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

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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

For more information, come to the HMS training classes!

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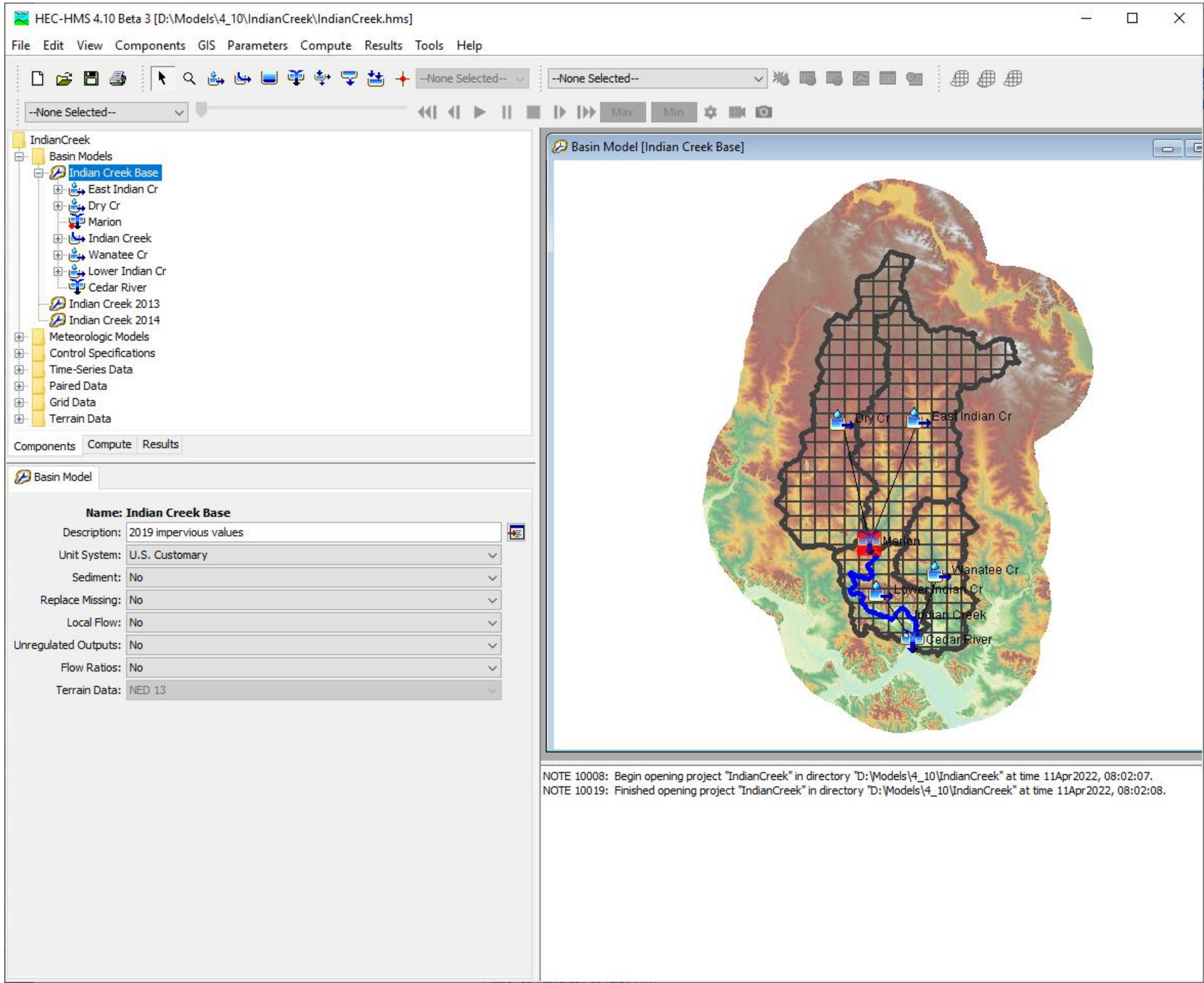
Keys to an HEC-HMS Model

- Basin model
- Meteorologic model
- Compute type



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Basin Model

- Representation of surface hydrology in watershed

- Seven basin elements:
  - Subbasin
  - Reach
  - Reservoir
  - Junction
  - Diversion
  - Source
  - Sink

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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

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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

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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

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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

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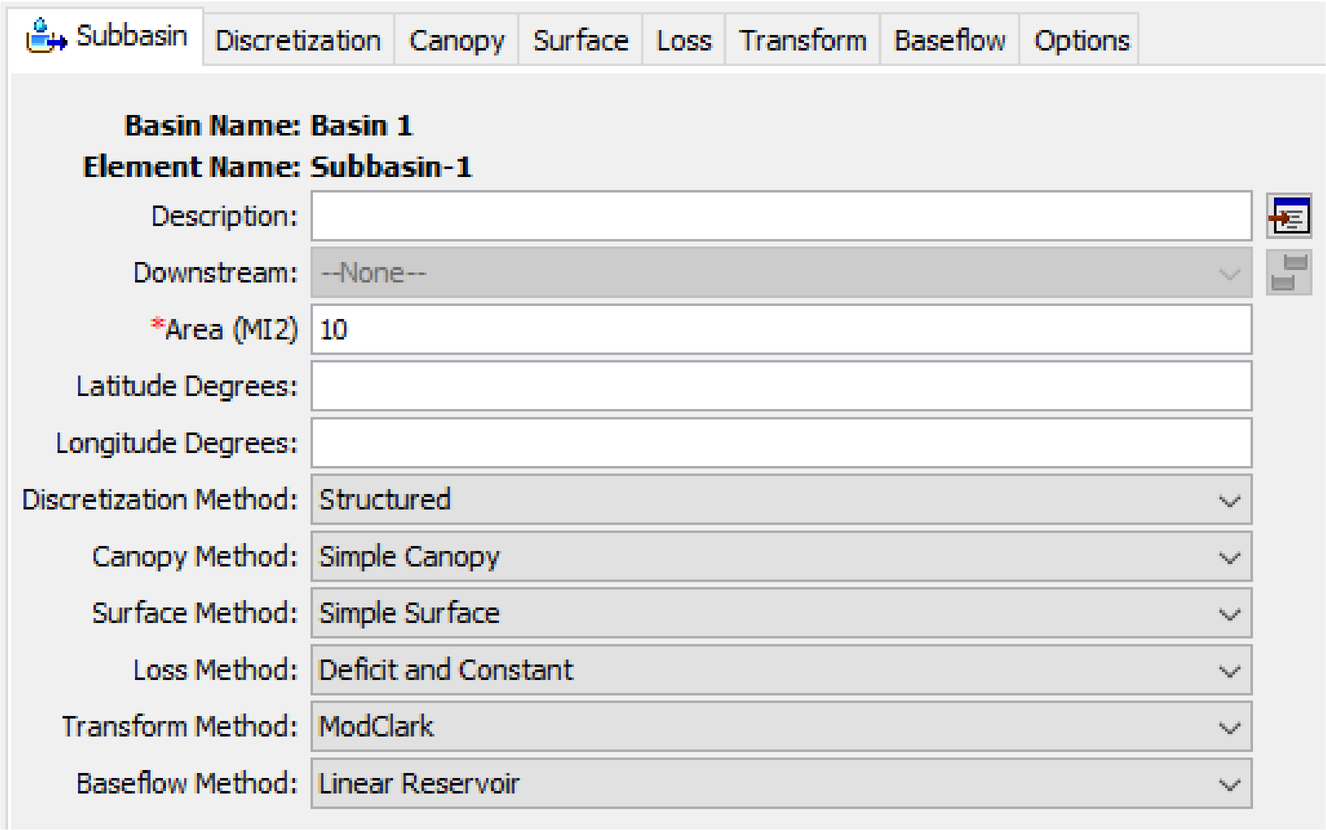
Subbasin Processes

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



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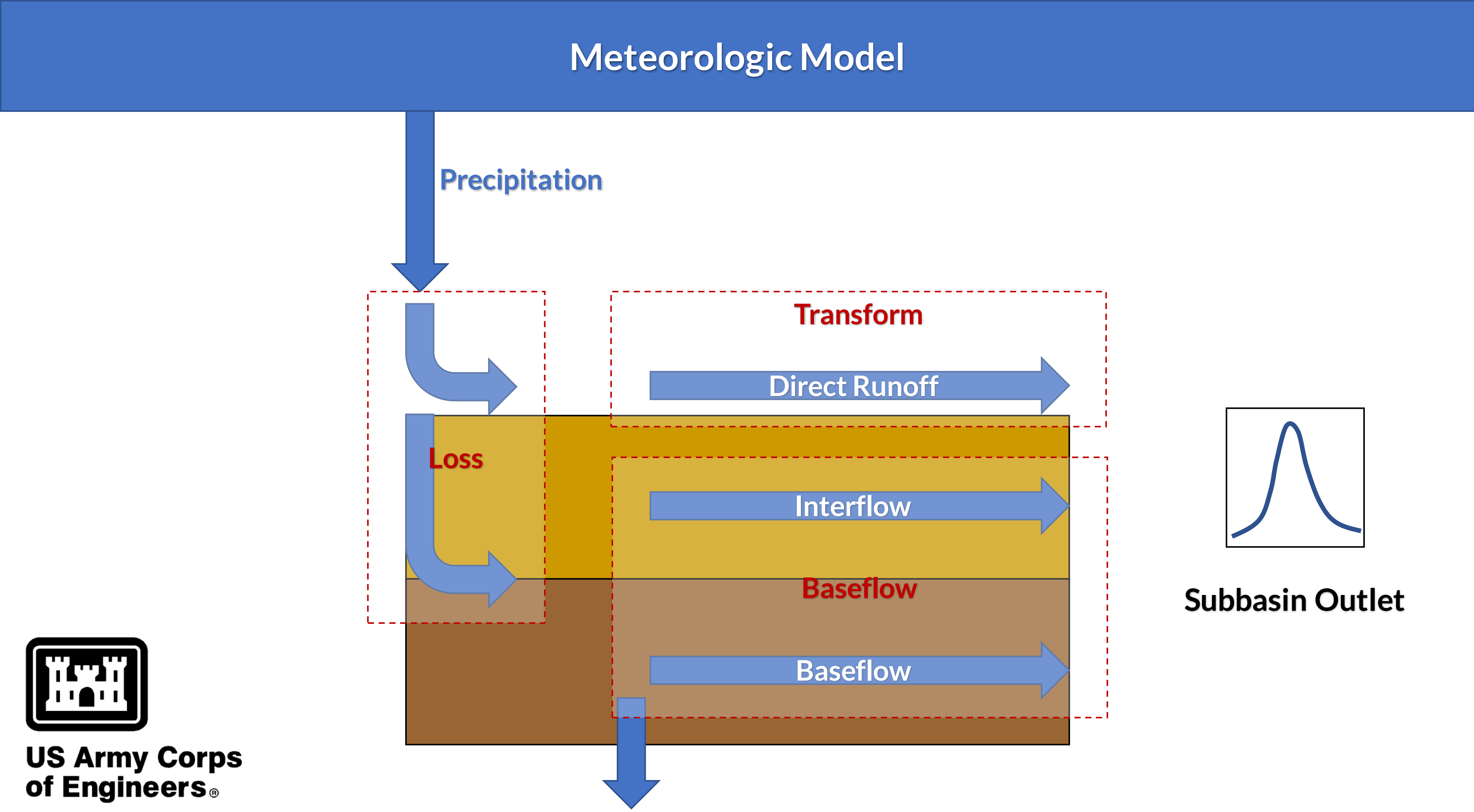

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Loss Methods

- 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)

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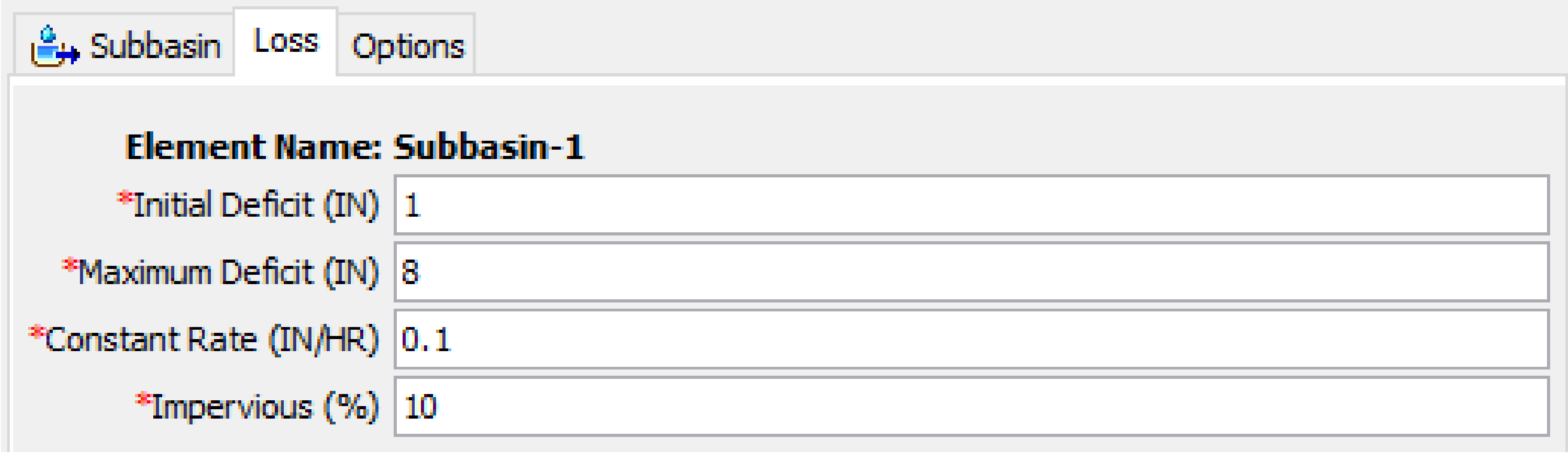
Deficit and Constant Loss



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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

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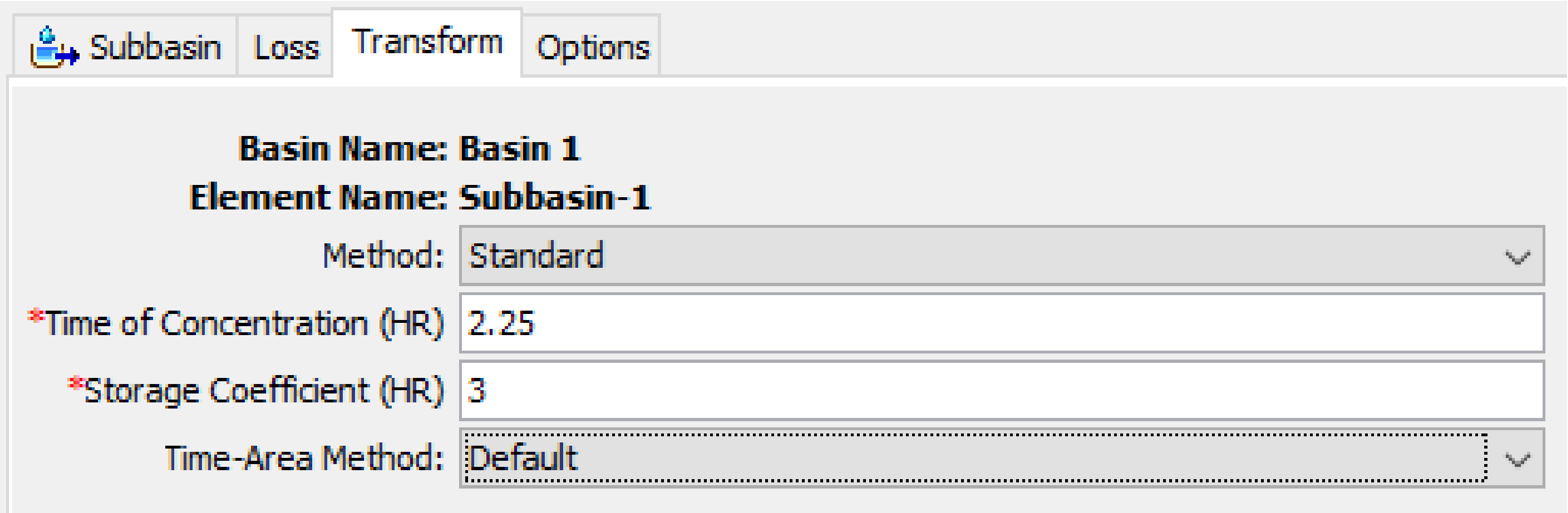
Clark Unit Hydrograph



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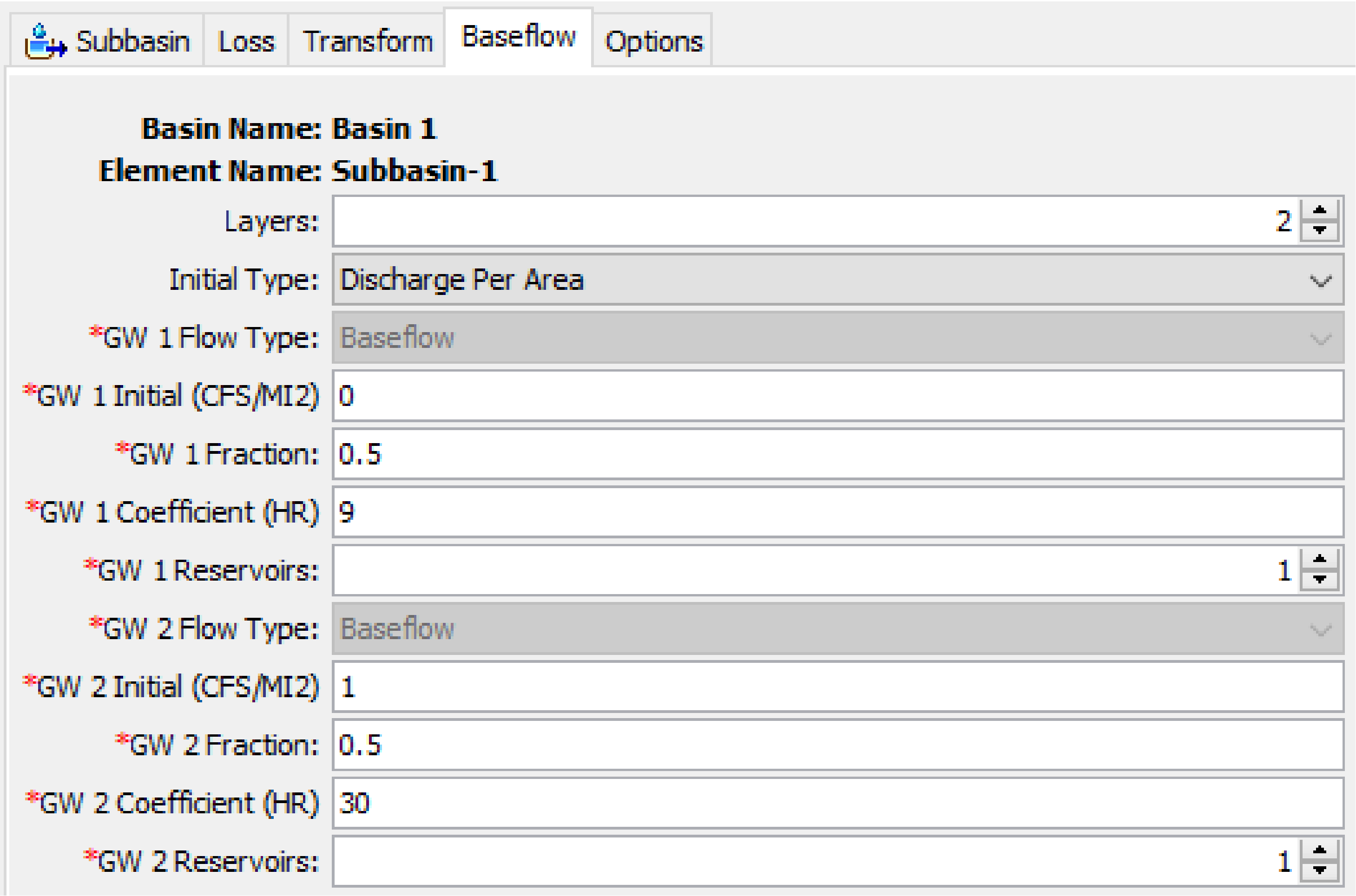
Baseflow Methods

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

Linear Reservoir Baseflow



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Precipitation Methods

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

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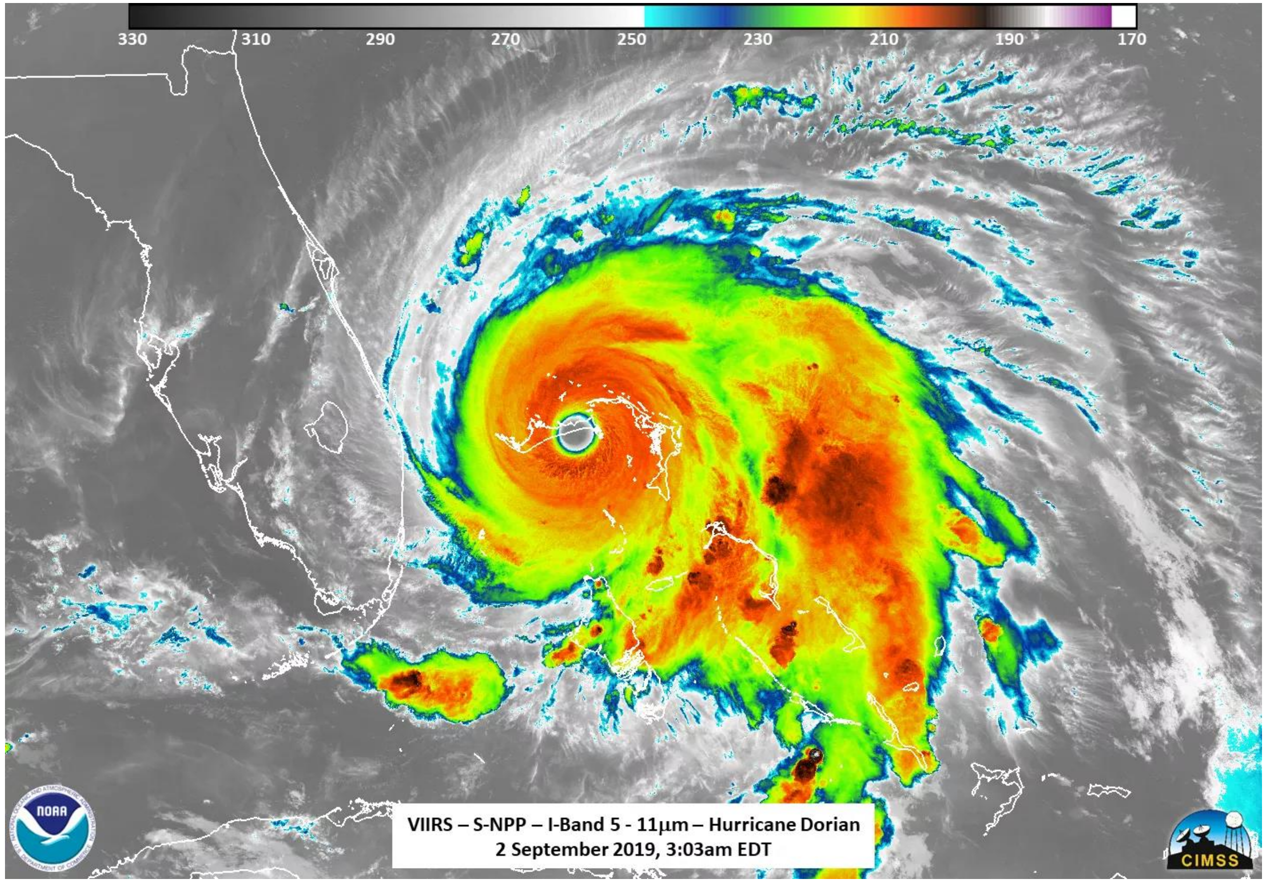
Gridded Precipitation

- 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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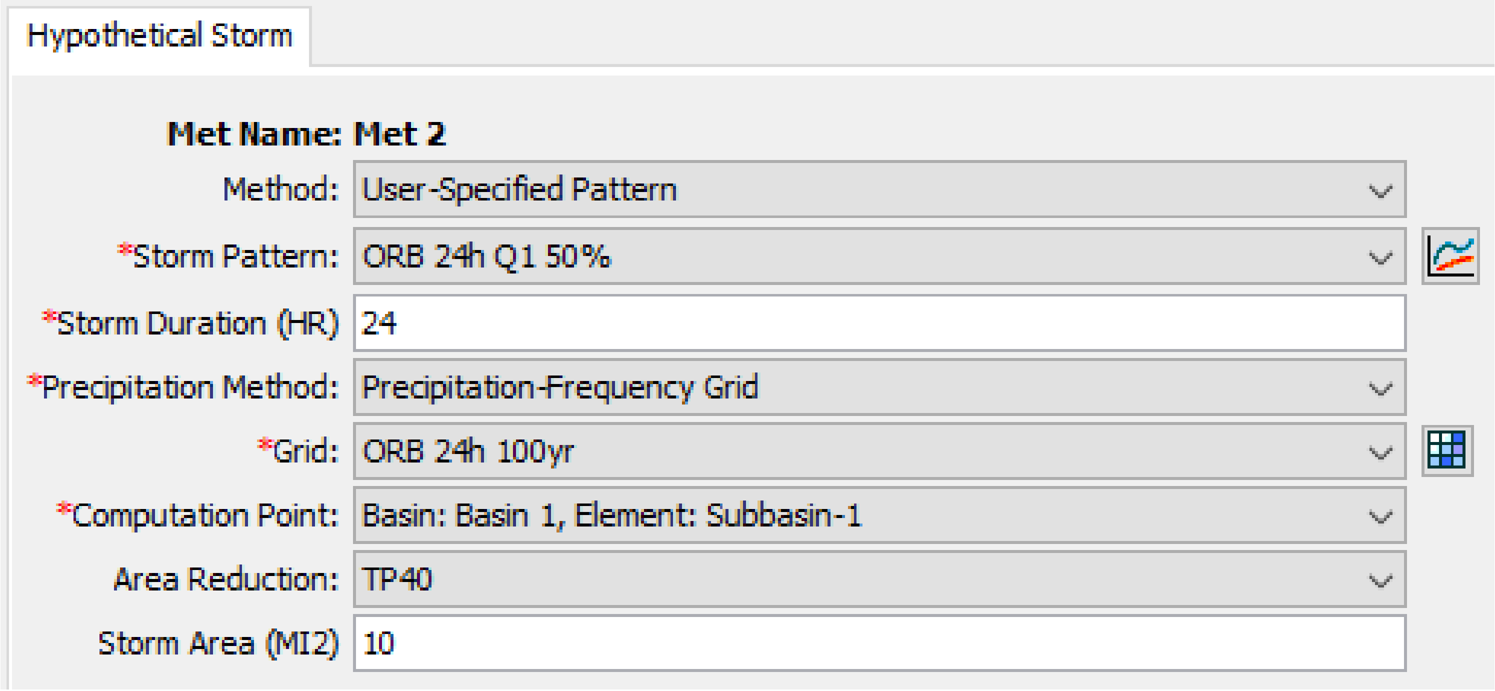
User-Specified Pattern Hypothetical Storm



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

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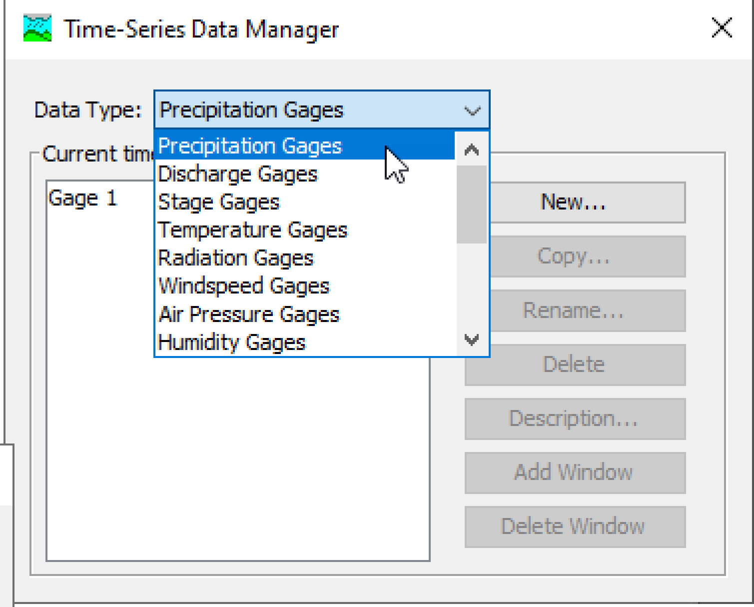
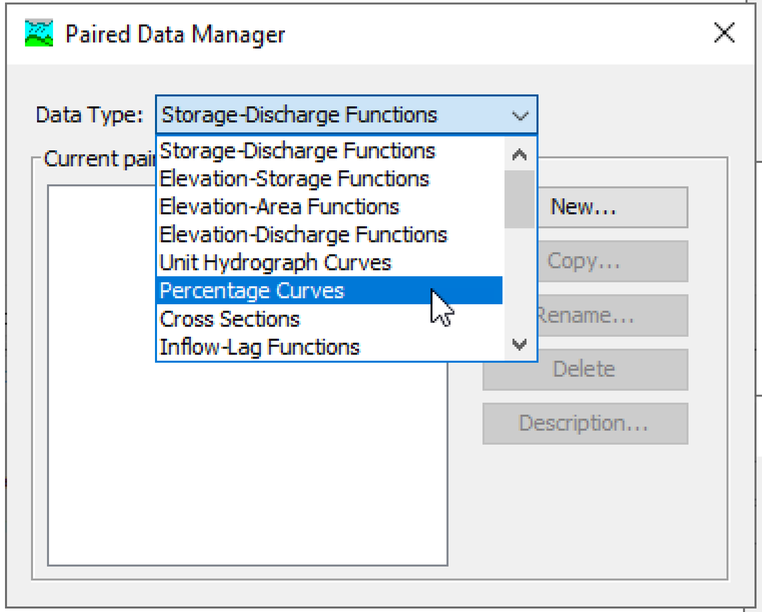
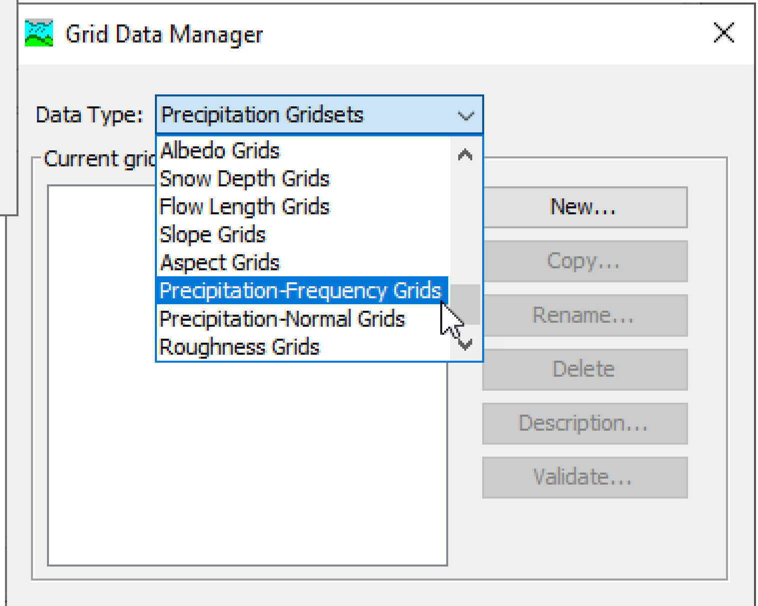
Data

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







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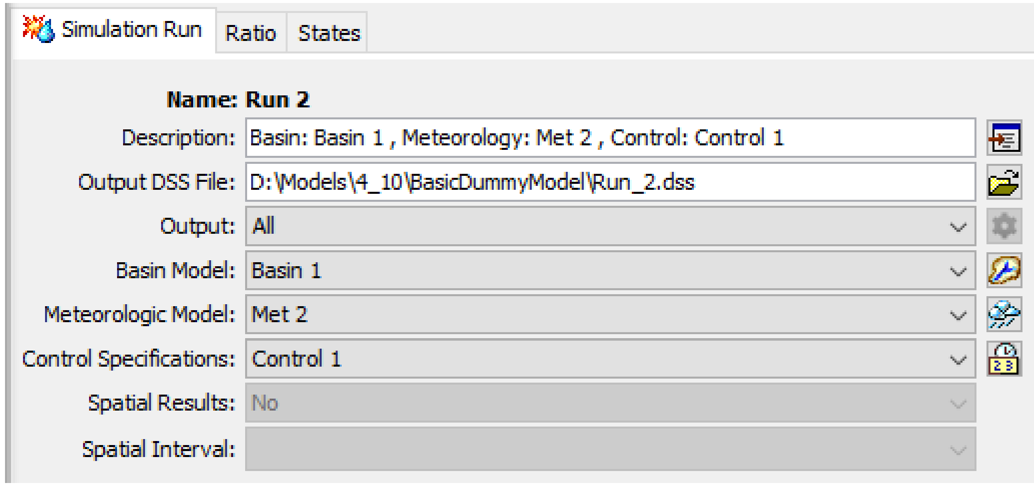
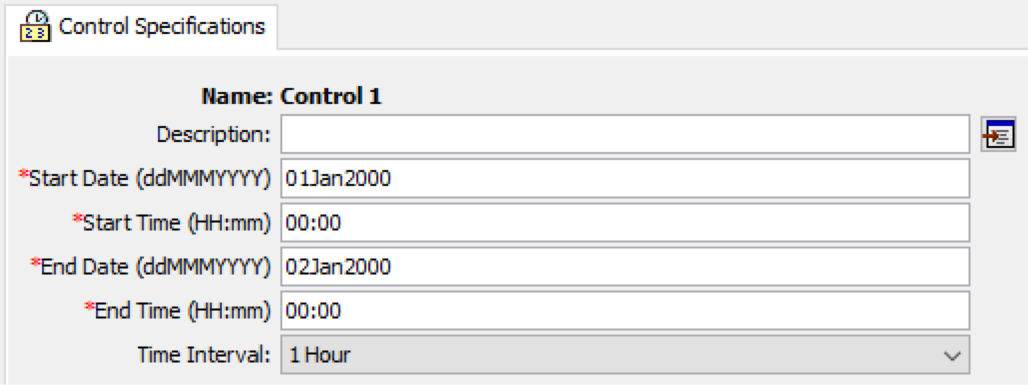
Simulation Run

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





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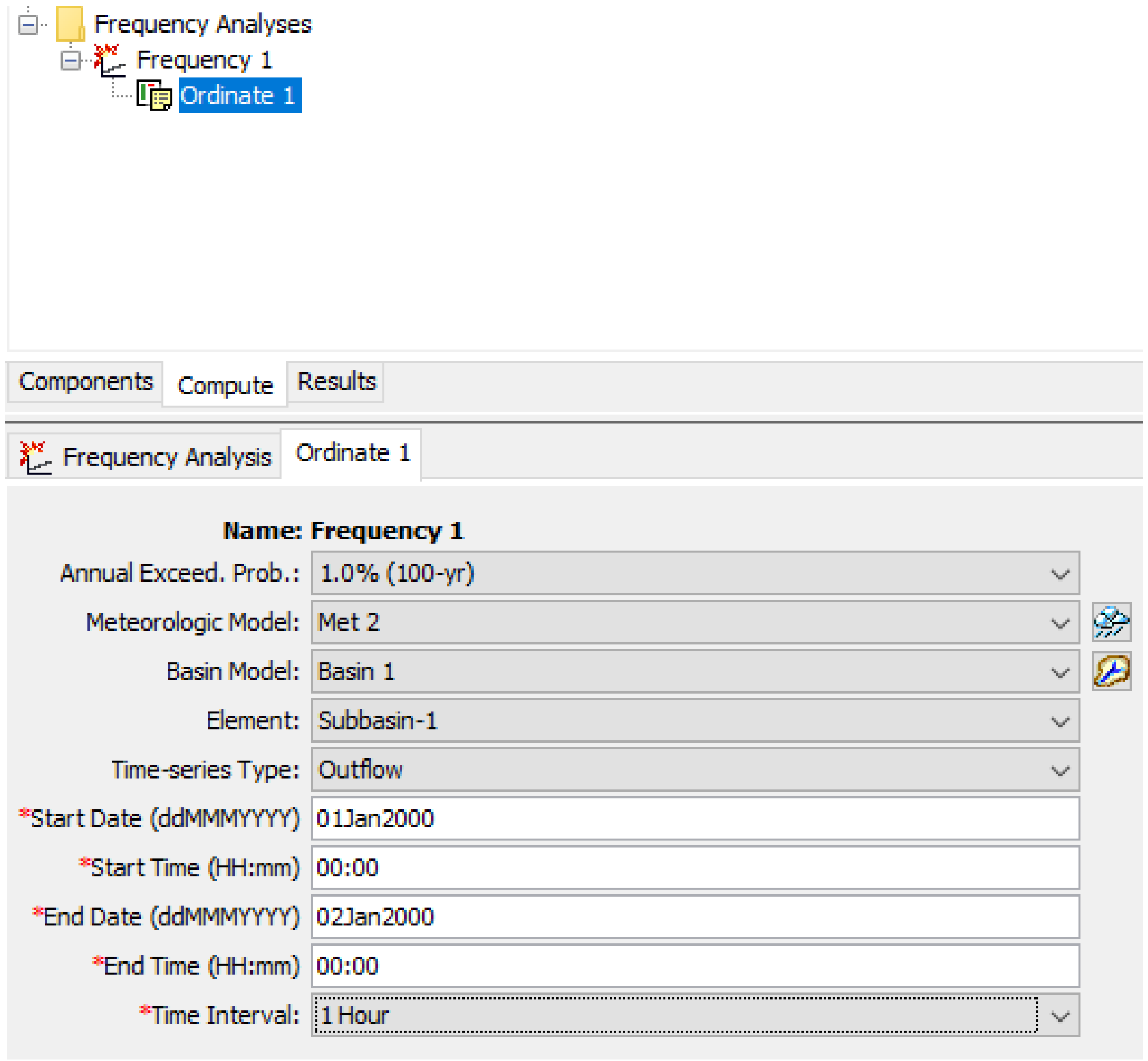
Frequency Analysis Compute

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



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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

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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!

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

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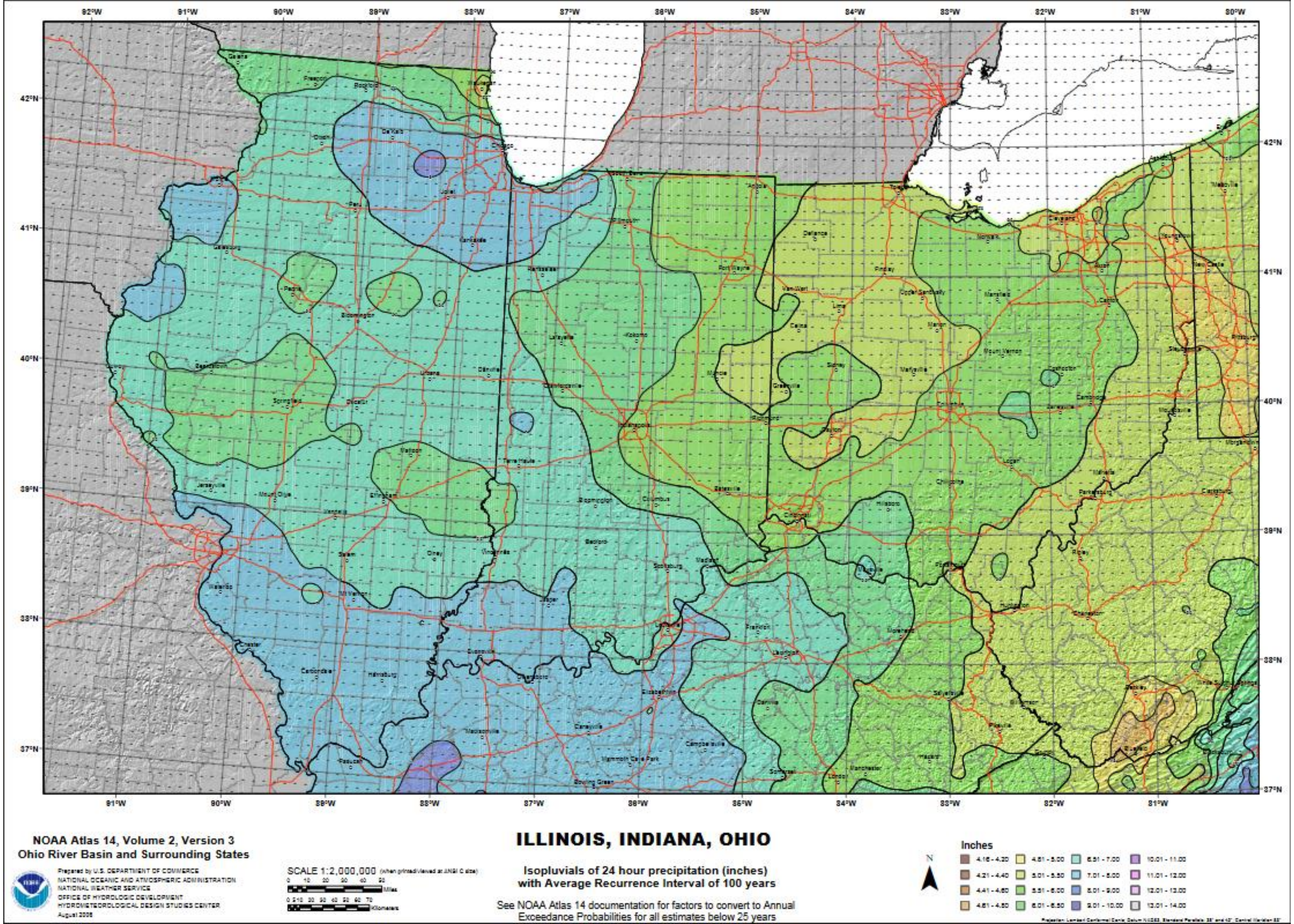
24-hour 1/100 AEP



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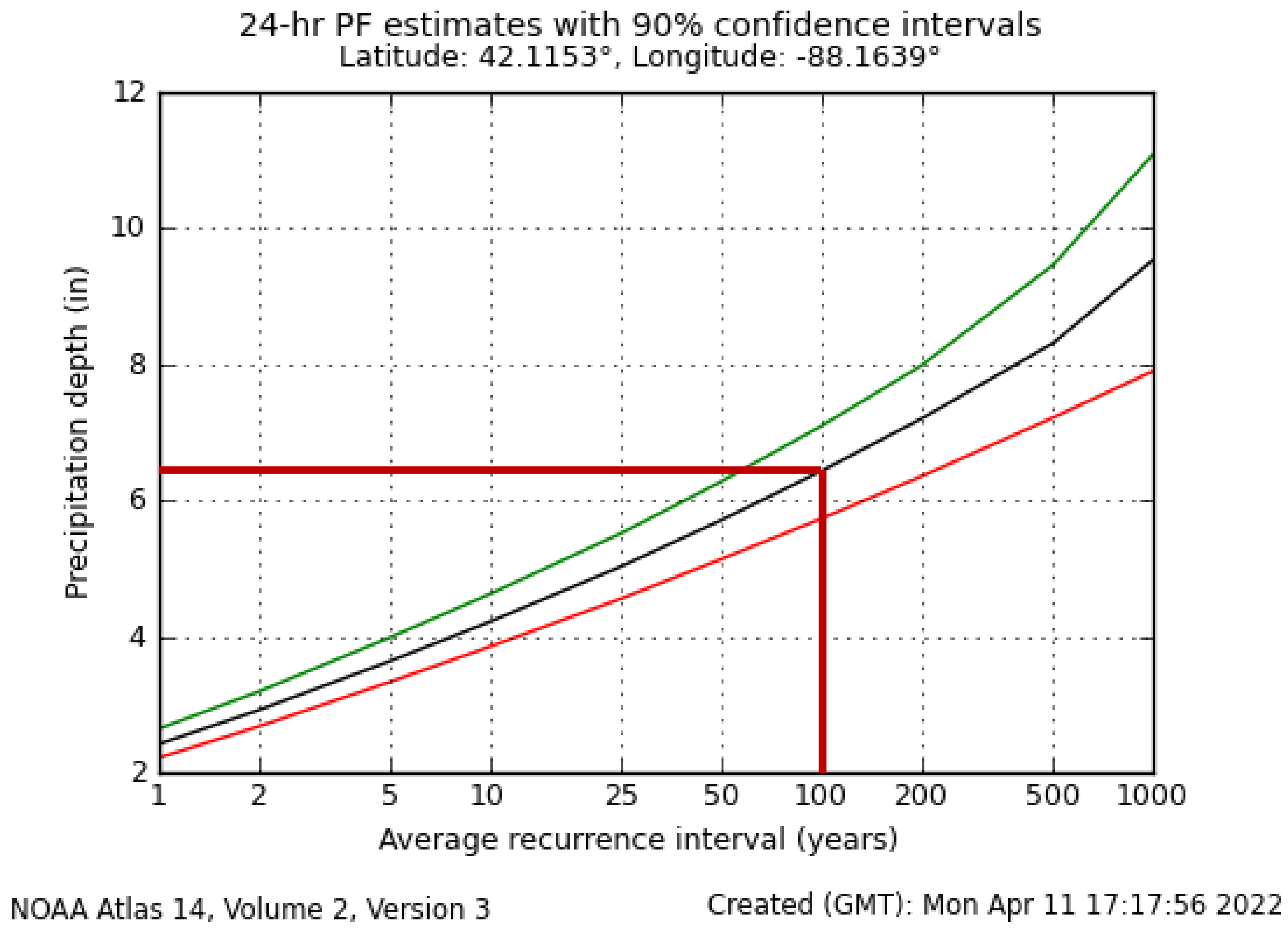
Precipitation-Frequency Curves



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Getting Data

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

NOAA Atlas 14 Precipitation Frequency Estimates in GIS Compatible Format

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

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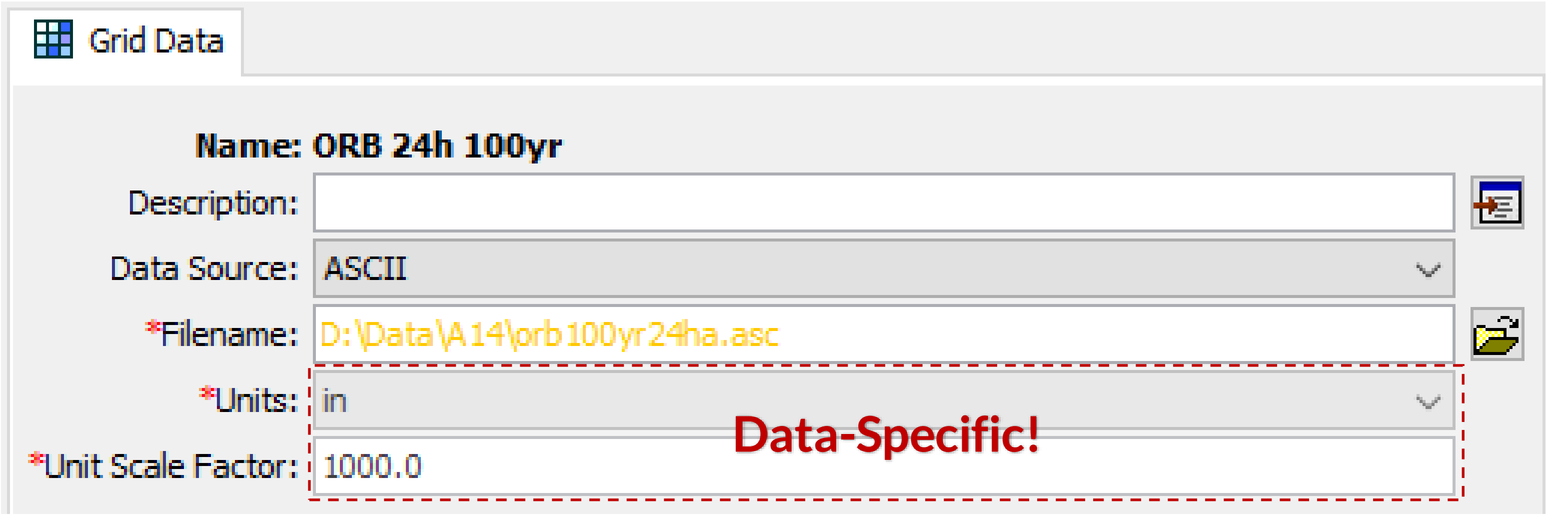
Precipitation-Frequency Grids in HMS

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



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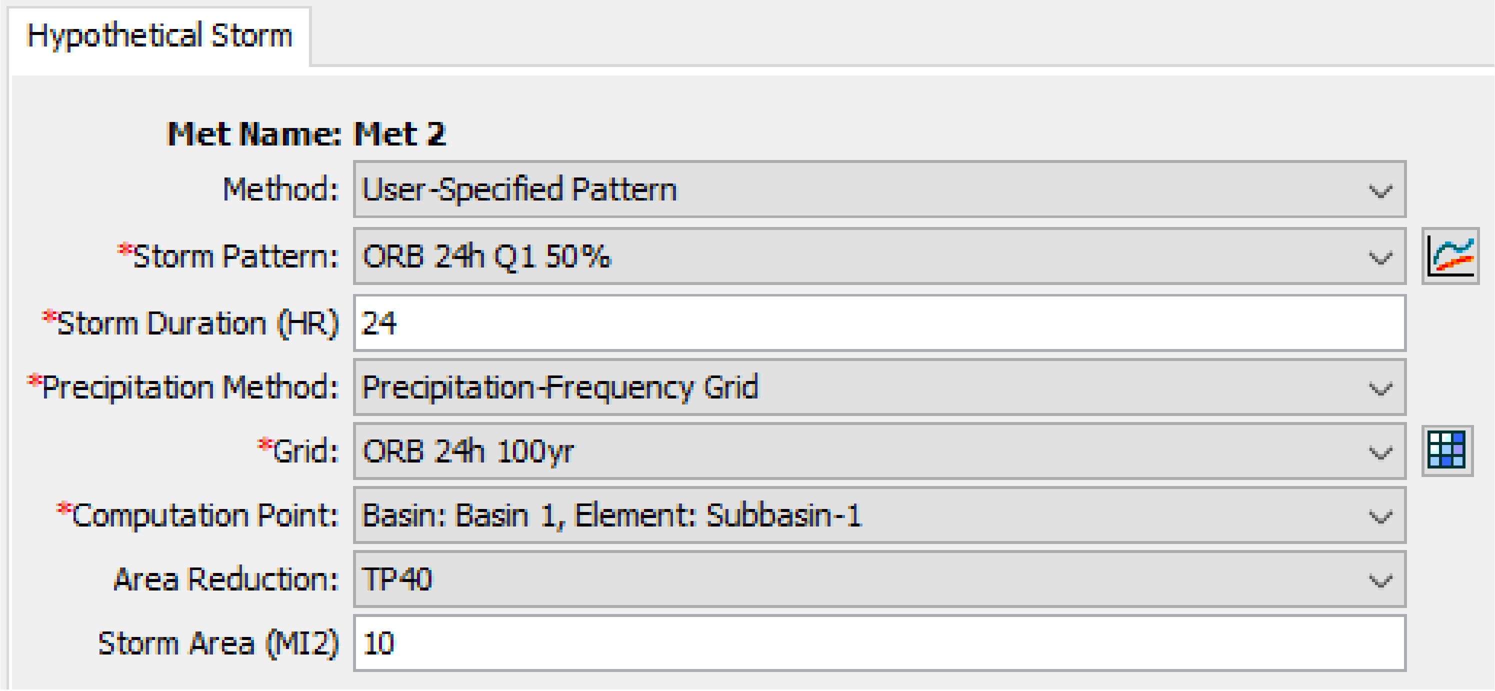
Hypothetical Storm + PF Grids



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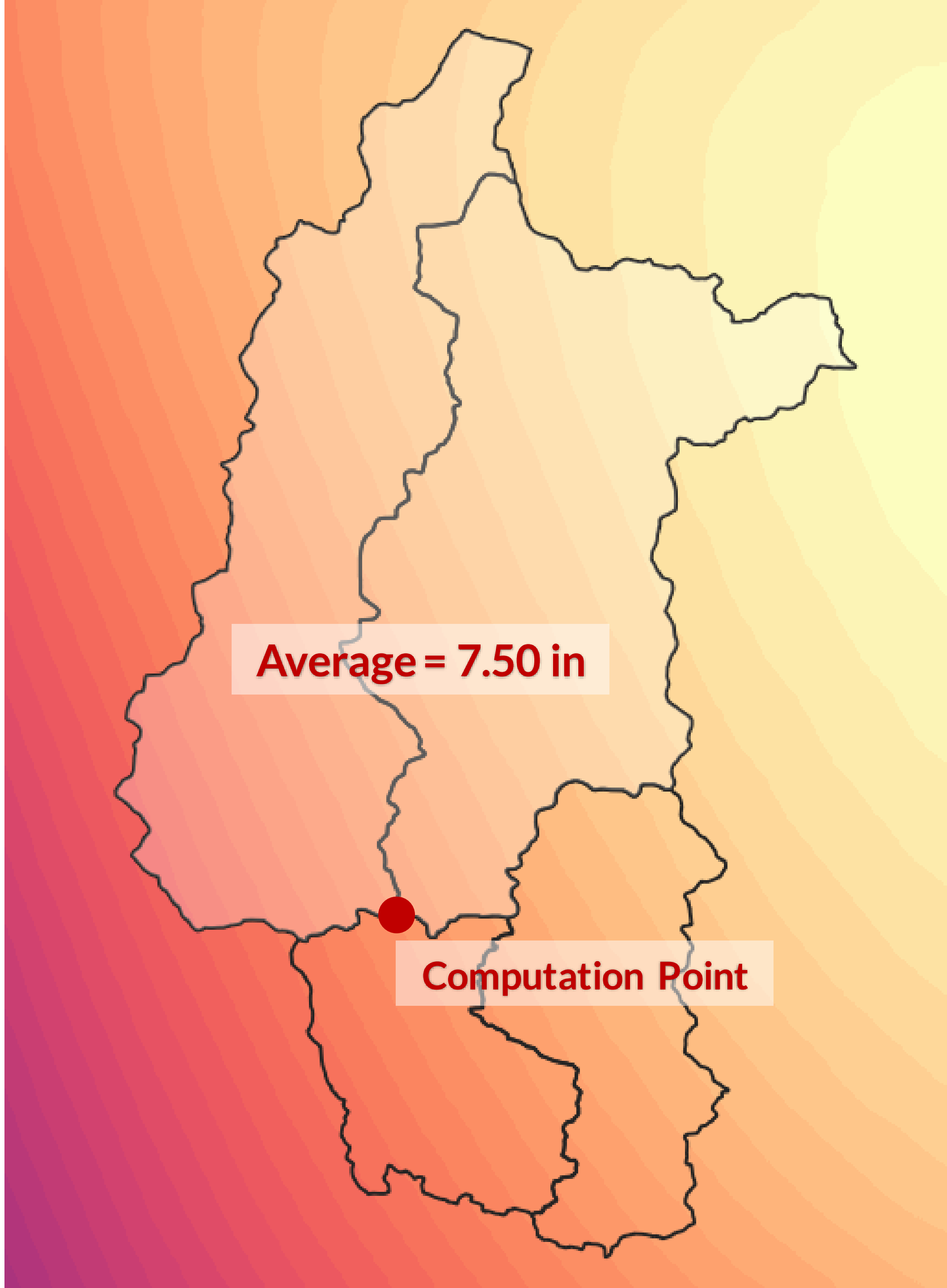
Precipitation Depth

- 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?

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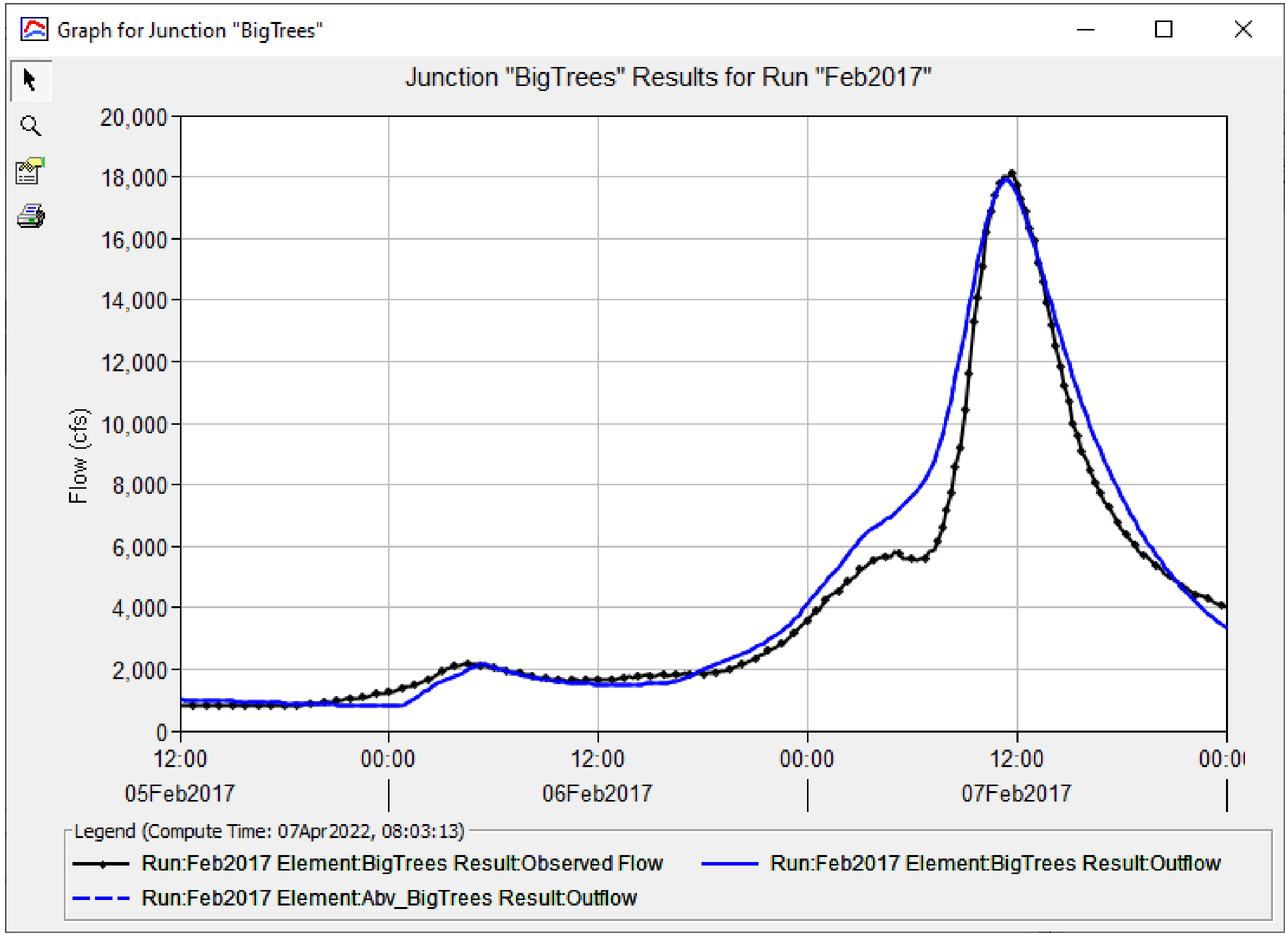
Hydrologic Considerations

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

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

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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

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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

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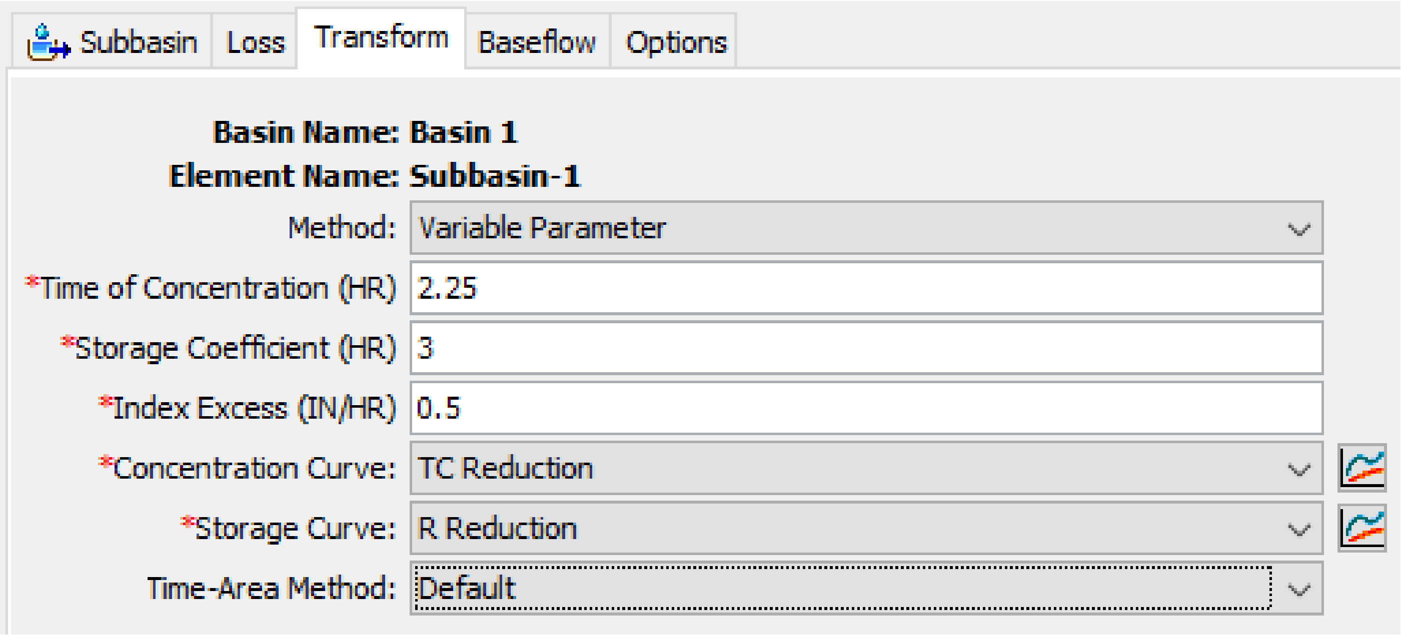
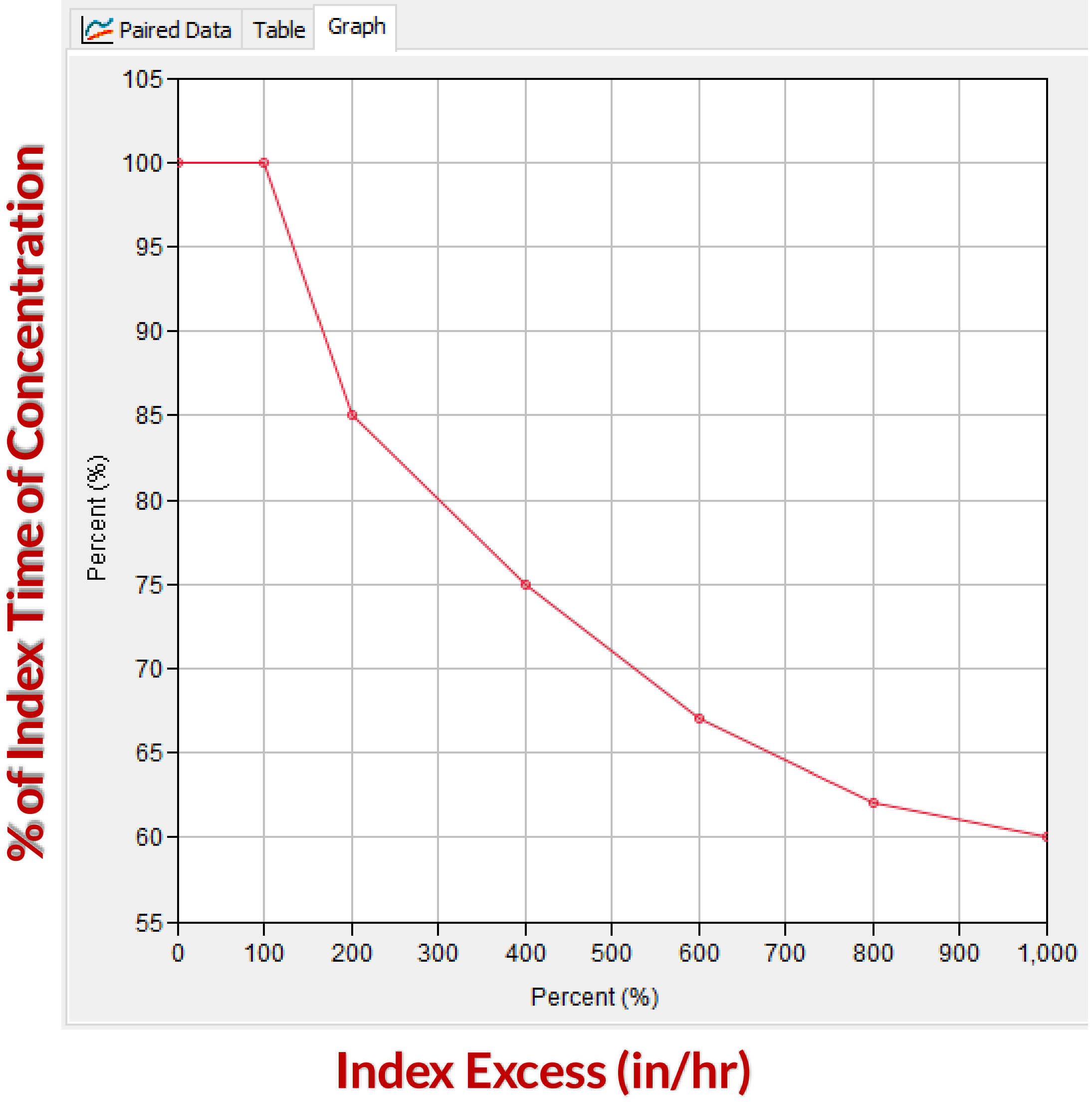
Variable Parameter Clark UH





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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)

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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

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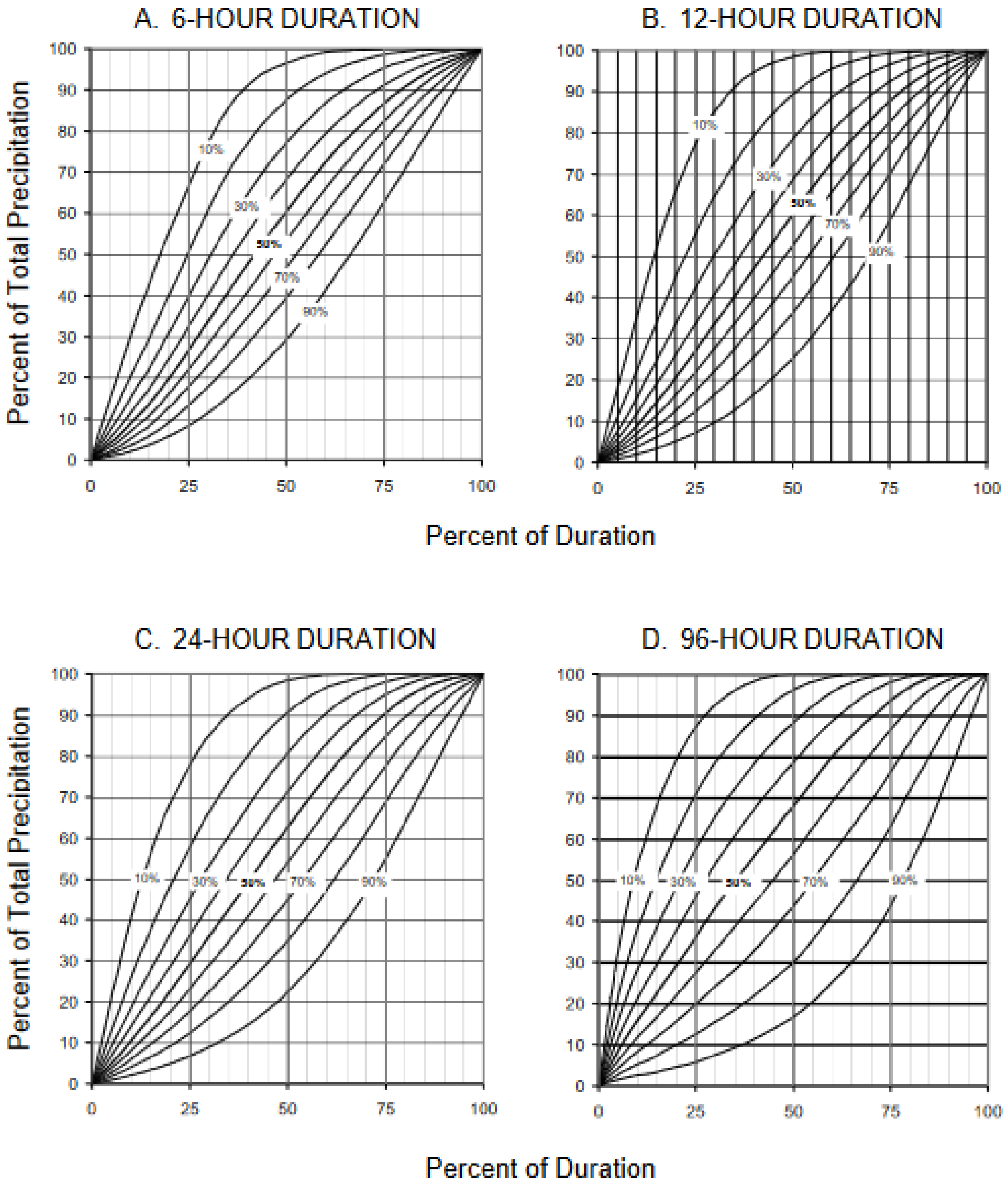
Time Patterns

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



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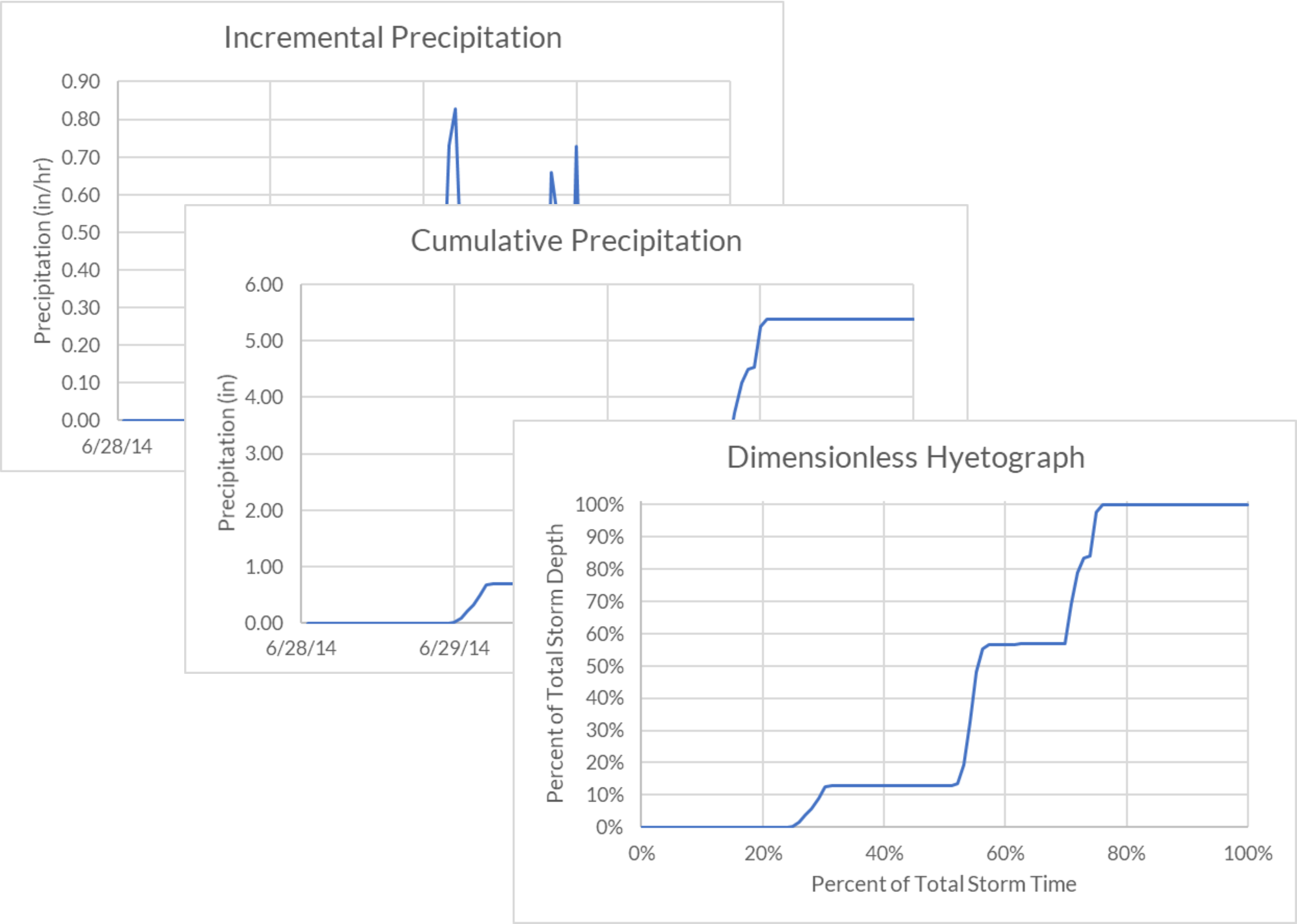
Time Pattern from Observed Storm

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



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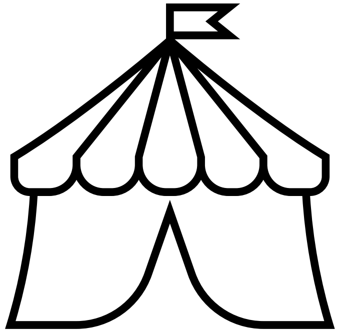
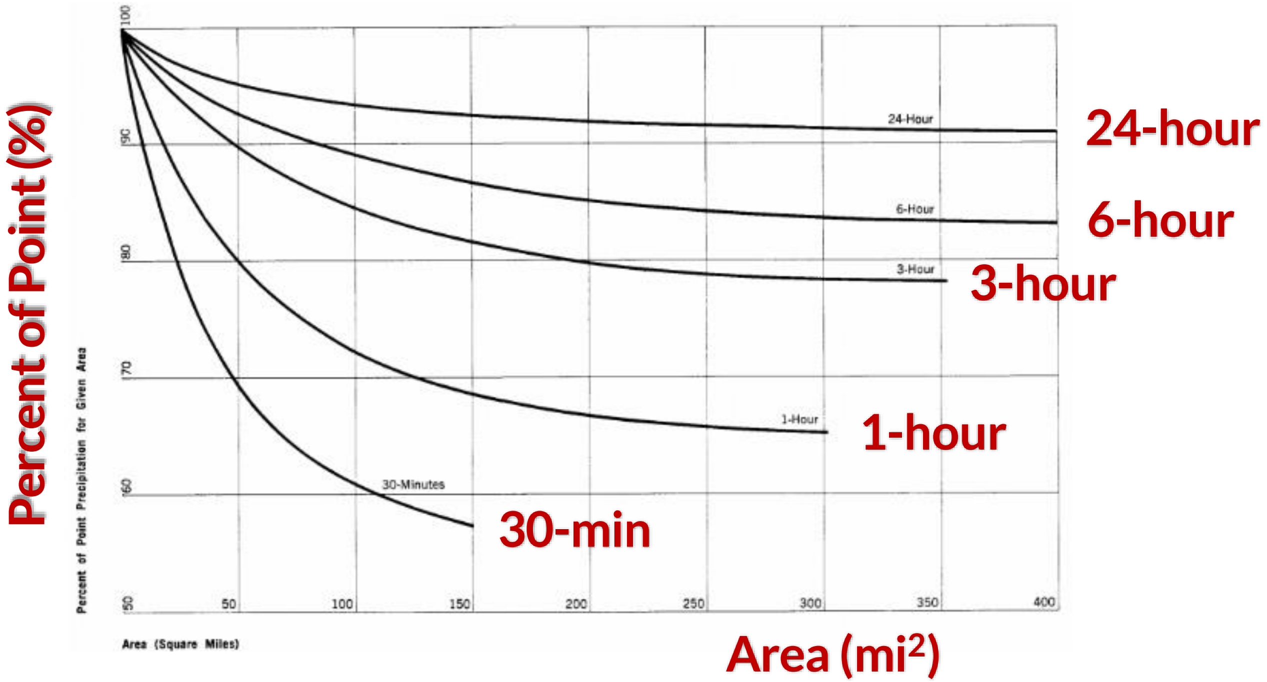
Area Reduction

- 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 (mi²)	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

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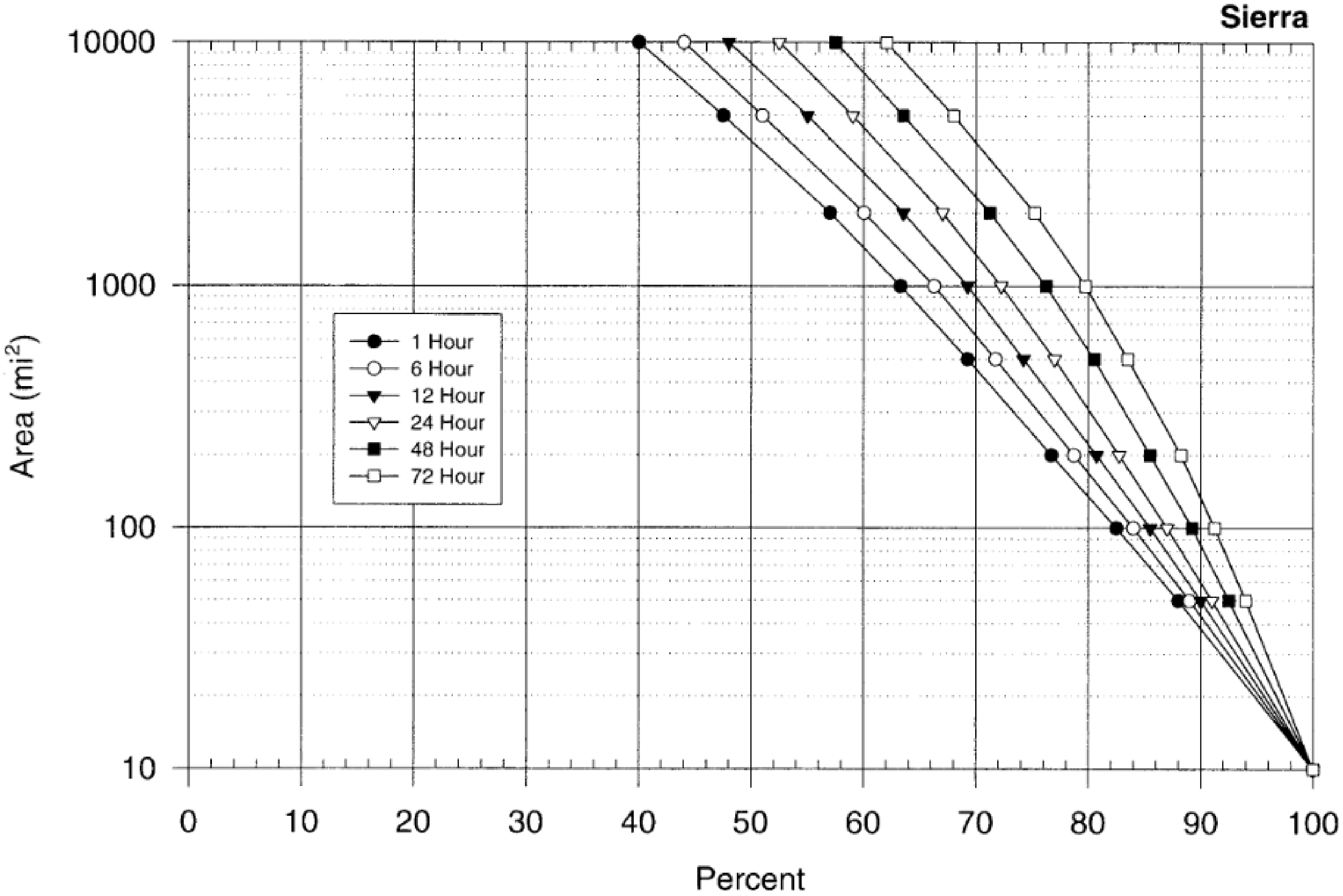
Example from HMR-59



< 10 mi^2 = 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

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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

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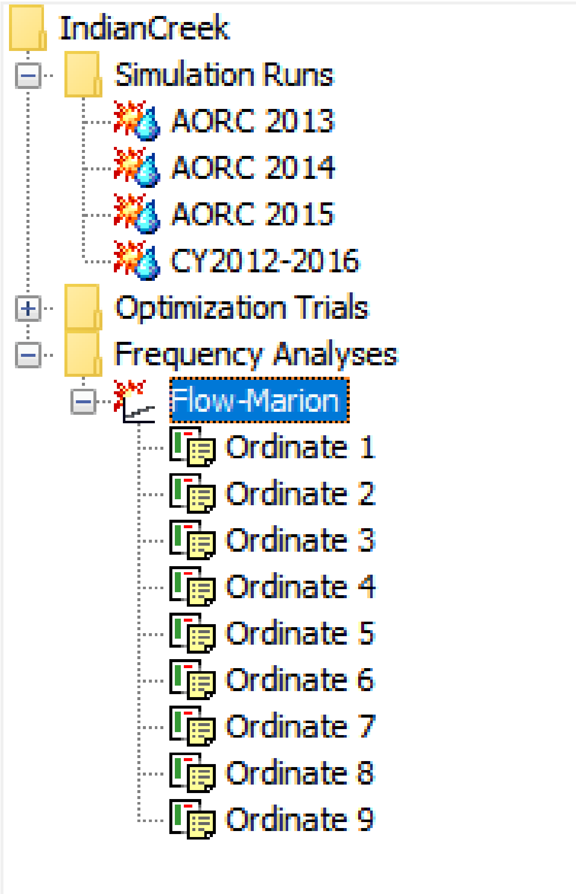
Frequency Analysis Compute

- 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



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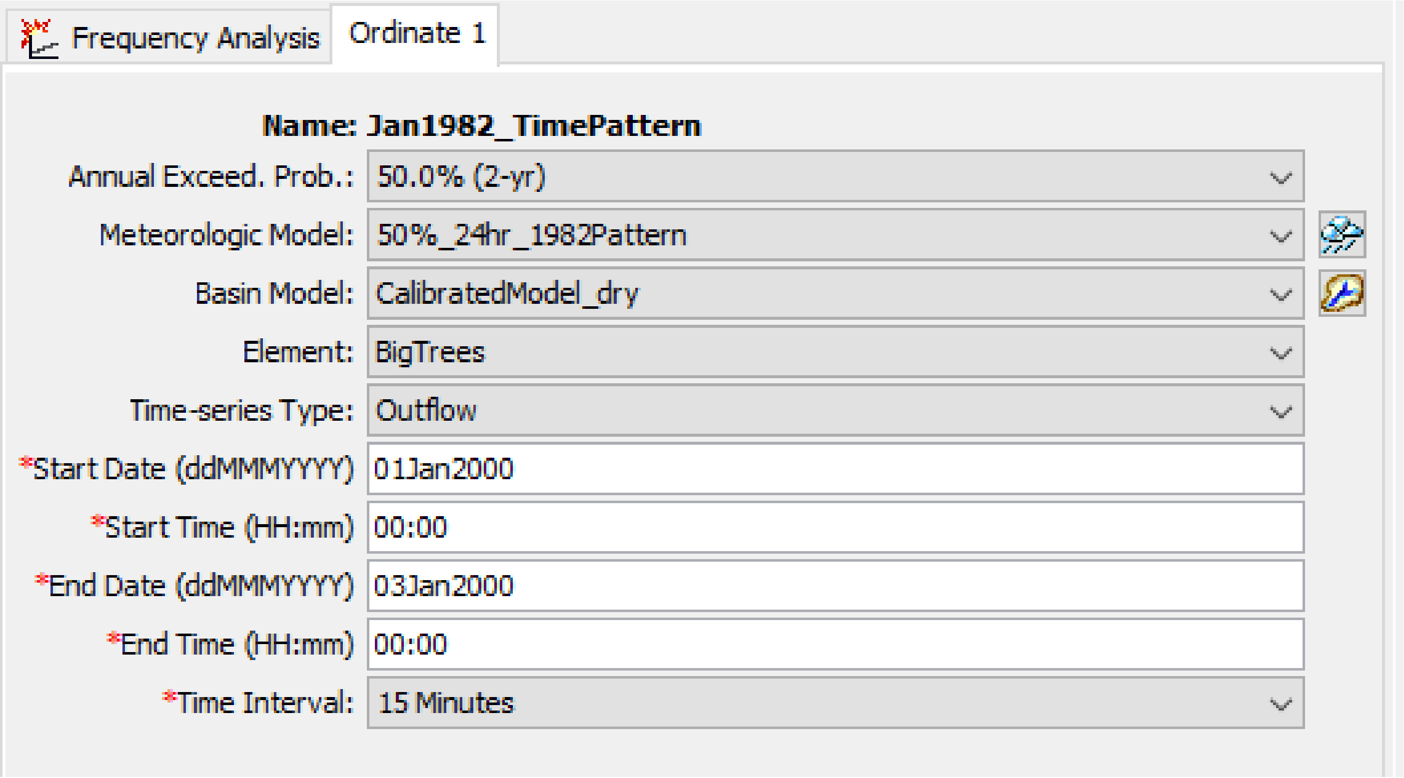
Frequency Analysis Ordinate



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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

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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

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Meteorologic Models

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

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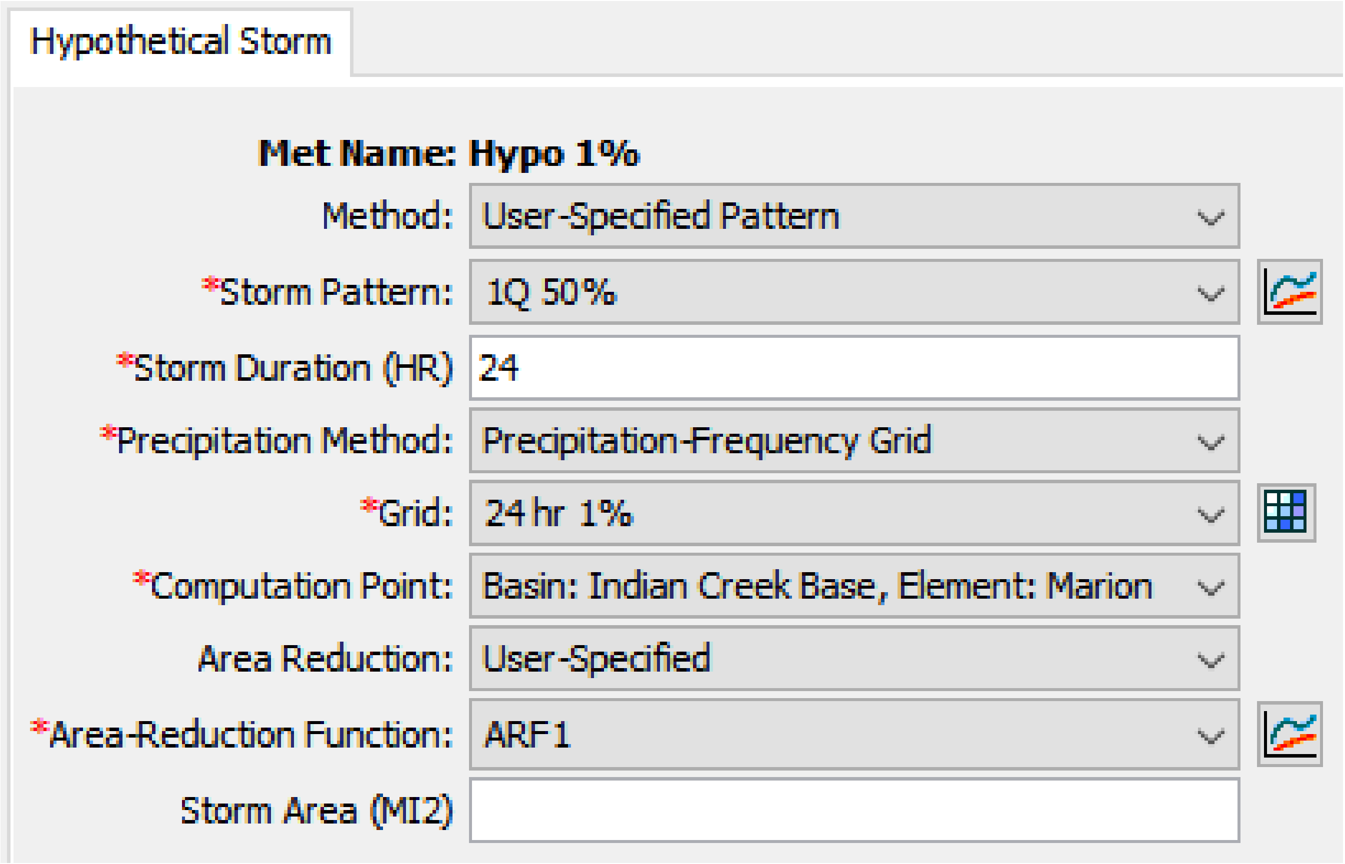
Hypothetical Storm



Paired Data: Percentage Curve

Grid Data: Precipitation-Frequency

Paired Data: Area-Reduction Func.

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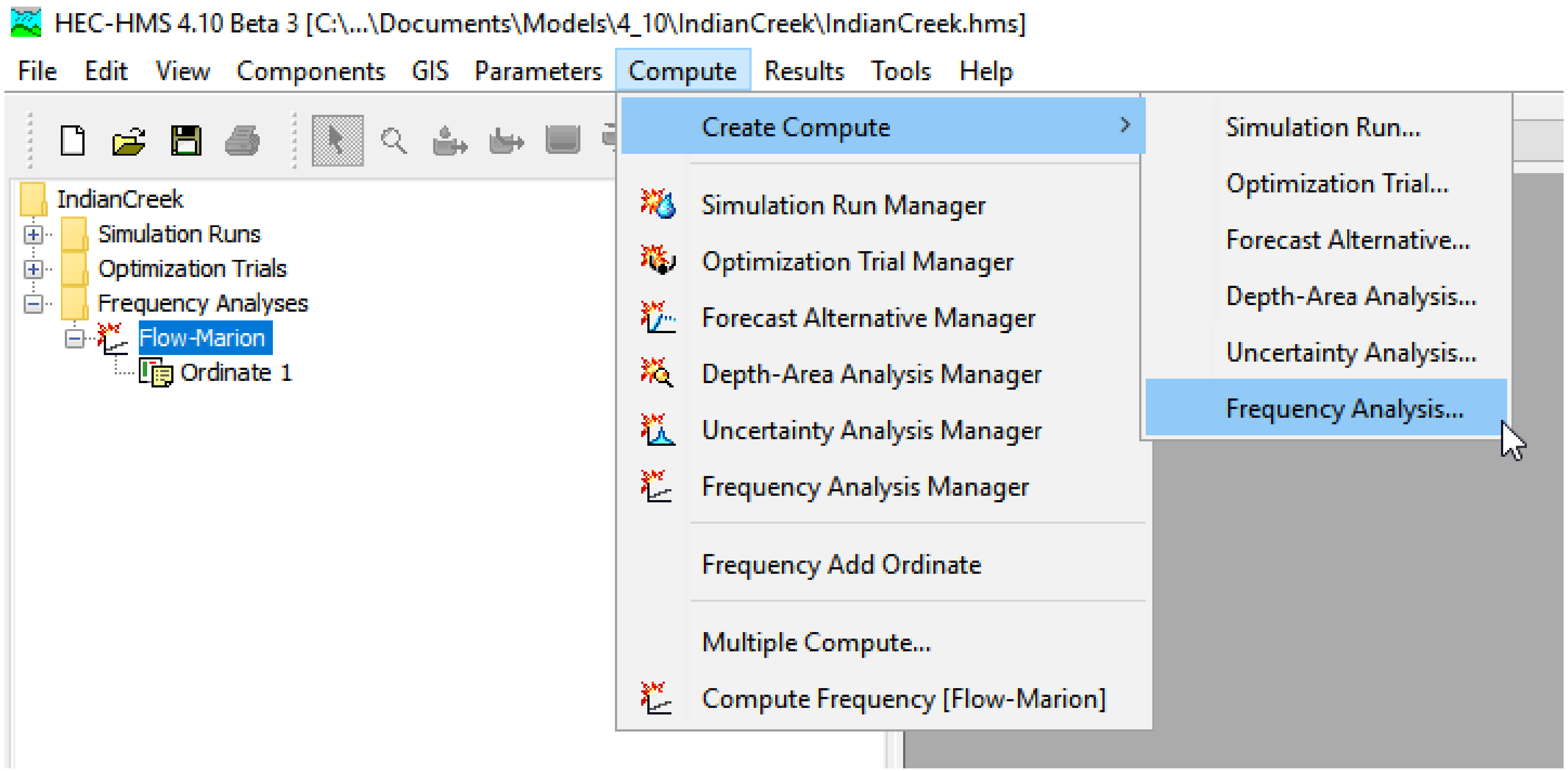
Create Frequency Analysis



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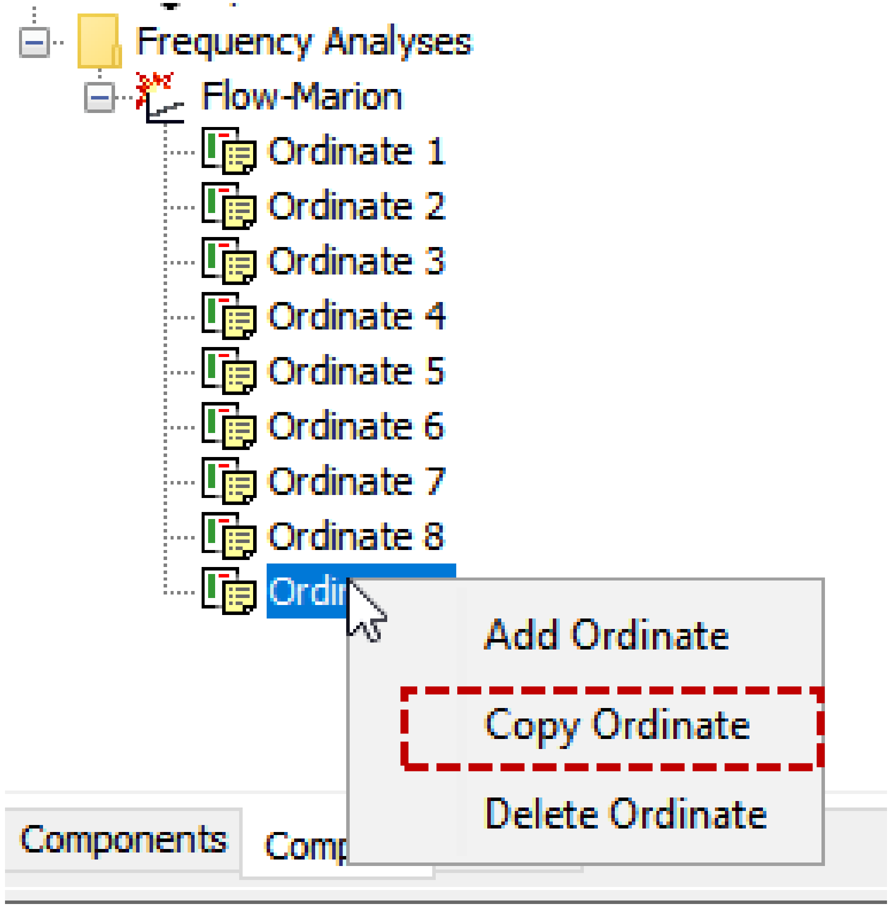
Add/Copy/Delete Ordinates

- Right-click menu



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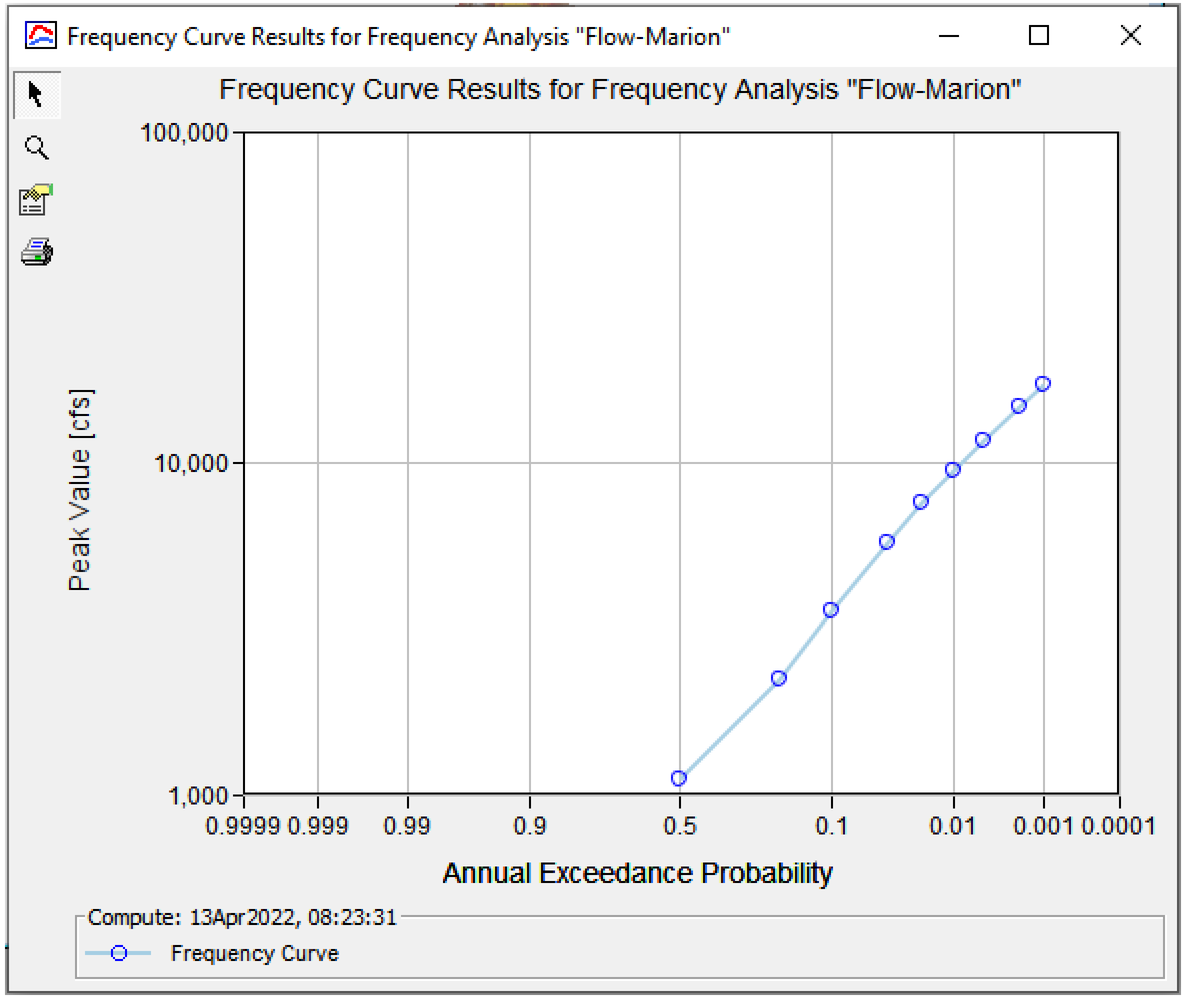
Frequency Analysis Results

Peak Summary Results for Frequency Analysis "Flow-Marion"

Project: IndianCreek Frequency Analysis: Flow-Marion

Compute Time: 13Apr2022, 08:23:31

Analysis Point	Drainage Area (MI²)	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



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Uncertainty

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

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Questions?

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