apply professional judgement. How changes in a 100-year storm are reflected in changes in a 100-year flood requires using a rainfall-based approach to a design flood calculation and is not discussed explicitly by the tool. Guidance about temperature scaling is not yet available from Engineers and Geoscientists B.C.

The other three climate tools that display downscaled climate indices neither reference this application of temperature data nor provide access to IDF curve stations. Unlike the others, Climate Explorer does not provide average temperature values directly, but instead provides maximum and minimum temperature values that can be averaged to obtain the same result. ClimateBC_Map has an average temperature index but at a monthly resolution, which can produce outputs that are different compared to referencing a daily resolution dataset instead. The fifth climate tool, IDF_CC, also can be integrated into a temperature scaling workflow since it provides access to historical IDF curve stations across Canada.

In mid-2022, PCIC released a new tool called [Design Value Explorer](Design Value Explorer) (DVE) that, as one of its functions, visualizes the result of temperature scaling for all of Canada, given a user input for a projected temperature increase. The result is referred to as a change factor for an IDF curve (or IDFCF) and is expressed as a percent change. DVE was created for building engineering and focuses on various temperature-based climate indicators**.**

### 3.1.3 Use IDF_CC: calculate precipitation-based intensity-duration-frequency curve projection

The third approach references only IDF_CC, which does not display GCM grid statistics. This approach uses IDF curves as the climate indicator that, depending on user selection, references either non-downscaled GCM grids or PCIC-produced downscaled climate index grids to inform projections. IDF_CC IDF curve outputs are intended to inform flow calculations for past and future climate scenarios at the 500+ Environment and Climate Change Canada precipitation station gauges, at user-inputted gauge locations with more than 10 years of data, and at ungauged locations. Background calculations involve complex statistical methods that include, but are not limited to, referencing historical observations of short-duration precipitation and their relationships to GCM climate index grid projections and derivative grid products (Simonovic et al., 2016; Gaur et al., 2020; Schardong et al., 2020). Applying IDF_CC does not require technical knowledge of its extensive technical underpinnings but only defining some parameters in a graphical user interface.

IDF_CC has detailed documentation that includes a user's manual and a technical manual. The resilient highway infrastructure design document from Engineers and Geoscientists B.C. (2020) does not address the use of IDF_CC explicitly but its appendix does. The appendix includes many climate assessment examples submitted by practicing professionals. Two examples of rural projects used IDF_CC to adjust a design flood for climate change at a local scale are: (1) a highway bridge project that used IDF_CC within an historical hydrotechnical data analysis; and (2) a limited-scope climate risk assessment that used IDF_CC as a central tool for a town sewer project.

The engineering guidance for flood assessments in Engineers and Geoscientists B.C. (2018) indicates that any approach that relates historical IDF curves to future IDF curve projections (i.e., IDF_CC and temperature scaling) assumes that relationships between daily and sub-daily precipitation intensities remain constant into the future. The authors of IDF_CC acknowledge and account for this stationarity assumption (Gaur et al., 2020), while guidance emphasizes that this assumption means that interpreting any IDF curve projections should be done with caution, especially when working with longer projection periods (Engineers and Geoscientists B.C., 2018).

## 3.2 Considering one or more approaches available to account for climate change

Designers are faced with choosing between hydrology design approaches and associated climate tools when developing DFH workflows. Table 1 categorizes the three different approaches that use climate tools, lists the tools' developers and websites, and summarizes the tools' underpinning and reported temporal and spatial resolution.

Table 1. Key information for five common Canadian climate tools

| Climate tool | Developers/Website | Approach(es) | Underlying and reported resolution ** |
|---|---|---|---|
| Plan2Adapt | Pacific Climate Impacts Consortium [https://www.pacificclimate.org/analysis-tools/plan2adapt](https://www.pacificclimate.org/analysis-tools/plan2adapt) | Grid-based adjustment to historical data | Daily ~56 $km^2$ grid – reported using seasonal and yearly resolution statistics |
| ClimateBC_Map | University of British Columbia – Centre for Forest Conservation Genetics [http://www.climatewna.com/ClimateBC_Map.aspx](http://www.climatewna.com/ClimateBC_Map.aspx) | Grid-based adjustment to historical data | Monthly 1.6 $km^2$ grid – reported using monthly and more coarse statistics |
| Climate Explorer | Pacific Climate Impacts Consortium [https://services.pacificclimate.org/pcex/app](https://services.pacificclimate.org/pcex/app) | Grid-based adjustment to historical data | Daily ~56 $km^2$ grid – reported using monthly or more coarse statistics |
| ClimateData.ca | Environment and Climate Change Canada, Pacific Climate Impacts Consortium, Computer Research Institute of Montréal, Ouranos, the Prairie Climate Centre, and HabitatSeven [climatedata.ca](climatedata.ca) | Grid-based adjustment to historical data<br><br>and/or<br><br>Temperature scaling-based adjustment to IDF curve* | Daily ~56 $km^2$ grid – reported using monthly or more coarse statistics |
| IDF_CC | Western University – Institute for Catastrophic Loss Reduction [https://idf-cc-uwo.ca/](https://idf-cc-uwo.ca/) | Precipitation-based IDF-curve adjustment | No continuous surface grid is displayed as each new point is calculated dynamically, which involves mathematical relationships between several grid and point networks:<br>• possible reference to ~10 000 $km^2$ or ~56 $km^2$ grids and grid-derived products for projections<br>• 10 or 25 nearest points from 500+ Environment and Climate Change Canada stations, and influence from user-inputted observation stations that have more than 10 years of data |

* Temperature scaling could also reference other climate tools but only ClimateData.ca provides instructions along with all required datasets in one place. ** Reported resolution is the resolution of the indices.

Engineers and Geoscientists B.C. do not endorse any approach over another or endorse certain climate tools or judgments. Broadly, their guidance encourages designers to consult climate specialists when practical and to explore available tools, review available location-specific historical flow characteristics, and conduct sensitivity analyses to quantify the uncertainty of climate change impacts on rainfall, and by extension, on DFH and design flood calculations. Engineers and Geoscientists B.C. also offer a [Climate Change Information Portal] with links to climate change-related information, tools, and resources to support registrants with considering climate change into their designs.

Both Engineers and Geoscientists B.C. (2018; 2020) and the IDF_CC documentation encourage the use of a sensitivity analysis to help account for unknowns of working with climate change models, especially when at a local scale. Illustrating this best practice, the case studies that used IDF_CC in Engineers and Geoscientists B.C. (2020) included sensitivity analyses that involved calculating permutations of possible tool inputs to gain better understanding of possibilities that inform risk tolerances. An extension of a sensitivity analysis could consider the importance of stationarity assumptions in the projections of a climate tool alongside the many other climate change uncertainties.

It is recommended to designers to consult with climate specialists under many circumstances encountered in climate change impact studies related to rural development (Engineers and Geoscientists B.C., 2018) and to highway infrastructure (Engineers and Geoscientists B.C., 2020). Unfortunately, DFH budgets for typical resource road crossing projects are limited and usually do not allow for consulting climate specialists or extensive analyses. Designers, therefore, need to be aware of risk levels that could trigger an increased climate change analysis budget.

## 3.3 Considering climate change as one of many uncertainties of design floods

To account for climate change, designers must incorporate their professional judgment, which may involve using one, a combination of, or no climate tools. An acceptable approach needs to conform to a typical resource road crossing budget and produce a reasonable answer. Applying professional judgment to account for climate change in crossing design should be based on an understanding of the:

A. assumptions and limitations of available climate tools;
B. relevance and implications of climate tool outputs to the design flood for a project site;
C. risk at the project site in the absence of climate change; and
D. uncertainty within a design flood flow estimate before taking climate change into account.

Understanding the first two points (A and B) requires some technical knowledge about climate tools, whereas the last two points (C and D) instead affect the use and interpretation of the climate tools. The ability to use any climate tools or analyze historical data (point C) is defined by or is constrained by the project budget, and by extension, the risk associated with the design. Understanding design flood uncertainties (point D) involves putting climate tool outputs and errors into the broader context of all other uncertainty factors within a Q100 design flood calculation and requires professional judgement.

Design flood uncertainties at a typical forestry crossing (point D) arise from the lack of relevant historical precipitation and streamflow data at the remote sites of many resource roads. Relevant data is sparse to begin with and is made more so through a B.C. resource road context (Tolland et al., 1998). Professional judgment must compensate for this and many other factors that relate back to lack of historical data. The subjective nature of DFH means that differences in professional opinions on how best to approach design flood calculations in certain contexts can happen. As an example, in small, remote watersheds designers often have differing solutions regarding what scale or context to apply to a rainfall-based analysis (rational method being the most common), extrapolating extremes from stream gauge data (regional method), or when to estimate Q2 to Q100 or similar ratios using developed regional relationships (incorporating a field method).

Uncertainties related to using rainfall-based methods relate to the need to define physical watershed characteristic parameters, such as the time of concentration and its inability to describe snow or snowmelt effects directly. Parameter uncertainties used to characterize watershed DFH grow with drainage area, so designers tend to stop using a rainfall approach as a primary or cross-check calculation for watersheds larger than ~20 to 25 km$^2$. Stream gauge-based methods provide direct information about flows but rely on far fewer stations compared to a precipitation approach. Either method leads to further judgments that require selecting between using the closest, most available, and what is judged to be the most representative data, or some combination of these options. Field methods can involve some subjective field interpretation and require integration and understanding of open flow hydraulics compared to the rational and regional methods. The field approach can be economical, especially if limited to some quick ground surveys paired with visual observation.

# 4 CLIMATE TOOL INPUTS, INTERPRETATION OF OUTPUTS

The process of using a climate tool can be defined in five steps, with the third and fourth steps dependent on the approach taken. Other than the final two steps, the sequence depends on the climate tool:

1. define required climate change input parameters or be aware of predefined options;
2. define the location of interest;
3. define the projection calculation using a climate indicator approach that selects either:
    - a downscaled climate index grid that is related to local flooding events (gridded climate indicator approach);
    - the annual average temperature grid (temperature scaling approach); or
    - a return period that defines an IDF curve (IDF_CC approach).
4. calculate and/or interpret percent change calculations in relation to changes in the design flood (unique to each climate indicator approach and can involve using climate tool outputs in ways that are not always recognized by the climate tool); and
5. compare results between approaches and/or climate tools.

The following subsections assume that the objective of steps 1 to 4 is to estimate the change in a local-scale rainfall-regime Q100 flood at a case study location using the five climate tools. Step 5 is considered in a following section that compares results between climate tools.

## 4.1 Define climate change input parameters/be aware of predefined options

Climate tools have several climate change modelling input parameters that are preselected or require user selection. Those with user-defined projections may require definition of a GCM(s), future emissions scenario, and time windows for future period projection range and the historical baseline.

### 4.1.1 Global climate models and ensembles

Global climate models apply first-principle climate physics to simulate past and projected climate using historical calibration data. They require extensive computational resources and usually produce summary outputs that have a daily resolution ~100 by 100 km grid. Approximately 40 models are in active development by various research institutions around the world (Gaur et al., 2020). When performing a climate change impact assessment for any project, working with climate index grids based on an ensemble (group) is best practice; an ensemble average has more certainty compared to a single GCM, and the variance of an ensemble can inform certainty-level reporting in terms of agreement between GCMs.

Some tools, such as Climate Explorer, have many climate indices, including some that are available for specific GCMs but not for ensembles. In these situations, it is possible to record results from several GCMs and then calculate an average to create a custom ensemble. For a B.C. context, Engineers and Geoscientists B.C. summarize PCIC research (Murdock et al., 2013) that lists the order of GCMs that maximize the spread in resulting projections, while increasing the number of GCMs incrementally. Engineers and Geoscientists B.C. do not recommend a minimum number of GCMs that should define an ensemble, but one case study is included in the appendix of the highway infrastructure resilient designs document (Engineers and Geoscientists B.C., 2020) in which a designer uses the most suitable three GCMs: CNRM-CM5-r1, CanESM-r1, and ACCESS1-0-r1. The latest information regarding the selection of GCMs most applicable for B.C. is available from PCIC on the Statistically Downscaled Climate Scenarios data portal.

### 4.1.2 Future emissions scenarios for global climate models

Every GCM or ensemble follows a specified future trajectory of greenhouse gas and aerosol emissions. The United Nations Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (2013) defined Representative Concentration Pathways (RCPs) that describe low (RCP 2.6), medium (RCP 4.5 and 6.0), or high (RCP 8.5) emissions futures. The low emissions future assumes that countries follow the 2016 Paris Agreement, which outlines goals of reducing emissions, while the highest emissions future assumes a business-as-usual mindset. For the middle ground, RCP 6.0 often is not included in analysis and climate tools in order to simplify and streamline modelling. PCIC advises using RCP 8.5 because it is the most conservative, while Engineers and Geoscientists B.C. (2020) states that RCP 8.5 is the most applicable to infrastructure design and should be considered as part of a sensitivity analysis that tests a range of RCPs. Often, there is not much difference between RCP 4.5 and 8.5 for the nearer-term future, but a divergence emerges when considering longer time periods. The recent Sixth Assessment Report of the IPCC introduced a new set of future emissions scenarios referred to as Shared Socio-economic Pathways (SSPs) (Riahi et al., 2017). Climate tools began to integrate SSPs starting in 2021. ClimateData.ca now can reference both SSPs and RCPs, IDF_CC can reference SSPs when presenting projection options alongside 6th generation grids, Climate Explorer can use SSPs for some individual GCM projections, and ClimateBC_Map has replaced reference to RCPs and uses only SSP scenarios.

Table 2 lists choices for GCM and future emissions combinations for each climate tool. Some of the climate tools have ensemble results for each climate indicator. When only individual GCMs are available for a climate indicator, designers may choose to build a custom ensemble by extracting results for multiple GCM runs of the tool.

Table 2. Global climate ensembles and emissions scenario combinations for each climate tool

| Climate tool | Global climate models (GCMs) | Future emissions scenarios * |
|---|---|---|
| Plan2Adapt | 1 ensemble of 12 downscaled GCMs | Has only RCP 8.5 |
| ClimateBC_Map | 2 ensemble options: 8 and 13 GCMs | Has 4 SSP options |
| Climate Explorer | 2 ensemble options: 12 and 9 downscaled GCMs. Custom ensemble required for climate indices not included in the ensembles. | 9 GCM ensemble has all RCPs, the 12 GCM ensemble does not have RCP 2.6. Individual models have variable collection of RCPs and SSPs. |
| ClimateData.ca | 1 ensemble of 24 downscaled GCMs | Has all RCP options |
| IDF_CC | If referencing 5th generation GCMs, either 30 or 24 (depending on which downscaled/non-downscaled GCM grid reference is selected) and if referencing 6$^{th}$ generation GCMs there are 104 GCMs | Has all RCP options for two 5$^{th}$ generation grids and all SSP options for 6$^{th}$ generation grids |

* RCP = regional concentration pathway; SSP = shared-socio-economic pathway

### 4.1.3 Future time periods and historical baselines

Projections use longer time periods, so they can gain high enough confidence in the result. While there are no standardized reporting periods, climate tools all at least include: 2010–2039, 2040–2069, and 2070–2099, or similar 30-year time periods around those times. These time periods are also often referred to as the 2020s, 2050s, and 2080s, respectively. For resource road stream crossings, selecting appropriate future time periods depends on the designer defining the design life needs. The historical baseline definition influences climate indices that report differences between the past and future, and its selection is up to the designer. Table 3 lists the options available for each climate tool.

Table 3. Available historical baselines within each climate tool

| Climate tool | Projection time frames | Historical normal(s) |
|---|---|---|
| Plan2Adapt | 2010–2039<br>2040–2069<br>2070–2099 | Predefined: 1961–1990 |
| ClimateBC_Map | 2014–2040<br>2041–2070<br>2070–2099 | Many options, down to specific years |
| Climate Explorer | 2010–2039<br>2040–2069<br>2070–2099 | 1961–1990<br>1971–2000<br>1981–2010 |
| ClimateData.ca | 2000–2031<br>2011–2040<br>2021–2050<br>2031–2060<br>2041–2070<br>2051–2080<br>2061–2090<br>2071–2100<br><br>+ custom ranges if data are downloaded as a csv file | 1951-1980<br>1961–1990<br>1971–2000<br>1981–2010<br>1991–2020<br><br>+ custom ranges between 1950 and 2005 if data are downloaded as a csv file |
| IDF_CC | Any period between 2015 and 2100 that spans at least 30 years | Predefined: 1950–2010 for models, historical precipitation data at nearby stations (with 10+ years of data) for temporal downscaling |

## 4.2 Define the location of interest

All tools require the designer to input a point or area on a map to define a location of interest. This step may occur before or after choosing a GCM, RCP, and historical baseline. Table 4 shows the differences in how the location of interest is defined for each tool.

Table 4. Tool interfaces to define the point or area of interest within each climate tool

| Climate tool | Define location by | Notes about map interface |
|---|---|---|
| Plan2Adapt | Choosing one of many areas from various industries including forestry regions, health authorities, and municipal districts | Choosing the area from a list produces a summary for several climate indices over the selected area |
| ClimateBC_Map | Inputting coordinates or clicking on a map that references the underlying grid cell | The desktop version allows many points to be input at once by using a list or raster data set as input and could therefore be used to get information for a larger area all at once |
| Climate Explorer | Drawing a shape or importing a file that defines an area | Drawing a very small area is allowed which equates to a point if it is entirely within a grid cell |
| ClimateData.ca | Clicking to select grid cells | It is possible to select single grid cells and groups of cells by drawing a shape that covers no more than 200 cells or by using pre-defined larger areas (e.g., watersheds) with summarized statistics |
| IDF_CC | Clicking a gauged point location or clicking a map to define a new ungauged point location | The ungauged map option does not visualize historical and projected values for grid cells or weather stations and the gauged map option visualises the locations of stations as points only |

## 4.3 Define the projection calculation

Defining percent change projection calculations to estimate future Q100 flows depends on the approach and climate tool(s) used by the designer. It requires defining one of three climate indicators that relate to a flood event:

a) (a) selected climate index grid(s) (if using a gridded climate indicator approach);
b) an annual average temperature index grid (if using a temperature scaling approach); or
c) a point on the IDF curve (if using an IDF_CC approach).

While options (b) and (c) have clear methodologies for applying a percent change to an historical Q100 flow, option (a) does not. Table 5 lists examples of the highest temporal resolution indices from each climate tool that are potential candidates for use in adjusting local rainfall-regime Q100 values. Many other candidate grid climate indicators also exist and may be relevant. Depending on historical data in the area or past statistical studies, certain grids may have more known relationships to flooding events.

Table 5. Climate tools and possible candidate highest temporal resolution climate indices that may be useful for linking to flooding projections

| Climate tool | Possible climate index grid | Reported resolution of climate indicator statistic |
|---|---|---|
| Plan2Adapt | (Possible candidate) Total winter precipitation | Seasonal (based on daily PCIC grid) |
| ClimateBC_Map | (Possible candidate) Total monthly precipitation for November | Monthly (highest resolution available) |
| Climate Explorer | (Possible candidate) 50-year return period maximum daily precipitation | 50 years (based on daily PCIC grid) |
| ClimateData.ca | (Possible candidate) Yearly maximum daily precipitation | Year (based on daily PCIC grid) |
| IDF_CC | N/A | N/A |

## 4.4 Calculate and/or interpret the percent change in the design flood

The calculation of design flood projections can range from being pre-calculated to requiring the user to make multiple runs of a climate tool. Plan2Adapt reports percent change directly, Climate Explorer shows percent change to a specified baseline in one of its summary tabs, while the other climate tools require that values from at least one historical and one future projection scenario be defined to derive a percent change for a climate index. Note that the percent change formula given by ClimateData.ca results in a change factor for future rainfall relative to historical data rather than a percent change (i.e., a 10% change from the historical value is expressed instead as a future value that is 110% of the historical value).

Table 6 summarizes differences in the effort to report a percent change calculation and accompanying information about percent change uncertainty. It uses the same possible candidate climate index grids as in Table 5 and adds the temperature scaling climate indicator relevant to using ClimateData.ca.

Table 6. Climate tools and factors affecting the ease and uncertainty of future precipitation projections

| Climate tool | Change in | Ensemble range reported | Percentage calculation* |
|---|---|---|---|
| Plan2Adapt | (Possible candidate) Total winter precipitation | $10^{th}$, $25^{th}$, $75^{th}$, $90^{th}$ | Reported directly |
| ClimateBC_Map | (Possible candidate) Total monthly precipitation for November | Not reported | Separate historical and projection periods need to be run |
| Climate Explorer | (Possible candidate) 50-year extreme precipitation (reported as daily average) | Reported graphically in the model context tab (maximum and minimum are easiest to estimate) | Reported directly in change from baseline tab (but only for 1981-2010 baseline) |
| ClimateData.ca | (Possible candidate) Yearly extreme daily precipitation | $10^{th}$ and $90^{th}$ (and more percentiles are available if data is downloaded as csv file) | Separate historical and projection periods need to be run |
| | Yearly annual average temperature (i.e., data to use for temperature scaling method) | | |
| IDF_CC | Intensity for a given duration—at a gauged / ungauged location | Minimum, $25^{th}$, $75^{th}$, maximum | |

* Some of the percentage information is available only in graphs within the climate tools.

Professional judgment in the interpretation of climate tools could extend to using the percentile information about GCM ensembles shown in Table 6. For example, selecting higher percentages could be a way of accounting for higher-risk sites, along with other modifications to the percentage. Whenever statistics are interpreted or modified, expanding the use of the climate tool to include a sensitivity analysis can help gain confidence in decisions through better understanding of uncertainties. Professional judgment could further modify any percent change outputs to account for uncertainties inherent with linking climate events to flooding. Best practice is to apply care and caution when applying a gridded climate indicator approach, given the lack of documentation explaining how to use climate tools in this way for local flooding.

# 5 EXAMPLE COMPARISON OF CLIMATE TOOL OUTPUTS

To follow best practices, a last step in using a climate tool may involve a sensitivity analysis to compare modelled outputs with those from other climate tools. Figure 1 shows a case study location that was selected to compare how using the five climate tools can lead to different percent change calculations for use in modelling future flooding events. The crossing site is within the University of British Columbia's Malcom Knapp Research Forest and is in a rain-dominated, small watershed at ~400 m elevation with an estimated time of concentration of 30 minutes.

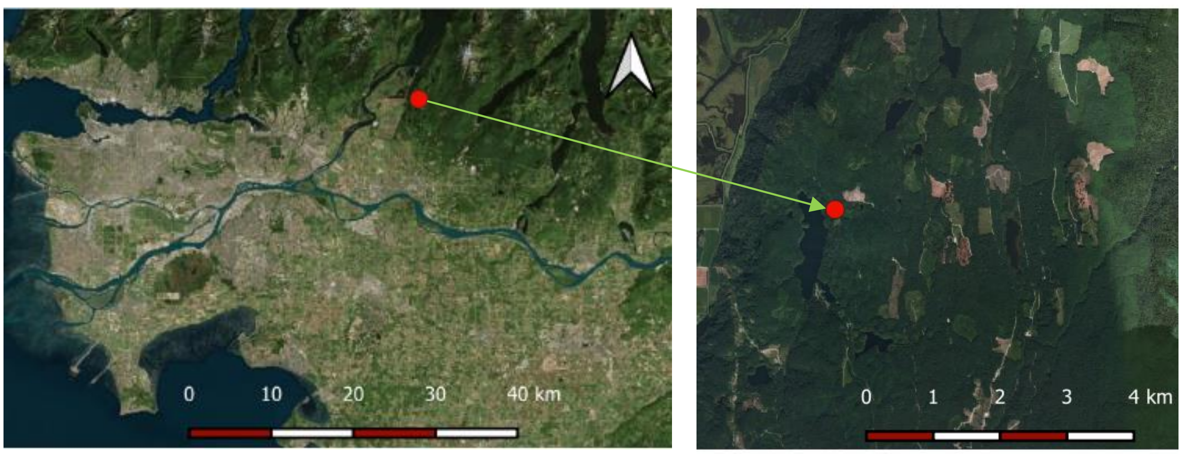


Figure 1. Coastal British Columbia case study crossing location in a small watershed east of Vancouver

The gridded climate indicator approach is neither documented nor recommended for small watersheds with rainfall-regime flooding. For illustrative purposes, however, rather than ignoring this approach, grids were selected and calculated using the four climate tools identified in Table 5. These model outputs are incomplete, since adjustments that are needed to calibrate results using local reference data are not considered.

The temperature scaling and IDF_CC approaches that adjust IDF curves were applied by following documentation. In calculating the temperature scaling approach, ClimateData.ca was the only climate tool considered. When using temperature-based gridded climate indicators, the documentation for the temperature scaling method indicates that referencing a single cell is acceptable. This same approach was taken to calculate the other precipitation-based grids; however, because precipitation typically varies more than temperature between cells, reporting the average of a group of cells may increase the quality and confidence of the output. In calculating the IDF_CC approach, the closest station (~6 km away) was selected rather than working with an ungauged location.

To support a comparison of outputs from climate tools, the inputs to climate tools were defined to be as consistent as possible. All the climate tools defined 1971–2000 as the historical baseline, except for IDF_CC which uses all available historical records for short-duration storms, and, except for ClimateBC_Map, the projected emissions scenario was RCP 8.5; ClimateBC_Map only works with SSPs, so the most analogous emissions scenario (SSP 585) was selected. Figure 2 compares percent change projections of climate indices related to flooding as calculated by the three approaches for the 2020s, the 2050s, and the 2080s. A range of percent projections generated by the tools are included, depending on the tool's available levels of statistical uncertainty (i.e., reporting of percentiles and extremes). The three boxes to the left for each projection period group the climate tools by the same approach to percent change projections. The results from the group of four tools with a dotted box outline (tools for use with a gridded climate indicator approach) are included for reference only since the tool outputs have not been transformed from the return period statistic, yearly, seasonal, or monthly resolution to the time of concentration of the watershed, or rationalized for use as the crossing site in any way. Details about the calculation methods and assumptions for each climate tool calculation are outlined for the 2050s on the [report's website](#).

| | | | min | p10 | p25 | p50 | p75 | p90 | max |
|---|---|---|---|---|---|---|---|---|---|
| **2020s** | Plan2Adapt | precipitation - winter | | -5% | | 0% | | 7% | |
| | ClimateBC_Map | precipitation - November | | | | 5% | | | |
| | Climate Explorer | 50-year one day precipitation | | | | 10% | | | |
| | ClimateData.ca | yearly one day precipitation | | 0% | | 7% | | 12% | |
| | Temperature scaling (using ClimateData.ca) | | | 8% | | 11% | | 15% | |
| | IDF_CC | 100-year 30-minute storm | -11% | | 2% | 7% | 14% | | 32% |
| **2050s** | Plan2Adapt | precipitation - winter | | -3% | | 0% | | 7% | |
| | ClimateBC_Map | precipitation - November | | | | 10% | | | |
| | Climate Explorer | 50-year one day precipitation | | | | 17% | | | |
| | ClimateData.ca | yearly one day precipitation | | 2% | | 13% | | 20% | |
| | Temperature scaling (using ClimateData.ca) | | | 18% | | 23% | | 32% | |
| | IDF_CC | 100-year 30-minute storm | -9% | | 9% | 22% | 40% | | 80% |
| **2080s** | Plan2Adapt | precipitation - winter | | -3% | | 7% | | 17% | |
| | ClimateBC_Map | precipitation - November | | | | 20% | | | |
| | Climate Explorer | 50-year one day precipitation | | | | 30% | | | |
| | ClimateData.ca | yearly one day precipitation | | 10% | | 17% | | 31% | |
| | Temperature scaling (using ClimateData.ca) | | | 30% | | 40% | | 53% | |
| | IDF_CC | 100-year 30-minute storm | -5% | | 19% | 26% | 39% | | 67% |

Figure 2. Climate tool projections using three approaches to calculate the percent change to a future design flood at the case study Coastal B.C. crossing location.

Results for the gridded climate indicator approach from four climate tools show that Plan2Adapt outputs the lowest percent change values, followed by ClimateBC_Map. Since statistical averages will tend to be less affected by climate change compared to extreme statistic variables (Engineers and Geoscientists B.C., 2020), this result was expected. The lower values of Plan2Adapt compared to ClimateBC_Map were also expected, given their seasonal and monthly resolutions summary statistics, respectively. Note that the use of longer-duration temporal resolutions for summarizing changes in precipitation during winter will tend to be influenced by snowfall.

Using precipitation information to define a gridded climate indicator approach for a crossing site with a rainfall-regime flooding could be considered, if there is good reason to select and adjust it accordingly. This would most likely involve working with extreme daily climate event data and require consulting with a climate scientist. As an example, statistical analysis could inform how to use and interpret the yearly extreme daily versus 50-year precipitation climate indices. Despite the 50-year statistic having a more direct relationship to the 100-year design storm, it also has more uncertainty compared to yearly statistics. The quality of any adjustments developed will depend on availability of relevant local data linked to small watershed extreme flooding.

Unlike results produced by the gridded climate indicator approach, percent change results from IDF_CC and temperature scaling can be compared directly. If the crossing at the case study location is to have a design life of ~35 years, then applying a 20% increase in flow (relying on Engineers and Geoscientists B.C., 2018) is approximately equivalent to using the 50$^{th}$ percentile from the temperature scaling approach or IDF_CC. Making assertions about this percentage or about the relative differences in medians and percentile distributions between the temperature scaling method and IDF_CC is possible but would require integration of a sensitivity analysis. This would involve accounting for as many factors as possible and could include referencing different historical periods and varying tool-specific selections, such as the IDF_CC tool's reference to downscaled versus original resolution GCM grids. If only the 50$^{th}$ percentile outputs are considered from the two IDF curve approaches without incorporating a sensitivity analysis, the case study indicates using a 20% increase to flow approach may be a suitable simplification for the 2050s but not the 2080s. A more detailed comparison of temperature scaling and IDF_CC by Schardong et al. (2018) summarizes statistical differences between these approaches for 358 locations across Canada.

# 6 CLIMATE TOOL LIMITATIONS AND DEVELOPMENTS

Publicly available climate tools can be useful resources when conducting climate change impact studies. Nevertheless, they have limitations for application in local-scale flooding contexts. The suitability of a climate indicator approach and associated climate tool(s) depends on the crossing site characteristics. Two factors to consider are whether the watershed is substantially larger than 25 $km^2$ or has snow-influenced extreme flooding events.

## 6.1 The transition to larger watersheds

At stream crossing sites subject to typical rainfall-regime floods, both IDF-based climate tool approaches are appropriate, unless the basin size is judged to be too large. In B.C., designers transition away from using precipitation-based methods to stream gauge-based methods for historical Q100 calculations for watersheds exceeding 20 to 25 $km^2$. It follows that a similar transition would be ideal when considering the climate change component used to adjust the design flood calculation. The options for transitioning away from IDF curve-based climate tools include the gridded climate indicator approach and moving beyond current climate tools to analyze PCIC's hydrologic projection dataset. The importance of considering this transitioning past IDF-based climate tools grows in proportion to the basin size which may reach 250 to 400 $km^2$ for less typical stream crossing projects.

Assuming that no climate index indicator studies for relationships to flooding are available, then analyzing the PCIC hydrologic dataset is likely easier, more applicable, and a better option, because it provides flow information directly. Until the hydrologic dataset is incorporated in a climate tool or guidance is published on climate indicators with a known relationship to local storm intensity, designers might not transition from IDF curve approaches regardless of watershed size. The suitability of not transitioning may or may not be appropriate, depending on watershed scale and climatic regions.

While there have been few research developments in the utility of developed relationships between changes in gridded climate indicators and changes to local flooding events, PCIC's hydrologic grid dataset has had continued scientific attention. Currently, PCIC is working to derive projected design flood outputs from these data for display in Climate Explorer (Schoeneberg and Schnorbus, 2021). As of December 2022, Climate Explorer has several of hydrologic grids that show one day stream flow change factors within the Fraser Basin for various return period (up to 200 years) for a single GCM (CanESM2). Improvements may also address the current 300 $km^2$ basin size limitation to interpreting the ~25 $km^2$ hydrologic projection grid (Schoeneberg and Schnorbus, 2021).

## 6.2 The influence of snow and snowmelt in design flood calculations

At snow and snowmelt-influenced design flood crossing sites, the gridded climate indicator approach that references variables related to snow is the most applicable approach. The other option for accounting for snow is to work with PCIC's hydrologic grid which includes snow influences in flow projections (Schoeneberg and Schnorbus, 2021). For now, the hydrologic grid approach remains less practical for typical stream crossings, given the technical approach required, a lack of guidance on the topic, and the incomplete nature of the dataset.

To consider the effects of climate change on snow variables, professional judgment needs to be used to define and interpret snow-related climate indices. Using a climate index grid(s) as a climate indicator for this task is possible but has no guidance. Climate indices of interest could relate to statistics like the average monthly snowpack (which can influence rain-on-snow events) or extreme daily temperature (which can promote rapid snow melt). Referencing climate tools that show PCIC daily or CFCG monthly grids may be useful for this purpose. Practically, a designer may not have the experience to deal with this calculation explicitly and may focus on other uncertainties within the DFH process instead.

# 7 CONCLUSIONS

This report outlined four approaches to accounting for climate change in design floods of small stream crossings, considering available professional guidance from Engineers and Geoscientists B.C. and recent climate science developments. One approach assumes a 20% increase to a design flood using a simplification in guidance, while the others calculate a percent change in a flood-related climate indicator by referencing publicly available climate tools. Five climate tools were reviewed, and these reference various GCM projections and cover at least the entire area of B.C. The review emphasized that professional judgement is needed to link percent change to extreme rainfall or snow-related climate events to a change in Q100 flow. To consider the uncertainties of climate change as part of DFH for a small stream crossing as compared to all other DFH uncertainties, the report identified a need for the designer to understand the site's risk levels along with the abilities and limitations of climate tools.

The definition of climate tool inputs and interpretation of outputs was reviewed using three identified approaches: a gridded climate indicator approach that relates precipitation and temperature grids to local flooding events through local data; a temperature scaling approach that uses change in temperature as a basis for a proxy variable to calculate changes to IDF curves; and an IDF_CC-specific workflow that references precipitation grids rather than temperature. The two approaches related to IDF curve adjustments are most appropriate for rainfall-regime Q100 flooding events in watersheds smaller than ~25 km$^2$ that have a weather or flow-historical dataset. Guidance on selecting and adjusting gridded climate indices as a climate indicator is not yet developed. At snow-influenced Q100 locations, referencing climate index grids with snow or snowmelt information could be useful for all watershed scales; however, referencing climate index grids for rainfall-regime Q100 locations is not best practice without calibrating to local historical data.

A case study compared results from climate tool outputs for a rainfall-regime flood location on the B.C. Coast. Comparable results were generated using temperature scaling and IDF_CC approaches for a stream crossing with a design life of ~35 years. While temperature scaling outputted larger percentage changes for the mid-term (2050s) and long-term (2080s) projections compared to IDF_CC, a sensitivity analysis would be needed to make any conclusions about these differences. The gridded climate indicator approach was included in the case study for four climate tools but only to illustrate the relative ranges of outputs; the approach is not appropriate for adjusting a rainfall-regime Q100 for a small watershed. Its results would need further analysis that references local data to gain confidence and adjustments that would account for spatial and temporal differences between the downscaled grid and the local-scale watershed.

Two current limitations of climate tools applied to local-scale DFH include lacking access to gridded flow projections data within an easy-to-use interface, and lacking documentation about using a gridded climate indicator approach when the Q100 has snow influences. Outside the Fraser Valley, Coastal B.C. does not yet have access to any hydrologic grid project data, because the model has not been completed for this part of the province. On the other hand, the lack of guidance about how to interpret snow influences within climate tools is less of an issue for Coastal B.C., where rainfall is a more dominant influence on flooding compared to the Interior. Improved guidance also could address best practices for working with downscaled GCM climate index grids that involve precipitation.

Designers must apply professional judgment when deciding how and when to integrate climate tools into historical design flood calculation methods. The choice to increase future design floods by 20% remains but is becoming more difficult to rationalize over the application of climate tools, especially at typical rainfall-regime flood stream crossings for which there are well-defined approaches to apply IDF curve methods. The two existing IDF approaches should be viewed as complimentary rather than exclusive, because referring to both leverages the different technical approaches and contributes to a more robust sensitivity analysis. More broadly, experimenting with various climate tools can lead to a greater understanding of their variables and give designers better insight into their relative and internal uncertainties, as compared to the uncertainties inherent in historical Q100 design flood calculations.

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