

Flood Frequency Analysis Using HEC-HMS

Flood Frequency Analysis PROSPECT

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Purpose

- Become familiar with HEC-HMS
- See how precipitation-frequency data becomes a flow-frequency analysis



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Outline

1. Introduction to HEC-HMS
2. Setting up an HEC-HMS model
3. Precipitation-frequency data
4. Modeling hypothetical storm events
5. Modeling flood frequency with HEC-HMS



Introduction to HEC-HMS



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Introduction to HEC-HMS

- HEC Hydrologic Modeling System
- Watershed hydrology model
 - “Rainfall-runoff” model
 - Event or continuous modeling
- User chooses hydrologic process methods/parameters
- Driven by user-specified boundary conditions
- Comprehensive data management
- GIS



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**For more
information, come
to the HMS
training classes!**

Keys to an HEC-HMS Model

- Basin model
- Meteorologic model
- Compute type

The screenshot displays the HEC-HMS 4.10 Beta 3 software interface. The main window shows a project titled "IndianCreek" with a file path of "D:\Models\4_10\IndianCreek\IndianCreek.hms". The interface includes a menu bar (File, Edit, View, Components, GIS, Parameters, Compute, Results, Tools, Help) and a toolbar. A tree view on the left lists the project components, including "Basin Models", "Indian Creek Base", "East Indian Cr", "Dry Cr", "Marion", "Indian Creek", "Wanatee Cr", "Lower Indian Cr", "Cedar River", "Indian Creek 2013", "Indian Creek 2014", "Meteorologic Models", "Control Specifications", "Time-Series Data", "Paired Data", "Grid Data", and "Terrain Data". The "Basin Model" component is selected, and its properties are displayed in the main window:

Name: Indian Creek Base	
Description:	2019 impervious values
Unit System:	U.S. Customary
Sediment:	No
Replace Missing:	No
Local Flow:	No
Unregulated Outputs:	No
Flow Ratios:	No
Terrain Data:	NED 13

The right side of the interface shows a map of the basin model, titled "Basin Model [Indian Creek Base]". The map displays a topographic view of the basin with a grid overlay. Several sub-basins are labeled: "Dry Cr", "East Indian Cr", "Marion", "Wanatee Cr", "Lower Indian Cr", "Indian Creek", and "Cedar River". The map also shows a network of streams and a central urban area.

At the bottom of the interface, there are two notes:

- NOTE 10008: Begin opening project "IndianCreek" in directory "D:\Models\4_10\IndianCreek" at time 11Apr2022, 08:02:07.
- NOTE 10019: Finished opening project "IndianCreek" in directory "D:\Models\4_10\IndianCreek" at time 11Apr2022, 08:02:08.



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Basin Model

- Representation of surface hydrology in watershed
- Seven basin elements:
 - **Subbasin**
 - Reach
 - Reservoir
 - Junction
 - Diversion
 - Source
 - Sink



Meteorologic Model

- Represents atmospheric boundary conditions
- Provides meteorologic data to basin model
- Shortwave radiation
- Longwave radiation
- **Precipitation**
- Temperature
- Windspeed
- Surface pressure
- Dew point
- Potential evapotranspiration
- Snow



Compute Type

- Method for setting model parameters and managing results
- Six compute types:
 - **Simulation Run**
 - Optimization Trial
 - Forecast Alternative
 - Depth-Area Analysis
 - Uncertainty Analysis
 - **Frequency Analysis**



Data Management

- Re-usable data components
 - Estimate or set parameters
 - Provide boundary conditions
- Four main types:
 - Time-series data
 - Paired data
 - Grid data
 - Terrain data



GIS

- Watershed delineation and parameter estimation framework
- Delineate watersheds from DEMs
 - Terrain reconditioning
- Estimate subbasin parameters
 - Raster data
 - Impervious area, soil properties, etc.



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Setting Up an HEC-HMS Model



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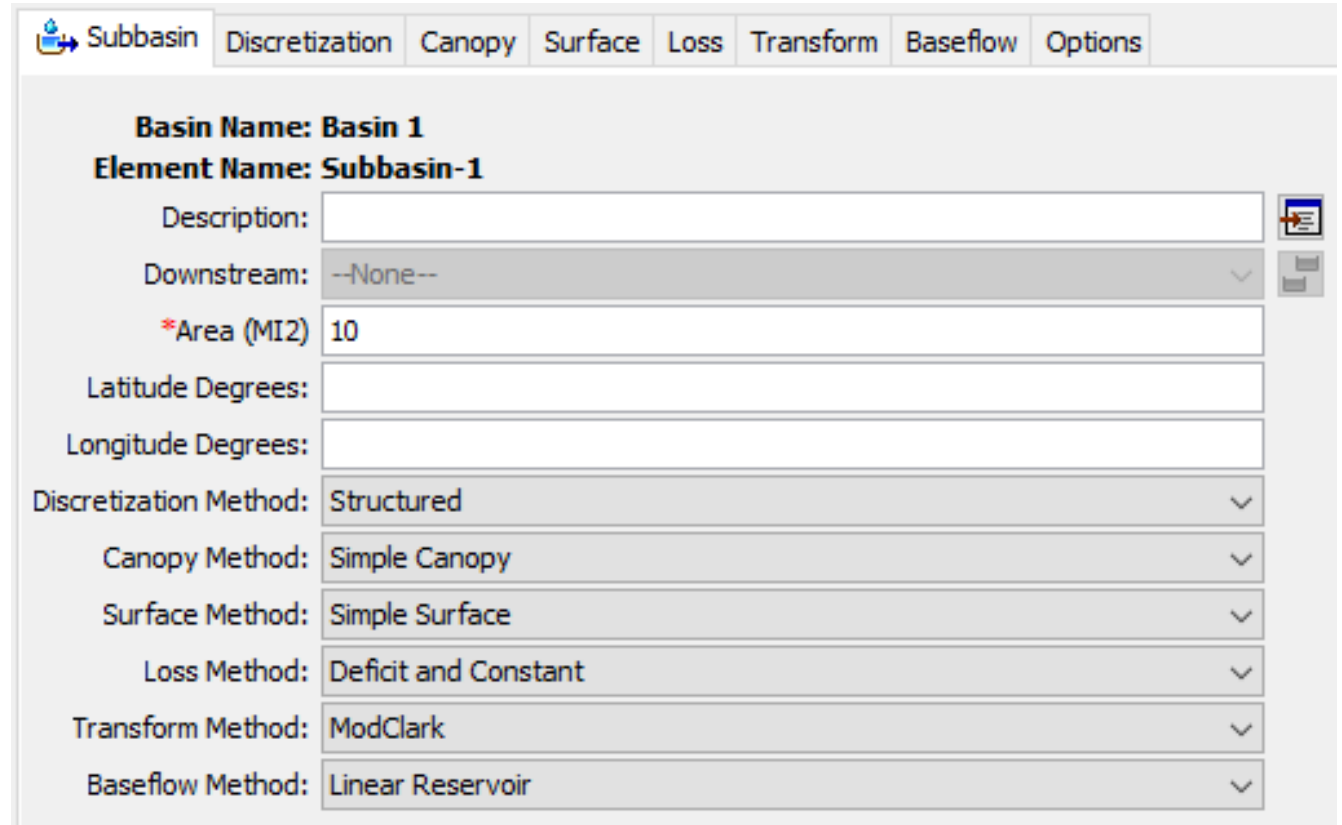
Model Inputs for a Basic Model

- Basin model
 - Subbasin element
- Meteorologic model
 - Precipitation method



Subbasin Processes

- Canopy
- Surface
- Loss
- Transform
- Baseflow
- Discretization

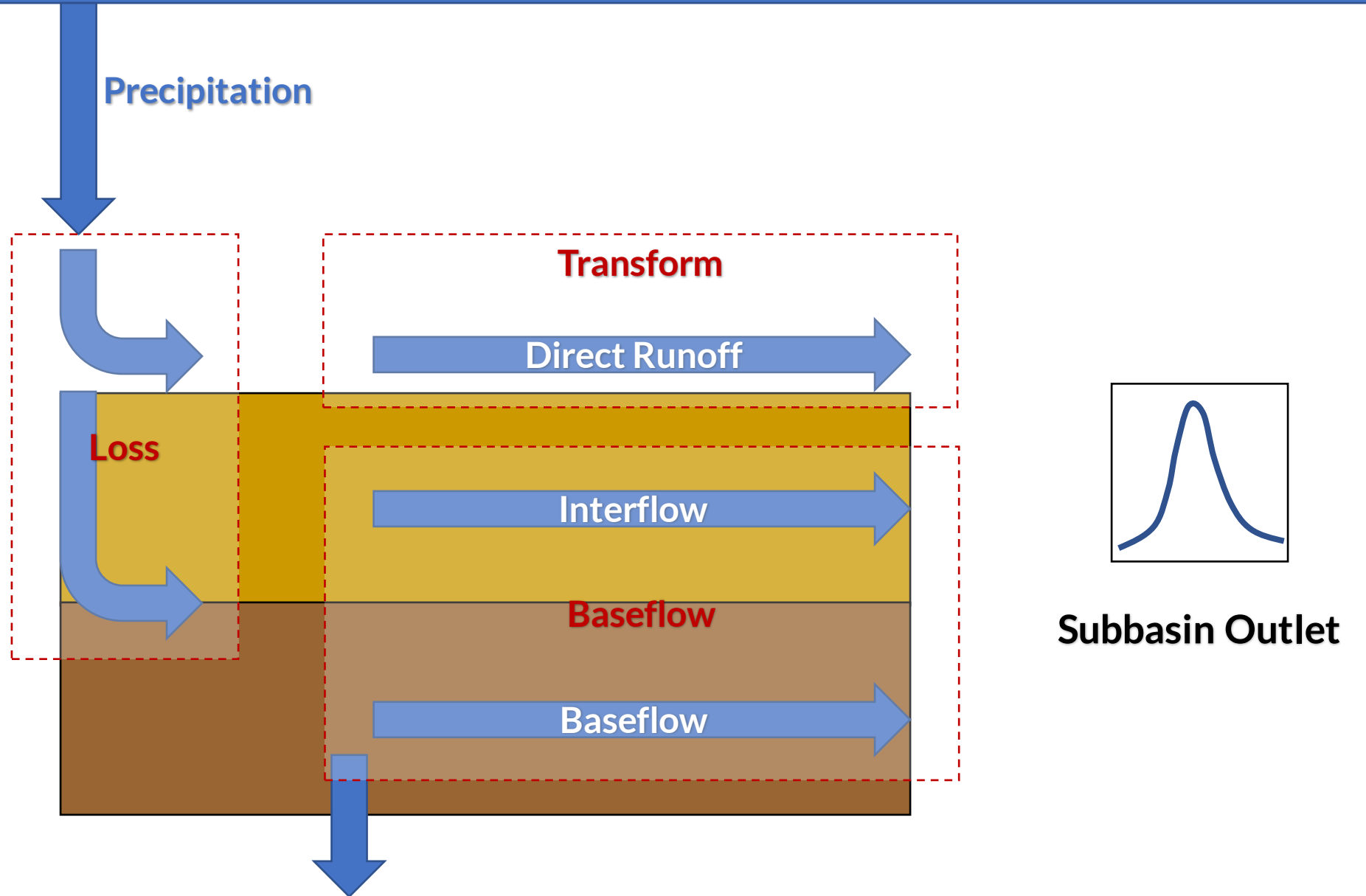


The screenshot shows a software interface for configuring a subbasin. At the top, there are several tabs: "Subbasin", "Discretization", "Canopy", "Surface", "Loss", "Transform", "Baseflow", and "Options". The "Subbasin" tab is currently selected. Below the tabs, the configuration is organized into a form with the following fields:

- Basin Name:** Basin 1
- Element Name:** Subbasin-1
- Description:** (empty text box)
- Downstream:** --None-- (dropdown menu)
- *Area (MI2):** 10 (text box)
- Latitude Degrees:** (empty text box)
- Longitude Degrees:** (empty text box)
- Discretization Method:** Structured (dropdown menu)
- Canopy Method:** Simple Canopy (dropdown menu)
- Surface Method:** Simple Surface (dropdown menu)
- Loss Method:** Deficit and Constant (dropdown menu)
- Transform Method:** ModClark (dropdown menu)
- Baseflow Method:** Linear Reservoir (dropdown menu)



Meteorologic Model



Loss Methods

- Determine how much of the water infiltrates or runs off
 - **Deficit and Constant** (+Gridded)
 - Exponential
 - Green and Ampt (+Gridded)
 - Initial and Constant
 - Layered Green Ampt
 - SCS Curve Number (+Gridded)
 - Smith Parlange
 - Soil Moisture Accounting (+Gridded)



Deficit and Constant Loss

Subbasin	Loss	Options
Element Name: Subbasin-1		
*Initial Deficit (IN)	1	
*Maximum Deficit (IN)	8	
*Constant Rate (IN/HR)	0.1	
*Impervious (%)	10	



Transform Methods

- Determine how runoff throughout the watershed becomes streamflow at the watershed outlet
 - Clark Unit Hydrograph
 - Kinematic Wave
 - ModClark
 - SCS Unit Hydrograph
 - Snyder Unit Hydrograph
 - User-Specified S-Graph
 - User-Specified Unit Hydrograph
 - 2D Diffusion Wave



Clark Unit Hydrograph

	Subbasin	Loss	Transform	Options
Basin Name: Basin 1				
Element Name: Subbasin-1				
Method:	Standard			
*Time of Concentration (HR)	2.25			
*Storage Coefficient (HR)	3			
Time-Area Method:	Default			



Baseflow Methods

- Determine how infiltrated water returns to the stream at the watershed outlet
 - Bounded Recession
 - Constant Monthly
 - **Linear Reservoir**
 - Nonlinear Boussinesq
 - Recession



Linear Reservoir Baseflow

Subbasin		Loss		Transform		Baseflow		Options	
Basin Name: Basin 1									
Element Name: Subbasin-1									
Layers:								2	▲▼
Initial Type:	Discharge Per Area ▼								
*GW 1 Flow Type:	Baseflow ▼								
*GW 1 Initial (CFS/MI2)	0								
*GW 1 Fraction:	0.5								
*GW 1 Coefficient (HR)	9								
*GW 1 Reservoirs:								1	▲▼
*GW 2 Flow Type:	Baseflow ▼								
*GW 2 Initial (CFS/MI2)	1								
*GW 2 Fraction:	0.5								
*GW 2 Coefficient (HR)	30								
*GW 2 Reservoirs:								1	▲▼



Precipitation Methods

- Frequency Storm
- Gage Weights
- Gridded Precipitation
- HMR52 Storm
- Hypothetical Storm
- Interpolated Precipitation
- Inverse Distance
- Specified Hyetograph
- Standard Project Storm

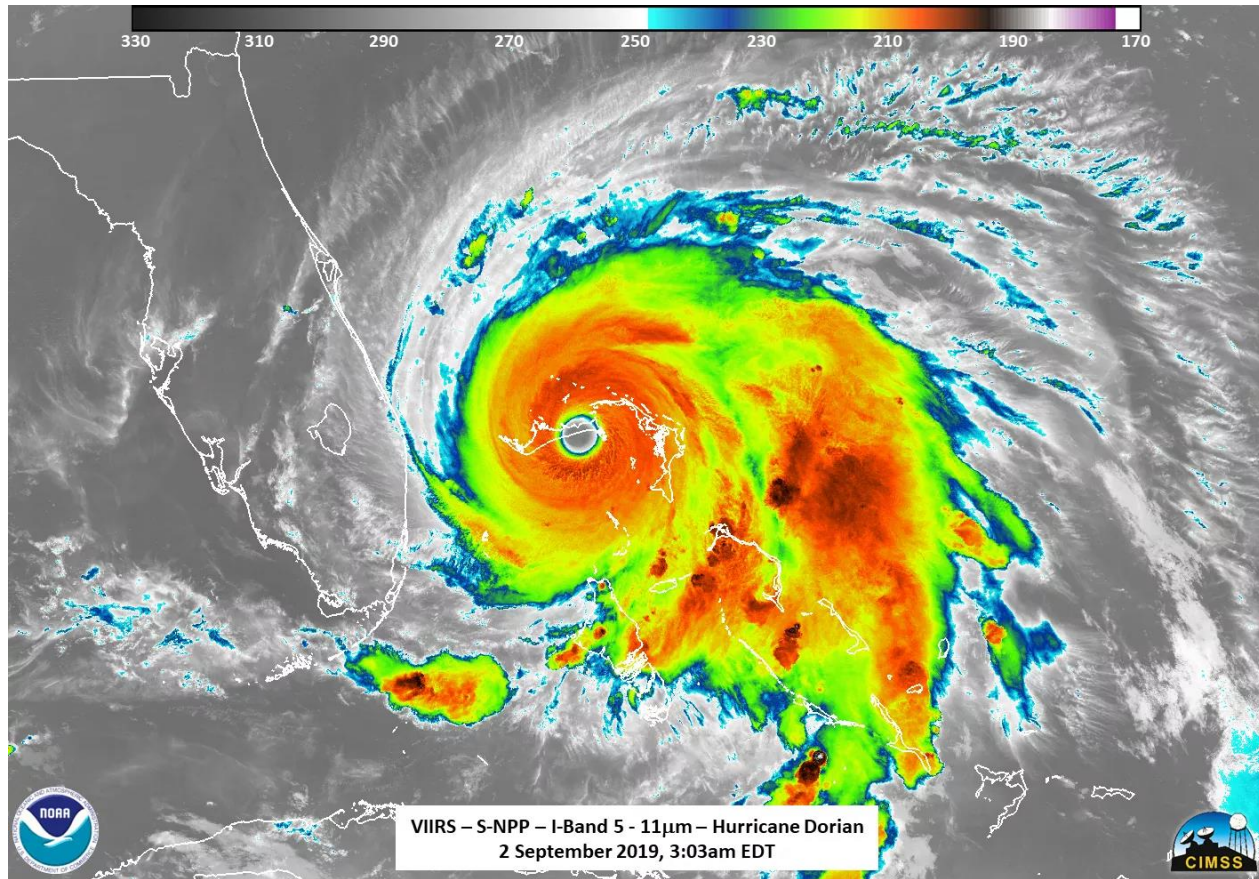


Gridded Precipitation

- Observed precipitation input based on precipitation grids
- Basin model changes:
 - Discretization method
 - ModClark transform



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Hypothetical Storm

- General method for modeling design storms
- Specify a number of storm properties:
 - Duration
 - Precipitation depth
 - Time pattern
 - Area reduction

Special storm specification methods:

- Area-Dependent Pattern
- SCS Storms
- **User-Specified Pattern**



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User-Specified Pattern Hypothetical Storm

Hypothetical Storm

Met Name: Met 2

Method: User-Specified Pattern

*Storm Pattern: ORB 24h Q1 50%

*Storm Duration (HR): 24

*Precipitation Method: Precipitation-Frequency Grid

*Grid: ORB 24h 100yr

*Computation Point: Basin: Basin 1, Element: Subbasin-1

Area Reduction: TP40

Storm Area (MI²): 10



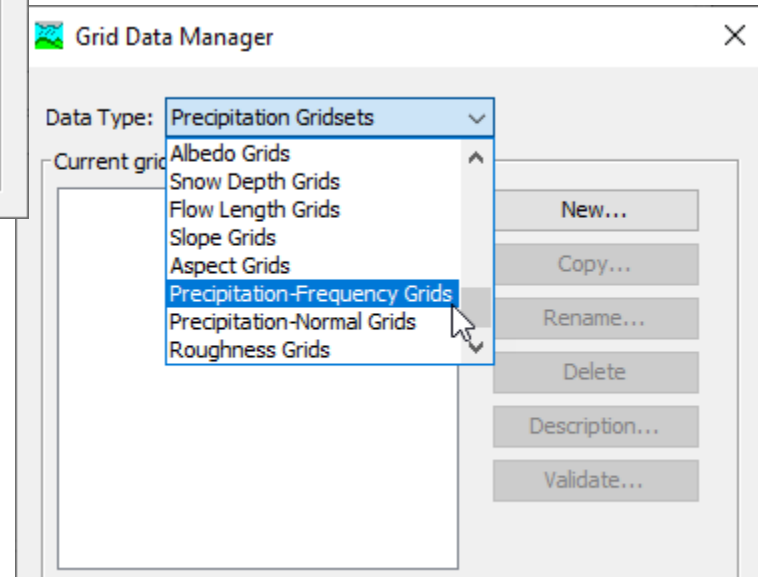
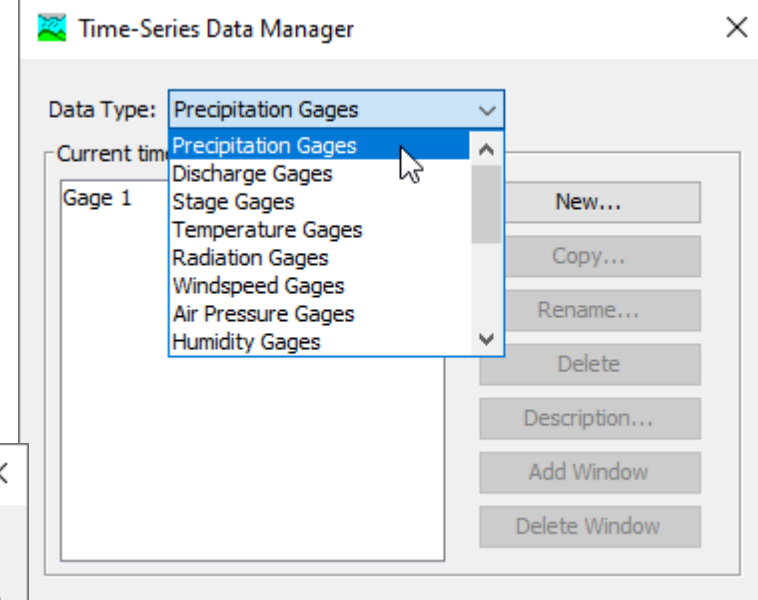
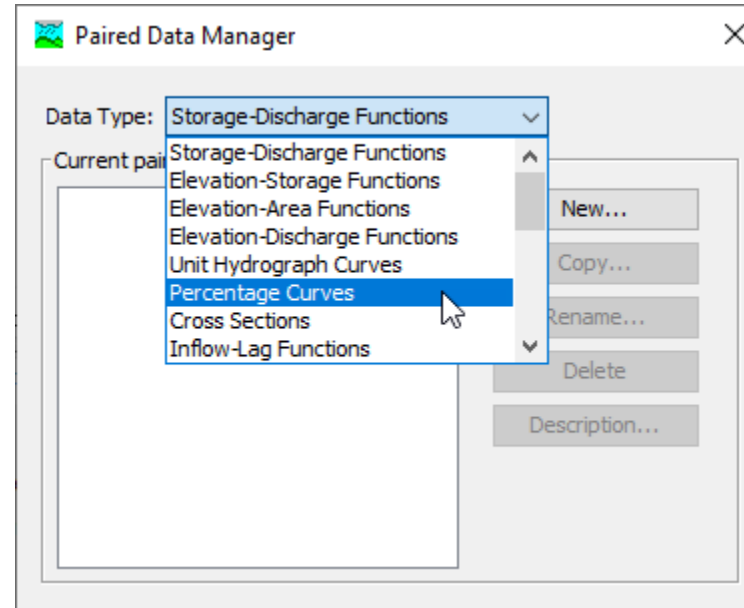
User-Specified Pattern Hypothetical Storm

- Time pattern (dimensionless %-% curve)
- Storm duration
- Source of precipitation depth (single value or raster)
- Basin model computation point
- Area reduction function
- Storm area



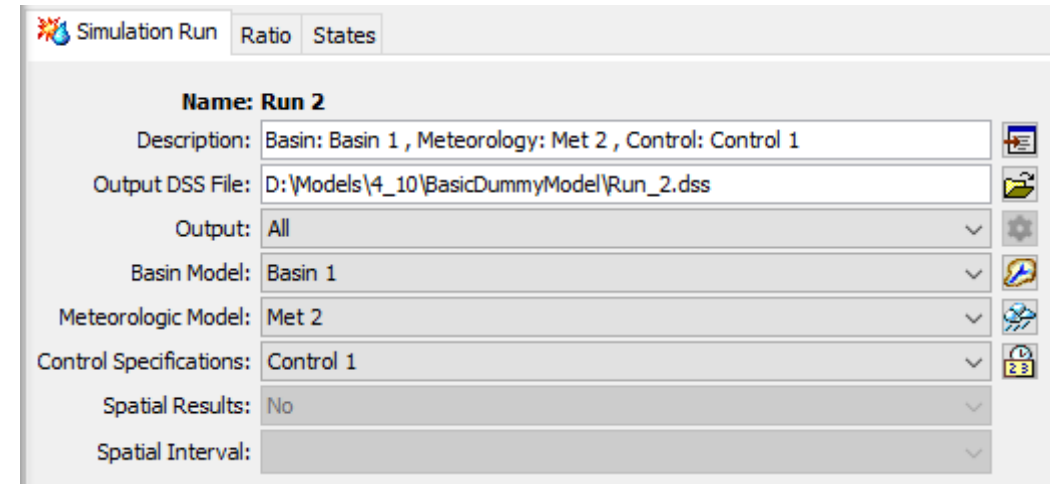
Data

- Time-Series Data
 - Time-indexed data
- Paired Data
 - Functional relationship
- Grid Data
 - Raster format data



Simulation Run

- Basin Model
- Meteorologic Model
- Control Specification
 - Time window
 - Time step



Simulation Run Ratio States

Name: Run 2

Description: Basin: Basin 1, Meteorology: Met 2, Control: Control 1

Output DSS File: D:\Models\4_10\BasicDummyModel\Run_2.dss

Output: All

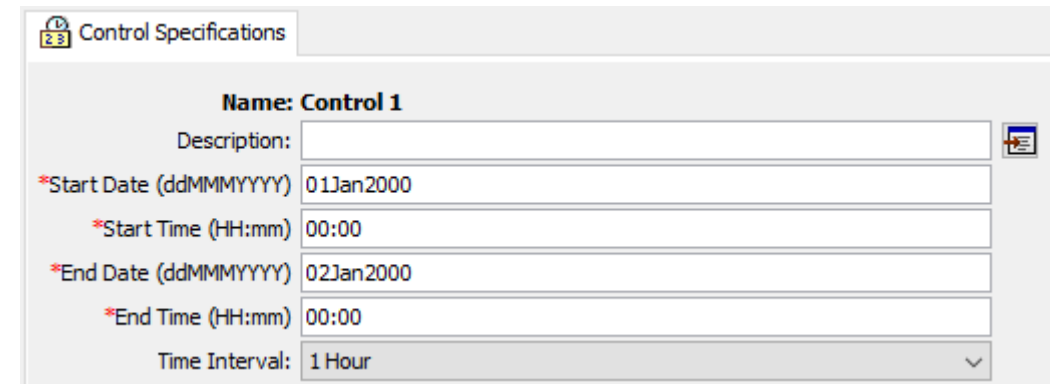
Basin Model: Basin 1

Meteorologic Model: Met 2

Control Specifications: Control 1

Spatial Results: No

Spatial Interval:



Control Specifications

Name: Control 1

Description:

*Start Date (ddMMMYYYY) 01Jan2000

*Start Time (HH:mm) 00:00

*End Date (ddMMMYYYY) 02Jan2000

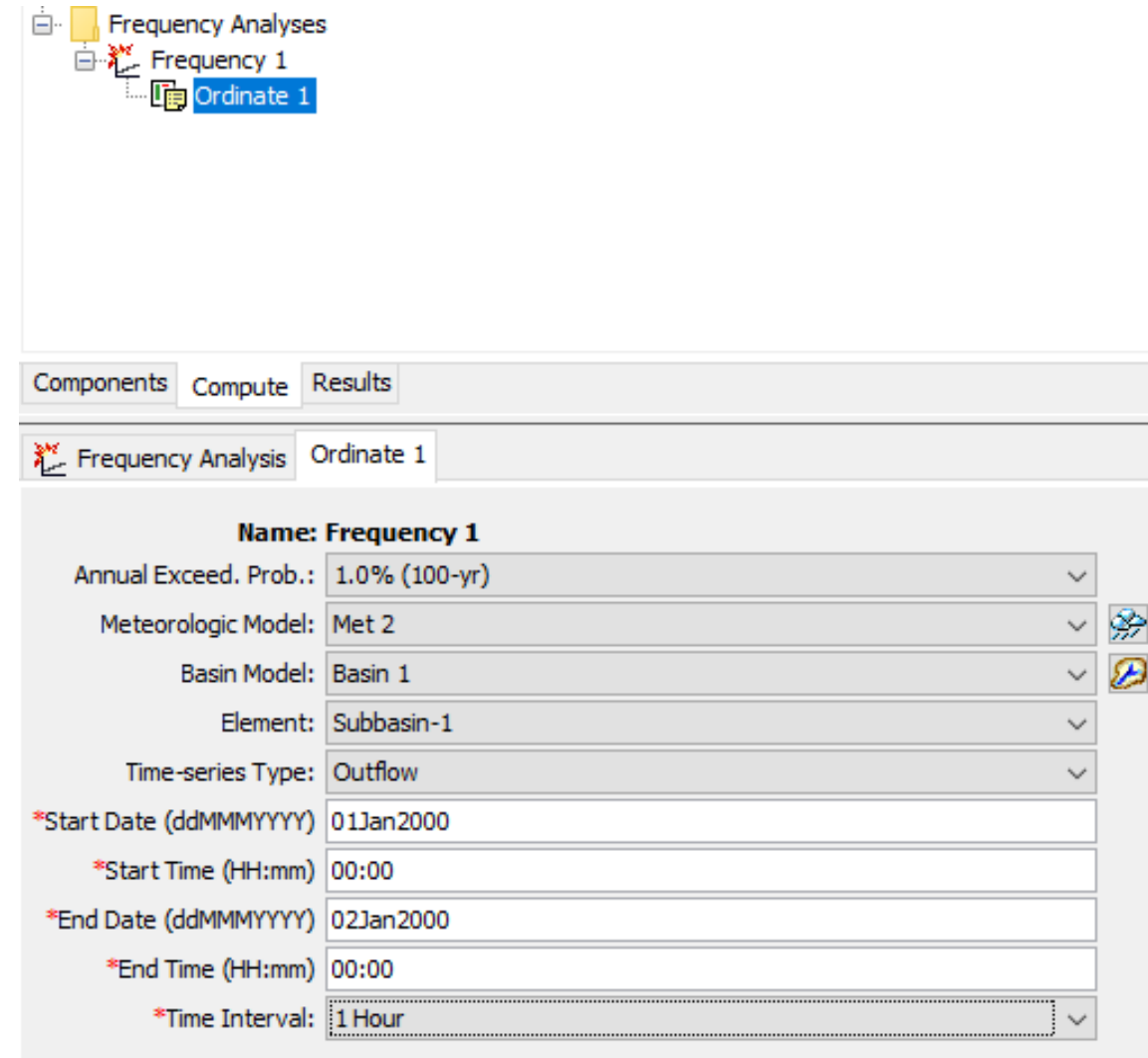
*End Time (HH:mm) 00:00

Time Interval: 1 Hour





Frequency Analysis Compute

- Each ordinate combines:
 - AEP
 - Meteorologic Model
 - Basin Model
- Extracts timeseries maximum
- Plots as frequency curve



The screenshot displays the software interface for Frequency Analysis. At the top, a tree view shows a folder named 'Frequency Analyses' containing 'Frequency 1', which in turn contains 'Ordinate 1'. Below this, a tabbed interface has 'Components', 'Compute', and 'Results' tabs, with 'Compute' selected. Under the 'Compute' tab, there are sub-tabs for 'Frequency Analysis' and 'Ordinate 1'. The main configuration area is titled 'Name: Frequency 1' and contains the following settings:

Annual Exceed. Prob.:	1.0% (100-yr)	▼
Meteorologic Model:	Met 2	▼ 
Basin Model:	Basin 1	▼ 
Element:	Subbasin-1	▼
Time-series Type:	Outflow	▼
*Start Date (ddMMMYYYY)	01Jan2000	
*Start Time (HH:mm)	00:00	
*End Date (ddMMMYYYY)	02Jan2000	
*End Time (HH:mm)	00:00	
*Time Interval:	1 Hour	▼



Precipitation-Frequency Data in HEC-HMS



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Precipitation-Frequency Data

1. Precipitation-frequency and data sources (quick review)
2. Using precipitation-frequency grids in hypothetical storm



Precipitation-Frequency Data

- For most applications, NOAA Atlas 14
- Other cases: NOAA Atlas 2/TP-49, custom studies
- Input data: *isopluvial raster*
 - Represents a storm of a single duration and frequency occurring everywhere
 - Not a storm pattern!



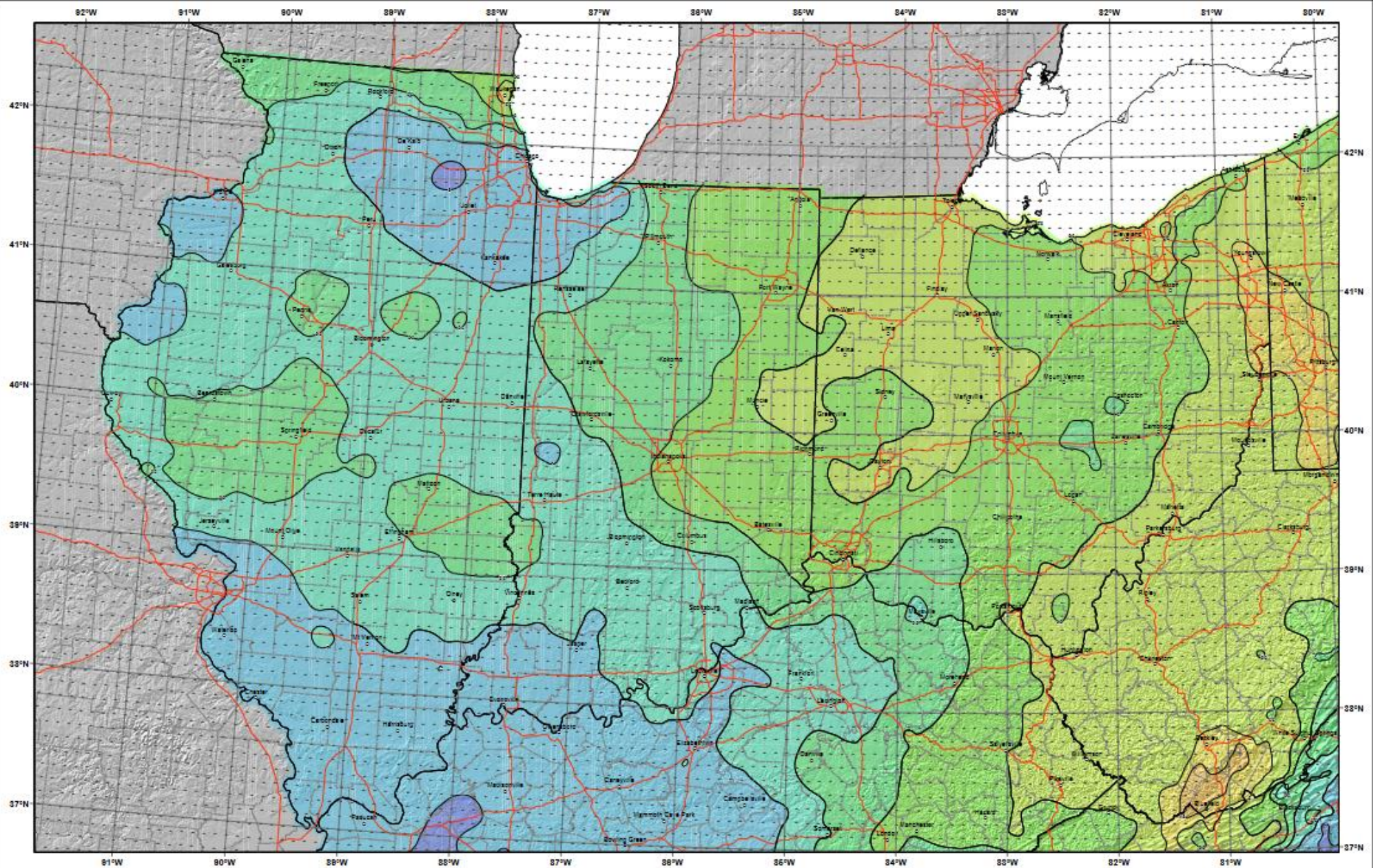
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Refer back to the
“What To Do With
Little Or No Gage
Data” lecture!

24-hour 1/100 AEP



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NOAA Atlas 14, Volume 2, Version 3
Ohio River Basin and Surrounding States



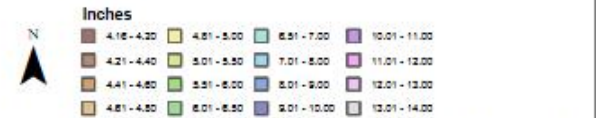
Prepared by U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE
OFFICE OF HYDROLOGIC DEVELOPMENT
HYDROMETEOROLOGICAL DESIGN STUDIES CENTER
August 2008

SCALE 1:2,000,000 (when printed/viewed at 8.5x11 in.)
0 10 20 30 40 50 Miles
0 20 30 40 50 60 70 Kilometers

ILLINOIS, INDIANA, OHIO

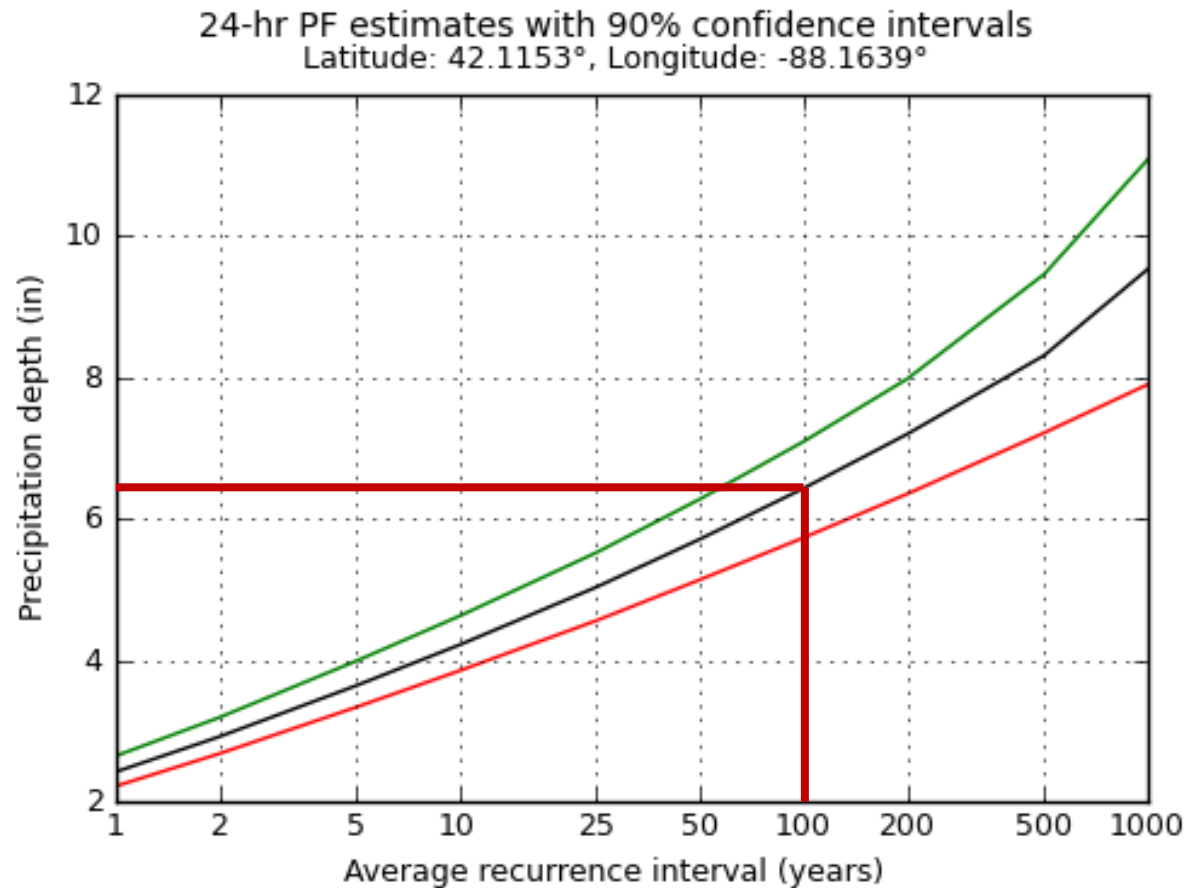
Isopluvials of 24 hour precipitation (inches)
with Average Recurrence Interval of 100 years

See NOAA Atlas 14 documentation for factors to convert to Annual
Exceedance Probabilities for all estimates below 25 years



Projection: Lambert Conformal Conic Datum: NAD83 Standard Parallels: 36° and 42° Central Meridian: 85°

Precipitation-Frequency Curves



Getting Data

- NOAA Precipitation Frequency Data Server (PFDS)
- ASC-format rasters for all volumes of A14

This web page provides access to NOAA Atlas 14 precipitation frequency estimates with upper and lower bounds of the 90% confidence interval in GIS compatible format. Please note that the precipitation frequency estimates for each volume of NOAA Atlas 14 were computed independently using all available data at the time. Some discrepancies between volumes at project boundaries are inevitable and they will generally be more pronounced for rarer frequencies.

DOWNLOAD GIS DATA:

To display and interpret the data, two separate files are needed:

1. **File with zipped ASCII grids** - This file contains the final, spatially interpolated, high-resolution NOAA Atlas 14 precipitation frequency estimates with confidence limits, and is the basis for the [PFDS interface](#) results.
2. **Grid metadata file** - This file contains information on projection, grid resolution, precipitation units, and other details relevant to data shown in ASCII grid files. The grid metadata file is in the XML format and is automatically downloaded with zipped ASCII grids. The grid metadata file can also be viewed and downloaded separately below (left-click to view, right-click/Save As to download):
 - [Volume 1: Semiarid Southwest \(sw\)](#)
 - [Volume 2: Ohio River Basin and Surrounding States \(orb\)](#)
 - [Volume 3: Puerto Rico and the U.S. Virgin Islands \(pr\)](#)
 - [Volume 4: Hawaiian Islands \(hi\)](#)
 - [Volume 5: Selected Pacific Islands - click to see sub regions](#)
 - [Volume 6: California \(sw\)](#)
 - [Volume 7: Alaska \(ak\)](#)
 - [Volume 8: Midwestern States \(mw\)](#)
 - [Volume 9: Southeastern States \(se\)](#)
 - [Volume 10: Northeastern States \(ne\)](#)
 - [Volume 11: Texas \(tx\)](#)

The files either can be downloaded 1) via pull-down menu, 2) by https via web browser. To obtain precipitation frequency estimates without downloading files, please visit the [PFDS interface](#).

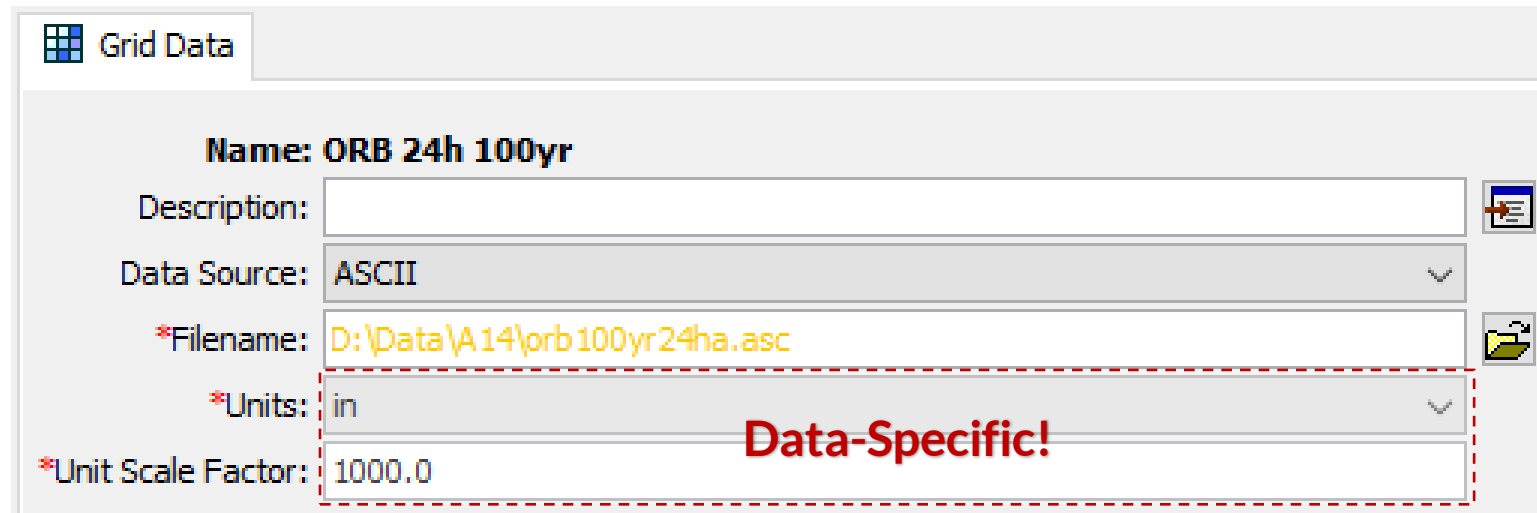
1) Via pull-down menu:

Volume:	2: Ohio River Basin and Surrounding States ▾
Type:	Precipitation frequency estimates ▾
Series:	Annual maximum series ▾
Annual exceedance probability:	1/100 ▾
Duration:	24-hour ▾
Click here to begin download	



Precipitation-Frequency Grids in HMS

- Native support for PF rasters in HMS
- Download A14 PFDS rasters and directly plug them in



Grid Data

Name: ORB 24h 100yr

Description:

Data Source: ASCII

*Filename: D:\Data\A14\orb100yr24ha.asc

*Units: in

*Unit Scale Factor: 1000.0

Data-Specific!



Hypothetical Storm + PF Grids

Hypothetical Storm

Met Name: Met 2

Method: User-Specified Pattern

*Storm Pattern: ORB 24h Q1 50%

*Storm Duration (HR): 24

*Precipitation Method: Precipitation-Frequency Grid

*Grid: ORB 24h 100yr

*Computation Point: Basin: Basin 1, Element: Subbasin-1

Area Reduction: TP40

Storm Area (MI²): 10

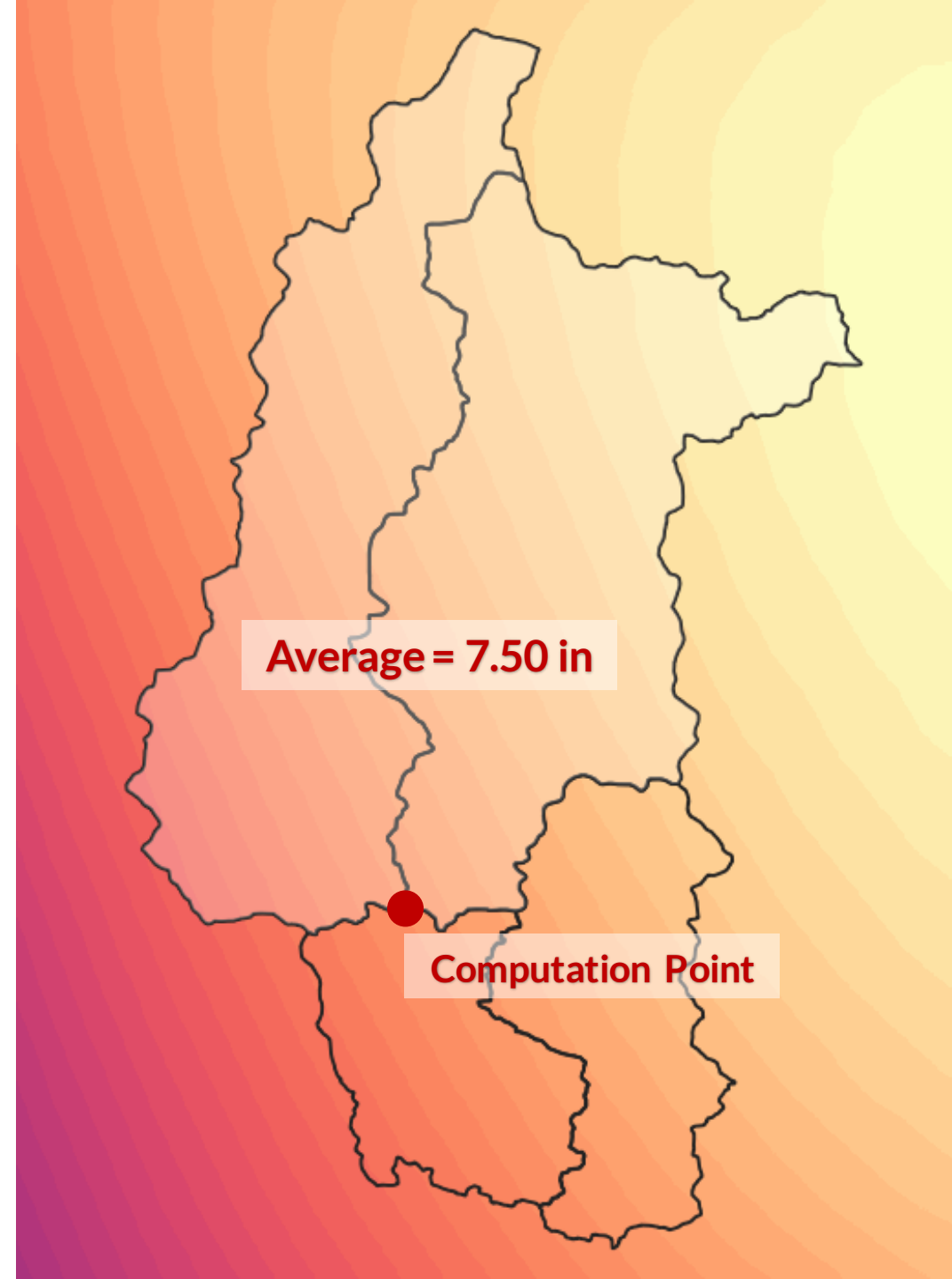


Precipitation Depth

- Computed as a watershed-average above the computation point



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Modeling Hypothetical Storm Events



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Modeling Hypothetical Storm Events

1. Hydrologic considerations
 - How does the watershed respond during a flood?
2. Meteorologic considerations
 - What meteorologic characteristics create a flood?



Hydrologic Considerations

- Model calibration
- Initial conditions for flood frequency analysis
- Non-linearity of hydrologic response
 - Dependency of hydrologic parameters on amount of rainfall



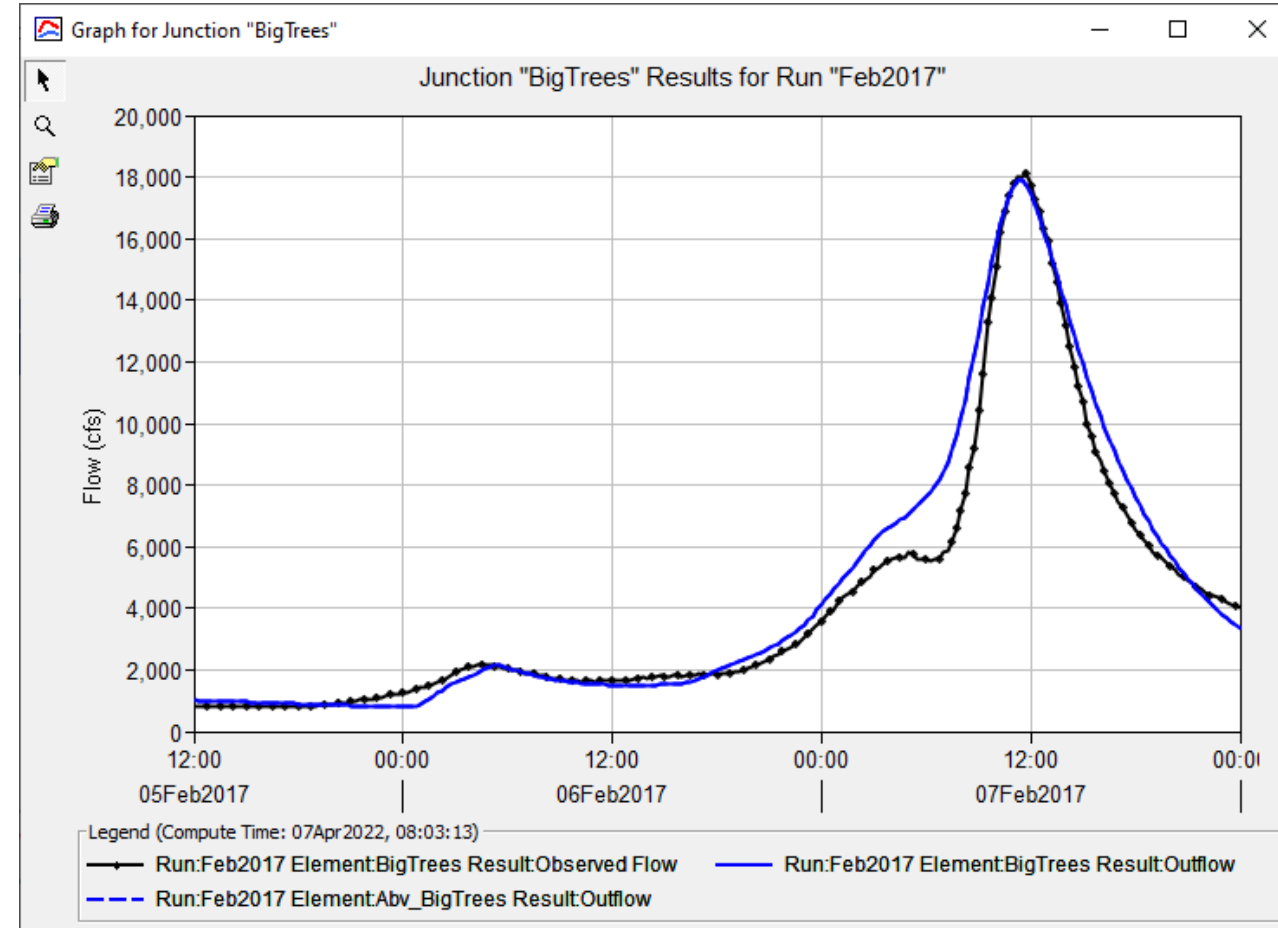
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Model Calibration

- Watershed model is a stand-in for reality
- Set parameters so the model can re-produce real flood events



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Model Calibration

- Calibrate to events of different magnitudes
- Identify varying initial conditions (wet vs. dry)
 - Loss: initial deficit
 - Baseflow: initial baseflow
 - Snow, reservoir, reach as needed
- Most important parameters:
 - Loss: constant loss rate
 - Transform: time of concentration, storage coefficient



Ungaged Watersheds

- Can't calibrate without observed streamflow data!
- Borrow parameters from neighboring similar watersheds
 - Transfer parameters
 - Regression equations
- Adjust with watershed-specific data
 - Compare soils and land-use data



Initial Conditions

- Flood severity related to watershed conditions prior to storm
- Model should reflect this variation
- Factors:
 - Soil water storage
 - Snow
 - Reservoir storage/outflow
 - Reach flow
 - Baseflow



Non-Linearity

- Runoff severity can increase with increased precipitation
 - Flood wave reaches outlet more quickly
 - Less attenuation
- More severe floods tend to be associated with wetter initial conditions



Variable Parameter Clark UH

Subbasin Loss Transform Baseflow Options

Basin Name: Basin 1
Element Name: Subbasin-1

Method: Variable Parameter

*Time of Concentration (HR) 2.25

*Storage Coefficient (HR) 3

*Index Excess (IN/HR) 0.5

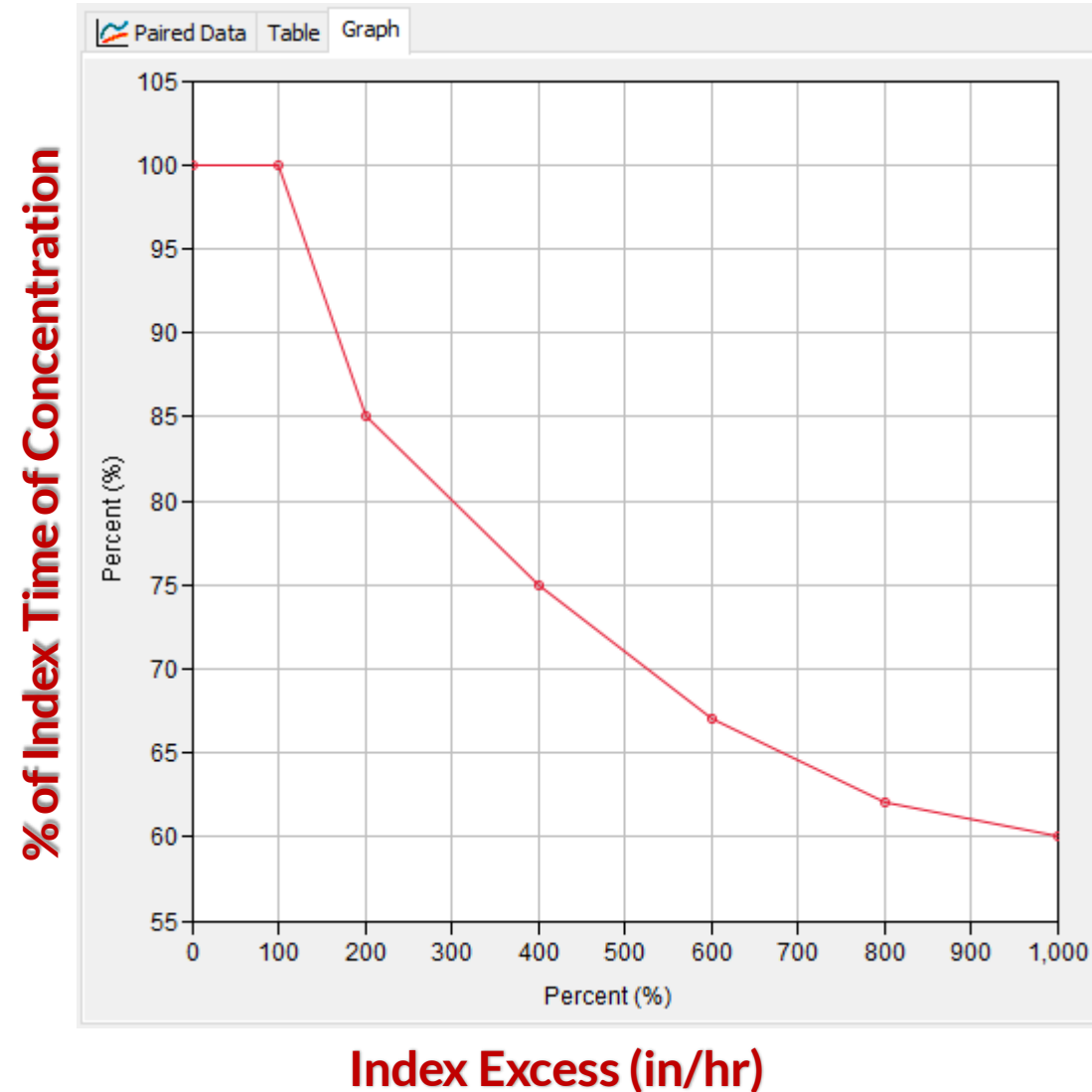
*Concentration Curve: TC Reduction

*Storage Curve: R Reduction

Time-Area Method: Default



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Meteorologic Considerations

- Storm duration
- Storm spatial pattern
 - Distribution of rainfall
 - Area reduction
- Storm temporal pattern

**Unique for all storms,
but we generalize**



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Watershed Response

- Peak flow is sensitive to all the hypothetical storm settings
 - Time pattern (most sensitive)
 - Storm duration
 - Area reduction
 - Spatial pattern (least sensitive)



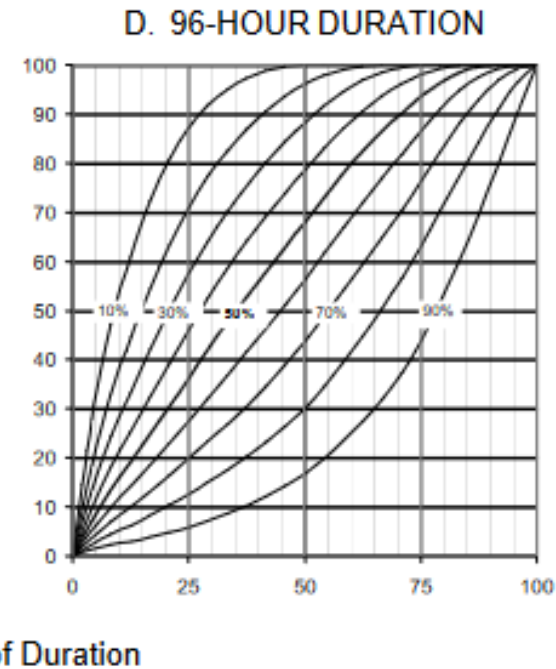
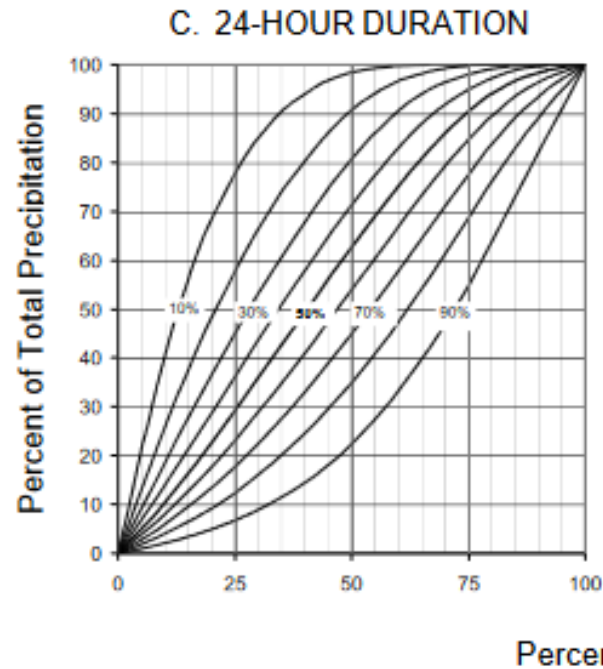
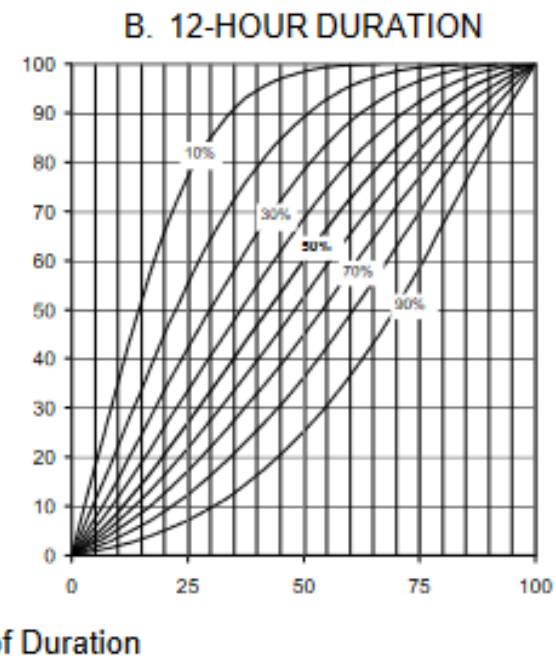
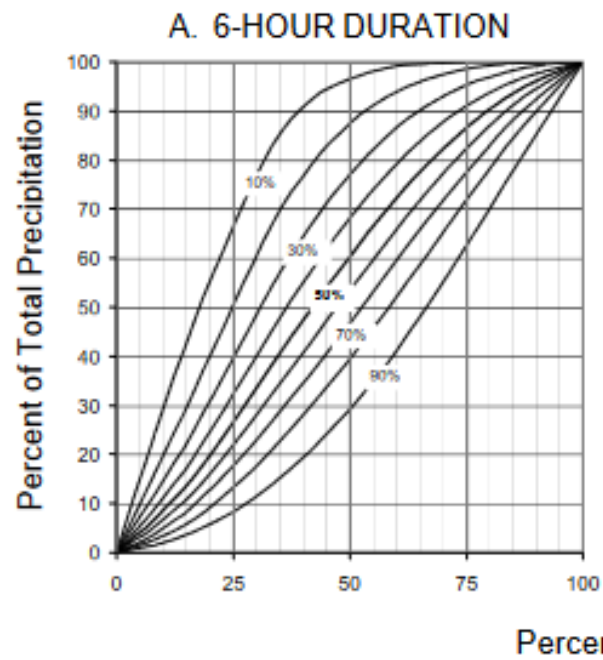
Storm Duration

- Total amount of time of rainfall
- Time pattern depends on it
- Chosen one of two ways:
 - Watershed-based (close to time of concentration)
 - Meteorologically-based



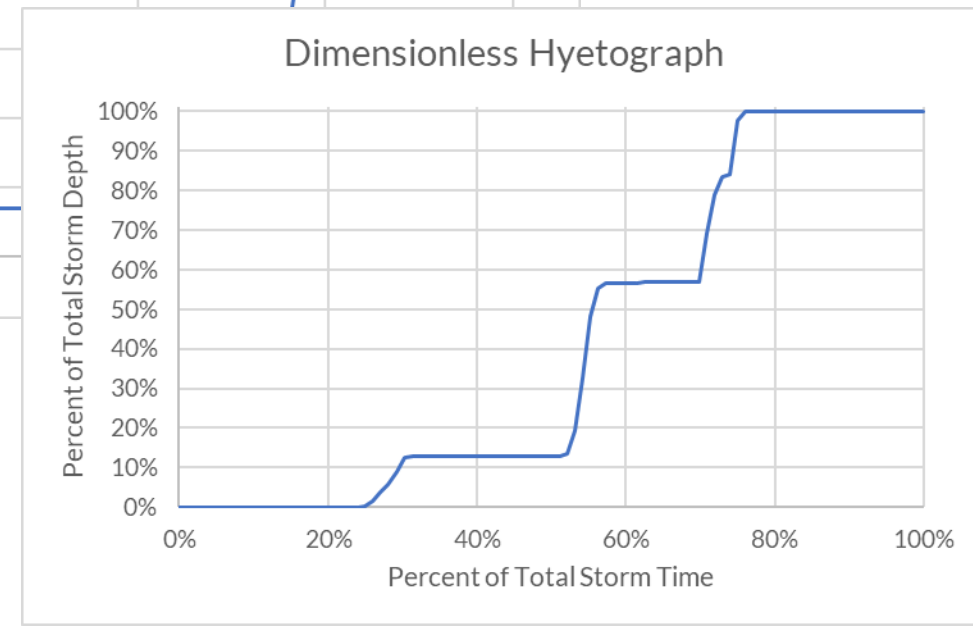
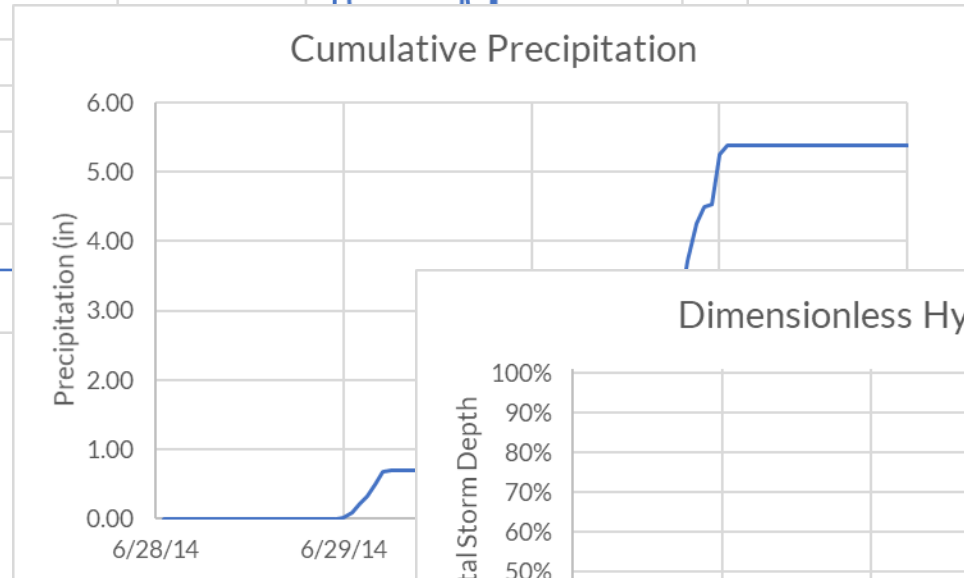
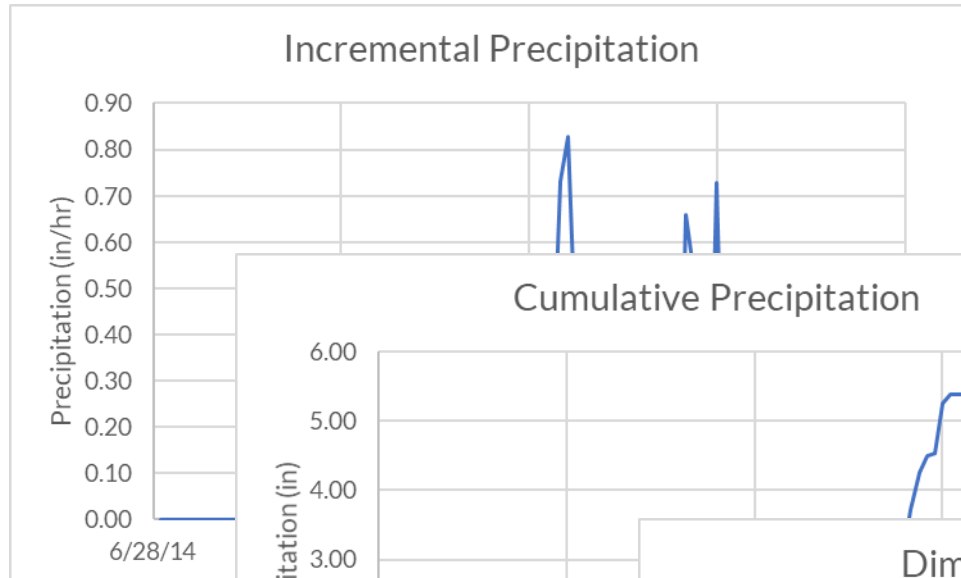
Time Patterns

- Dependent on storm duration
- Two sources:
 - Observed storms
 - Synthetic patterns
- Input as a Paired Data curve
 - Percentage curve



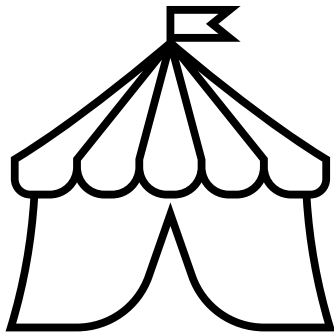
Time Pattern from Observed Storm

- Dimensionless %-% cumulative pattern
- % of total duration
- % of total depth

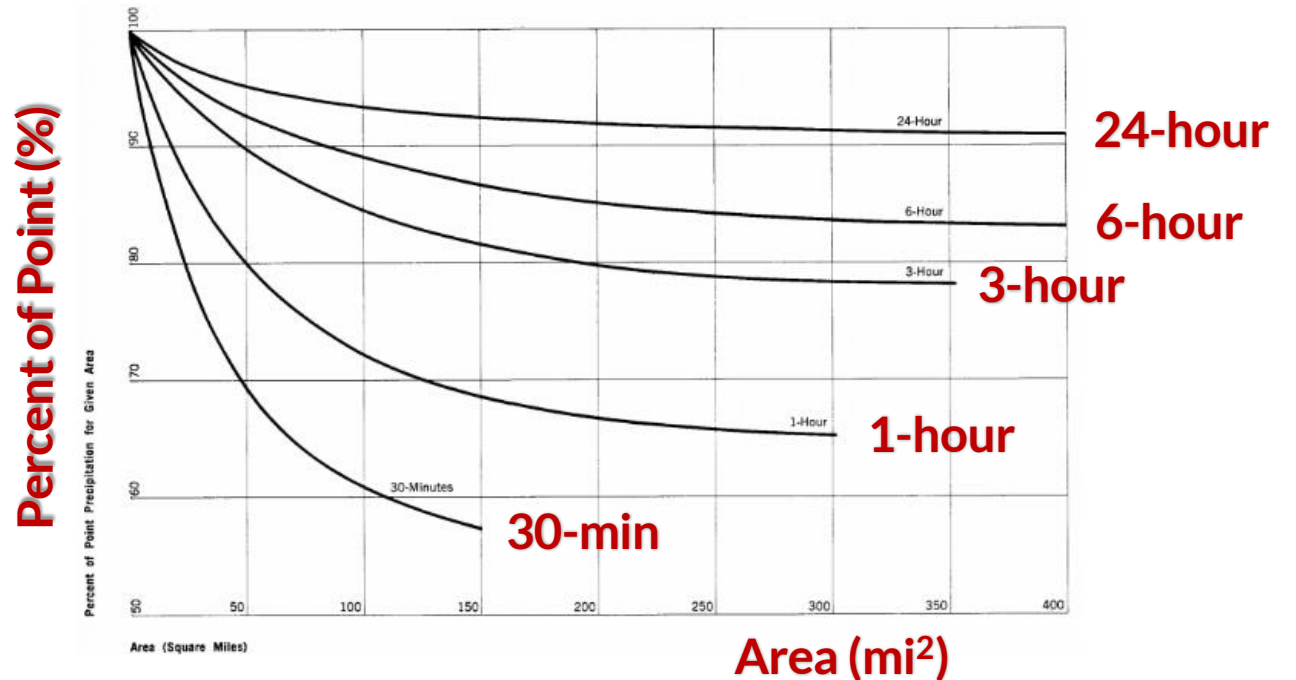


Area Reduction

- Precipitation-frequency describes precipitation at a **point**
- Compute area-average from point depths
- Area-average *reduced* from point-average



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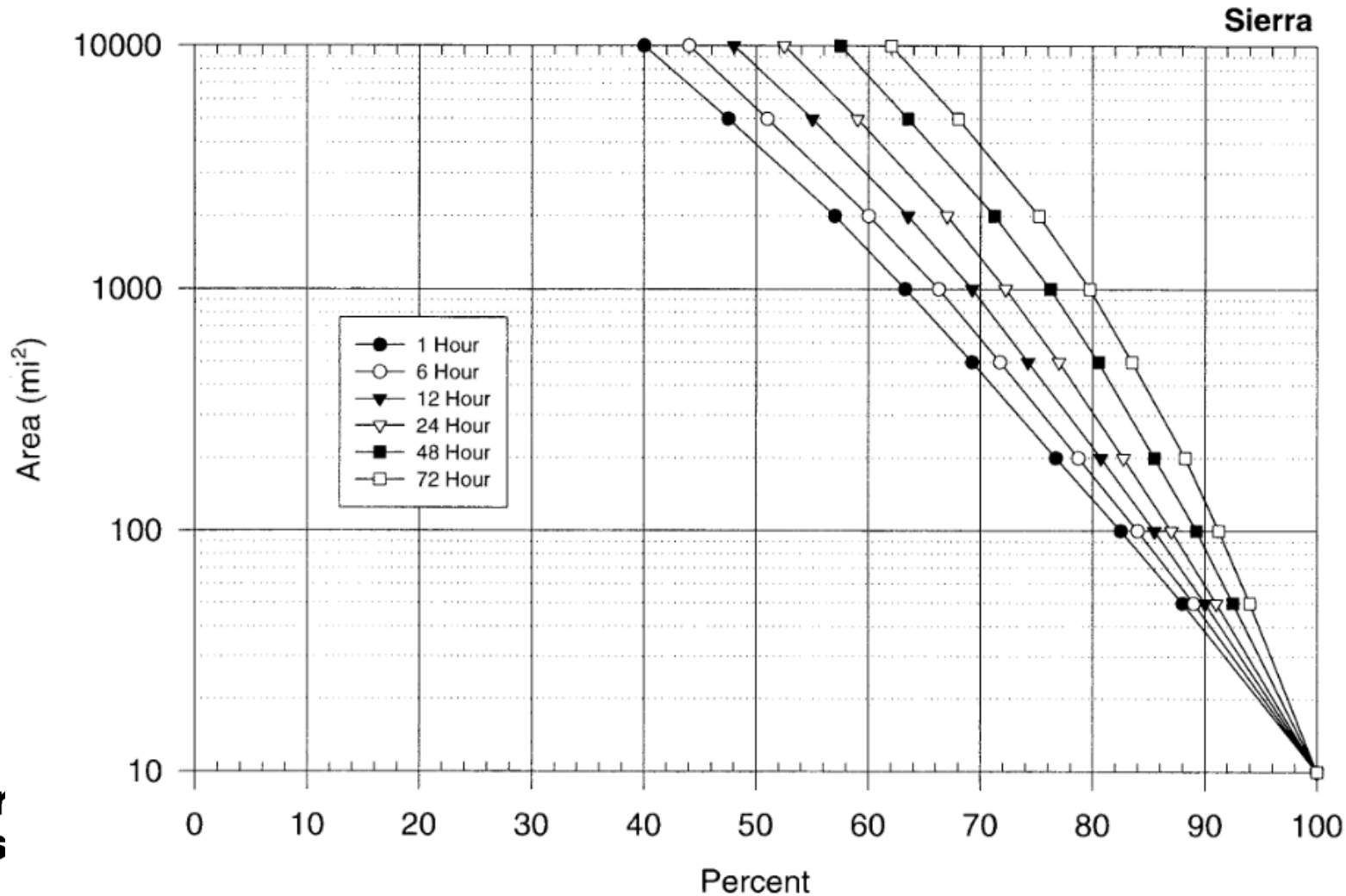
Depth-Area Reduction from Observed Events

- Storm information summarized in depth-area-duration table

Area (mi ²)	Duration (hours)								
	1	3	6	12	18	24	36	48	60
1	2.39	2.77	3.45	5.33	5.33	5.86	5.86	6.24	6.25
10	2.27	2.65	3.34	5.26	5.26	5.70	5.70	6.16	6.17
50	2.21	2.55	3.30	5.18	5.18	5.59	5.59	6.12	6.12
100	2.07	2.51	3.27	5.17	5.17	5.53	5.53	6.03	6.03
200	1.89	2.48	3.26	4.92	4.92	5.49	5.49	5.82	5.82
500	1.65	2.44	2.89	4.53	4.53	5.02	5.02	5.28	5.28
1000	1.49	2.10	2.60	4.01	4.01	4.44	4.44	4.81	4.81
2000	1.31	1.69	2.11	3.16	3.16	3.52	3.53	3.85	3.85
5000		1.49	1.55	2.10	2.10	2.47	2.57	2.88	2.88
10000				1.63	1.68	1.80	1.89	2.37	2.39
20000				1.23	1.39	1.63	1.70	1.86	1.91



Example from HMR-59



< 10 mi² = 100%



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Spatial Pattern

- Currently HMS assumes spatially-uniform rainfall above the computation point
- Will change in a future version
- For small watersheds, usually an OK assumption



Modeling Flood Frequency with HEC-HMS



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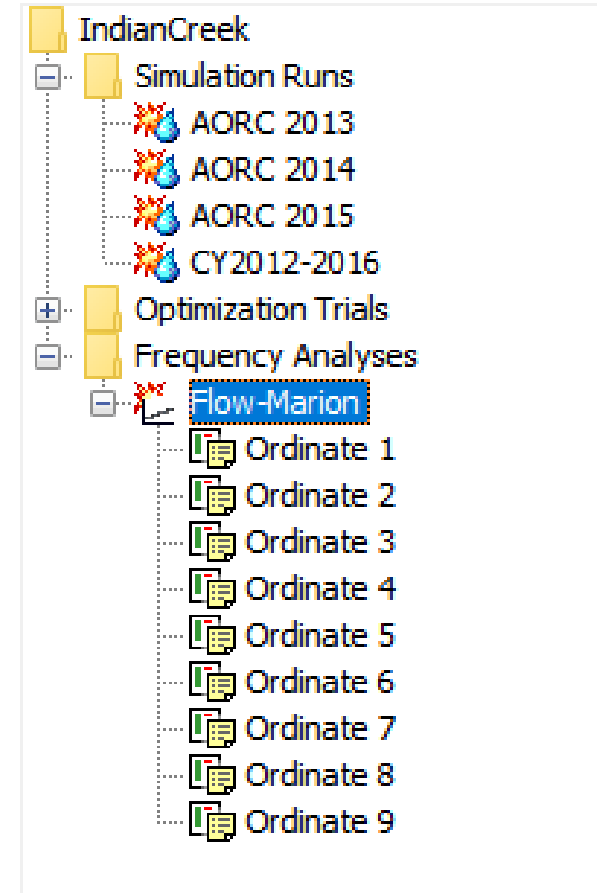
AEP Neutral Approach

- Assumption:
 - Precipitation frequency for a particular depth and duration equals the flood frequency
 - i.e., 1/100 AEP rainfall causes 1/100 AEP flood
- More advanced techniques are required to break free of this assumption



Frequency Analysis Compute



- Collection of frequency ordinates (AEPs)
- User specifies a basin model and met model combination that represents a specific AEP
- HEC-HMS runs each ordinate as a separate simulation
- Collects the results
- Creates a frequency curve plot



Frequency Analysis Ordinate

Frequency Analysis Ordinate 1

Name: Jan1982_TimePattern

Annual Exceed. Prob.:	50.0% (2-yr)	▼
Meteorologic Model:	50%_24hr_1982Pattern	▼ 
Basin Model:	CalibratedModel_dry	▼ 
Element:	BigTrees	▼
Time-series Type:	Outflow	▼
*Start Date (ddMMYYYY)	01Jan2000	
*Start Time (HH:mm)	00:00	
*End Date (ddMMYYYY)	03Jan2000	
*End Time (HH:mm)	00:00	
*Time Interval:	15 Minutes	▼



Frequency Analysis Ordinate

- Meteorologic model defines the AEP
 - Frequency from the precipitation-frequency data
- Basin model captures appropriate hydrologic conditions for AEP
 - Based on a calibrated model (if data available)
 - Initial conditions
 - Considerations for non-linearity
- Time window
 - Make sure window big enough to capture the peak



Basin Models

1. Calibrate model across range of events
2. Choose calibration parameter sets to represent range of conditions
 - e.g. “dry”, “average”, “wet”
3. Create a basin model for each condition set
4. Decide which AEPs need which conditions



Meteorologic Models

- The Frequency Analysis will use ANY meteorologic model!
- You should probably use:
 - Hypothetical storm
 - Frequency storm
 - Specified hyetograph (in specific instances)



Hypothetical Storm

Hypothetical Storm

Met Name: Hypo 1%

Method: User-Specified Pattern

*Storm Pattern: 1Q 50%

*Storm Duration (HR): 24

*Precipitation Method: Precipitation-Frequency Grid

*Grid: 24 hr 1%

*Computation Point: Basin: Indian Creek Base, Element: Marion

Area Reduction: User-Specified

*Area-Reduction Function: ARF1

Storm Area (MI2)

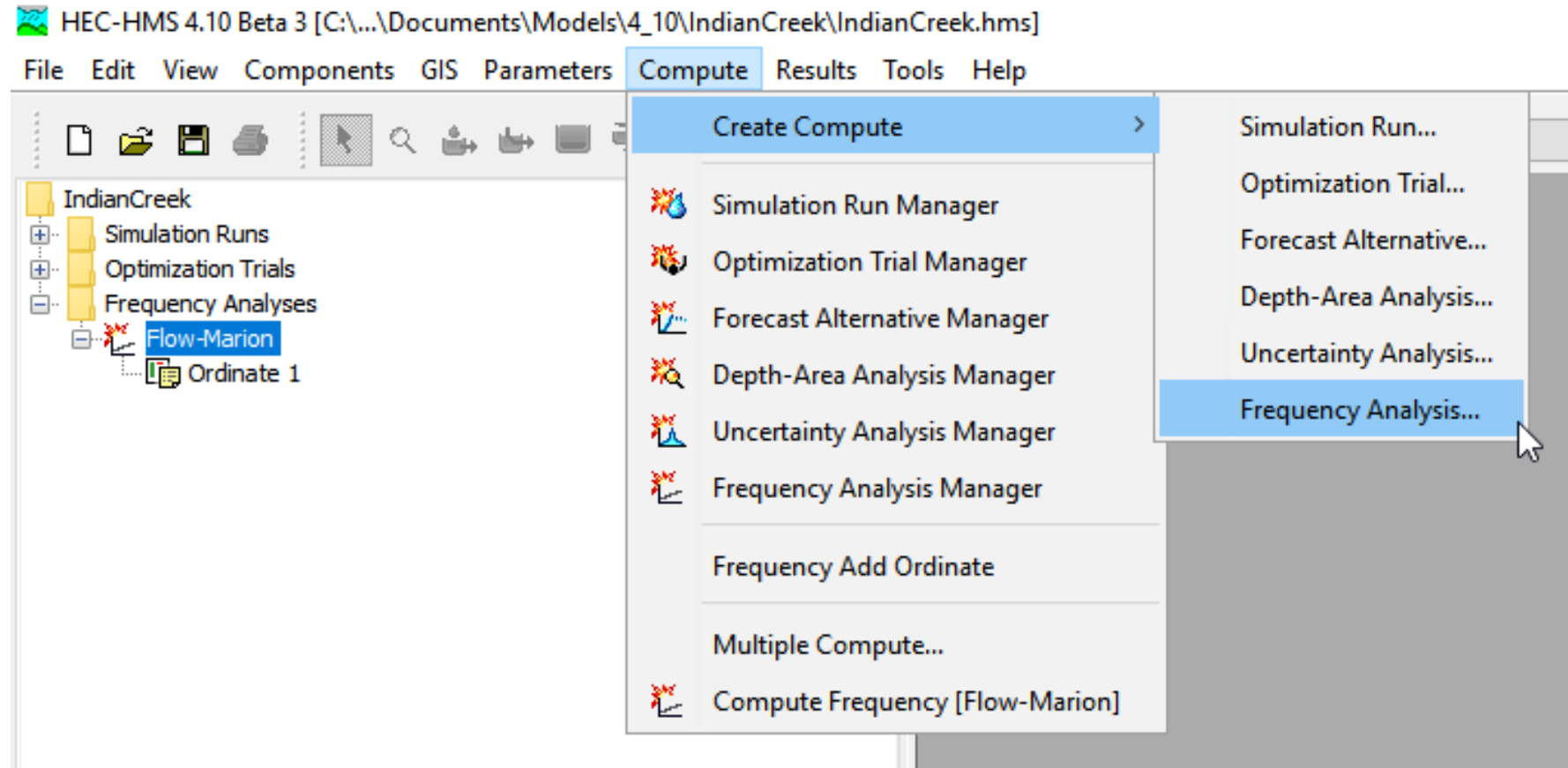
Paired Data: Percentage Curve

Grid Data: Precipitation-Frequency

Paired Data: Area-Reduction Func.

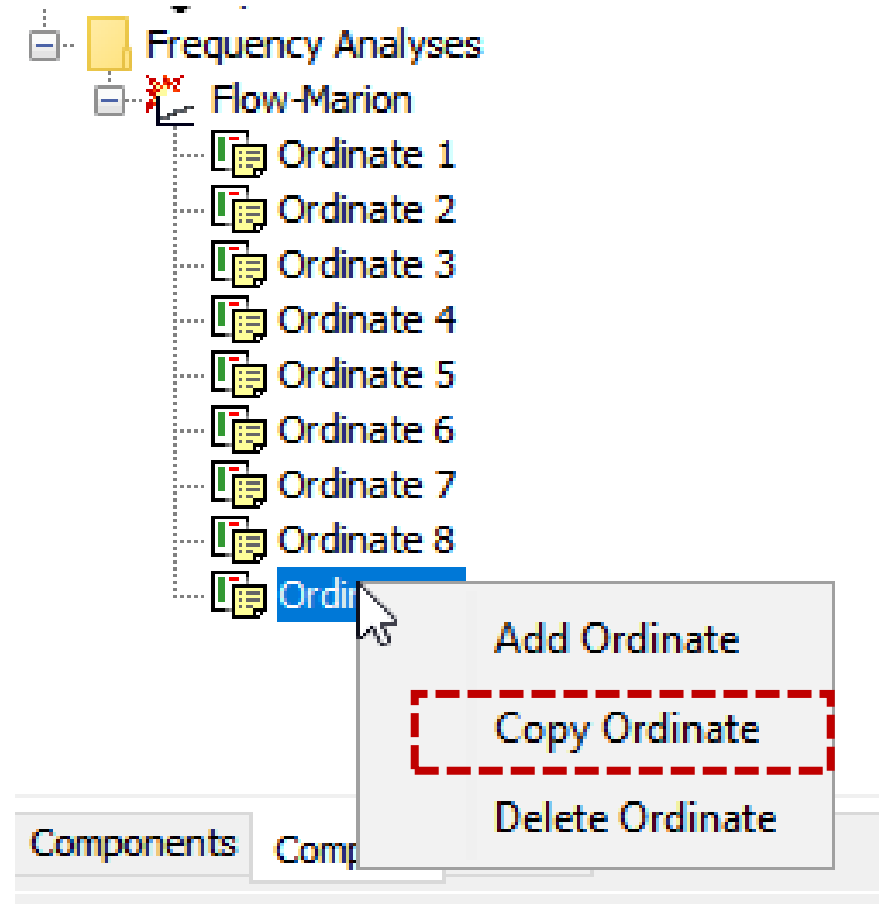


Create Frequency Analysis



Add/Copy/Delete Ordinates

- Right-click menu

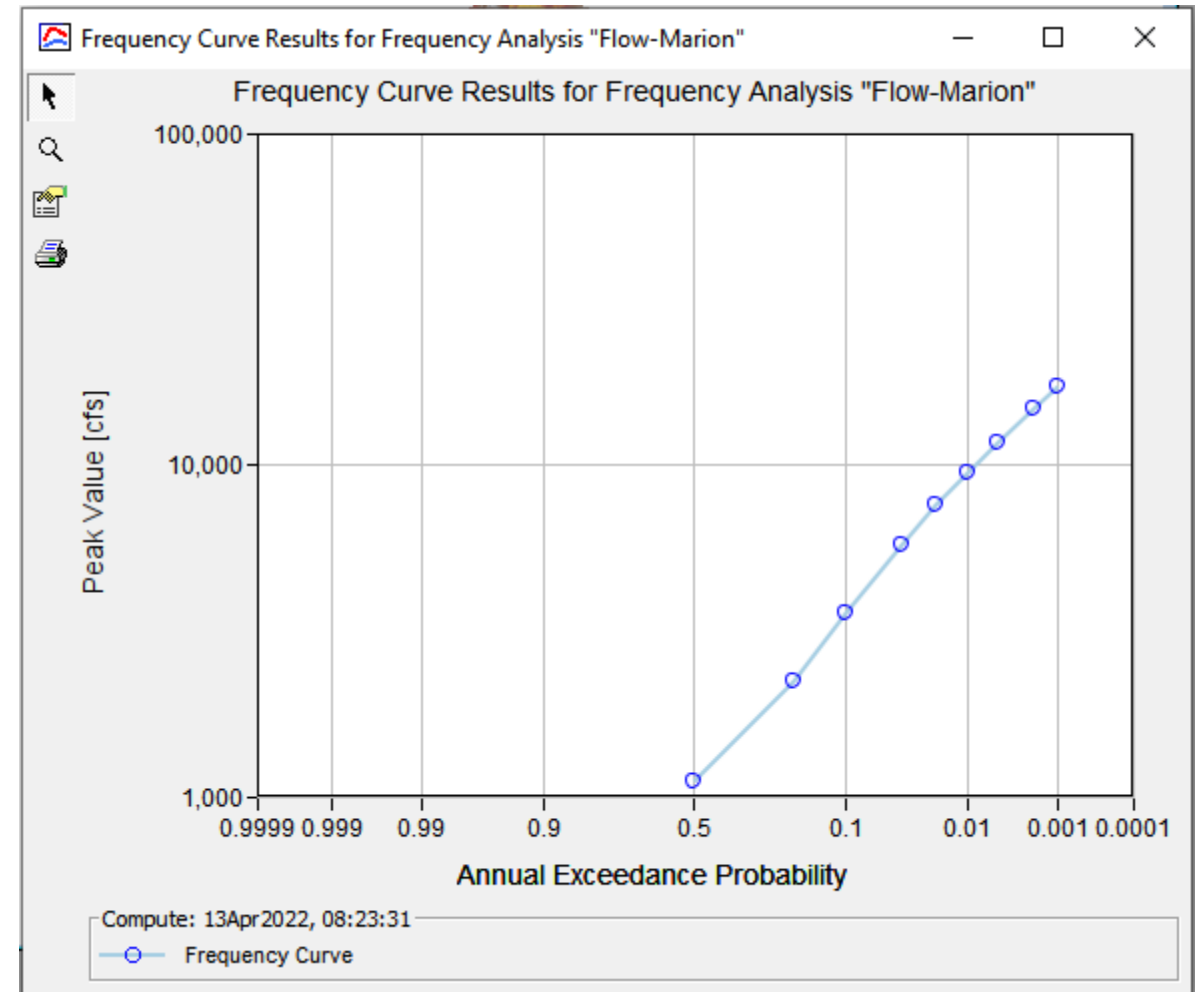


Frequency Analysis Results

Peak Summary Results for Frequency Analysis "Flow-Marion"

Project: IndianCreek Frequency Analysis: Flow-Marion
Compute Time: 13Apr2022, 08:23:31

Analysis Point	Drainage Area (MI ²)	AEP	Peak Value (CFS)
Marion	67.7	50.0% (2-yr)	1114.5
Marion	67.7	20.0% (5-yr)	2219.0
Marion	67.7	10.0% (10-yr)	3579.2
Marion	67.7	4.0% (25-yr)	5705.8
Marion	67.7	2.0% (50-yr)	7537.5
Marion	67.7	1.0% (100-yr)	9508.6
Marion	67.7	0.5% (200-yr)	11635.5
Marion	67.7	0.2% (500-yr)	14679.7
Marion	67.7	0.1% (1000-yr)	17119.8



Uncertainty

- Copy hypothetical storm met models with varied parameters
 - Time patterns
 - Area reduction functions
- Copy frequency analyses to vary the met models



Questions?



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