Peak Flows, from the 100 Year to the Probable Maximum

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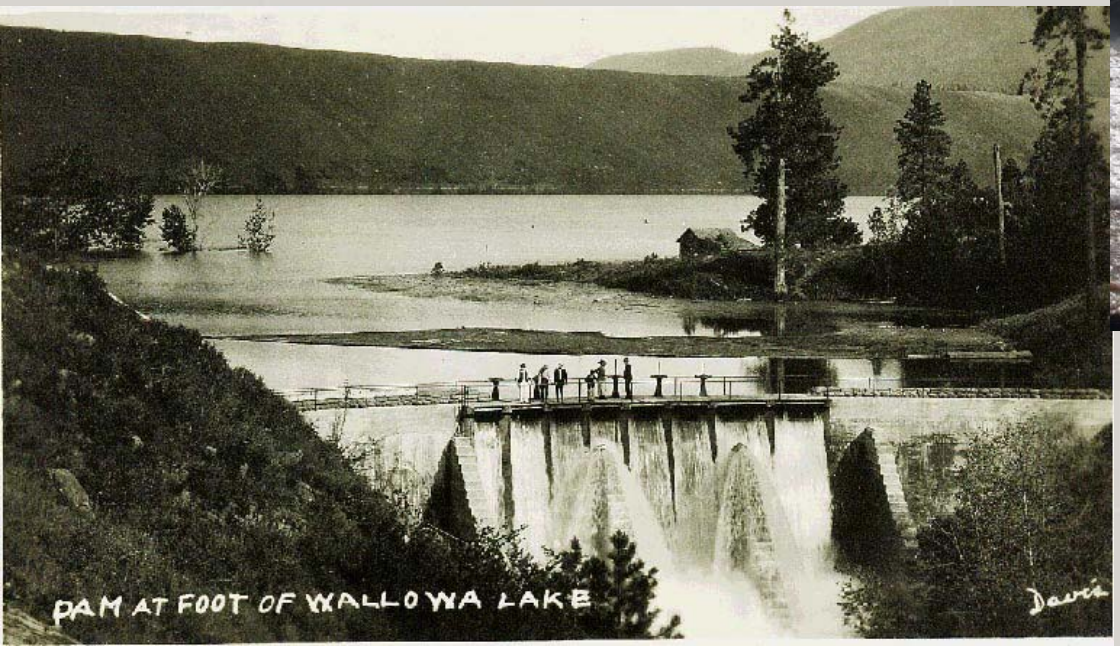


McMILLEN

DESIGN with Vision. BUILD with Integrity.

Outline

- Evolution of guidelines vs. historic periods of dam building
- Patterns in climate and possible effects on high flow estimates
- Does Oregon have a spillway design problem?
- Using PMP and Frequency derived values to estimate spillway design flows as well as breach flows.
- Avoiding malpractice when developing PMF values for spillways and inundation analysis

Guideline evolution

- Early on dams were designed for a “spillway design flood” SDF which was a big flood that was the biggest expected to occur.
- In the 1950’s equations for “t-year” flows, frequency analysis using Gumball distributions, and the PMP came into accepted use.
- PMP with HMR-57 only since 1994! HMR-43 PMP was in 1966! What was used for dams before this?

Guidelines today

- Spillway capacity:100 year event standard for Low Hazard dams calculated with Regional Regression or if available Frequency analysis using nearby stream gage data
- Capacity for Significant and High Hazard Dams uses PMP or ½ PMP based on HMR-57 unless you have better credible regional PMP information derived by custom study.
- Flood PMF is usually developed with software such as HEC-HMS usually with overland flow assumptions.
- Elevated flows for Dam Break Inudation studies vary in percent frequency or percent of PMP but will use one of the two approaches above

Example Modeling evolution Ia

While the actual inflows are similar the sophistication of routing and attenuation and overflow over reservoir is much more advanced: See example for Fish Hawk Lake

Summary of HMS Model vs. Phase I HEC-1 Model, Fishhawk Lake				
General Storm				
Result	HMS	HEC-1	Diff.	% of HEC-1
Peak Inflow (cfs)	6429	6808	-379	-6%
Hydrograph Volume (ac-ft)	15071	15400	-329	-2%
Base Flow (ac-ft)	757	756	1	0%
Routed Peak Outflow (cfs)	6126	6637	-511	-8%
Length of Dam Overtopping (hrs)	10	16	-6	-38%
Max Depth Above Dam (ft)	1.1	2.2	-1.1	-50%

Note: Phase 1 conducted late 70's and HMS ~ 2008-09; PMP based on HMR-43 in both cases: 19.53 inches in 72 hours.

Example Modeling evolution Ib

Another example is the PMP values have changed between HMR-43, HMR-57 : another example for Fish Hawk Lake

Summary of PMF Generated by: Report No. 57 PMP vs. Phase 1 PMP				
General Storm				
Result	No. 57	Phase I	Diff.	% of Phase I
Peak Inflow (cfs)	8308	6429	1880	+29%
Hydrograph Volume (ac-ft)	25868	15071	10797	+72%
Base Flow (ac-ft)	757	757	0	0%
Routed Peak Outflow (cfs)	8180	6126	2054	+34%
Length of Dam Overtopping (hrs)	13	10	3	+30%

Note: No. 57 PMP is based on HMR-57 30.04 inches and HMS based on HMR-43 both run through same HMS model. Note HMR-57 used for current design work! ***Peak for latest PMF (McMillen, 2011) is 10,524 cfs***

Example Modeling evolution IIa

Differences in guidelines are not always this extreme for Barnes Butte we have the following changes over time with changes in Modeling approach used:

Summary of HMS Model vs. Phase I HEC-1 Model, Barnes Butte Dam				
General Storm				
Result	HMS	HEC-1	Diff	% of HEC-1
Peak Inflow (cfs)	1511	1642	-131	-8%
Hydrograph Volume (ac-ft)	2902	3047	-145	-5%
Base Flow (ac-ft)	147	149	-2	-1%
Routed Peak Outflow (cfs)	1486	1641	-155	-9%
Length of Dam Overtopping (hrs)	50	52	-2	-4%
Thunderstorm				
Result	HMS	HEC-1	Diff	% of HEC-1
Peak Inflow (cfs)	4997	5176	-179	-3%
Hydrograph Volume (ac-ft)	1998	2093	-96	-5%
Base Flow (ac-ft)	3.4	2	1	70%
Routed Peak Outflow (cfs)	4983	5150	-167	-3%
Length of Dam Overtopping (hrs)	24	23	1	4%

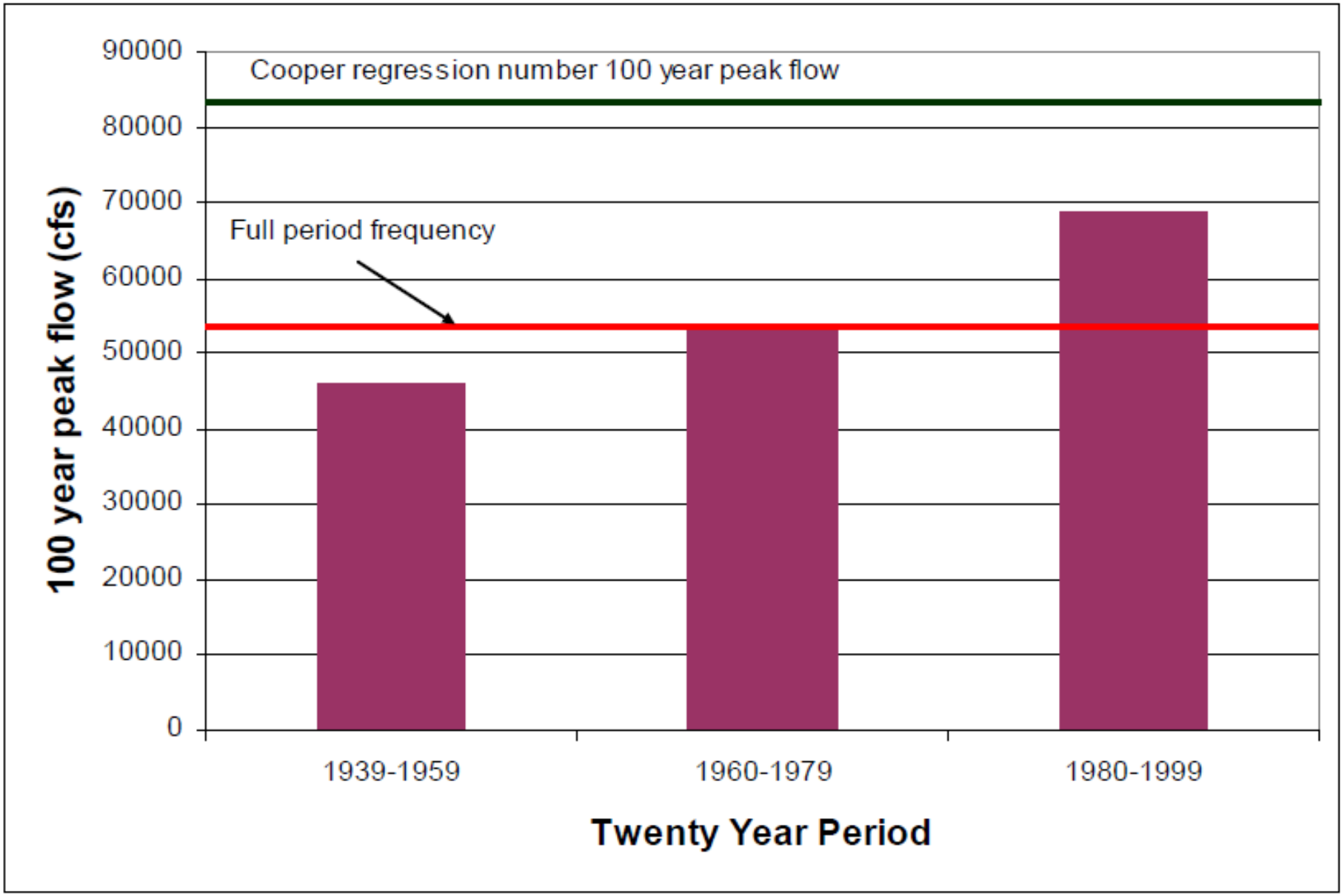
Note: Both PMP's are based on HMR-43 and are 16.32" for General Storm and 11.94" for Thunderstorm

Example Modeling evolution IIb

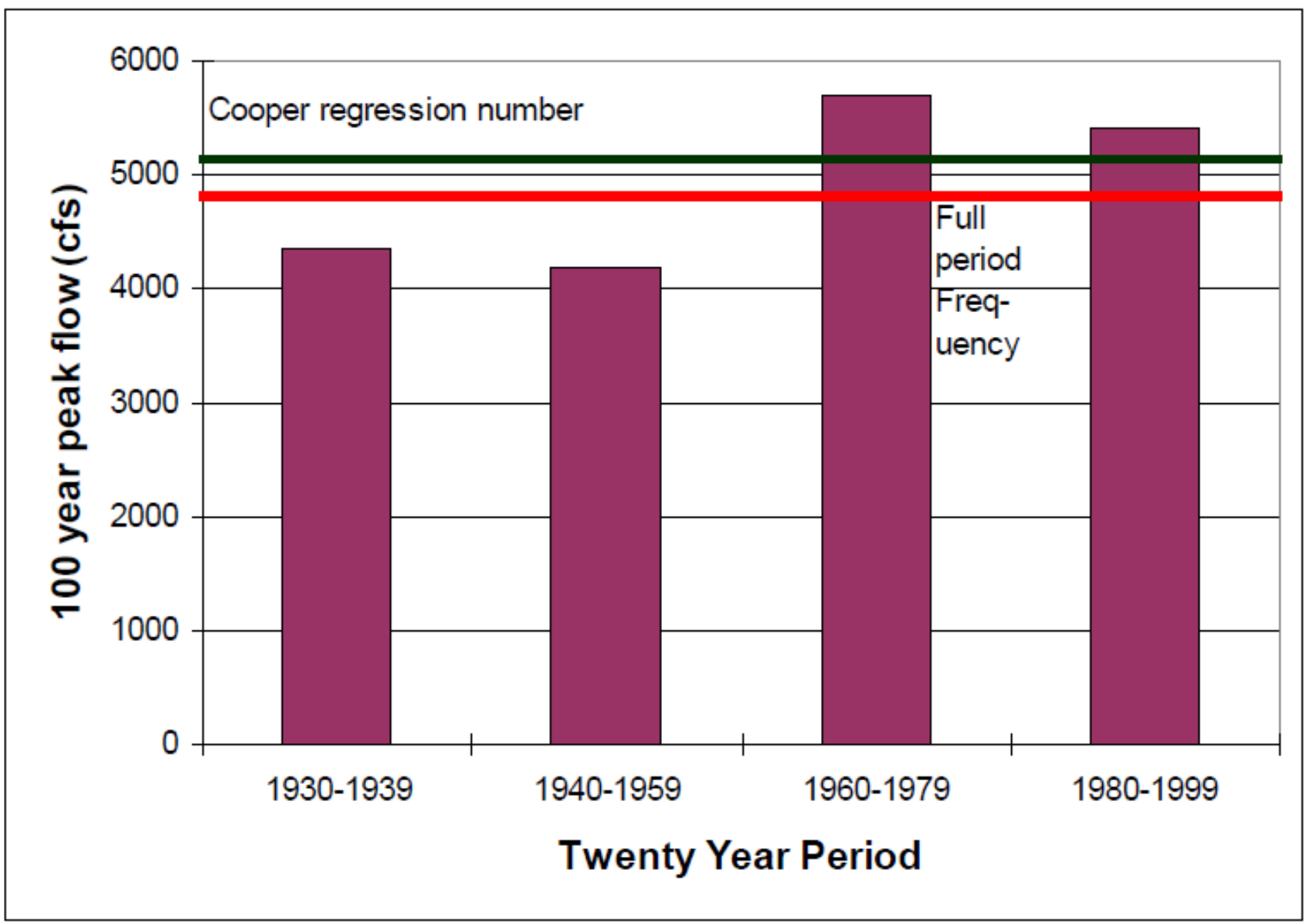
Unlike Fish Hawk, Barnes Butte experiences reductions with newer PMP standards especially for the Thunderstorm PMP which is governing for PMF estimate:

Summary of Report No. 57 PMP vs Phase I PMP				
General Storm				
Result	No. 57	Phase I	Diff	% of Phase I
Peak Inflow (cfs)	1479	1511	-32	-2%
Hydrograph Volume (ac-ft)	2005	2902	-898	-31%
Base Flow (ac-ft)	148	147	1	1%
Routed Peak Outflow (cfs)	1463	1486	-23	-2%
Length of Dam Overtopping (hrs)	42	50	-8	-16%
Thunderstorm				
Result	No. 57	Phase I	Diff	% of Phase I
Peak Inflow (cfs)	3997	4997	-1000	-20%
Hydrograph Volume (ac-ft)	1507	1998	-491	-25%
Base Flow (ac-ft)	1.8	3.4	-2	-47%
Routed Peak Outflow (cfs)	3979	4983	-1004	-20%
Length of Dam Overtopping (hrs)	22	20	2	10%

Note: PMP's based on HMR-43 16.32" GS; and 11.14" for TS
For HMR-57 these reduce to 11.94' GS and 8.41" for TS

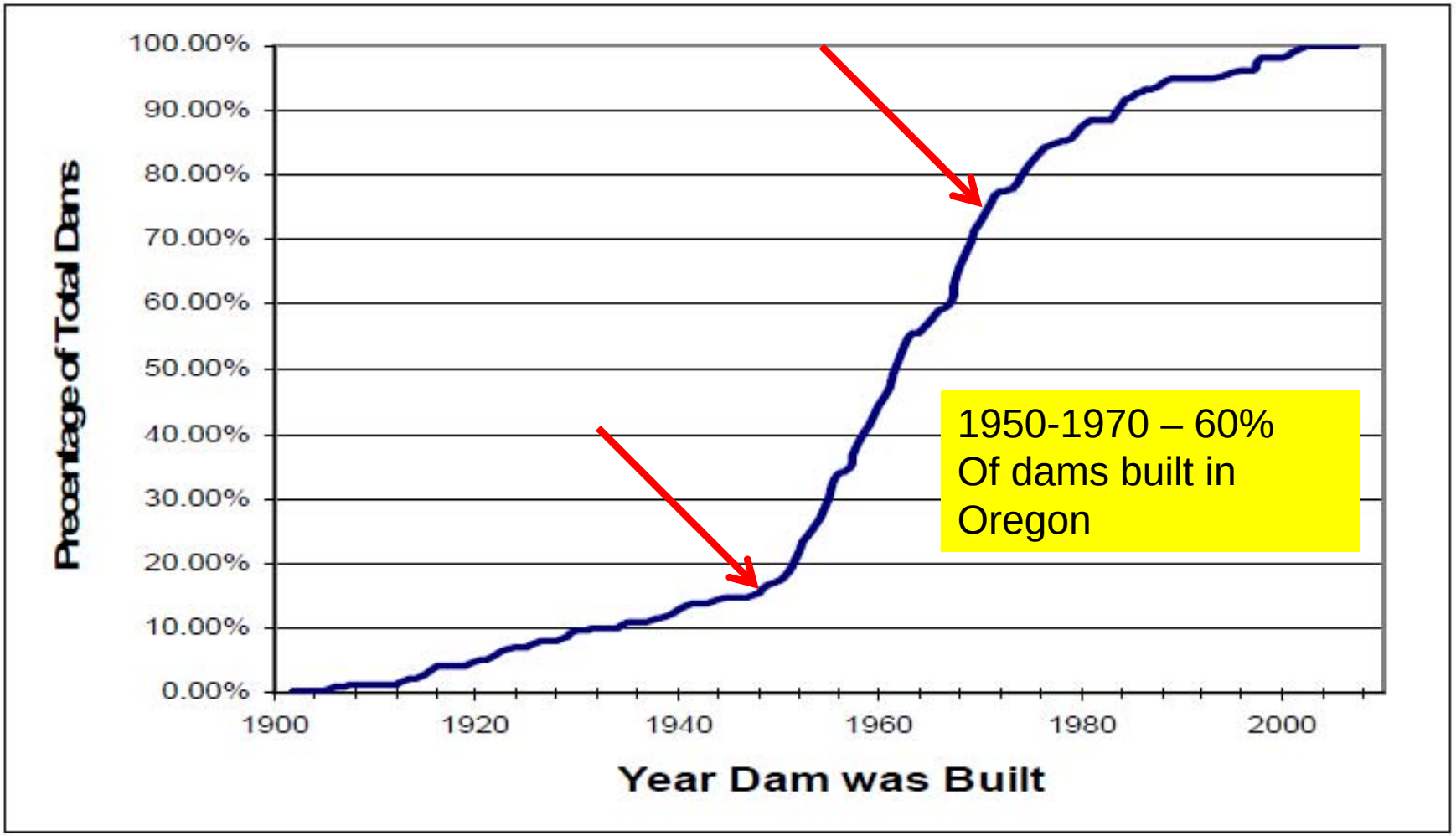


Log Pearson III Frequency Analysis for different time periods vs. long-term Record Nehalem R. at Foss (Robison and Craven, 2010)



Log Pearson III Frequency Analysis for different time periods vs. long-term Record: John Day R. at Ritter (Robison and Craven, 2010)

When were dams built in Oregon?

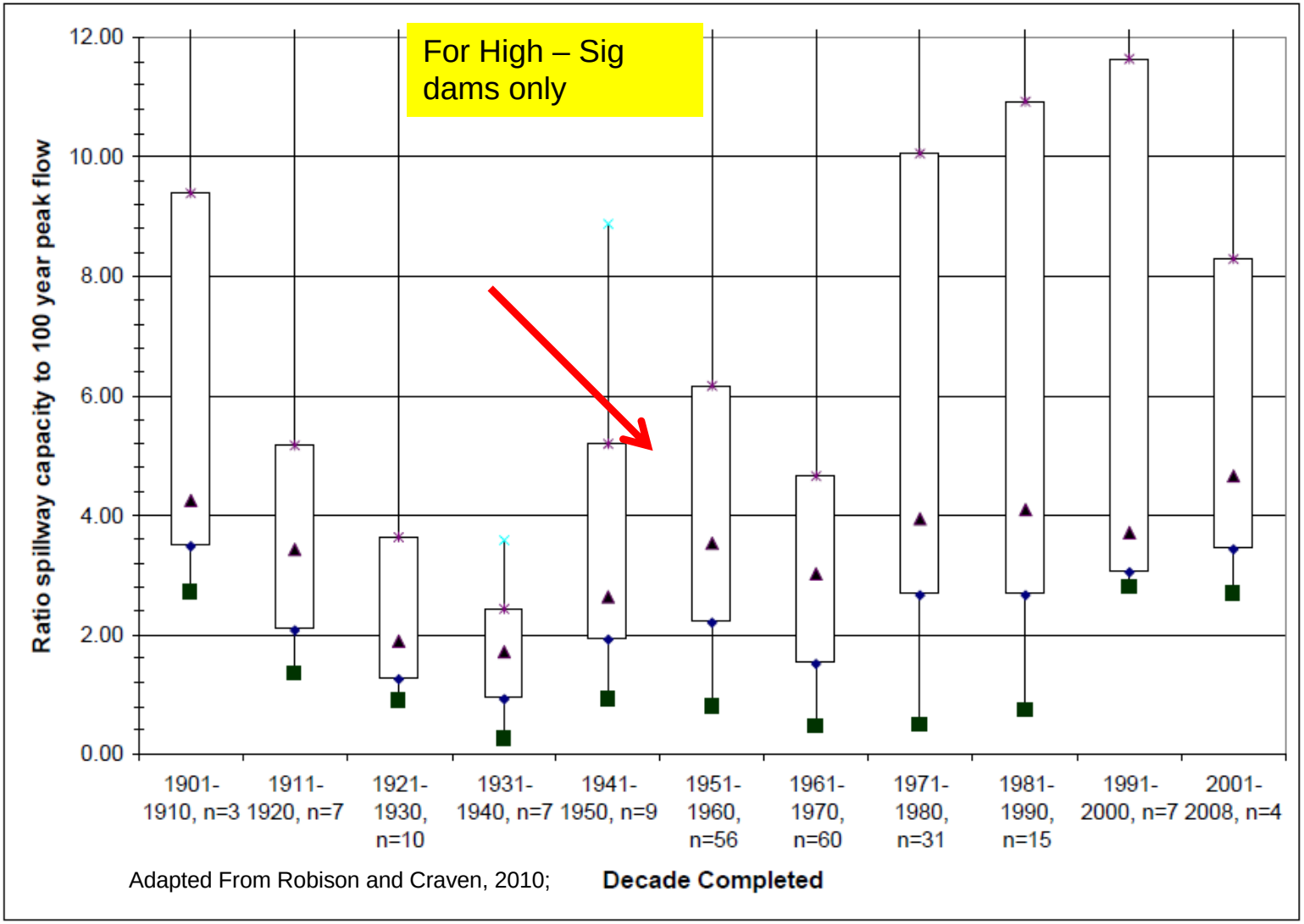


Adapted From Robison and Craven, 2010

Do 100 year values and PMF shift with time?

- For Frequency ***yes!*** If a series of large storms occur over a period, it will influence the 100 year flow or any other frequency based value.
- For PMF, ***Yes.***
  - As more information and sophistication is known, the PMP maps change as does methods for reduction with increasing area etc.
  - In many cases PMF calculations were crude and not able to account for issues such as flow routing. With the advent of computer models these factors can be accounted for.
- Please note: Freq, PMP and PMF techniques are very “Young Sciences”, 60-70 years old

End result: there is variation in spillway capacity vs. flow with time



Adapted From Robison and Craven, 2010;

Notes: This is in relation to a regression based 100 year flow (Cooper, 2006 and 2006).
Box and whisker plots, by decade in which the dam was constructed, of the ratio of spillway capacity to 100-year peak flow. The triangle represents the median value and the box represents the standard deviation about the mean with the lines being the range. The black square represents the minimum value.

Second Issue – Hazard Creep

- When a dam is first built it is often in a rural setting with no real infrastructure downstream of the dam. Over time land is developed into homes and businesses downstream and the orginally low hazard dam becomes a significant or high hazard dam.
  - Low Hazard Standard 100 year + 2 feet of Freeboard
  - Significant Hazard Standard ½ PMP
  - High Hazard Standard Safely pass the full PMP

Does Oregon have a spillway capacity problem?

- **<u>Yes</u>**, but it is limited. In the Robison and Craven paper most high and significant dams have values greater than 3 times the 100 year flow which is similar to a PMP like value if calculated today. However, as you can see, there are some dams on in this figure that are High and Significant Hazard that are actually lower than the 100 year flow.

Picture: Barnes Butte Spillway Capacity 160 cfs PMF nearly 5000 cfs!

Steps and issues in creating a PMF

- Example General Storm Western Oregon (Part 1 PMP Input to Models) (Note: This varies between General and Local as well as Thunderstorm PMPs)
  - Step 1, Drainage Outline: GIS was used. Basin characteristics needed also developed from GIS (how good are they?)
  - Step 2, User Decision: all season PMP estimate will be used.
  - Step 3, All-Season Index PMP Estimate (Step 4 – did not use seasonal PMP)
  - Step 5, Depth Duration: Fishhawk is in sub region No. 4. From Figure 15.9 and Map No. 1

Fishhawk, General PMP Step 5: Depth Duration

Duration (hr)	1	6	24	48	72
Region 4	0.1	0.4	1	1.49	1.77
Fishhawk (in)	1.85	7.39	18.48	27.53	32.70

  - Step 6, Areal Reduction Factors
  - Step 7, Incremental Estimates
  - Step 8, Temporal Distribution (Group 6 hour increments into 24 hour periods) (Can do this a lot of ways and use Modeling software)
  - **Step 9, Areal Distribution of PMP: Basin is small, assuming equal PMP over Basin**

Steps and issues in creating a PMF II

- Part II: Issues in using Hydro and Hydraulic Models to create and Route PMF
  - Issue 1: Typically you are picking a method that is assuming “Hortonian overland flow” that is generally not occurring! The parameters such as “Curve Number” are purely fiction and are as only as good as your judgment and whatever calibration you can do. Be careful compare 100 year precipitation output to gage or empirically modeled values. At least do sensitivity analysis so you can understand what CN effects are.
  - Issue 2: Should look carefully of largest flow hydrographs from gages nearby and/or use conservative distribution of precipitation (hyetograph) that you can defend.
  - Issue 3: There is a temptation to use HMS or another simple hydro model and shortchange the attenuation that occurs in the Reservoir as water is routed. This temptation should be resisted and you should use more sophisticated routing available in a model like HMS or even input to something like HEC-RAS for routing through reservoir.

Summary

Fish Hawk Lake in the Fall note Glory hole spillway on left : Photo credit Glen Post

- Do not assume that an existing dam has adequate spillway sizing nor assume that past inundation studies done decades ago are correct due to changes and improvements in methodologies over the years as well as issues such as “hazard creep.”
- Picking a PMP value for a PMF model is more than just picking a value off a chart and then quickly running it through a hydro model. Need to make judgments on what type of storm (local vs. general) and how precipitation should be distributed both spatially and temporally.
- Strongly encourage running lesser events and comparing to stream gage or empirical model values to insure you have calibrated parameters.
- Remember past published values of empirical models or gage records are based on a period of record and this should be evaluated.