Regional Precipitation-Frequency Analysis And Extreme Storms Including PMP Current State of Understanding/Practice

Mel Schaefer Ph.D. P.E.

MGS Engineering Consultants, Inc.
Olympia, WA

NRC Workshop - Probabilistic Flood Hazard Assessment Jan 2013

Overview of Topics of Interest

Regional Frequency Analysis

Point Precipitation-Frequency

- Regional concepts, homogeneous regions
- At-site versus regional methods – sampling variability
- Trading space for time: Equivalent Independent Record Length
- L-moment statistics: at-site mean, L-Cv, L-Skewness
- Regional behavior L-Cv, L-Skewness:
  - Arid to rainforest climates, duration
  - Convective, stratiform, tropical storms
  - Storms at local, meso-scale and synoptic scale
- Spatial mapping of at-site means, L-Cv and L-Skewness
- Identification of regional probability distribution

Overview of Topics of Interest

Regional Frequency Analysis

Areal (Watershed) Precipitation-Frequency

- Storm spatial analysis: Isopercental method
- Storm spatial analysis: radar & ground-based precipitation
- Relationship of point to areal precipitation
- Uncertainties in components for developing areal precipitation-frequency relationship
- Developing mean precipitation-frequency curve and uncertainty bounds for watersheds

Overview of Topics of Interest

Probable Maximum Precipitation (PMP)

- Is there a physical upper limit ?
- Uncertainties in PMP estimation
  - Sampling limitations of storm database
  - Simplifying assumptions, policy versus science decisions
  - Effect of analyst's judgment
- Annual Exceedance Probabilities (AEP) of published PMPs
  - Varies with nearness to sources of atmospheric moisture
  - Varies with length of storm season
  - Varies with storm characteristics of interest:
    short-duration intensities
    long-duration volume

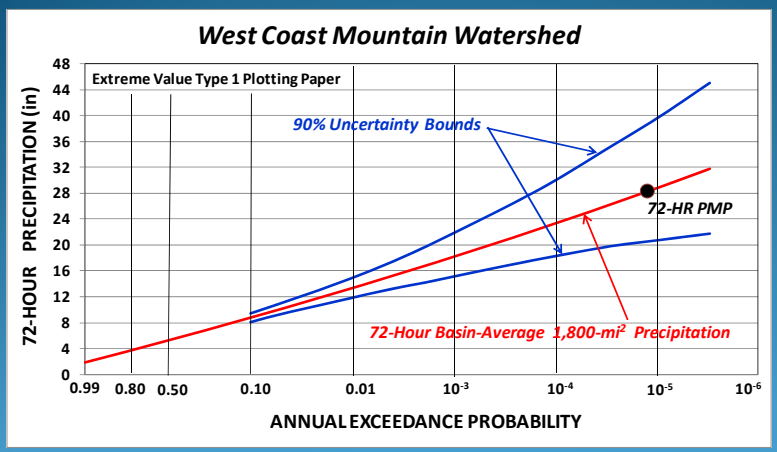
What's the Status of Regional Precipitation-Frequency Analysis for Use with Extreme Storms ?

Precipitation-Frequency Relationships Needed for Watersheds for Rainfall-Runoff Modeling of Extreme Storms and Floods

Precipitation-Frequency Relationships Have Been Developed for Watersheds using Regional Analysis Methods since 1998

Hydrologic Risk Assessments - 20 Dam Projects
USBR BChydro USCOE Hydropower Utilities

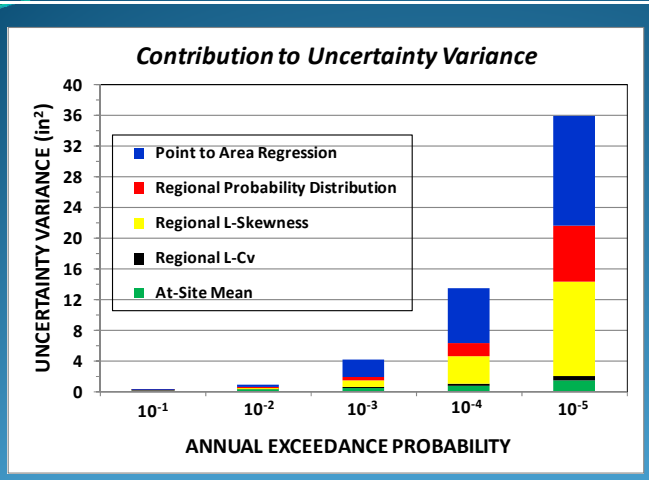
Precipitation-Frequency for Watersheds What Does End-Product Look Like ?



PMP is just another point on the curve

Methodologies Have Been Developed for Computation of Mean Frequency Curve and Uncertainty Bounds

Precipitation-Frequency for Watersheds



Regional Analysis Dramatically Reduces Uncertainties for More Common Events

Largest Contributions to Total Uncertainty are Typically:
Uncertainties in Regional L-Skewness
and Relationship for Point to Areal Precipitation

What Has Made Development of Precipitation-Frequency Relationships for Watersheds Possible ?

Regional Analysis Methodology

grouping of datasets of like phenomenon to reduce uncertainties, improve identification of parent probability distribution

Jim Wallis – IBM Research

L-Moment Statistics

major advancement in statistical measures for small datasets exhibiting marked skewness

Jon Hosking – IBM Research

PRISM Model

spatial mapping of precipitation and L-moment statistics

Chris Daly – Oregon State University

Why This is Now Possible

Isopercental Analysis

spatial interpolation methods for spatial mapping of precipitation (storm events) in mountainous areas

Improvements in NWS Techniques

SPAS Software

use of radar data and ground-based precipitation for spatial mapping of precipitation (storm events)

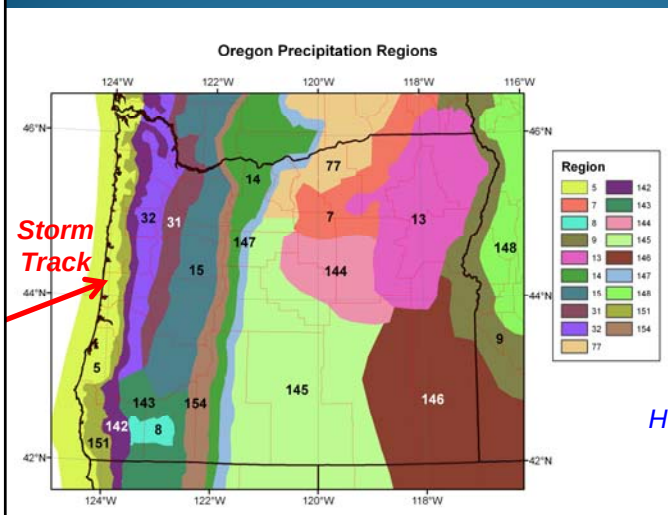
Applied Weather Associates and MetStat Software

Building Foundation of Experience

experienced gained from analyses in variety of climatic settings has lead to better understanding and improvements in methodologies

Regions - Concepts

Datasets for stations (sites) within a Homogeneous Region are grouped for analysis



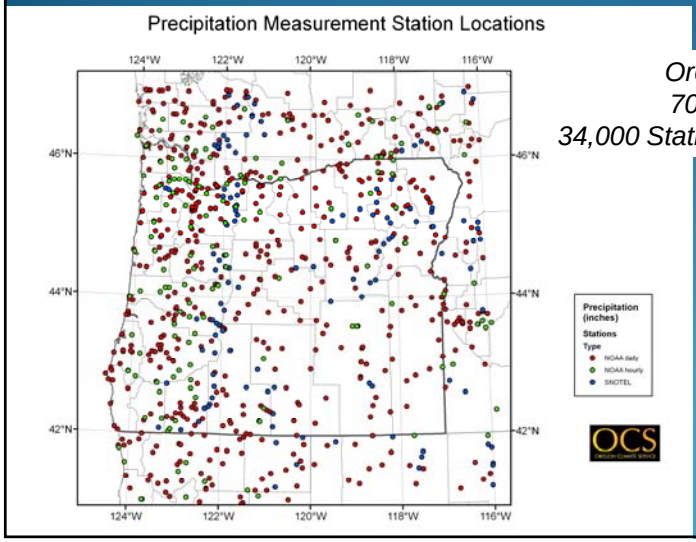
Heterogeneous Super-Regions for Oregon

Similar Climatic and Topographic Setting

Homogeneous Regions are Subsets of Heterogeneous Super-Regions

Large Regional Datasets

Numerous stations (datasets) available for conducting Regional Precipitation-Frequency Analysis



Oregon State
700 Stations
34,000 Station-Years of Record

The Need for Regionalization

At-Site Analysis

Subject to High Sampling Variability

Regional Analysis

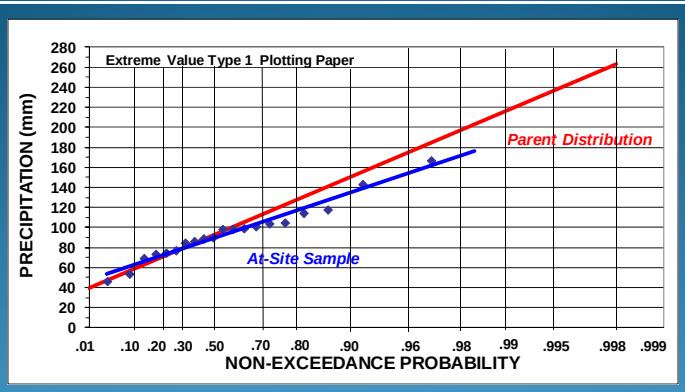
Reduces Sampling Variability

Groups datasets of same phenomenon from a homogeneous region for analysis

Greatly improves reliability of identification of underlying parent probability distribution and estimation of regional magnitude-frequency relationship

Excel Workbook Simulations

Simulations from Excel Workbook



At-Site Analyses

subject to high sampling variability

Regional Analyses

converges toward parent probability distribution

Benefits of Regional Analysis (Trading Space for Time Sampling)

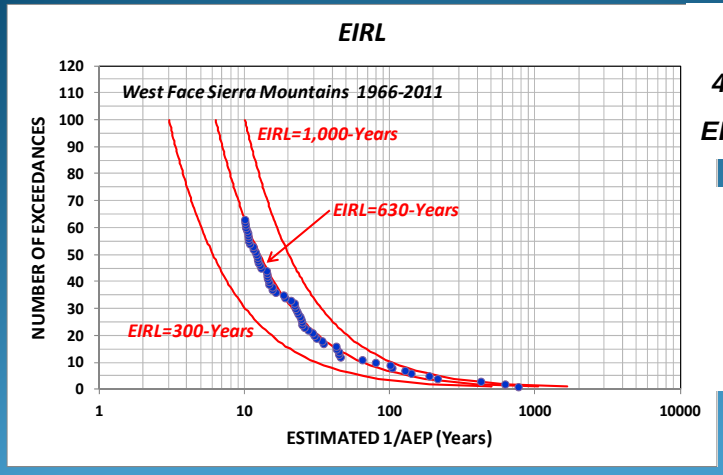
Large Geographic Regions relative to Storm Areal Coverage Results in Independence or Low Correlation of Datasets at Distant Stations

Equivalent Independent Record Length (EIRL) is a measure of the statistical information in the regional dataset

EIRL is a function of:

- ***Size of region relative to typical areal coverage of storms***
- ***Number of storms per storm season***
- ***Density of precipitation measurement stations***
- ***Chronological length of dataset (1966-2011)***

Equivalent Independent Record Length (EIRL)



130 stations

4,599 station-yrs

EIRL=14% stn-yrs

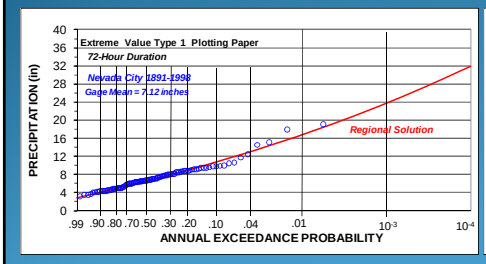
63 storms (distinct dates) exceeding 1:10 AEP

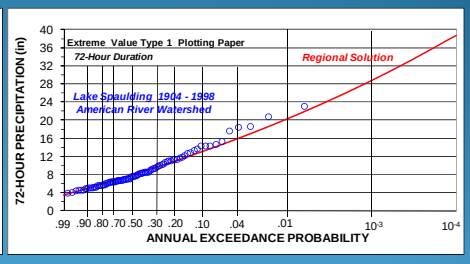
Greater EIRL results in greater reliability (smaller uncertainty bounds) for estimates of extreme precipitation

Regional Frequency Analysis - Origins

Regional precipitation-frequency analysis uses Index Flood Methodology which originated in 1950s at USGS

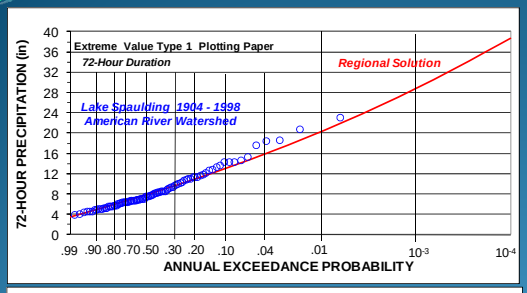
Probability-Plots for same phenomenon exhibit similar behavior

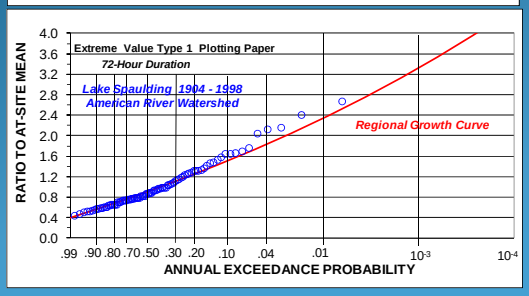




Similar slope and shapes of probability-plots

Regional Frequency Analysis - Concepts





Station datasets are made dimensionless by division of the annual maxima data by the station mean (at-site mean)

Sample statistics for the datasets can then be grouped for analysis
Regional L-Cv
Regional L-Skewness

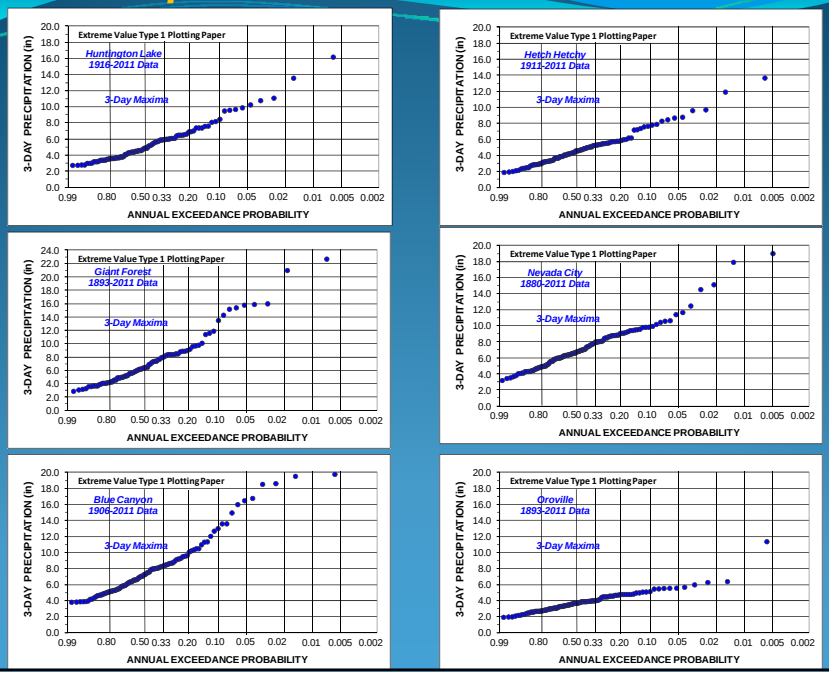
Graphical Example of Regional Analysis

Comparing Slope and Shape of Dimensionless Probability-Plots for Sites on West Face of Sierra Mountains

Physical Interpretation

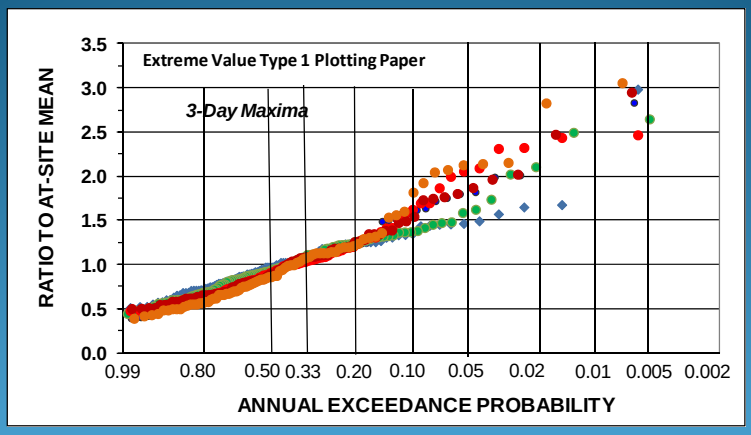
Dimensionless Probability-Plots Reflect Frequency Characteristics of Storms Generated by Pacific Ocean Measured on Upwind Mountain Faces

72-Hr Precipitation West Face Sierra Mountains



Graphical Example of Regional Analysis

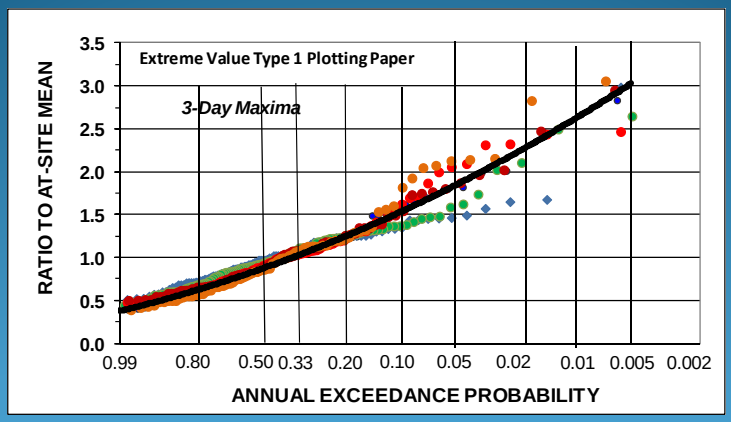
Rescaled by Station Mean (At-Site Mean)



Similarity of Shapes of 6 Dimensionless Probability-Plots

Graphical Example of Regional Analysis

Region Growth Curve
Dimensionless Regional Frequency Curve



Differences in probability-plots attributed primarily to sampling variability

Numerical Solution of Regional Growth Curve

Regional L-Moment Ratios

L-Cv (dimensionless scale)

L-Skewness (dimensionless shape)

used to obtain robust solution

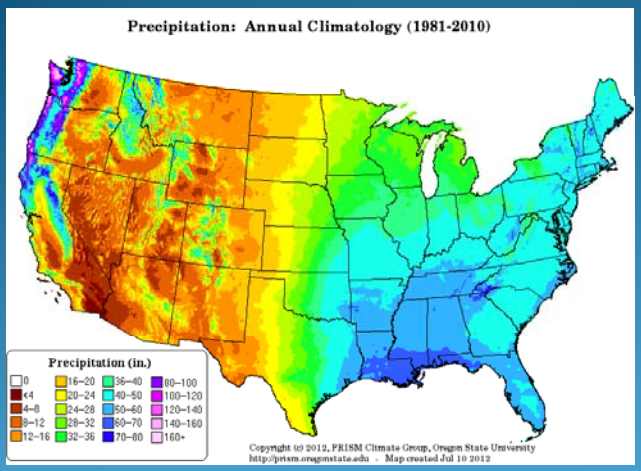
of Regional Growth Curve

for Identified Regional Probability Distribution

Numerical counterpart to graphical solution

PRISM Model

Expert System for Spatial Mapping of Climatic Variables



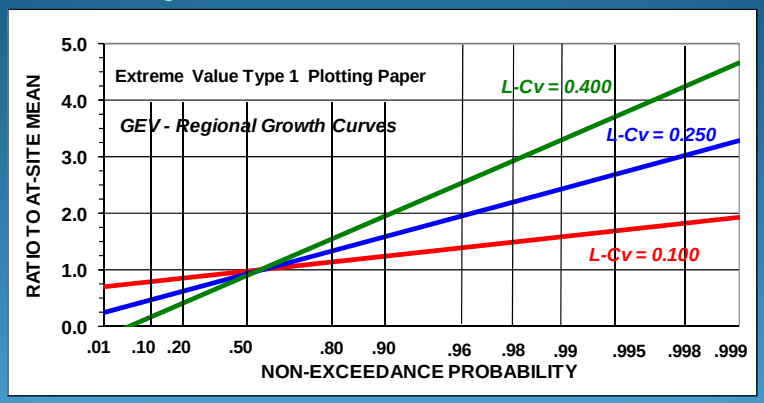
Resolution
30 arc-seconds
800-meters
gridded data

Provides Base Layer Explanatory Variable for Regression Analysis

Precipitation – monthly, annual, specific storms
Snowpack, Temperature, Dewpoint

Example – Spatial Mapping of L-Cv

L-Cv is a Dimensionless Measure of Dispersion Analogous to the Coefficient of Variation

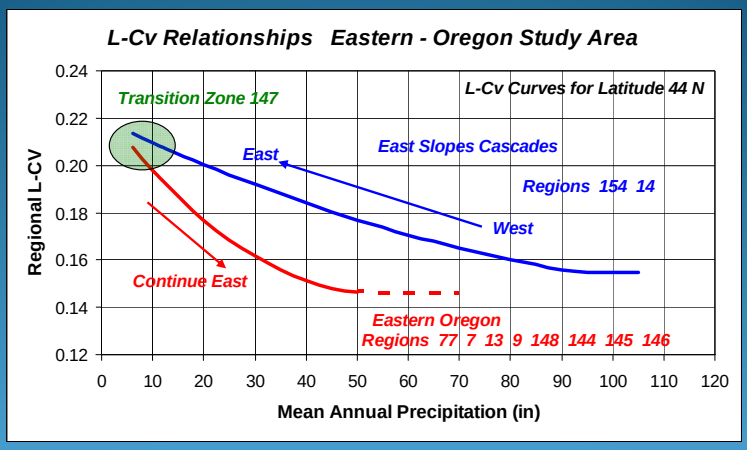


Regional L-Cv is Indicative of Slope of the Regional Growth Curve

Regional L-Cv and L-Skewness can be Spatially Mapped

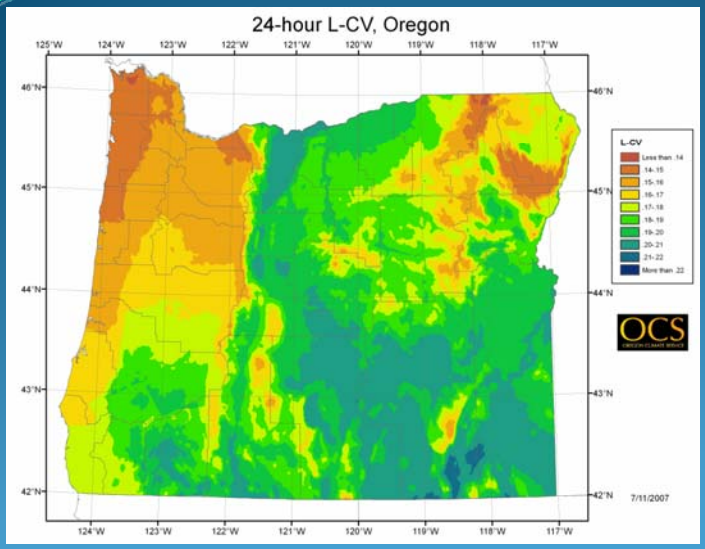
Example – Spatial Mapping of L-Cv

PRISM Mean Annual Precipitation is Explanatory Variable



Variation of L-Cv from Crest of Cascade Mountains East ward into Semi-arid Plains and Intermountain Areas

Example – Spatial Mapping of L-Cv

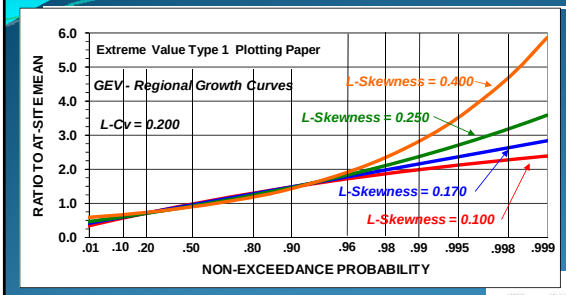


Lower L-Cv in humid and rain-forest climates

Higher L-Cv in arid and semi-arid climates

L-Cv is a Continuum – Regional Boundaries Eliminated

Regional L-Moments L-Skewness

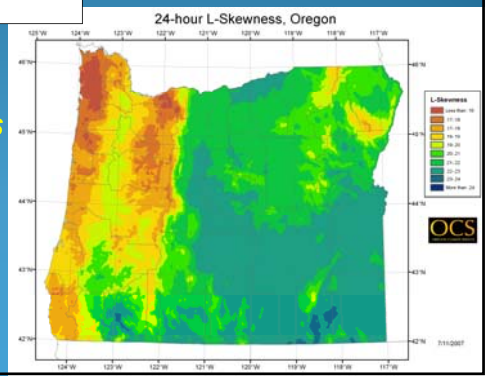


L-Skewness
a dimensionless measure of skewness (volatility)

seen as curvature of Regional Growth Curve

Lower L-Skewness in humid and rain-forest climates

Higher L-Skewness in arid and semi-arid climates

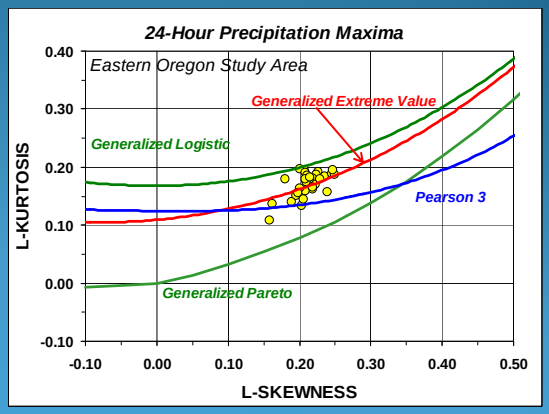


Regional Probability Distribution

Studies in Western United States and British Columbia have shown 1-Day to 7-Day Precipitation Annual Maxima to be Described by a Probability Distribution Near the Generalized Extreme Value (GEV) Distribution

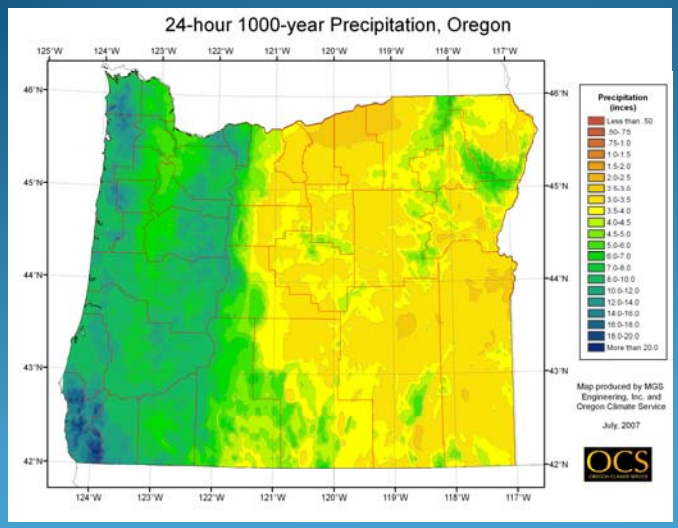
Results from Regions in Oregon for 24-Hour Precipitation Annual Maxima

4-Parameter Kappa Distribution Used for Watersheds



Precipitation-Frequency Mapping

Mapping of At-Site Means, Regional L-Cv and L-Skewness Allows Mapping of Precipitation-Frequency



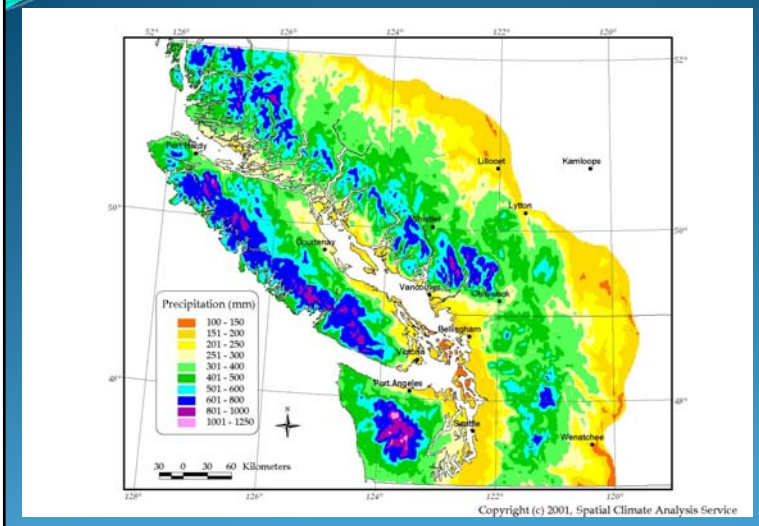
Oregon State

24-Hour

1:1,000 AEP

Precipitation Maxima

Precipitation-Frequency Mapping



72-Hour

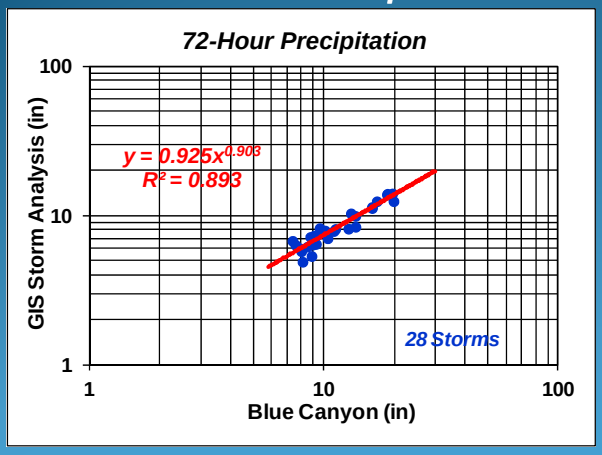
1:1,000 AEP

Precipitation Maxima

Southwest British Columbia

Development of Precipitation-Frequency Relationships for Watersheds

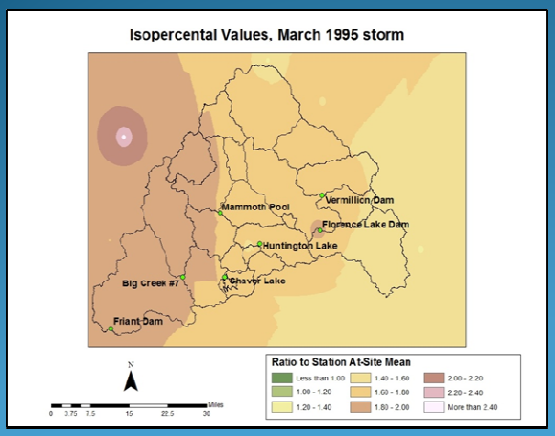
Need Relationship between Point Precipitation and Areal Precipitation for Major Storms



GIS Storm Analysis (Spatial Analysis) using Isopercental Method or SPAS Radar Analysis

Spatial Mapping of Precipitation with Isopercental Method

Convert from Precipitation Domain to Frequency Domain, Divide 72-hr Station Precipitation by At-Site Mean



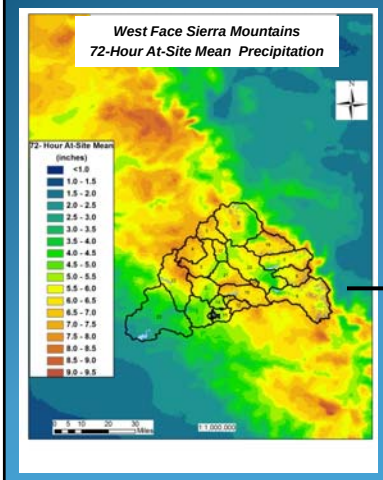
Over 100 Major Storms Analyzed

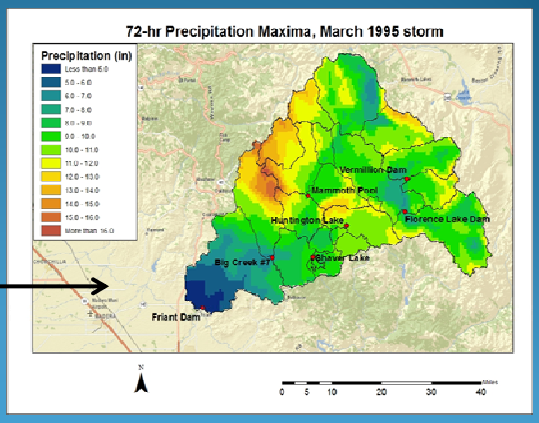
Well-Behaved Mild Isopercental Gradients in Frequency Domain

Inverse Distance Weighting (IDW) in Frequency Domain

Spatial Mapping of Precipitation with Isopercental Method

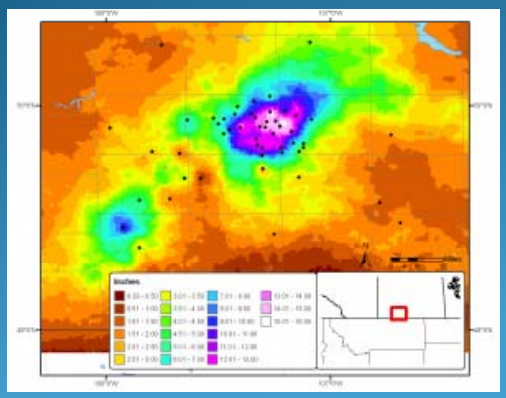
Transform from Frequency Domain (Isopercental) to Precipitation Using Spatial Map of At-Site Means





Spatial Mapping of Precipitation with SPAS Software

Spatial Mapping of Precipitation Using Radar Data and Precipitation Data – MetStat and Applied Weather Associates



NEXRAD Radar Data since mid-1990s

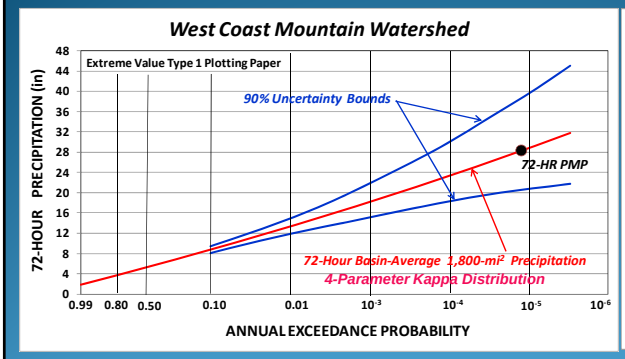
Allows for Computation of Depth-Area-Duration for Storm and Basin-Average Precipitation for Watershed

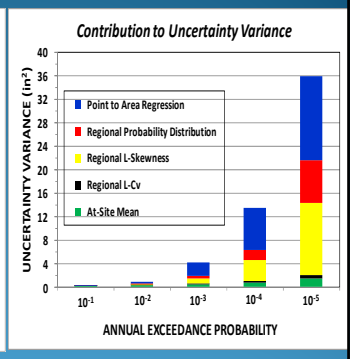
Characterize Uncertainties for Use in Developing Precipitation-Frequency Curve for Watershed

Develop Probability Distributions for Uncertainties

- Point Precipitation At-Site Mean
- Regional L-Cv
- Regional L-Skewness
- Regional Probability Distribution
- Relationship of Point to Areal Precipitation

Monte Carlo Simulation Used to Develop Mean Precipitation-Frequency Curve and Uncertainty Bounds





Precipitation-Frequency Relationship for the Watershed is Often the Dominant Contributor to Behavior of Flood-Frequency Relationships

Summary: Precipitation-Frequency

Key Components for Developing
Precipitation-Frequency Relationships
and Reliable Estimates of Extreme Precipitation
for Watershed-Specific Applications

Regional Analysis Methods

Large Regional Datasets

L-Moment Statistics

GIS Spatial Mapping Tools, PRISM model

Spatial Analysis of Storms (Isopercental, SPAS)

Annual Exceedance Probabilities (AEPs) of Published PMP Estimates

AEPs for PMP based on Regional Precipitation-Frequency and Analyses of Historical Extreme Storms (%PMP)

AEPs of PMP vary from about 10^{-4} to perhaps 10^{-10}

AEP varies - nearness to sources of atmospheric moisture
(Coastal versus Inland Areas)

AEP varies - number of storms in storm season
(Arid versus Humid Climates)

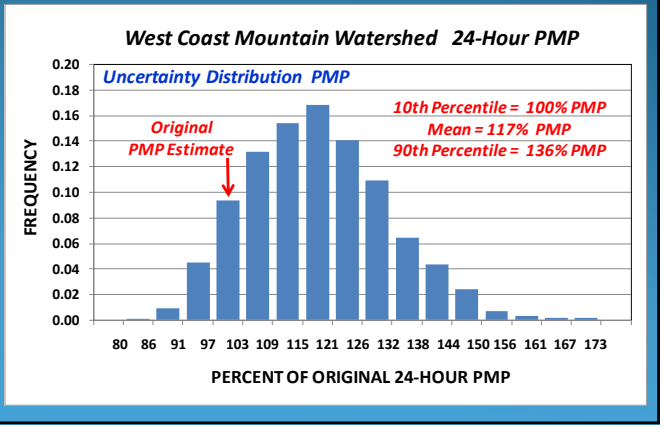
AEP varies with storm characteristics of interest
(Short-duration intensities, Long-duration volume)

Uncertainties in PMP Estimates

- *Inflow moisture flux for moisture maximization*
- *Sampling limitations of storm database (storm efficiency)*
- *Simplifying assumptions, policy versus science decisions*
- *Effect of analyst's judgment*

Uncertainty Analysis for PMP

First of its kind Jan 2013



Summary - PMP

AEPs for PMP Have Much Wider Range Than "Assumed" in Engineering Community

Magnitude of Uncertainties in PMP Estimation Will Likely Surprise Many in Engineering Community

End of Slides