REGIONAL-BASED HYDROLOGIC STUDIES FOR RISK ESTIMATION

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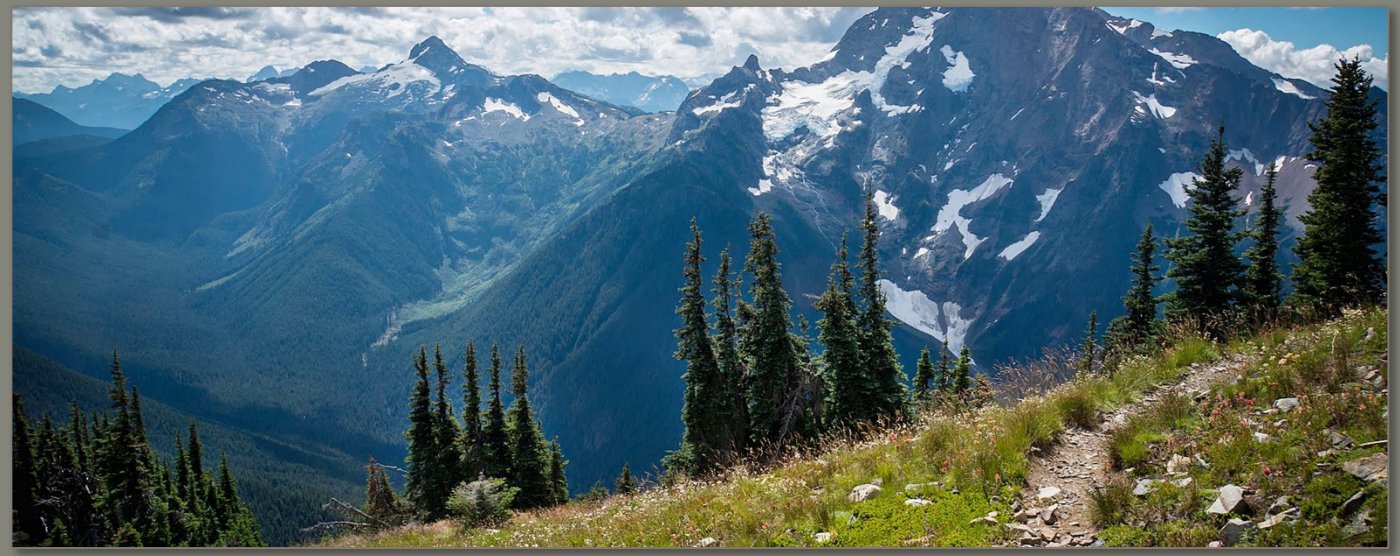
USACE Northwestern Division
Senior Hydrologist
2020 NRCS Workshop
February 2020



Pasayten Wilderness, WA
Photo by Jeff Kish

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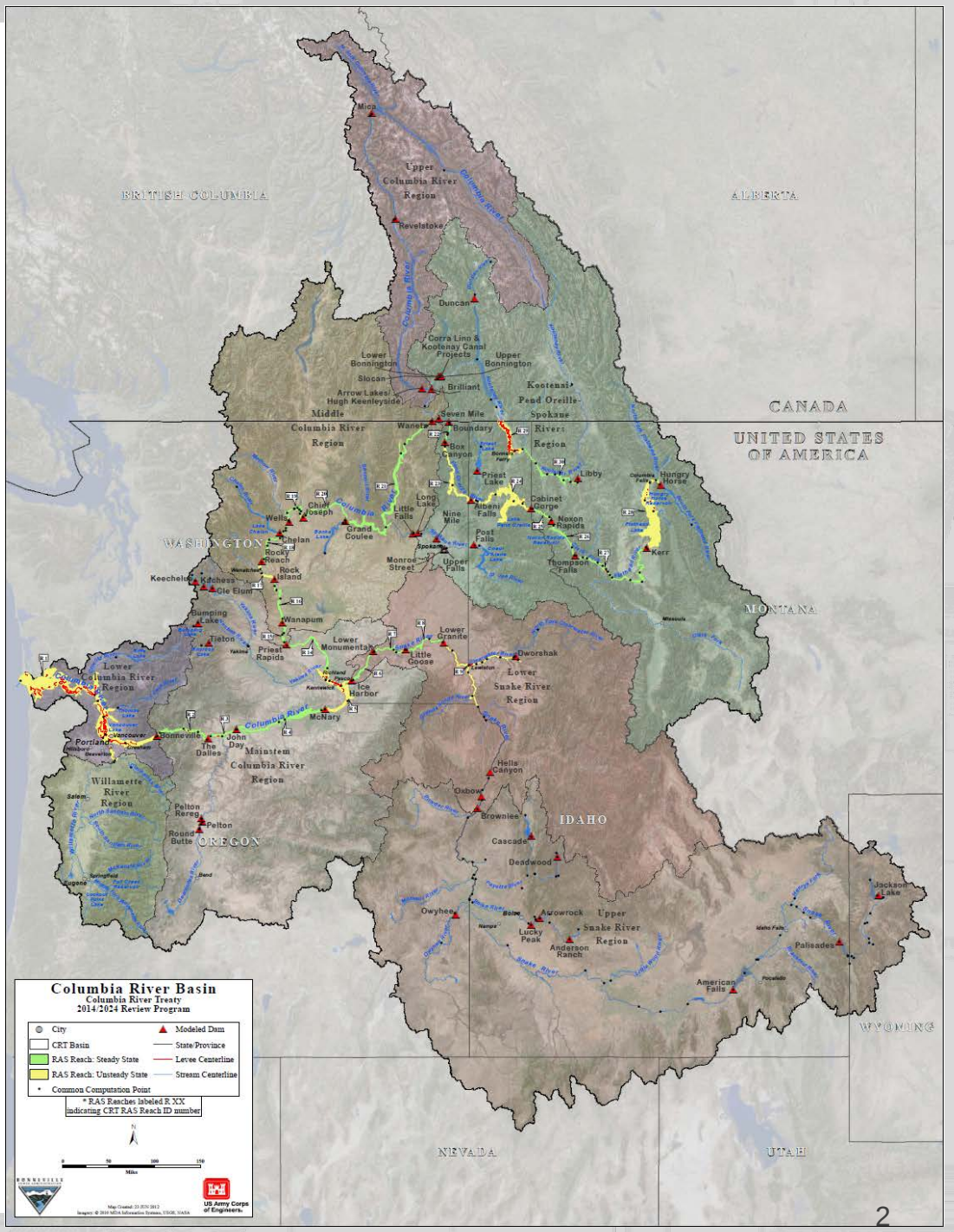
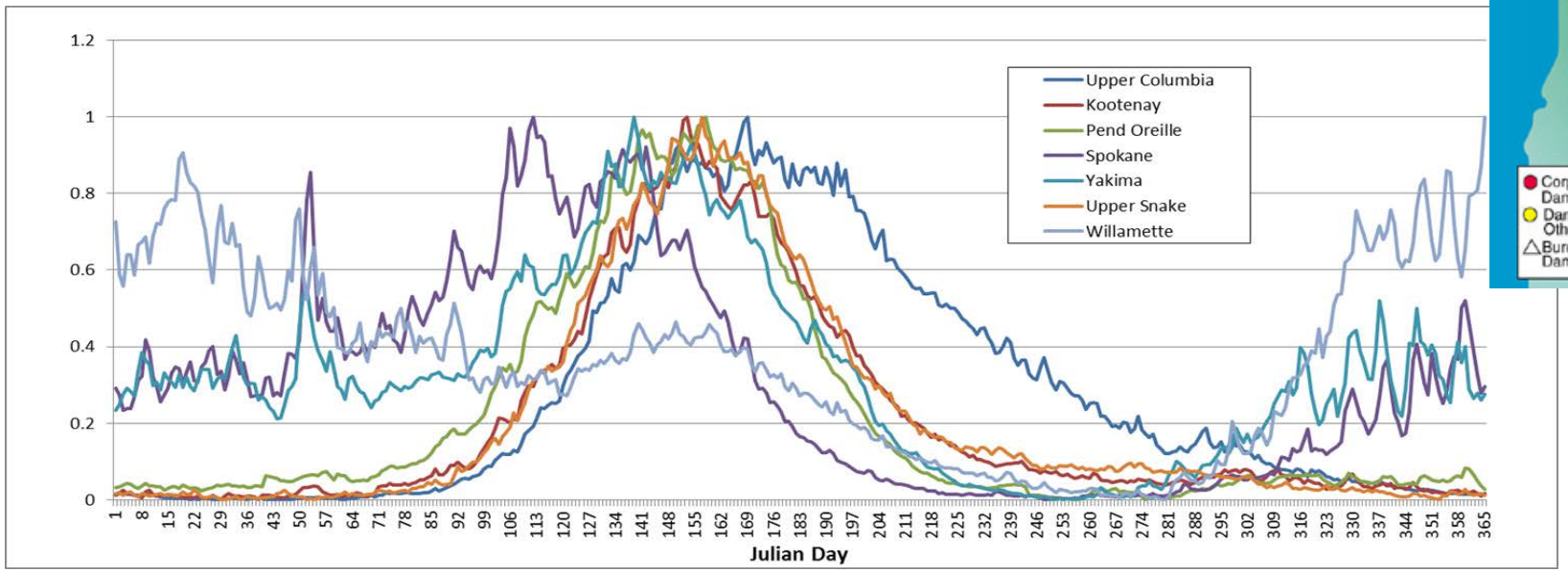
OUTLINE

- Flood Risk Assessment
  - Synthetic Hydrographs
  - Synthetic Stage
- Key Components of Stage/Regulated Flow Frequency Curves
- Willamette Stage Frequency Curve Analysis – Key Lessons Learned
- Moving Forward: Columbia River Basin Hydrology Studies



COLUMBIA RIVER BASIN

- 260,000 square miles and extending throughout the Pacific Northwest and into Canada.
- There are more than 250 reservoirs and around 150 hydroelectric projects in the basin, including 18 mainstem dams on the Columbia and its main tributary, the Snake River.



Basin-wide Average Runoff Signal

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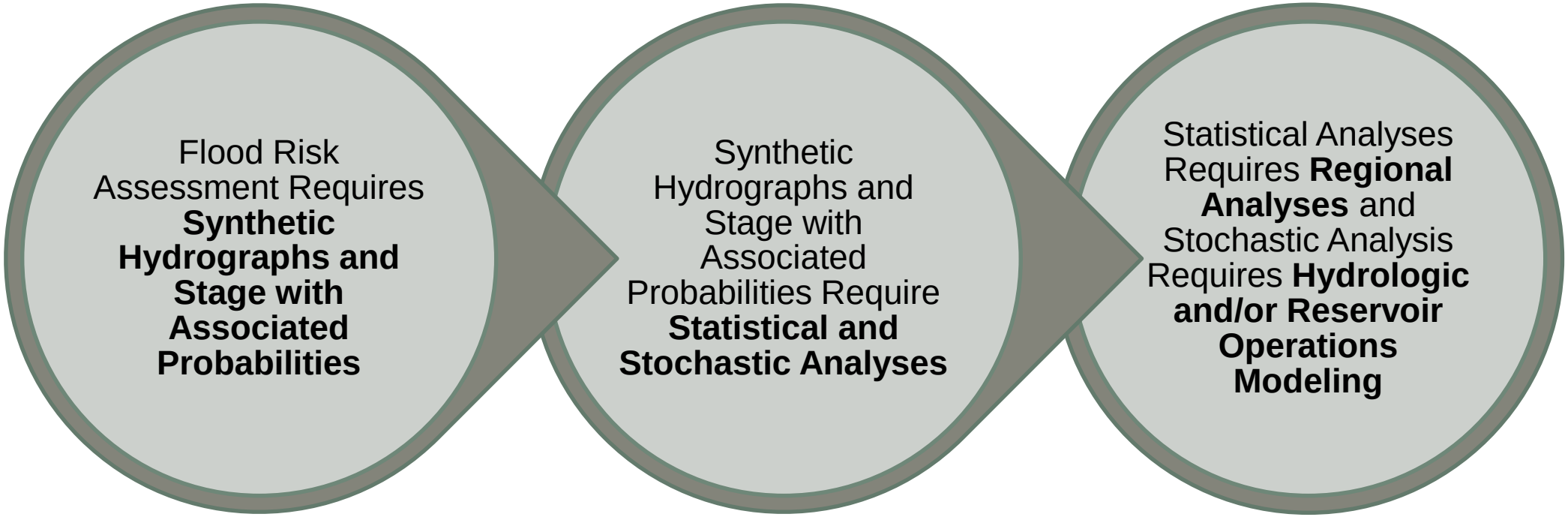
USACE MISSION: FLOOD RISK



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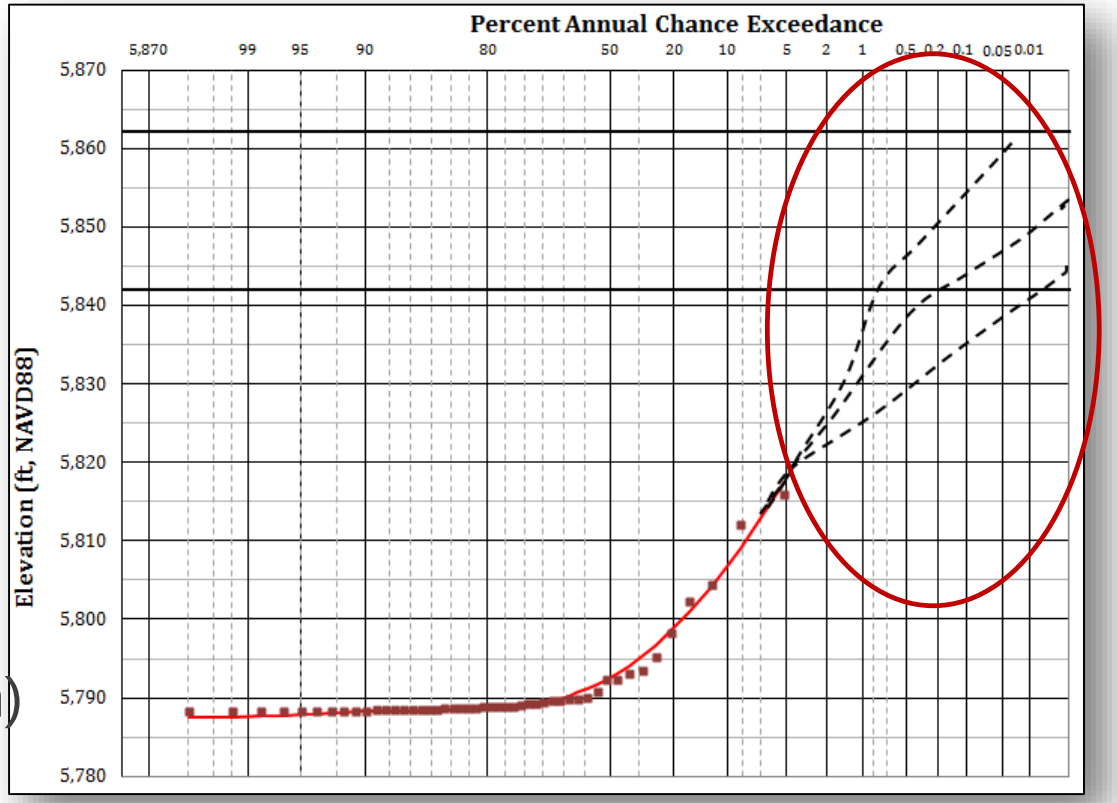
STAGE/REGULATED FLOW FREQUENCY CURVE (RESERVOIR OR RIVER CHANNEL)
(STAGE/REGULATED FLOW, UNCERTAINTY VS PROBABILITY)

Some Factors that Affect the Peak Flow and Elevation for Any Given Event

- Temperature
- Precipitation intensity
- Spatial/temporal distribution of precipitation
- Antecedent snowpack
- Antecedent elevations
- Operations
- Baseflow
- Soil infiltration capacity
- Rainfall-runoff transformation (unit hydrograph)



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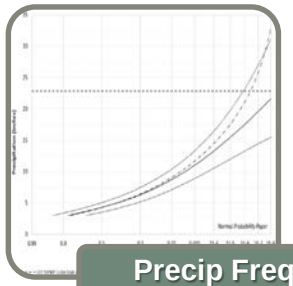
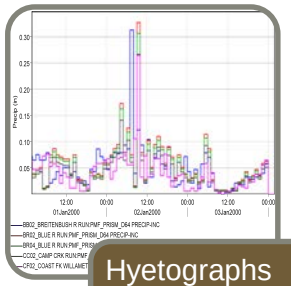
KEY COMPONENTS OF STAGE FREQUENCY CURVES

WILLAMETTE BASIN STAGE FREQUENCY CURVES

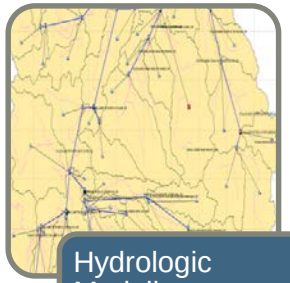


Precip Freq Curve Sampling



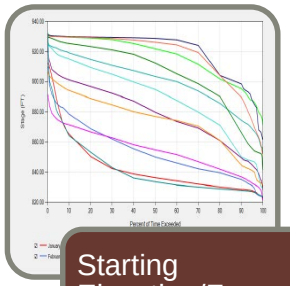
Hyetographs Shapes Sampling

- Temporal/Spatial Variability
- Temperature

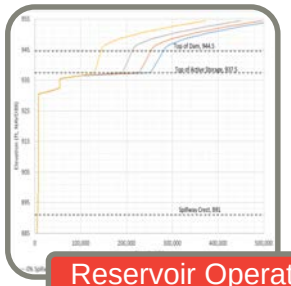


Hydrologic Modeling

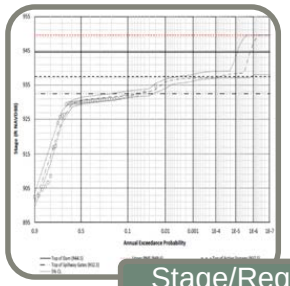
- Hydrologic Parameter Sampling



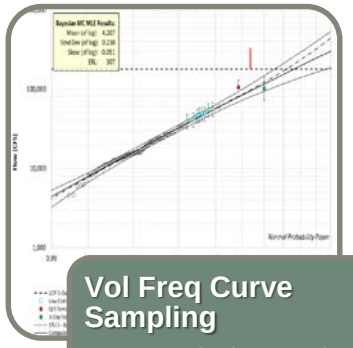
Starting Elevation/Forecast/ Other ResOps Uncertainty Sampling



Reservoir Operations Modeling

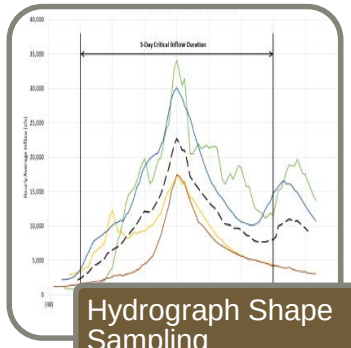


Stage/Reg Flow Frequency

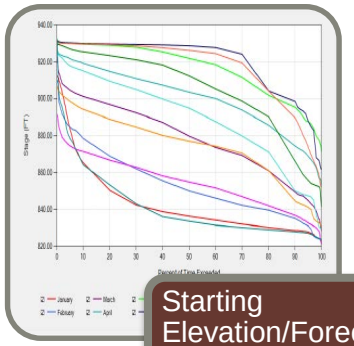


Vol Freq Curve Sampling

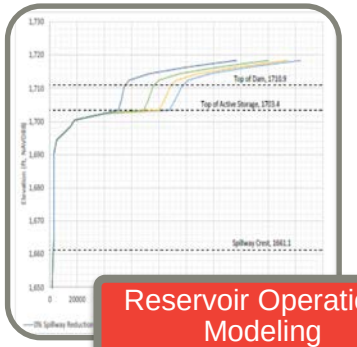
- Can Include Precip Freq Converted to Vol, Paleohydro, Historical Floods



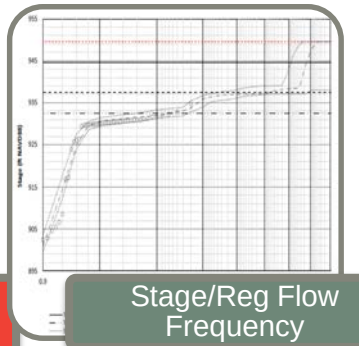
Hydrograph Shape Sampling



Starting Elevation/Forecast/ Other ResOps Uncertainty Sampling



Reservoir Operations Modeling



Stage/Reg Flow Frequency

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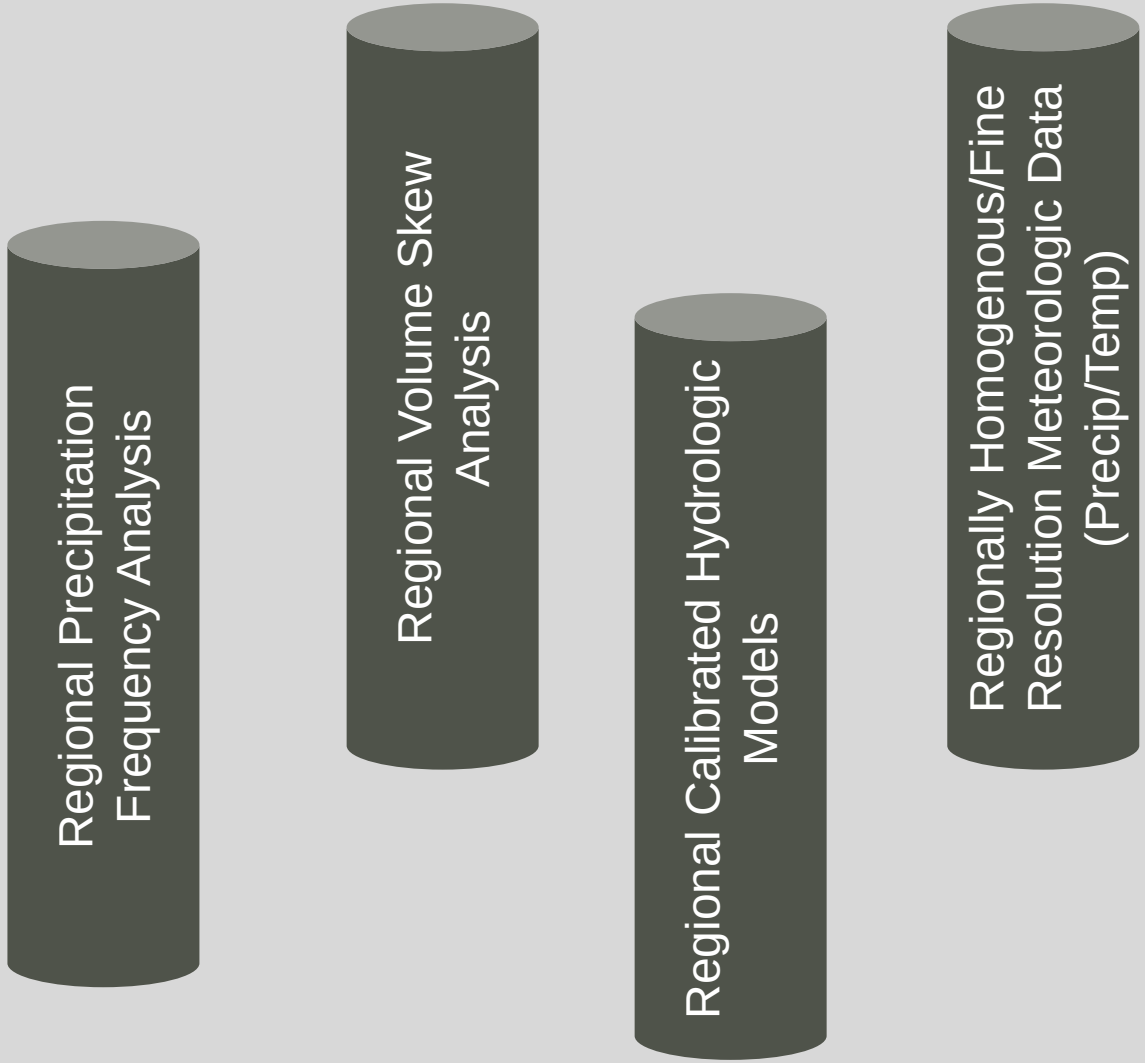
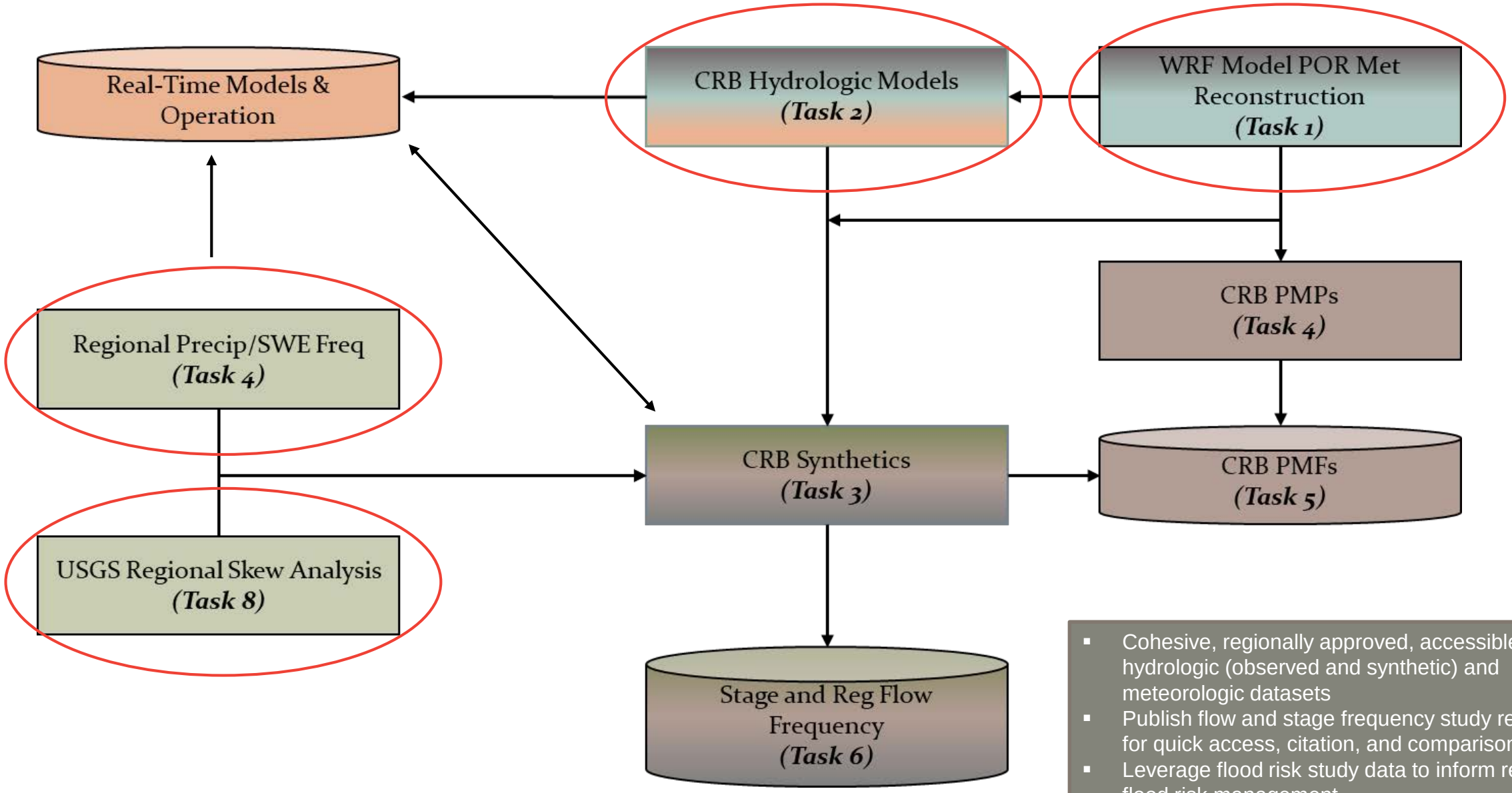
Pillars of Optimal Flood Risk Management Hydrology



Optimal Hydrologic Studies for Risk Estimation Includes Regional Corroboration and a Solid Foundation:

- Regionally Homogenous/Fine Resolution Spatial/Temporal/Temperature Data
- Regional Hydrologic Models
- Regional Precipitation Frequency
- Regional Volume Frequency Curve Analysis

COLUMBIA RIVER BASIN (CRB) HYDROLOGIC STUDIES



- Cohesive, regionally approved, accessible hydrologic (observed and synthetic) and meteorologic datasets
- Publish flow and stage frequency study results for quick access, citation, and comparison
- Leverage flood risk study data to inform real-time flood risk management
- Update hydrology from original design

CRB DURATION FLOW FREQUENCY CURVES REGIONAL SKEW ANALYSIS

Key Points:

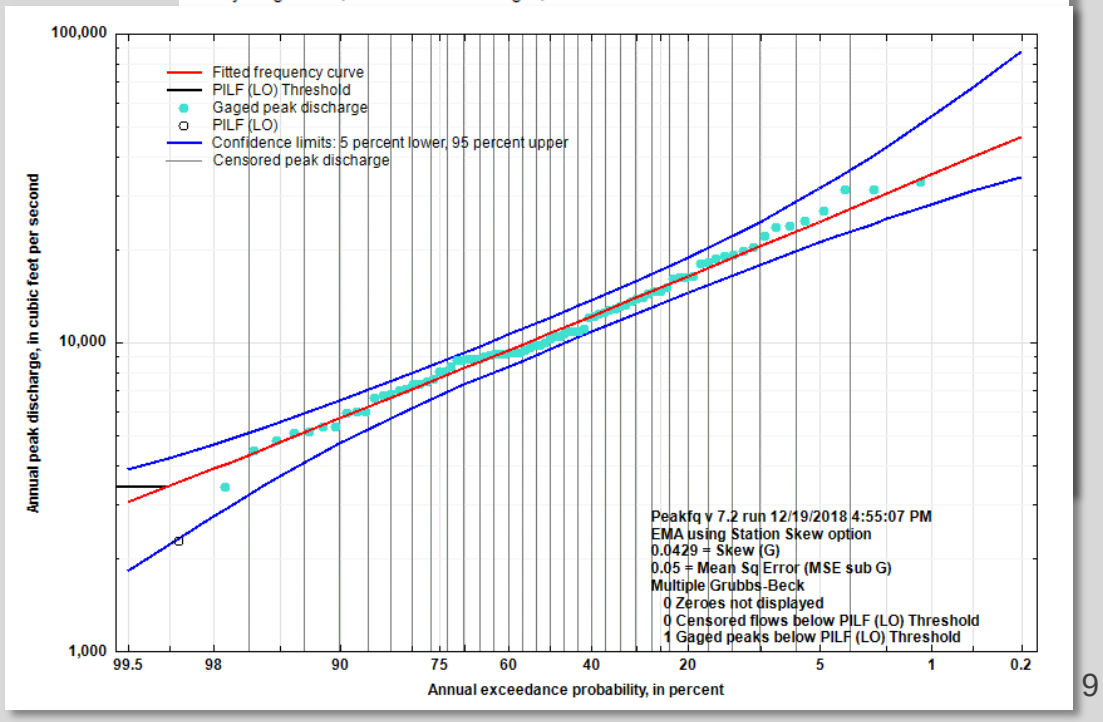
- Durations 1-day through 60-day; flooding season only
- This report utilized Bayesian statistical methods, which have been used for numerous flood-frequency studies, to develop and analyze regional models based on hydrologically significant basin characteristics.
- Using incremental steps of mean annual precipitation while developing skew models, it was found that 40 inches of annual precipitation seemed to be a natural breakpoint for the relationships between basins and their skew coefficients. As such, a regression model was fitted to precipitation with a sigmoidal function used to smoothly transition the boundary of 40 inches of precipitation a year.

USGS
science for a changing world

Prepared in cooperation with the U.S. Army Corps of Engineers and the Bureau of Reclamation

Development of Regional Skew Coefficients for Selected Flood Durations within the Columbia River Basin

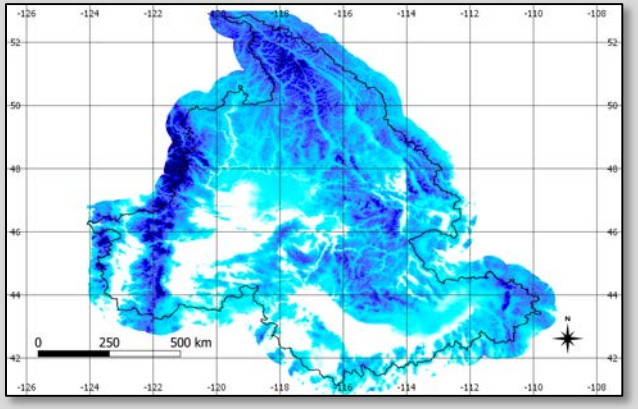
By Greg D. Lind, Jonathan R. Lamontagne, and Adam J. Stonewall

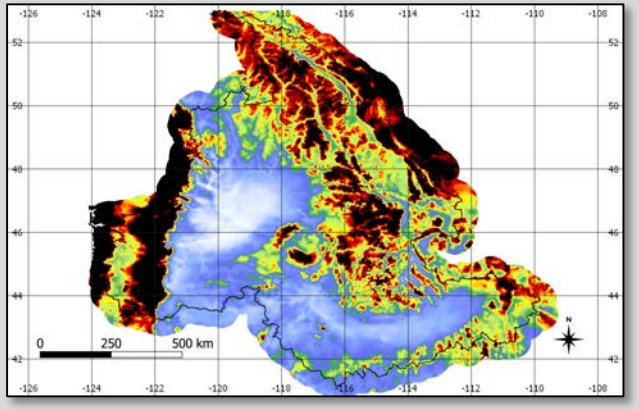


CRB DURATION PRECIPITATION AND SNOW WATER EQUIVALENT (SWE) FREQUENCY CURVES REGIONAL ANALYSIS

Key Points:

- Durations 1-day through 60-day
- Warm season & cool season for precipitation; cool season for SWE
- Pointwise and areal-based exceedance probabilities of precipitation and SWE using a spatial max-stable process model and observed pointwise maxima data.
- Each max-stable modeling analysis leverages extreme value theorem (EVT), at-site estimates of extreme PREC/SWE, physiographic and climatological covariate data, and recent advances in model calibration.
- No areal reduction factors required





Point-wise 100-year return level maps for SWE (top) and precipitation (right)

Title: Spatial Analysis of Precipitation and Snow Water Equivalent Extremes for the Columbia River Basin

Authors:

Brian E. Skahill, Research Civil Engineer, US Army Corps of Engineers, Engineer Research and Development Center, Coastal and Hydraulics Laboratory, Portland, Oregon

Angela M. Duren, Senior Hydrologist, US Army Corps of Engineers, Northwestern Division, Portland, Oregon

Luciana Cunha, Senior Engineer, WEST Consultants, Folsom, California

Chris Bahner, Senior Project Manager, WEST Consultants, Salem, Oregon

Abstract:

Recent advances in the spatial statistics of extremes and model calibration were applied to develop and deliver areal-exceedance estimates for precipitation, by season and duration, and snow water equivalent, by cool season month and for the water year, for 758 delineated sub-basins of the Columbia River Basin which correspond to a new Columbia River Basin hydrology model watershed delineation. Understanding that future USACE-NWD mission requirements may change, project execution also included the development and delivery of an application guidance document to credibly compute areal-exceedance estimates, including uncertainty, for PREC or SWE for any arbitrary area within the CRB. R, a free software environment for statistical computing and graphics (https://www.r-project.org/), and QGIS, a free and open source geographic information system (https://qgis.org/en/site/index.html), were the primary tools used for product development and delivery. The following R software packages were primarily used during project execution: evd, Glmnet, maps, raster, rgdal, SDMTools, sp, and SpatialExtremes.

CRB NUMERICAL ATMOSPHERIC MODEL (WEATHER RESEARCH AND FORECAST (WRF)) FOR:

- HISTORIC DATA RECONSTRUCTION
- PMP
- SYNTHETIC STORMS

Key Points:

- Dynamical downscaling of reanalysis datasets to reconstruct high resolution historical meteorologic data (1929-2017) (4km x 3 hr)
  - Used for calibration and continuous simulation of hydrologic models
- Calibration and validating of WRF model using historical events (PRISM; Corroborating with Regional WRF models)
- Maximization of the integrated vapor transport jet
- stream and lateral boundary shifting for maximization of storms over a given region for PMP and synthetic events (publication pending).

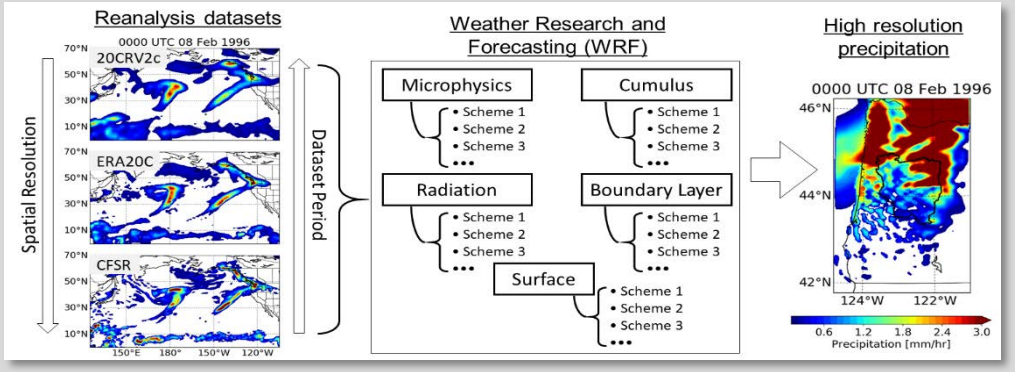
Evaluation of physical parameterizations for atmospheric river induced precipitation and application to long-term reconstruction based on three reanalysis datasets in Western Oregon

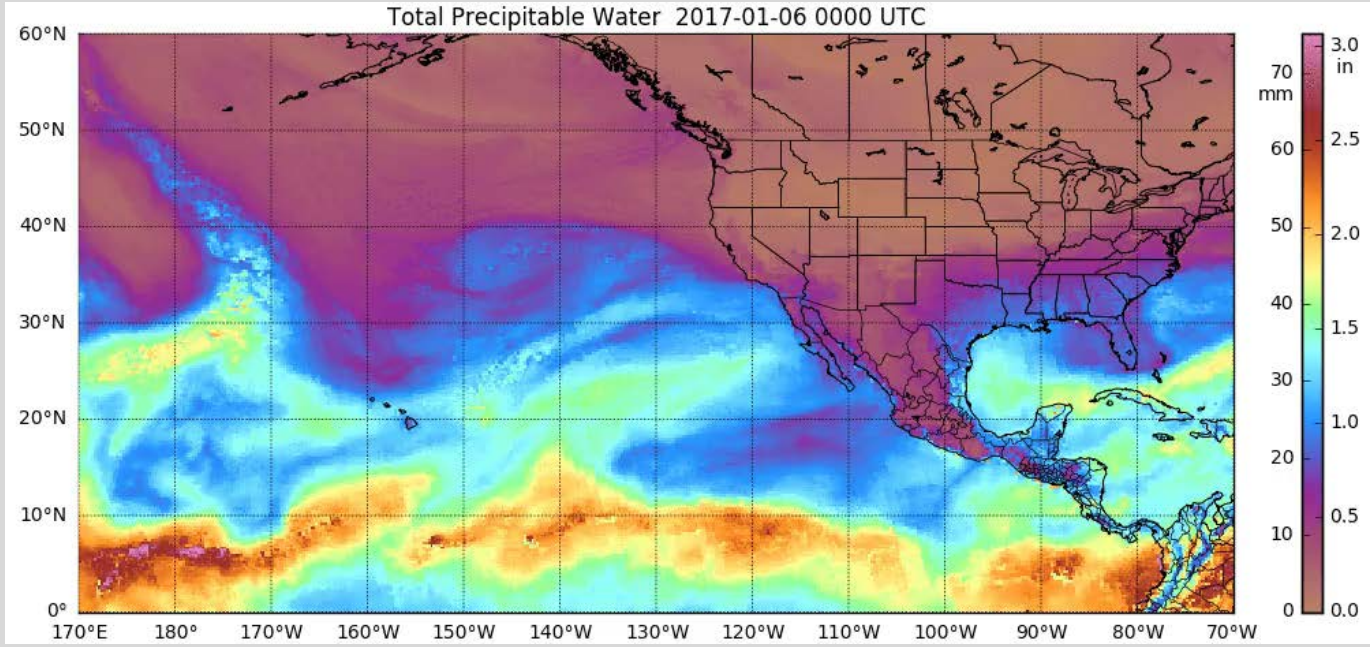
Kinya Toride[a] Yoshihiko Iseri[a], Angela M. Duren[b], John F. England[c], and M. Levent Kavvas[a]

[a] Department of Civil and Environmental Engineering, University of California, Davis, 1 Shields Ave, Davis, CA 95616

[b] U.S. Army Corps of Engineers, Portland District, Portland, OR, USA

[c] U.S. Army Corps of Engineers, Risk Management Center, Lakewood, CO, USA

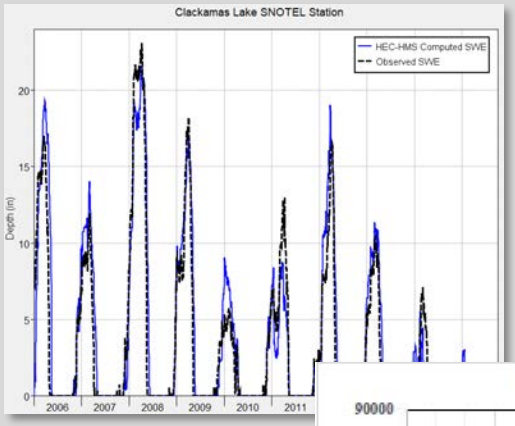


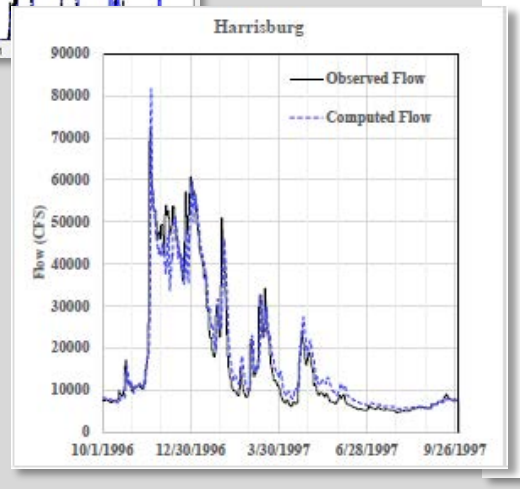


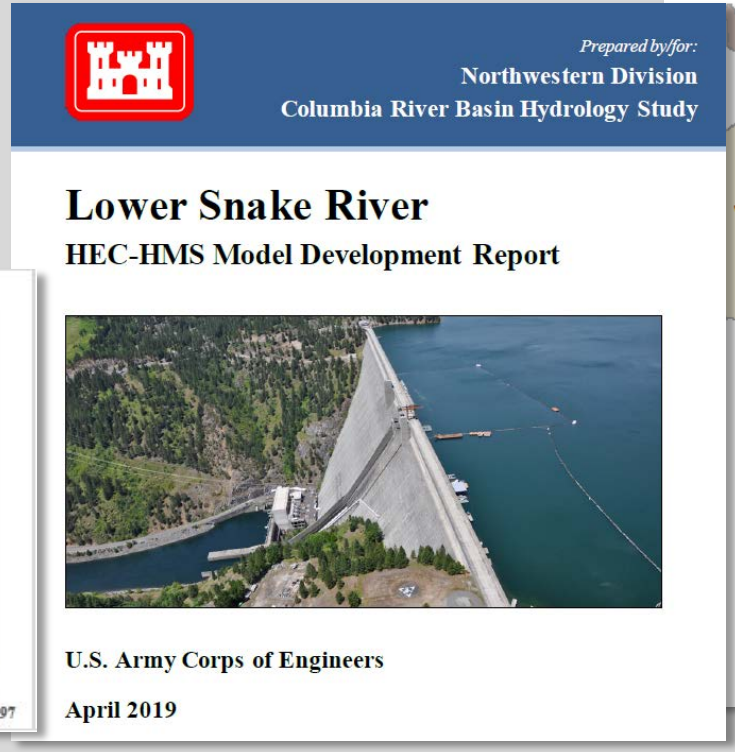
CRB BASIN-WIDE CALIBRATED HYDROLOGIC MODELS

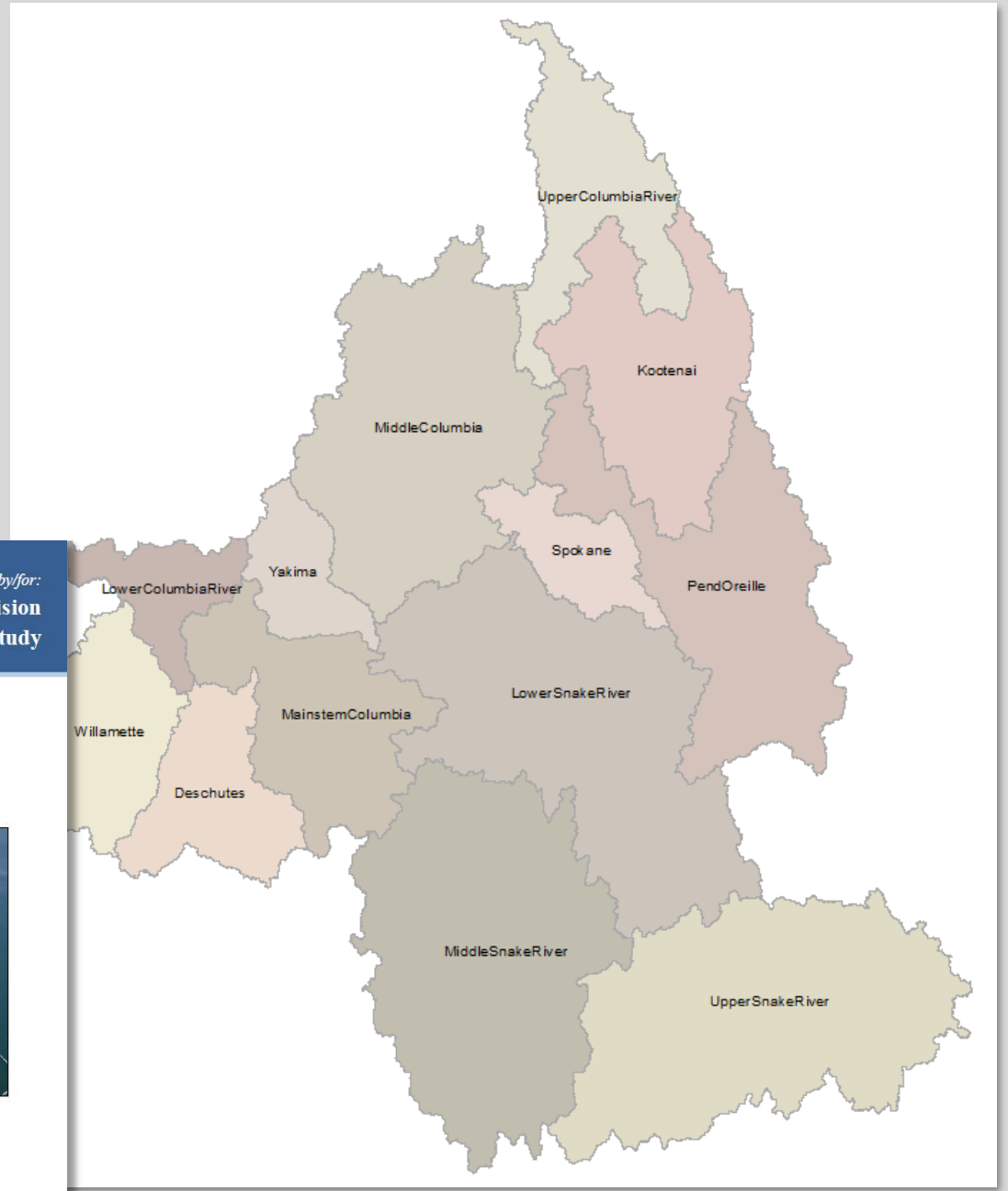
Key Points:

- Columbia River Basin (260,000 square miles) broken out into 13 models by tributary
- Coarse-level Calibration to four key water years in terms of variability in meteorology and water management challenges
- Models reflect both rainflood and snowmelt (dominant) seasons
- Models being used for both real-time and planning/dam safety efforts
- Regionally-approved









CRB HYDROLOGY STUDIES: THE END GAME

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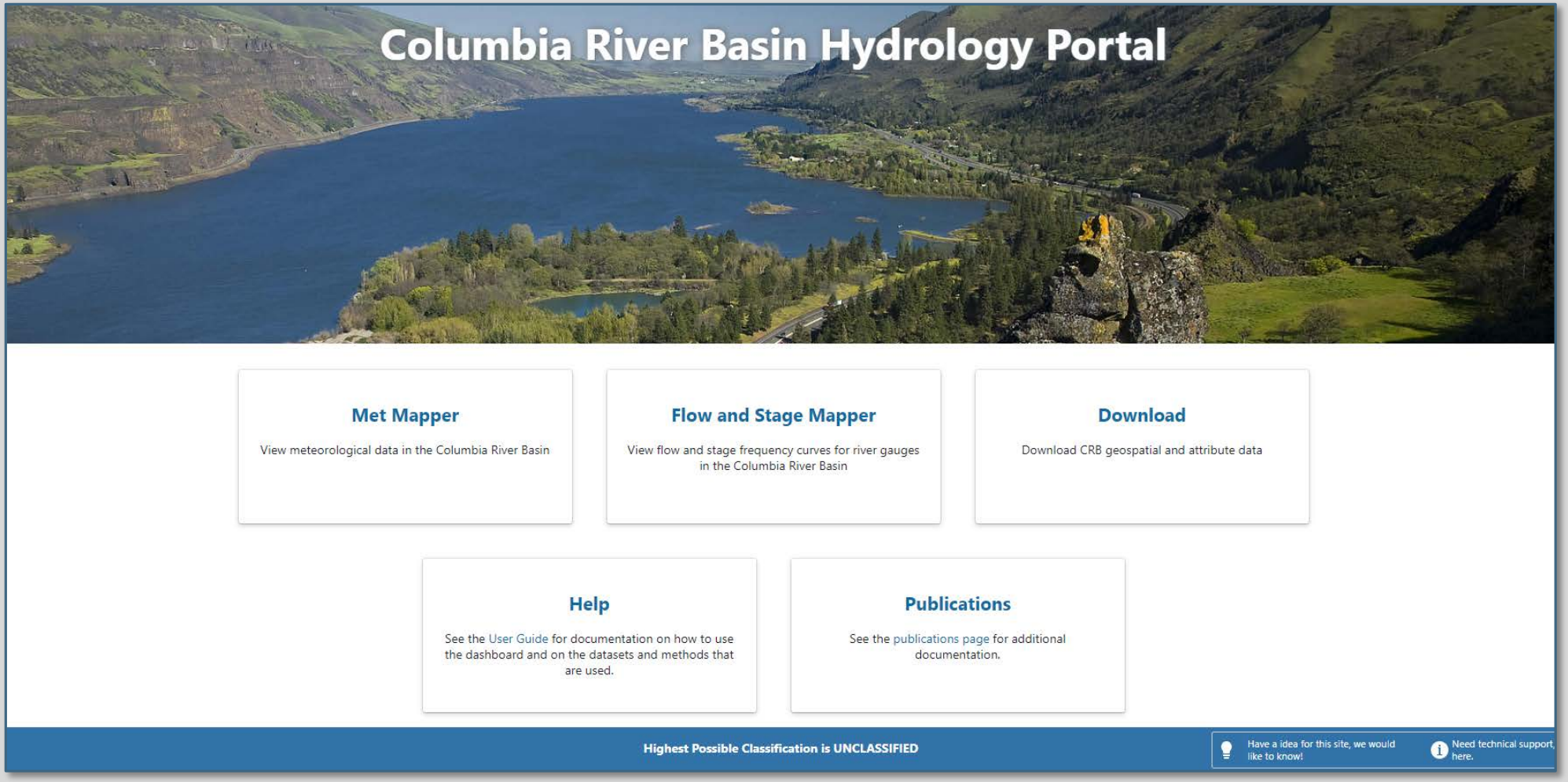
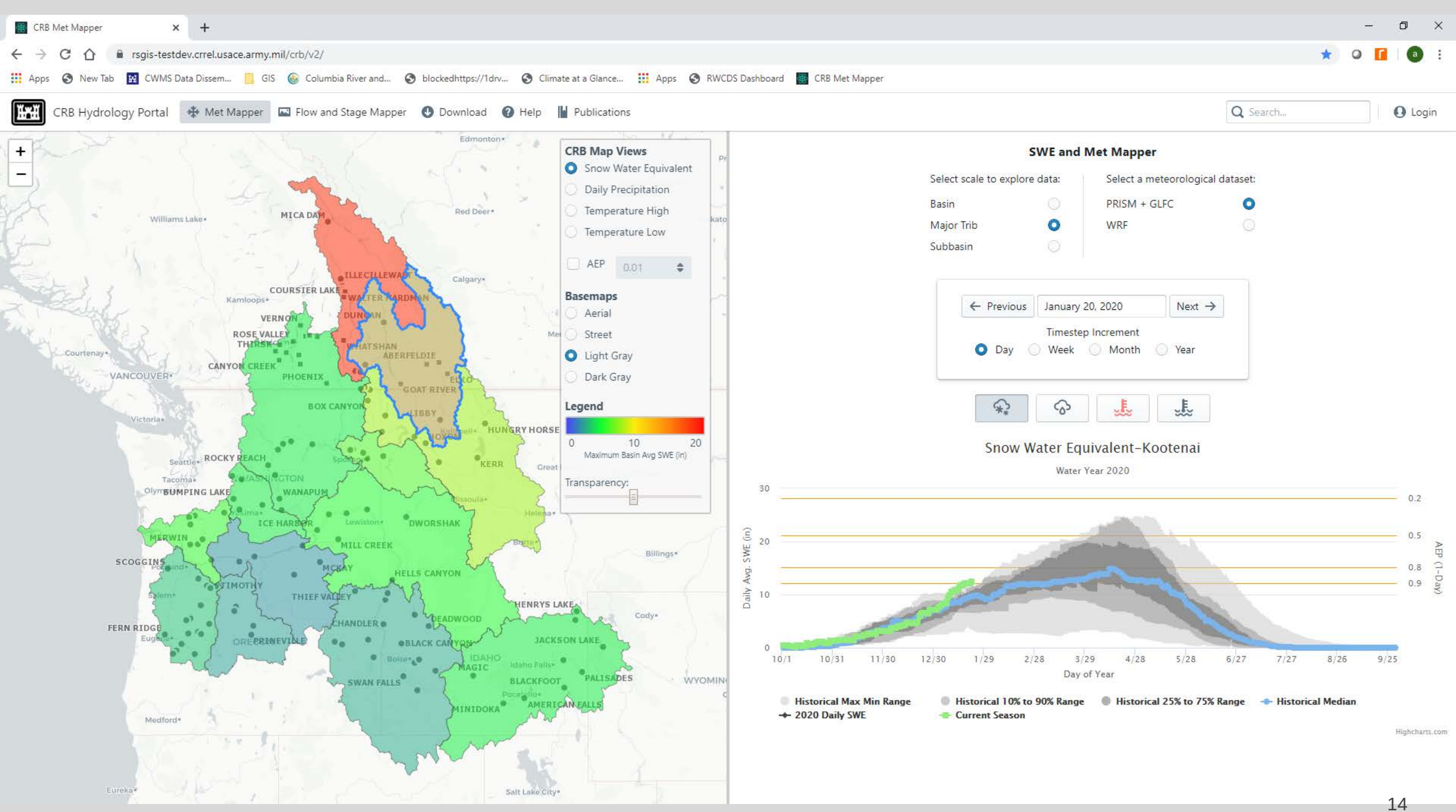


https://rsgis-testdev.crrel.usace.army.mil/crb/v2/


CRB Met Mapper
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GIS
Columbia River and...
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CRB Met Mapper
CRB Hydrology Portal
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Temperature High
Temperature Low
AEP
0.01
Basemaps
Aerial
Street
Light Gray
Dark Gray
Legend
0
10
20
Maximum Basin Avg SWE (in)
Transparency:
MICA DAM
ILLECILLEWAET
COURSIER LAKE
WALTER HARDMAN
DUNCAN
VERNON
ROSE VALLEY
THIRSK
WHATSHAN
ABERFELDIE
CANYON CREEK
PHOENIX
GOAT RIVER
ELKO
BOX CANYON
LIBBY
HUNGRY HORSE
KERR
ROCKY REACH
WANAPUM
BUMPING LAKE
ICE HARBOR
DWORSHAK
MERWIN
MILL CREEK
SCOGGINS
MCKAY
HELLS CANYON
TIMOTHY
THIEF VALLEY
HENRYS LAKE
DEADWOOD
FERN RIDGE
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VANCOUVER
Victoria
Seattle
Tacoma
Spokane
Great
Missoula
Helena
Billings
Cody
Boise
Idaho Falls
Medford
Eureka
Salt Lake City
WYOMIN
SWE and Met Mapper
Select scale to explore data:
Basin
Major Trib
Subbasin
Select a meteorological dataset:
PRISM + GLFC
WRF
Previous
January 20, 2020
Next
Timestep Increment
Day
Week
Month
Year
Snow Water Equivalent-Kootenai
Water Year 2020
Daily Avg. SWE (in)
AEP (1-Day)
30
20
10
0
0.2
0.5
0.8
0.9
10/1
10/31
11/30
12/30
1/29
2/28
3/29
4/28
5/28
6/27
7/27
8/26
9/25
Day of Year
Historical Max Min Range
Historical 10% to 90% Range
Historical 25% to 75% Range
Historical Median
2020 Daily SWE
Current Season
Highcharts.com

CRB Met Mapper

rsgis-testdev.crrel.usace.army.mil/crb/v2/

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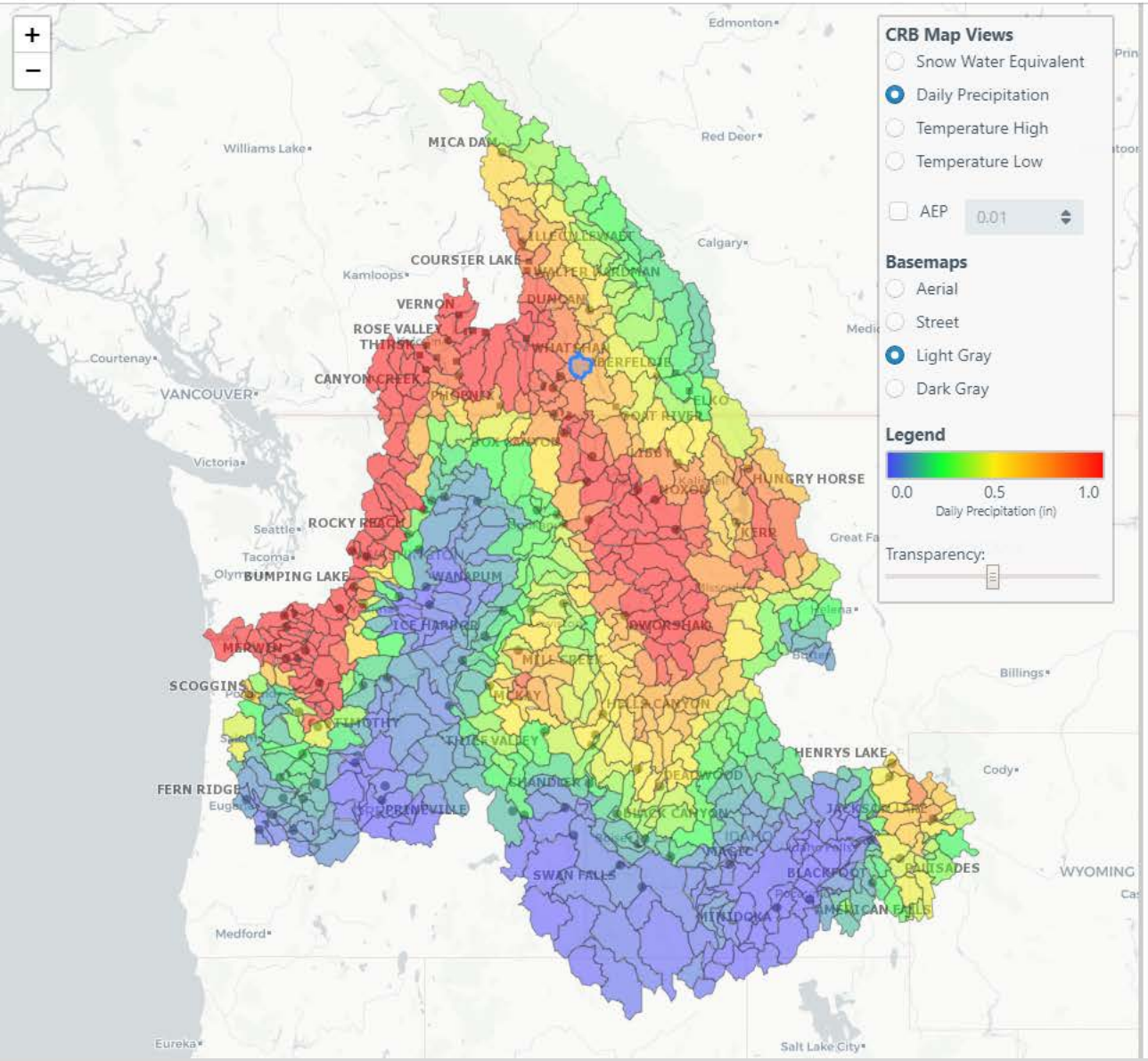

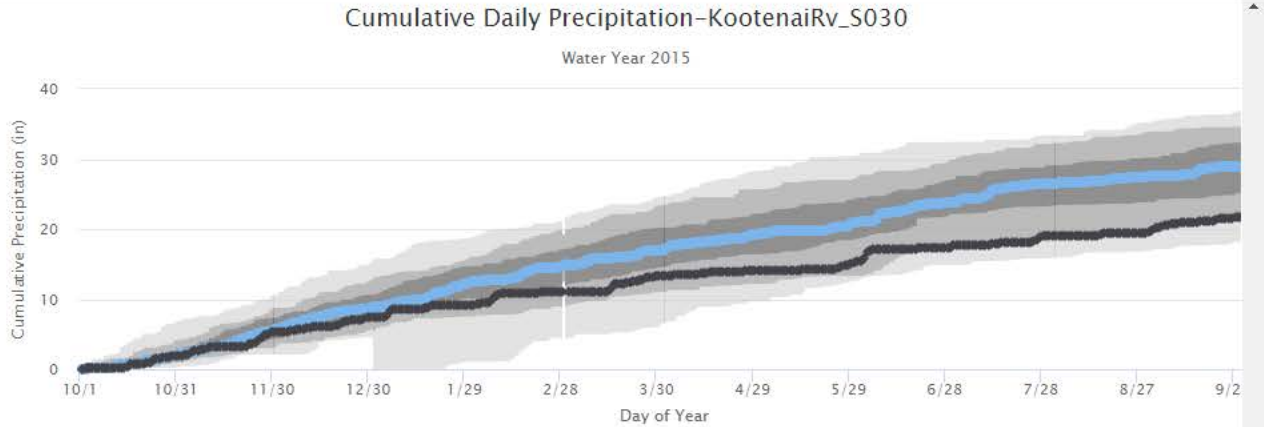

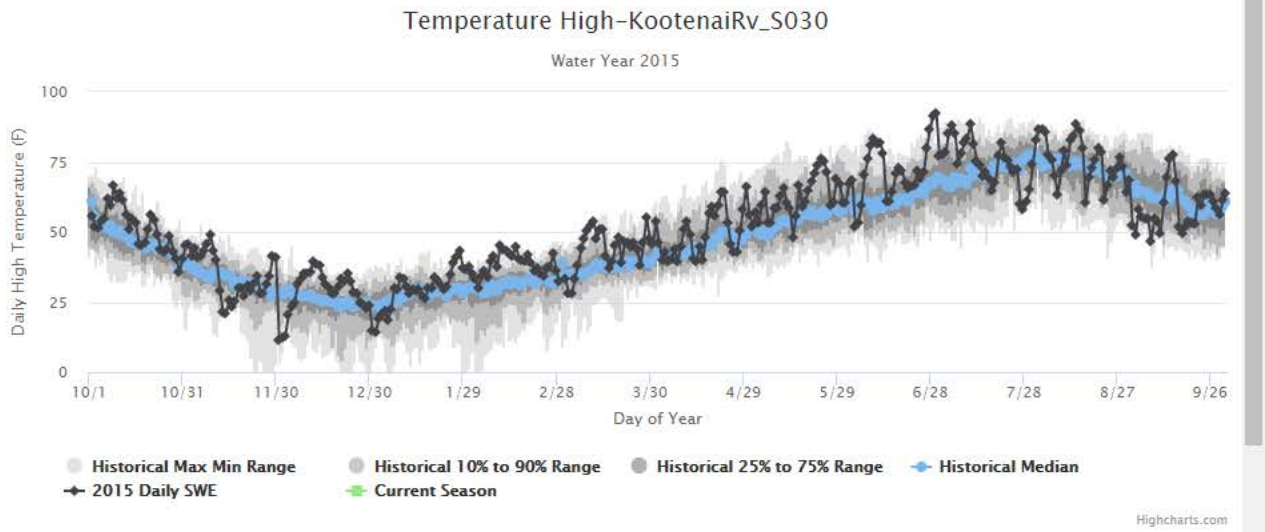

CRB Met Mapper

rsgis-testdev.crrel.usace.army.mil/crb/v2/

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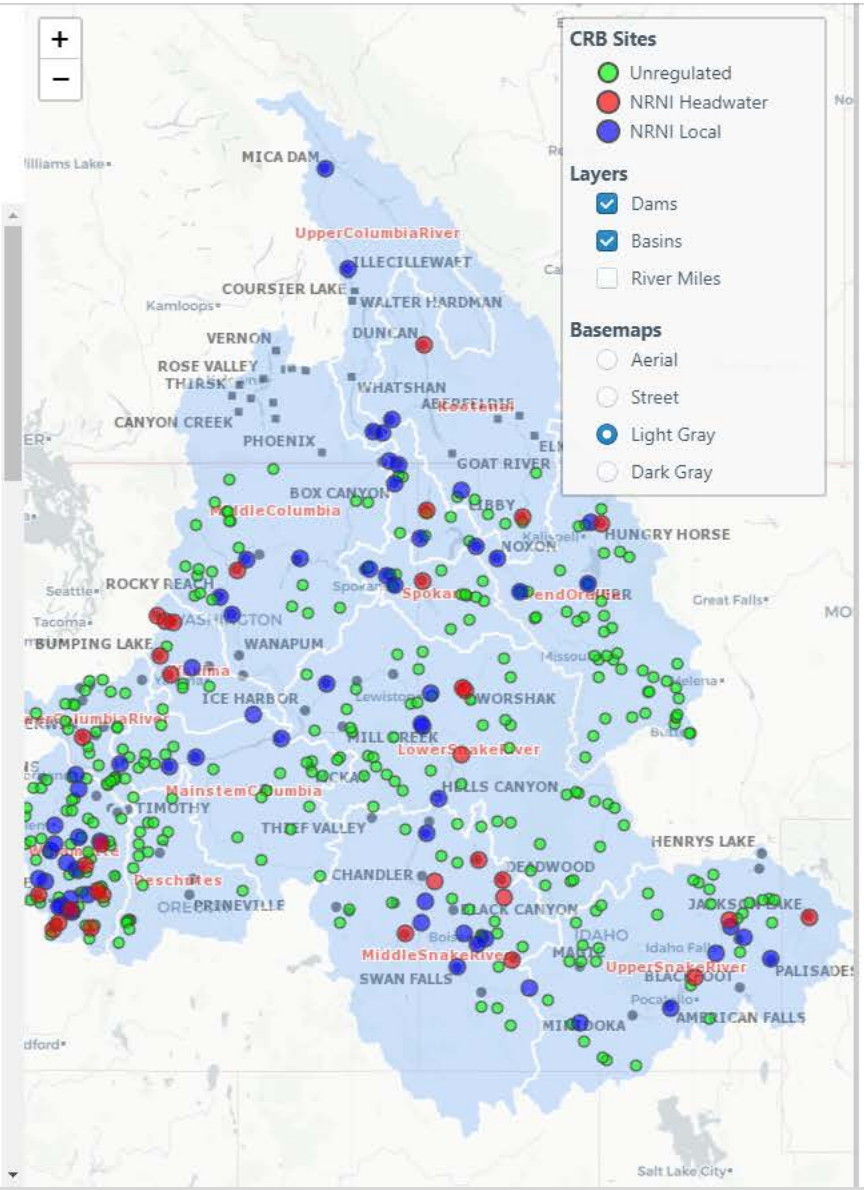
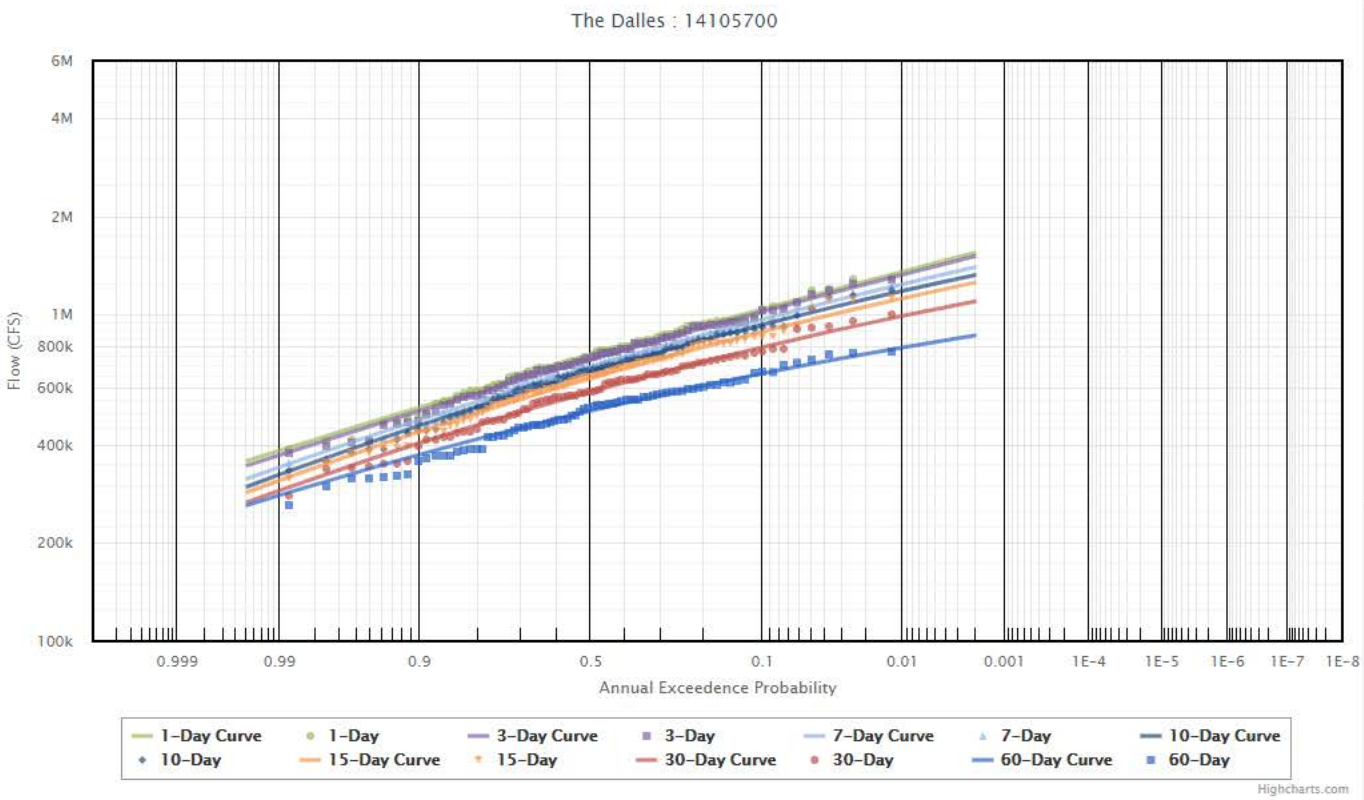
This tool provides access to Flow and Stage frequency data for CRB sites. Select a site on the map, or from the list below.

Filter CRB sites...

- Aerial (Merwin)
- Albany
- Albeni Falls
- American Falls Dam
- Anatone, WA Gage
- Anderson Ranch Dam
- Arrow (Hugh Keenleyside)
- Arrowrock Inflow
- Big Cliff Dam
- Blackfoot River Headwater
- Blue River Dam
- Boise River at Glenwood Bridge, ID Gage
- Bonners Ferry, ID Gage
- Bonneville
- Boundary
- Box Canyon
- Brilliant
- Brownlee
- Bumping Lake
- Cabinet Gorge
- Cascade Dam
- Chelan
- Cle Elum
- Columbia Falls, ID Gage
- Corra Linn
- Cottage Grove Dam





▲ Flow Frequency Details for The Dalles : 14105700

CRB Location	14105700
Applicable Months	Sep-Oct
Unreg or Reg	Unregulated
Chart Source	Source: 2020 USGS Columbia River Basin Regional Volume Skew Study (USGS, 2020).
Author	Author: USGS
Obs Data Source	NRNI 2017
Chart Source Year	Year: 2020
POR	1929-2008

CRB Met Mapper

rsgis-testdev.crrel.usace.army.mil/crb/v2/

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- Blackfoot River Headwater
- Blue River Dam
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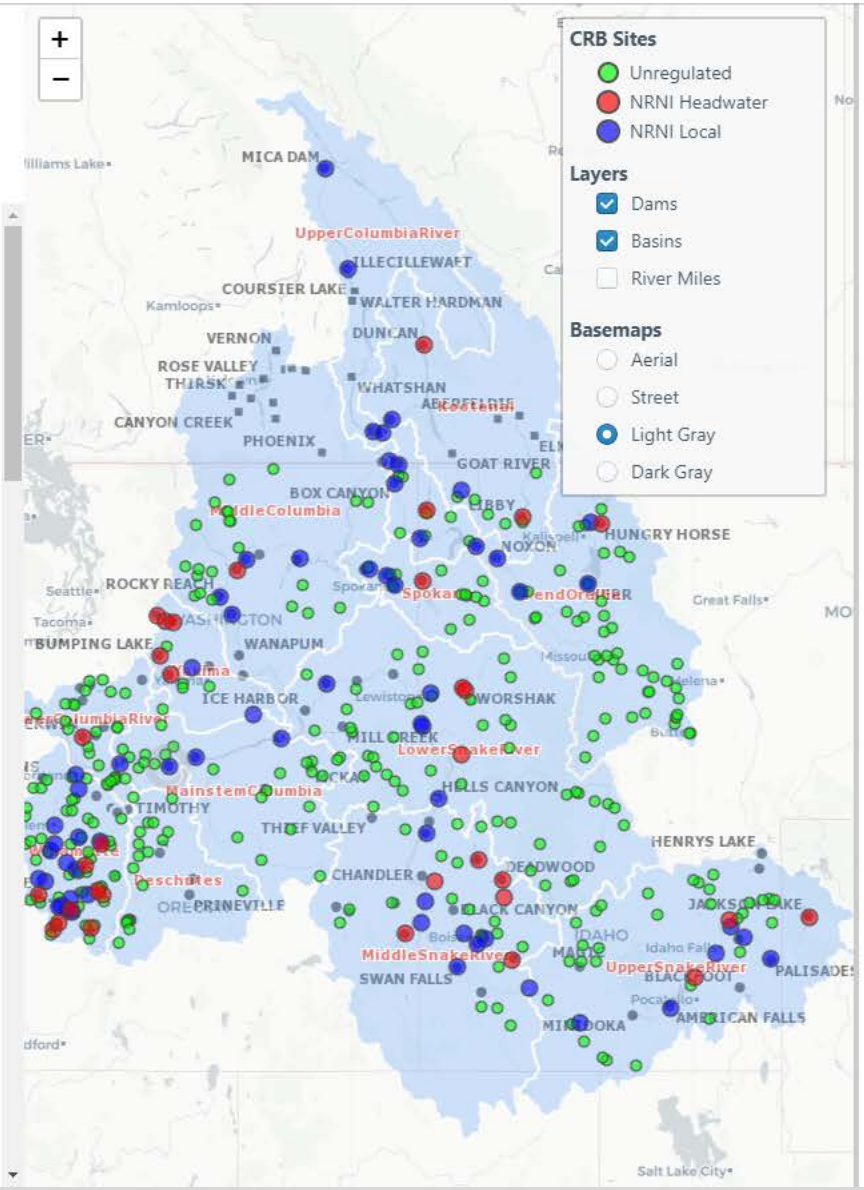
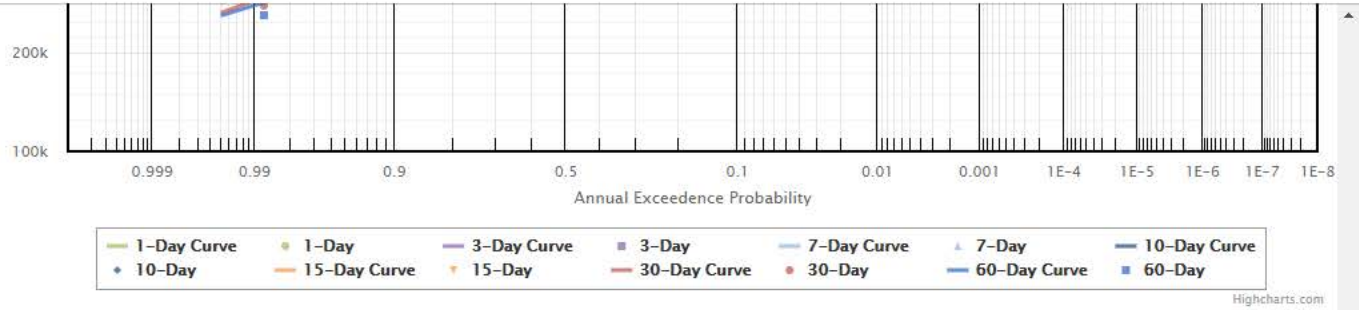
- Bonners Ferry, ID Gage
- Bonneville
- Boundary
- Box Canyon
- Brilliant
- Brownlee
- Bumping Lake
- Cabinet Gorge
- Cascade Dam
- Chelan
- Cle Elum
- Columbia Falls, ID Gage
- Corra Linn
- Cottage Grove Dam





▲ Flow Frequency Details for The Dalles : 14105700

CRB Location	14105700
Applicable Months	Sep-Oct
Unreg or Reg	Unregulated
Chart Source	Source: 2020 USGS Columbia River Basin Regional Volume Skew Study (USGS, 2020).
Author	Author: USGS
Obs Data Source	NRNI 2017
Chart Source Year	Year: 2020
POR	1929-2008
Notes	Notes: Does not include estimated historical flows beyond the NRNI record. Low outliers or Potentially Influentail Low Flows (PILFs) are not depicted on the chart but can be determined by using the number of low outliers and couting from the lowest observed flow upwards. Mean and standard deviation presented here reflect the values after the regional skew is applied. Details provided in the 2020 USGS CRB regional volume skew study.

EMA Statistics

Start Year	End Year	PT Low	PT High	Comment
1900	2016	0.0	Inf	Total Record

Obs Stats

Obs	Mean	Standard Dev	Station Skew	Regional Skew	Weighted Skew	Adopted Skew	Equivalent Record Length	Low Outliers/Zero Flows	# Years with Missing Data
1-Day	5.868	0.1178	-0.283	-0.1	-0.117	-0.117	80	0	0
3-Day	5.8591	0.1187	-0.291	-0.13	-0.145	-0.145	80	0	0
7-Day	5.8352	0.1206	-0.32	-0.24	-0.247	-0.247	80	0	0
10-Day	5.819	0.1211	-0.309	-0.31	-0.31	-0.31	80	0	0
15-Day	5.7989	0.12	-0.251	-0.32	-0.314	-0.314	80	0	0
30-Day	5.7579	0.115	-0.43	-0.34	-0.344	-0.344	80	7	0
60-Day	5.6997	0.0974	-0.374	-0.37	-0.37	-0.37	80	17	0

Critical Values

Type	AEP	Low	Best	High

CRB Met Mapper

rsgis-testdev.crrel.usace.army.mil/crb/v2/

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- Chelan
- Cle Elum
- Columbia Falls, ID Gage
- Corra Linn
- Cottage Grove Dam
- Cougar Dam
- Deadwood Dam
- Detroit Dam
- Dexter Lake
- Dorena Dam
- Duncan
- Dworshak
- Fall Creek Dam
- Fern Ridge
- Foster Dam
- Goshen
- Grand Coulee
- Green Peter Dam
- Harrisburg
- Heise, ID Gage
- Hells Canyon
- Hills Creek

CRB Sites
- Unregulated
- NRNI Headwater
- NRNI Local

Layers
- Dams
- Basins
- River Miles

Basemaps
- Aerial
- Street
- Light Gray
- Dark Gray

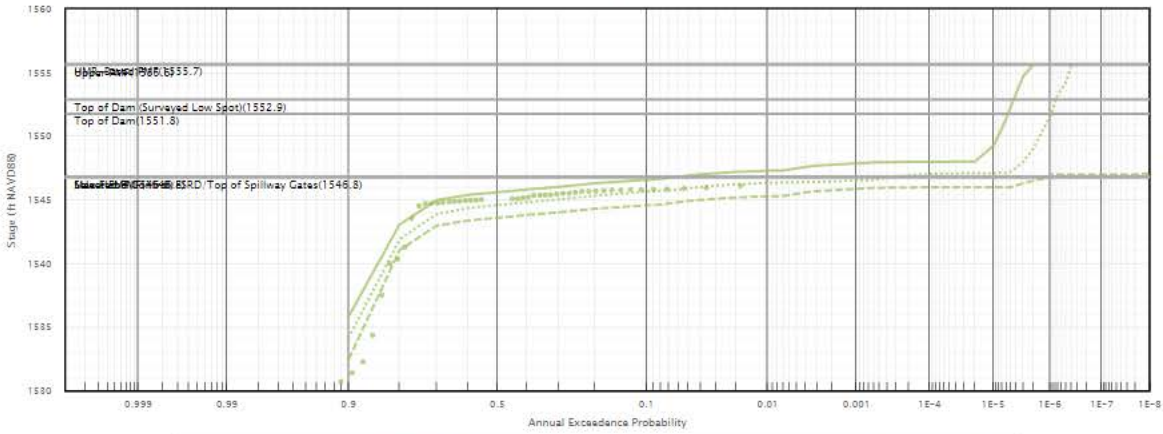
Selected Site: Hills Creek

Flow Frequency Datasets: USGS-2020

Stage Frequency Datasets: NWP-2019

Hills Creek Dam Stage Frequency Curve

Season: Annual



Stage Frequency Details for Hills Creek Dam Stage Frequency Curve

CRB Location	14145100
Season	Annual
Operations	Record adjusted to reflect current operations; modelling reflects current operations
Chart Source	Source: 2019 Hills Creek IES Phase 2 Analysis (RMC, 2019)
Author	Author: NWP
Obs Data Source	NWP DataQuery
Datum	NAVD88
Chart Source Year	Year: 2019
POR	1962-2015
Notes	Notes:
Document Link:	Willamette_River_Basin_Loading_Curve_Report_DRAFT_29Aug2019.pdf

Critical Values

Type	Elevation
Lower PMF	1546.8
Selected PMF	1546.8
Upper PMF	1555.6
Top of Dam	1551.8
Top of Dam (Surveyed Low Spot)	1552.9
HMR-Based PMF	1555.7
Spillway Crest Elevation	1498.3
Max Flood Control/ESRD/Top of Spillway Gates	1546.8

REFERENCES

Beard, L. R. (1960, July). Probability Estimates Based on Small Normal-Distribution Samples. *Journal of Geophysical Research*.
Beven, K., & Hall, J. (2014). *Applied Uncertainty Analysis for Flood Risk Manageement.* London, England: Imperial College Press.
Bonneville Power Agency. (2017). *NRNI_Flows_1929-2008_Corrected_04-2017.csv*.
Cohn, T. A., Lane, W. M., & Baier, W. G. (1997). An Algorithm for Computing Moments-Based Flood Quantile Estimates When Historical Flood Information is Available. *Water Resources Research*, 2089-2096.
Harr, R. (1981). Some Characteristics and Consequences of Snowmelt During Rainfall in Western Oregon. *Journal of Hydrology*, 244-304.
Hosking, J. R., & Wallis, J. R. (1997). *Regional frequency analysis: an approach based on L-moments.* Cambridge: Cambridge University Press.
MGS Engineering Consultants, Inc. (2005). *Stochastic Modeling of Extreme Floods on the American River at Folsom Dam; Flood-Frequency Curve Extension.* Olympia.
O'Connell, D. R., Ostenaa, D. A., Levish, D. R., & Klinger, R. E. (2002). Bayesian flood frequency analysis with paleohydrologic bound data. *Water Resources Research, 38*(5). Retrieved from doi:10.1029/2000WR000028
Perreault, L. (2000). *Bayesian retrospective analysis of a break in sequences of hydrologic random variables.* Paris: ENGREF.
PRISM Climate Group, Oregon State University. (2004). *Northwest Alliance for Computational Science and Engineering*. Retrieved from http//prism.oregonstate.edu
Skahill, B. E., Viglione, A., & Byrd, A. (2016). *ERDC/CH: CHETN-X-1 A Bayesian Analysis of the Flood Freqeuncy Concept.* U.S. Army Corps of Engineers.
Smith, C. H. (2017). *Risk Management Center - Reservoir Frequency Analysis User's Manual.* Lakewood, CO: Risk Management Center.
Smith, C. H., & England, J. F. (2017). Estimating the reservoir stage-frequency curve with uncertainty bounds for Cherry Creek Dam using the reservoir frequency analysis software (RMC-RFA). *U.S. Society on Dams (USSD).*
Stedinger, J. R., & Cohn, T. A. (1986). Flood frequency analysis with historical and paleoflood information. *Water Resources Research, 22*(5).
U.S. Army Corps of Engineers. (1966). *Post-Flood Report: December 1964, January 1965 Flood.* Portland.
U.S. Army Corps of Engineers. (2016a). *Willamette Headwater Dams Critical Flow Duration Analysis.* Portland.
U.S. Army Corps of Engineers. (2016b). *Hydrologic Model Calibration and Validation Report.* Portland.
U.S. Army Corps of Engineers. (2017). *HEC-WAT Watershed Analysis Tool - User's Manual, Version 1.0.*
U.S. Army Corps of Engineers. (2017). *RMC-TR-2017-05 Willamette Basin Regional 72-Hour Wintertime Precipitation Frequency Analysis.*
U.S. Army Corps of Engineers. (2017). *Water Control Manual: Lookout Point and Dexter Lakes.* Portland.
U.S. Army Corps of Engineers. (2018). *RMC-TR-2018-03 An Inflow Volume-Based Approach to Estimating Stage-Frequency Curves for Dams.* Lakewood,CO.
U.S. Army Corps of Engineers. (2018a). *Lookout Point Paleohydrology Study.* Denver.
U.S. Army Corps of Engineers. (2018b). *RMC-TR-2018-03 - An Inflow Volume-Based Approach to Estimating Stage-Frequency for Dams.* Lakewood.
U.S. Army Corps of Engineers. (2018c). *Willamette Basin Dam Probable Maximum Flood (PMF) Report.* Risk Management Center (RMC).
U.S. Army Corps of Engineers. (2019). *RMC-TR Draft Report: Spillway Capacity for Seven Dams in the Willamette Basin.* Lakewood: Risk Management Center (RMC).
U.S. Geological Survey. (2018). *Guidelines for Determining Flood Flow Frequency Bulletin 17C.* https://doi.org/10.3133/tm4B5.
Viglione, A., Merz, R., Salinas, J. L., & Bloschl, G. (2013). Flood frequency hydrology: 3. A Bayesian analysis. *Water Resources Research, 49*(2). Retrieved from doi:10.1029/2011WR010782

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