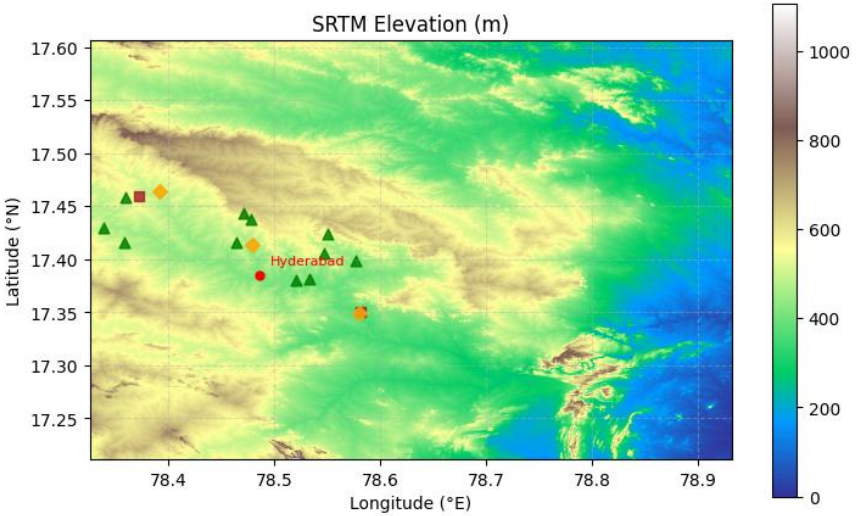
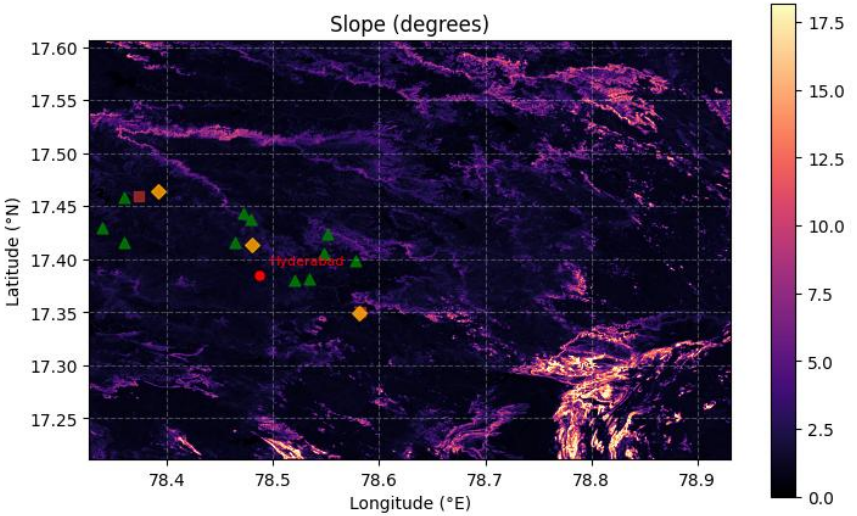
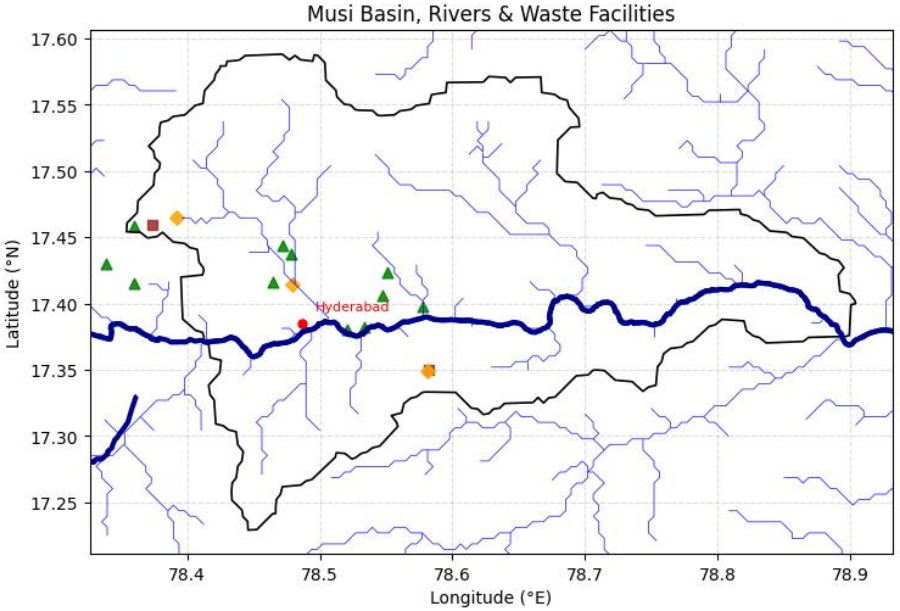
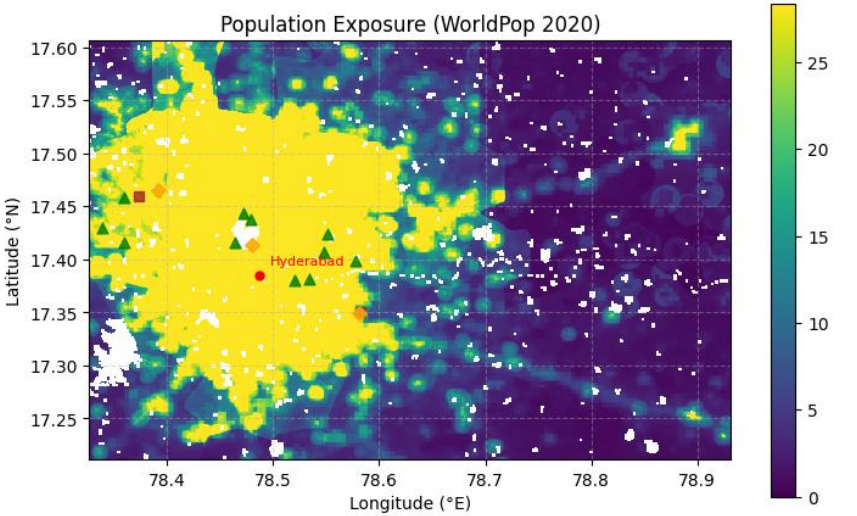
Static Hazard and Exposure Baseline

Musi Basin–Scale Integrated Exposure, Hydro-Terrain & Waste Infrastructure Context

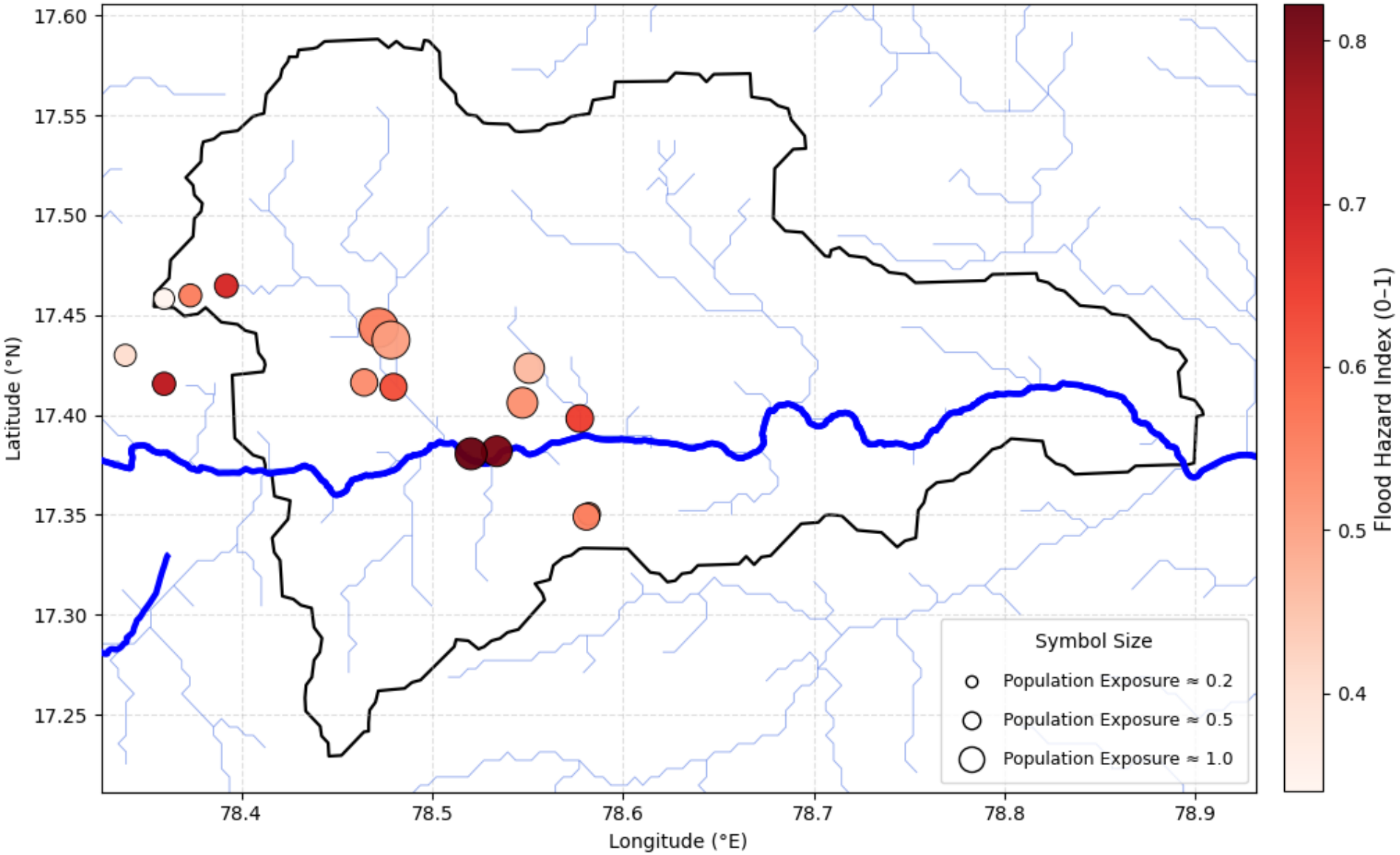




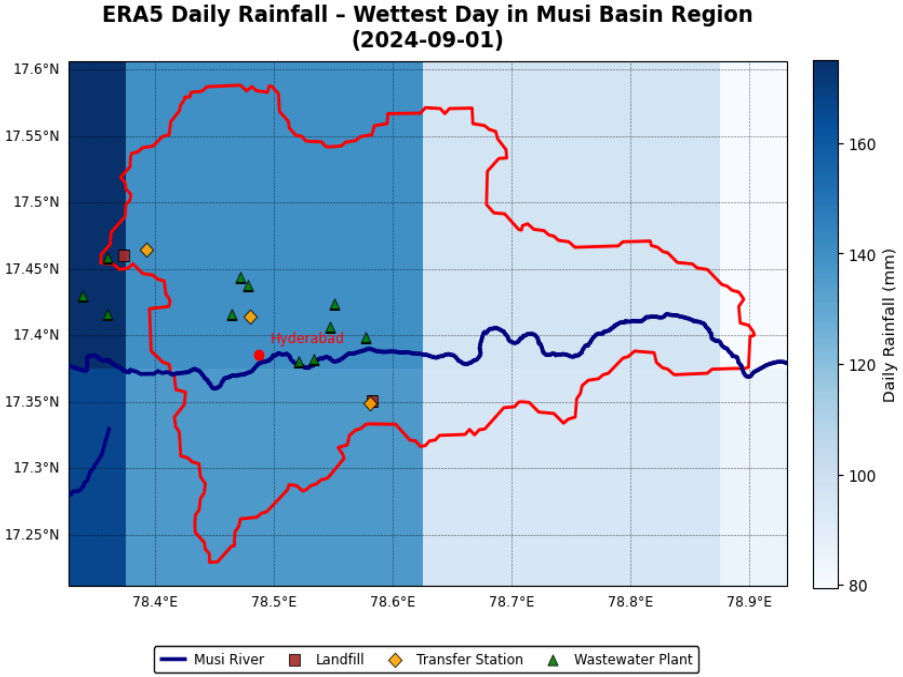


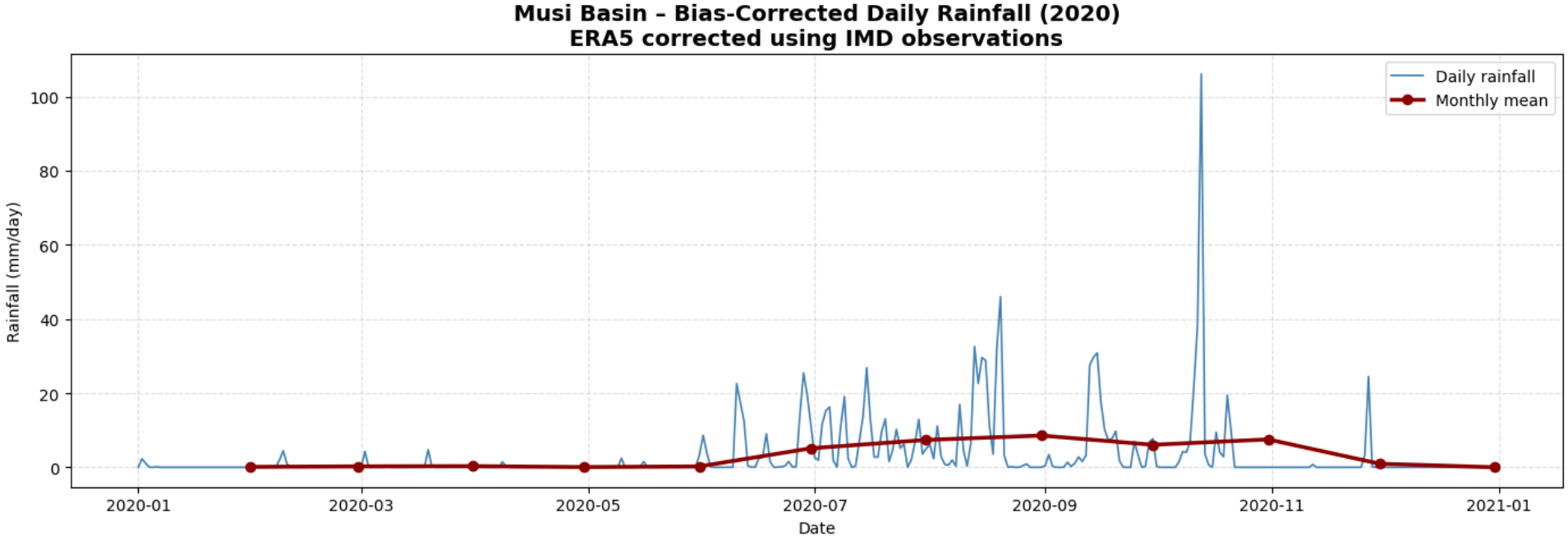


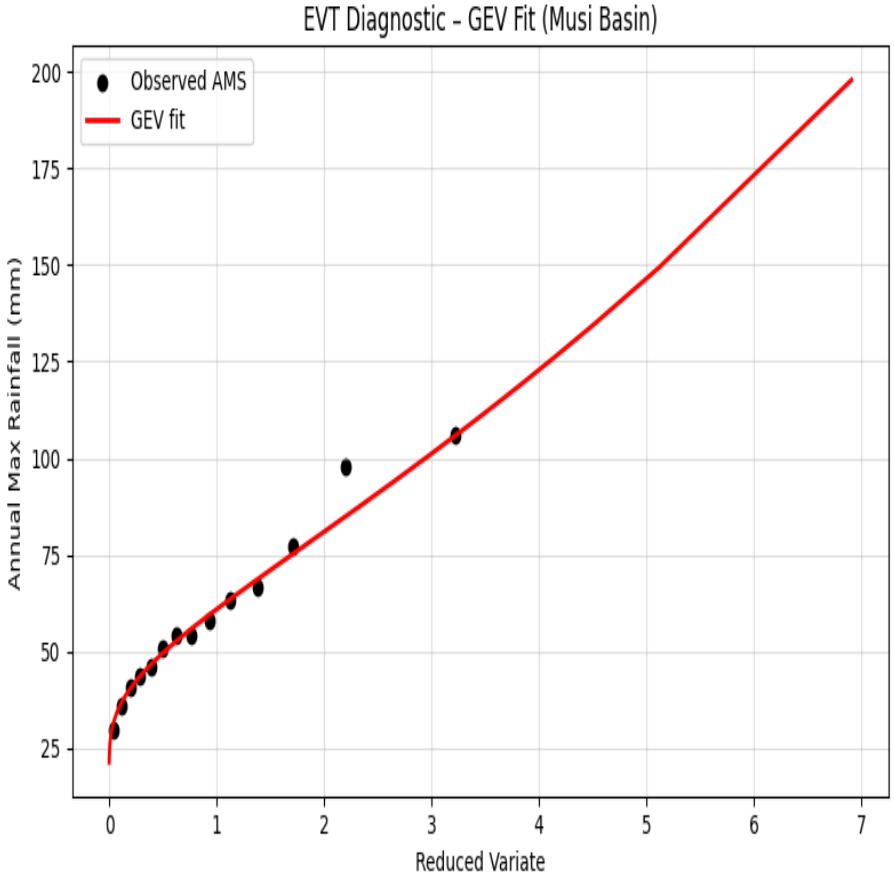
Musi River Landfill Transfer Station Wastewater Plant

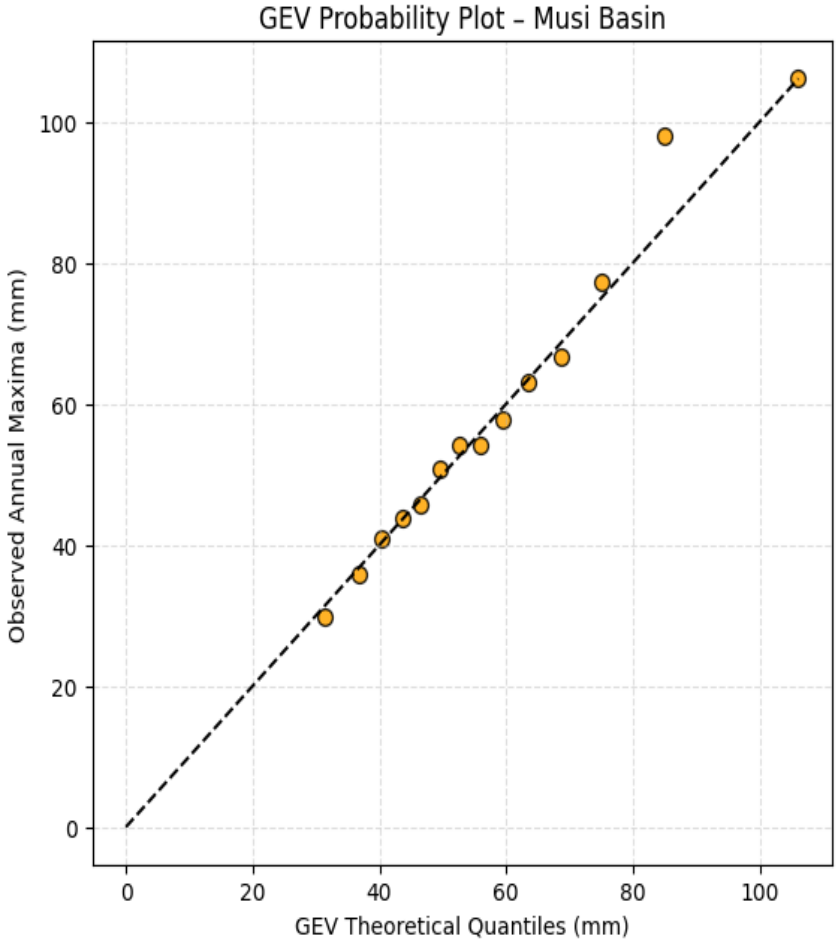

Musi Basin – Flood Hazard Index of Waste Facilities
Color = Physical Flood Hazard | Size = Population Exposure
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
Flood Hazard Index (0–1)
0.8
0.7
0.6
0.5
0.4
Symbol Size
Population Exposure ≈ 0.2
Population Exposure ≈ 0.5
Population Exposure ≈ 1.0

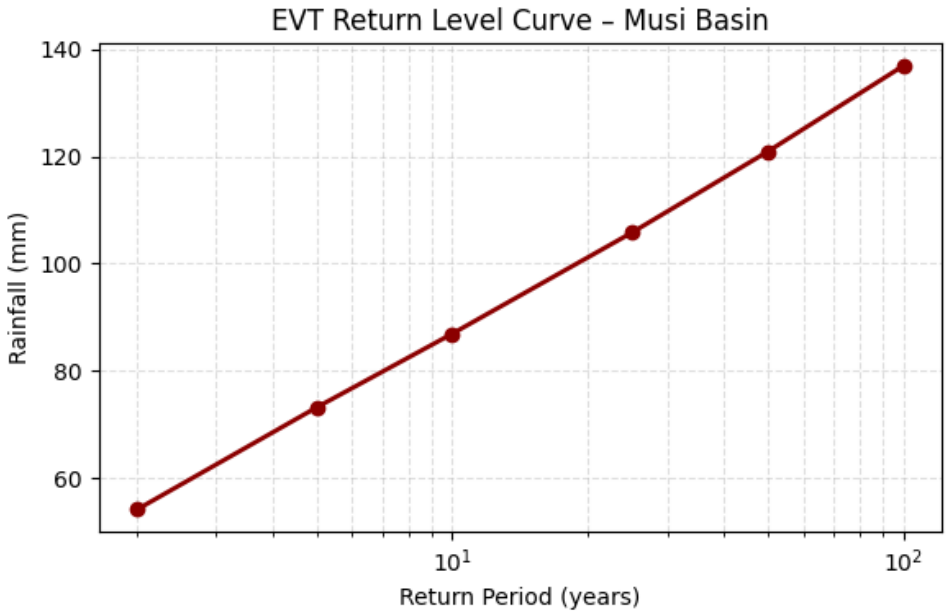
DYNAMICS, EVT & DAMAGE
(Rainfall, Bias Correction, EVT, Hazard Scaling)

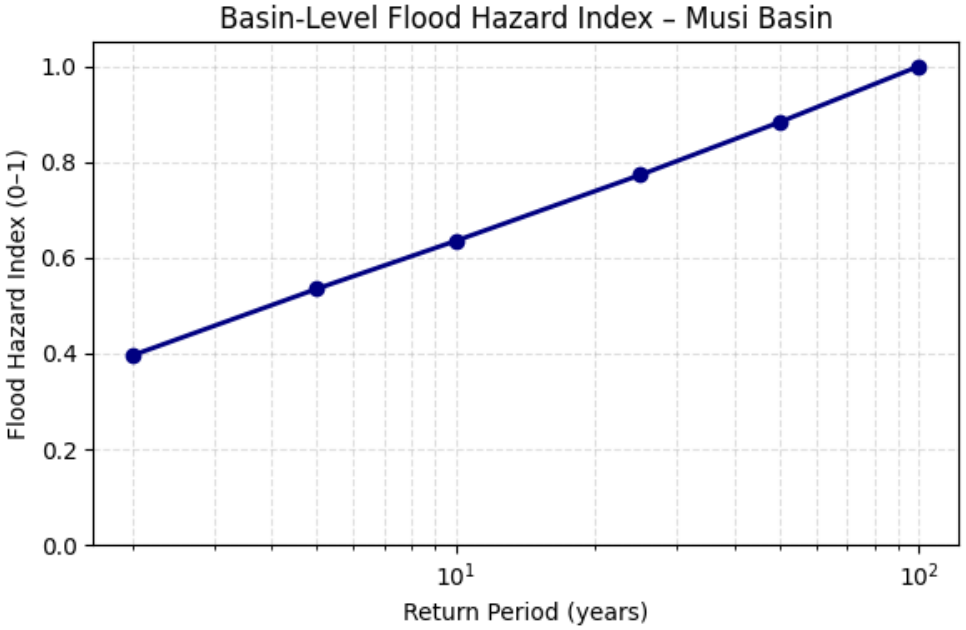

ERA5 Daily Rainfall – Wettest Day in Musi Basin Region
(2024-09-01)
17.6°N
17.55°N
17.5°N
17.45°N
17.4°N
17.35°N
17.3°N
17.25°N
78.4°E
78.5°E
78.6°E
78.7°E
78.8°E
78.9°E
Hyderabad
160
140
120
100
80
Daily Rainfall (mm)
Musi River
Landfill
Transfer Station
Wastewater Plant

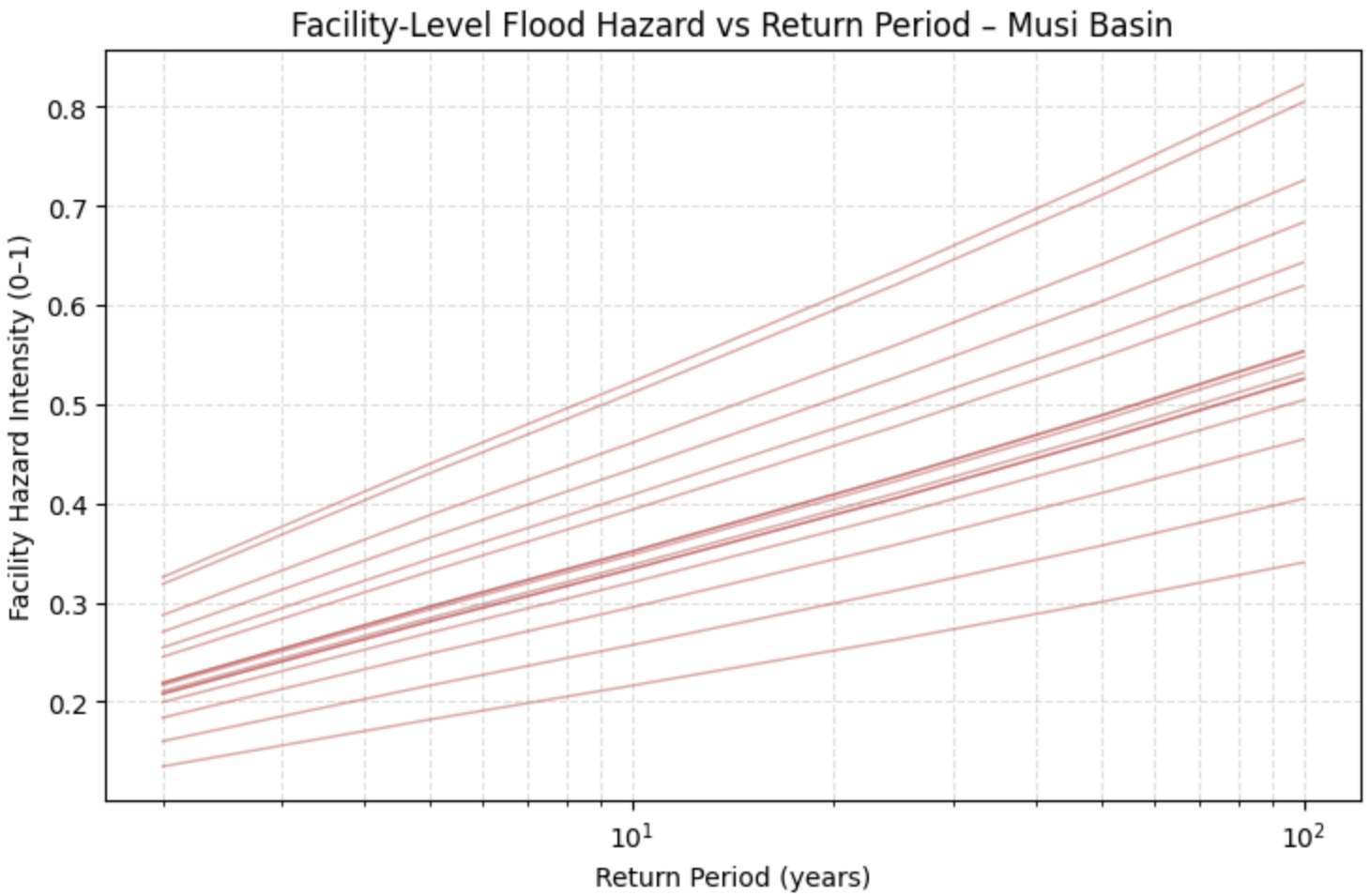

Musi Basin – Bias-Corrected Daily Rainfall (2020)
ERA5 corrected using IMD observations
Daily rainfall
Monthly mean
Rainfall (mm/day)
100
80
60
40
20
0
2020-01
2020-03
2020-05
2020-07
2020-09
2020-11
2021-01
Date

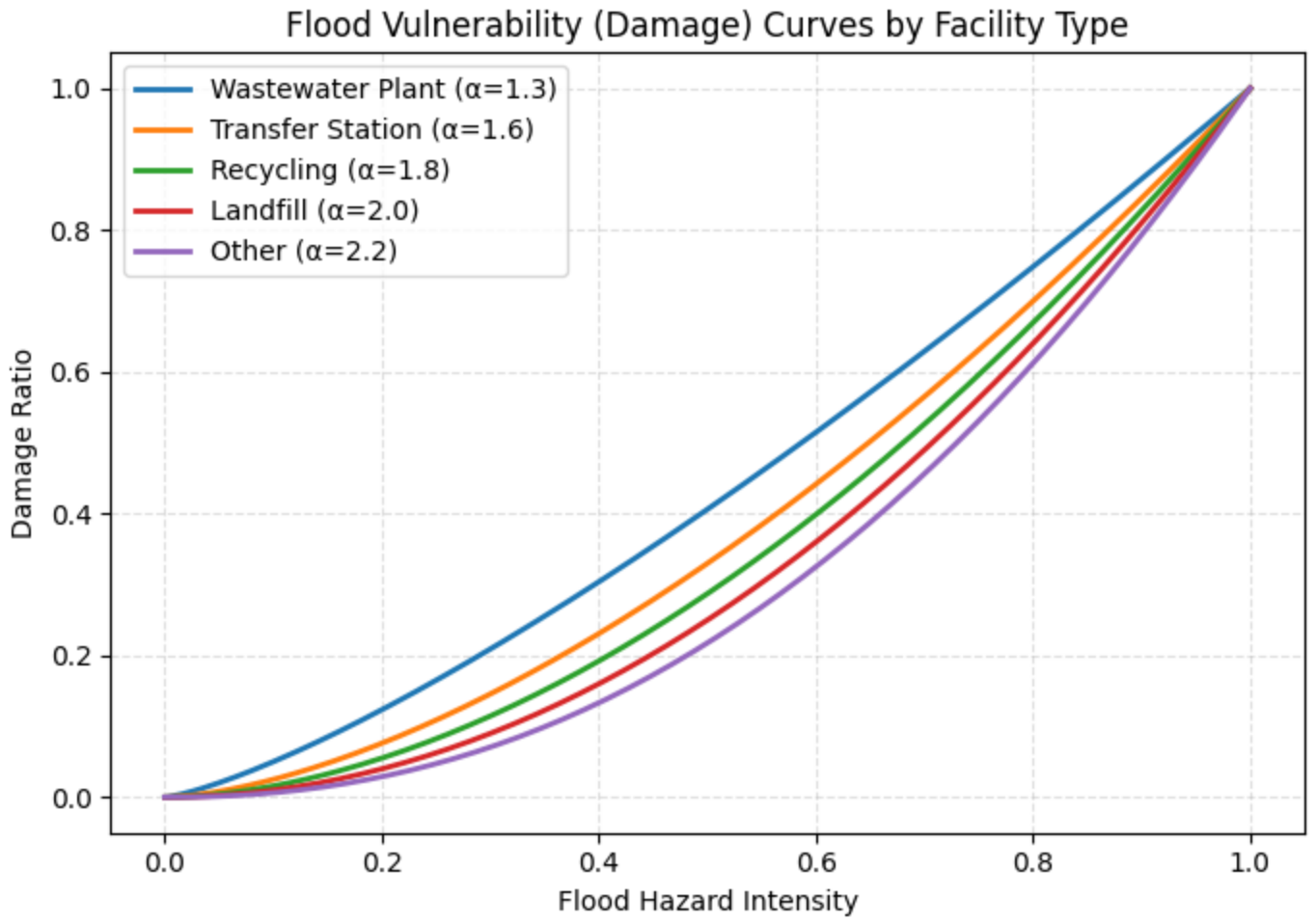

EVT Diagnostic – GEV Fit (Musi Basin)
Observed AMS
GEV fit
Annual Max Rainfall (mm)
Reduced Variate
200
175
150
125
100
75
50
25
0
1
2
3
4
5
6
7

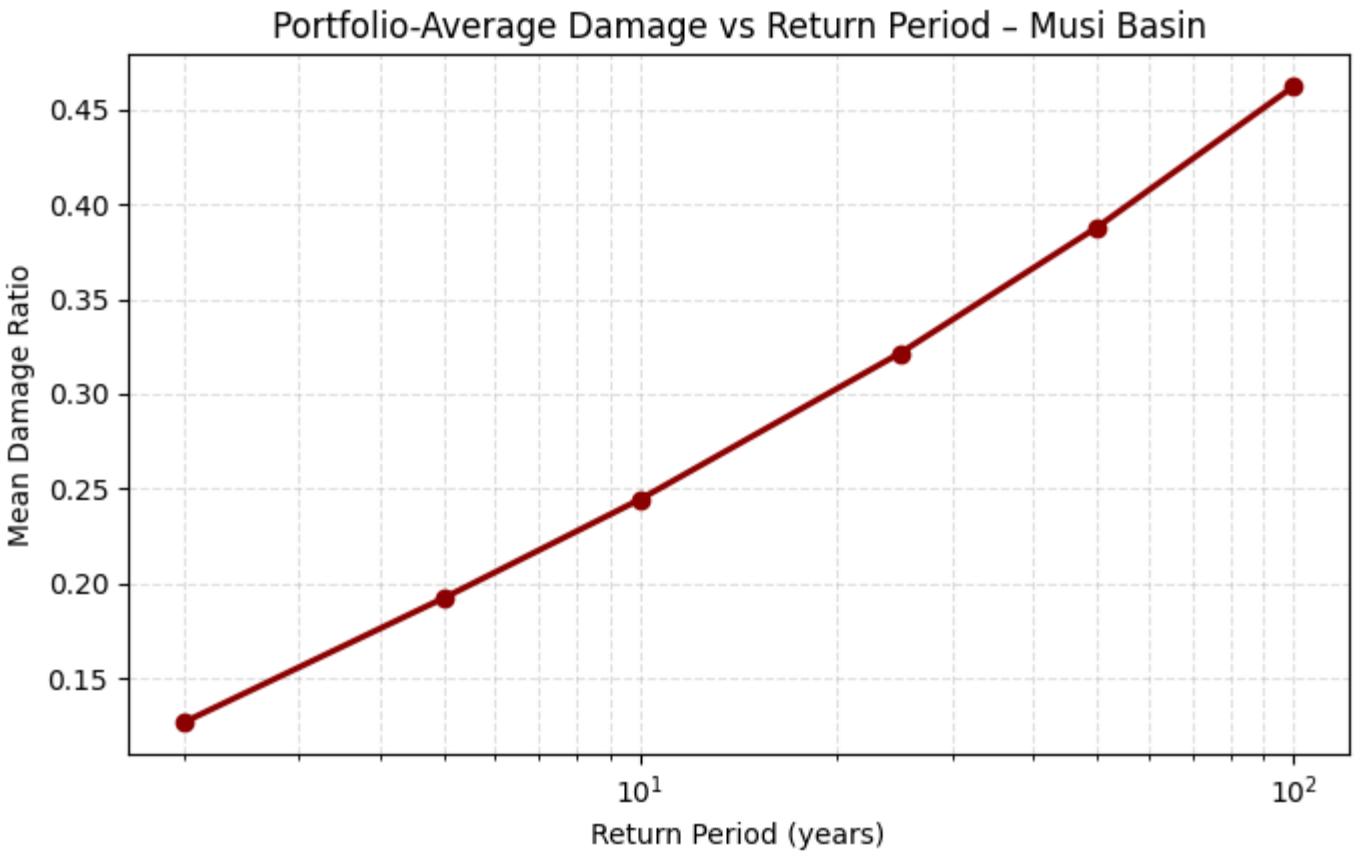

GEV Probability Plot – Musi Basin
Observed Annual Maxima (mm)
GEV Theoretical Quantiles (mm)
100
80
60
40
20
0
0
20
40
60
80
100


EVT Return Level Curve – Musi Basin
Rainfall (mm)
140
120
100
80
60
10^1
10^2
Return Period (years)


Basin-Level Flood Hazard Index – Musi Basin
Flood Hazard Index (0–1)
1.0
0.8
0.6
0.4
0.2
0.0
10^1
10^2
Return Period (years)

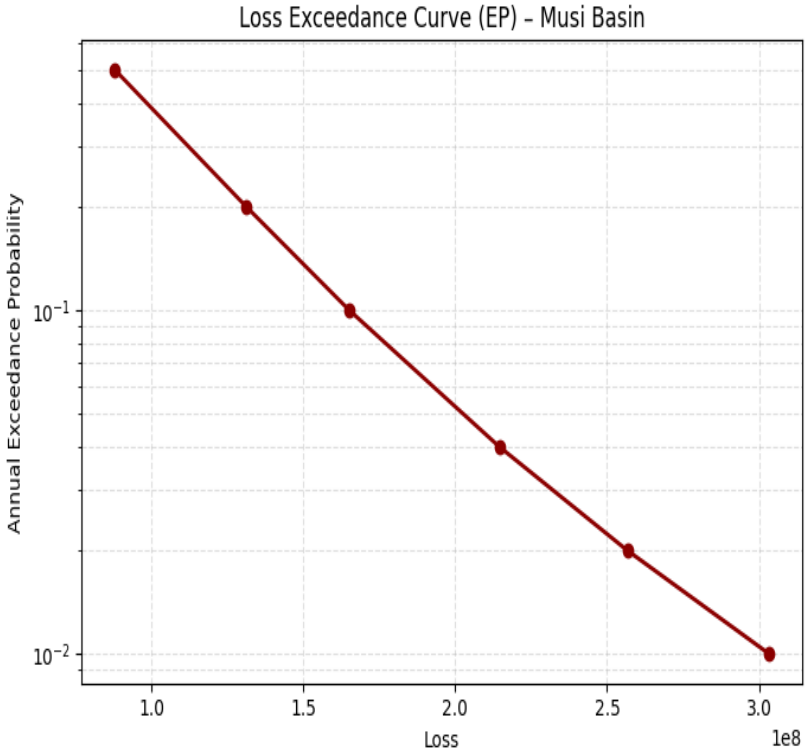

Facility-Level Flood Hazard vs Return Period – Musi Basin
Facility Hazard Intensity (0–1)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
10^1
10^2
Return Period (years)

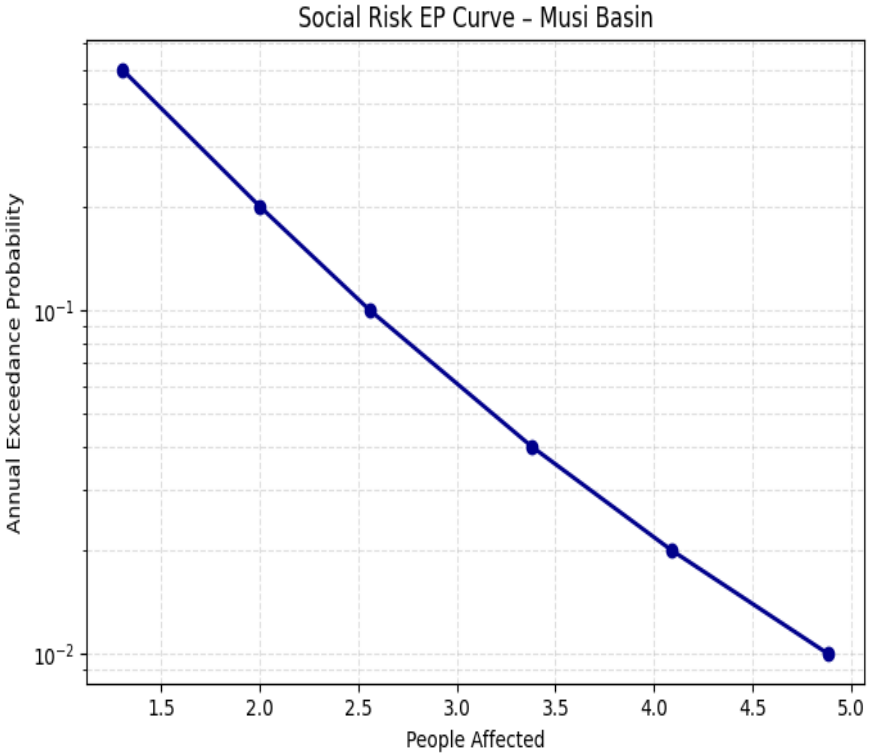

Flood Vulnerability (Damage) Curves by Facility Type
Wastewater Plant (α=1.3)
Transfer Station (α=1.6)
Recycling (α=1.8)
Landfill (α=2.0)
Other (α=2.2)
Damage Ratio
Flood Hazard Intensity
0.0
0.2
0.4
0.6
0.8
1.0


Portfolio-Average Damage vs Return Period – Musi Basin
Mean Damage Ratio
0.45
0.40
0.35
0.30
0.25
0.20
0.15
10^1
10^2
Return Period (years)

EVT Based Loss, EP curves, AAL, Casualties

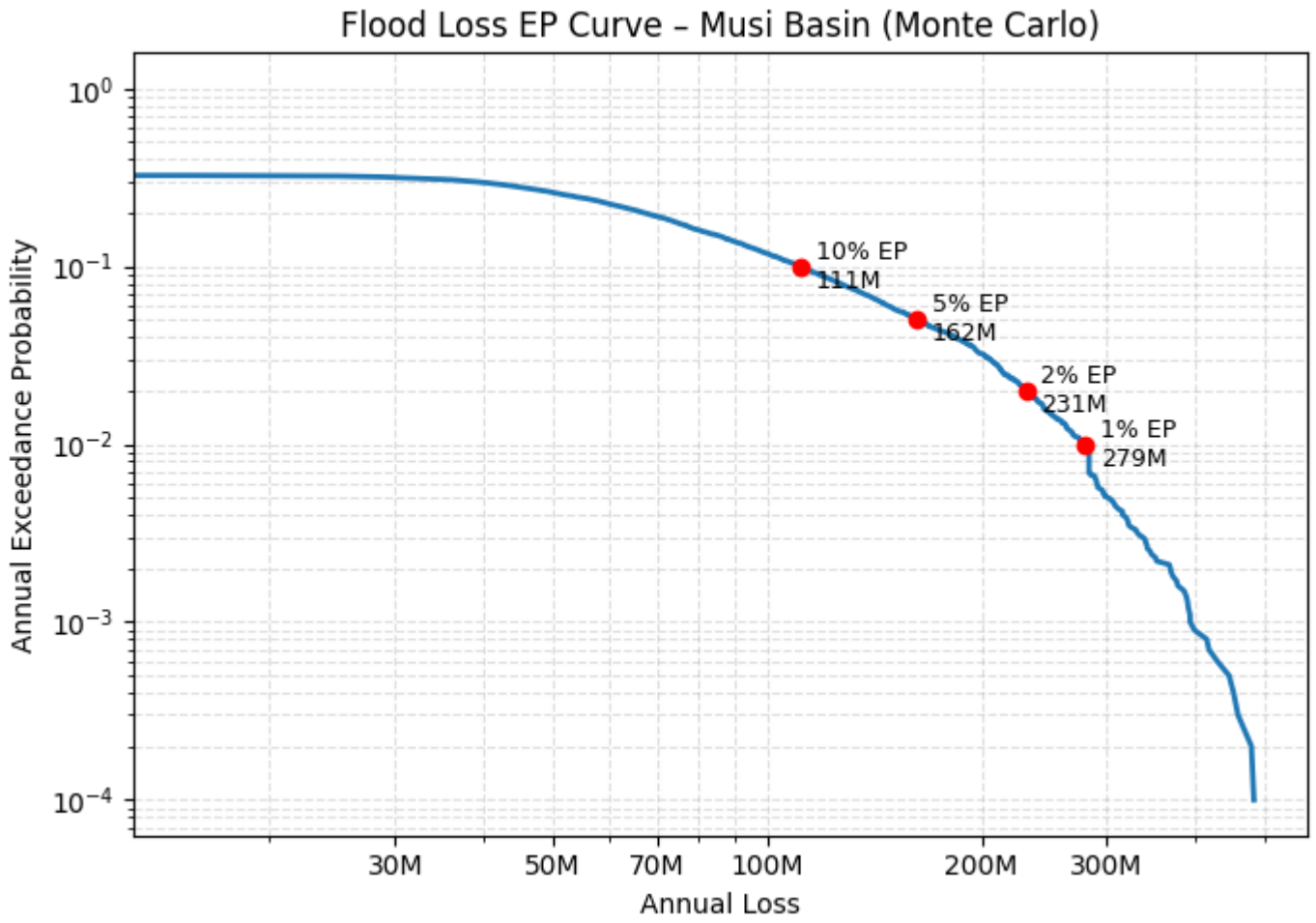
Average Annual Loss (AAL): 66,545,749.65

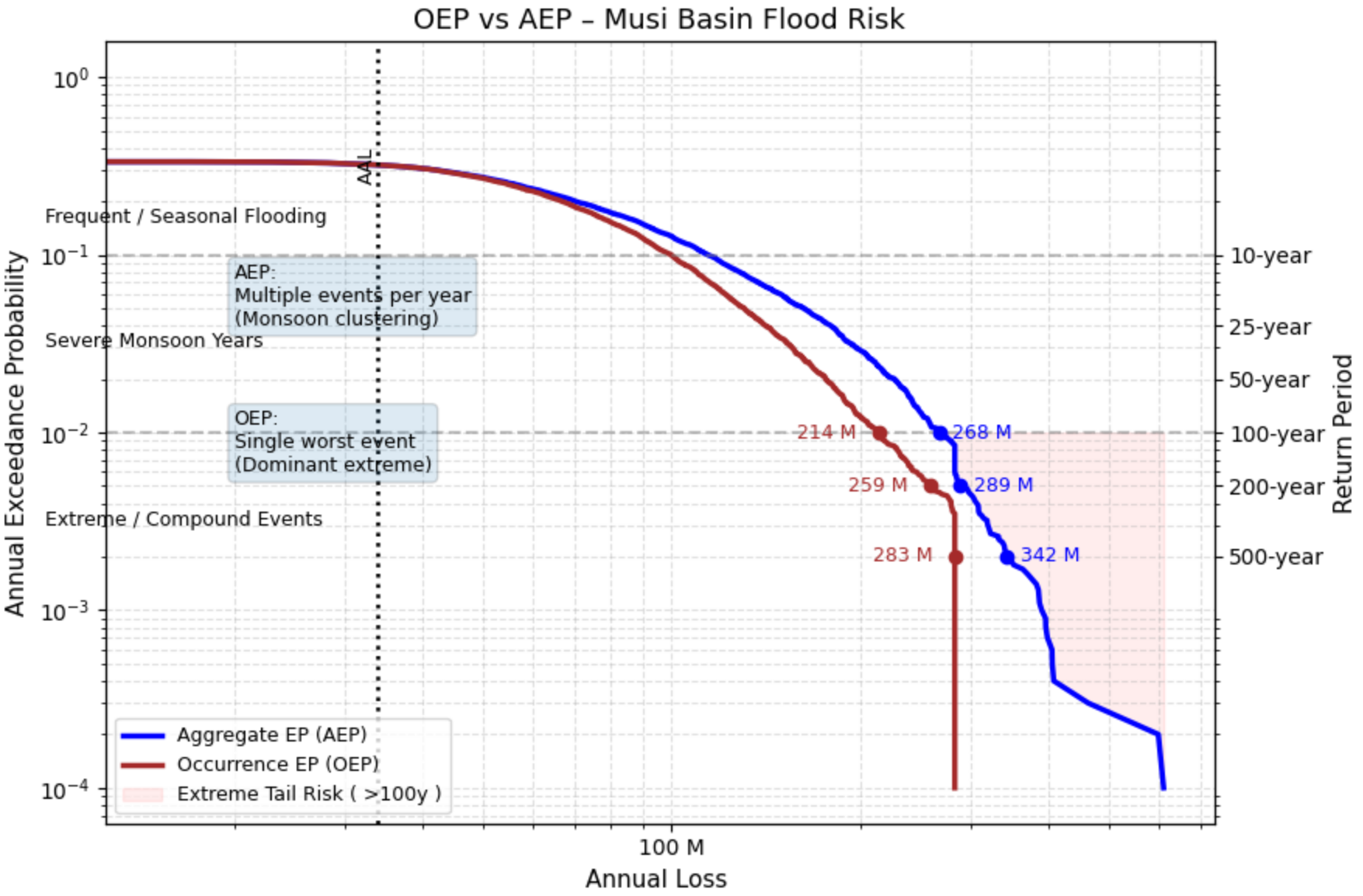


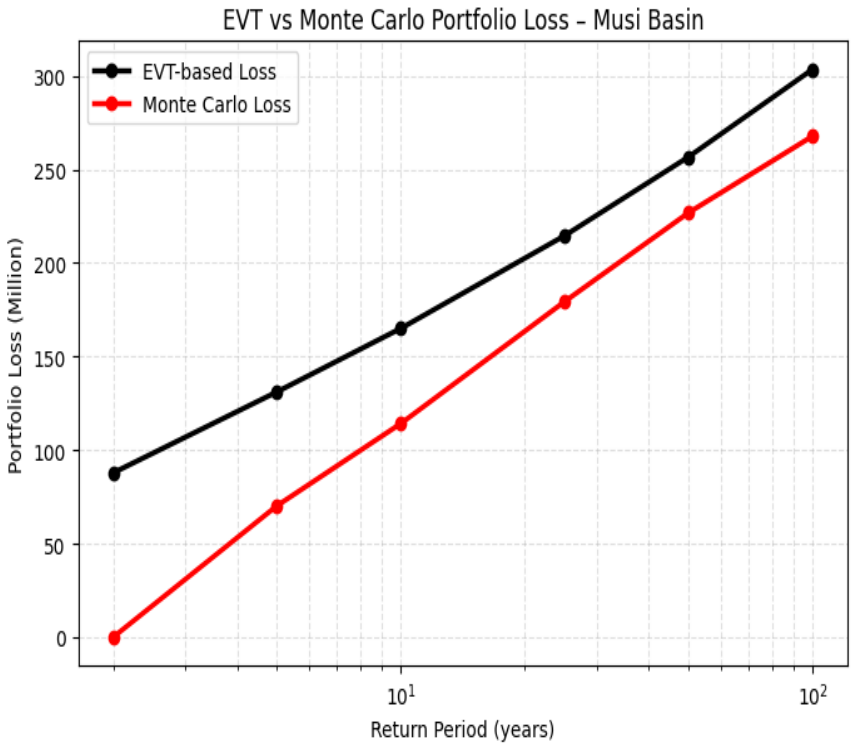


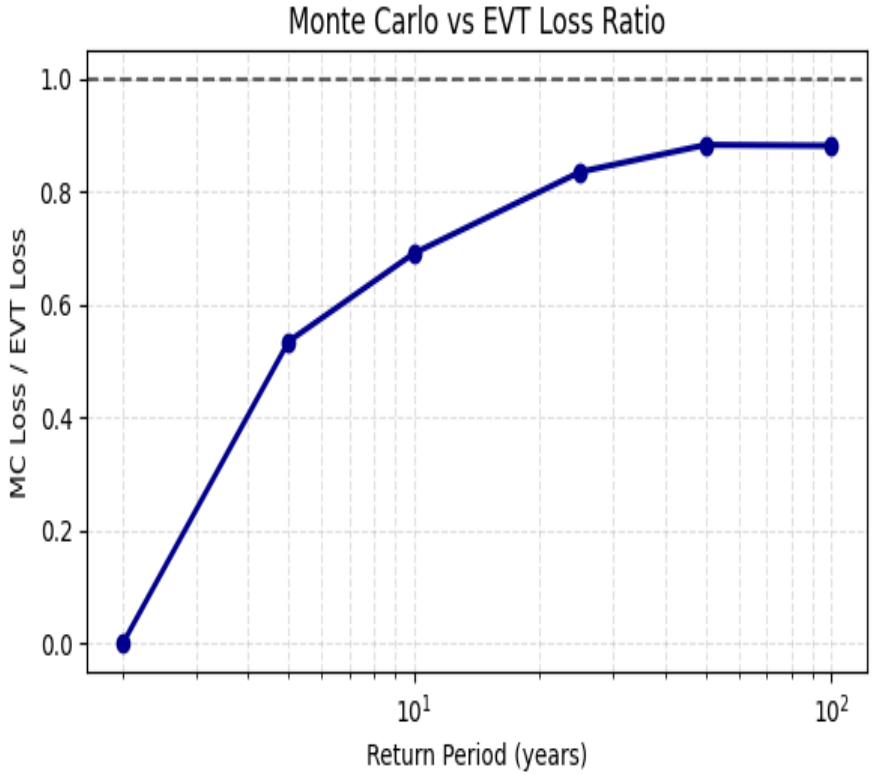
Monte Carlo

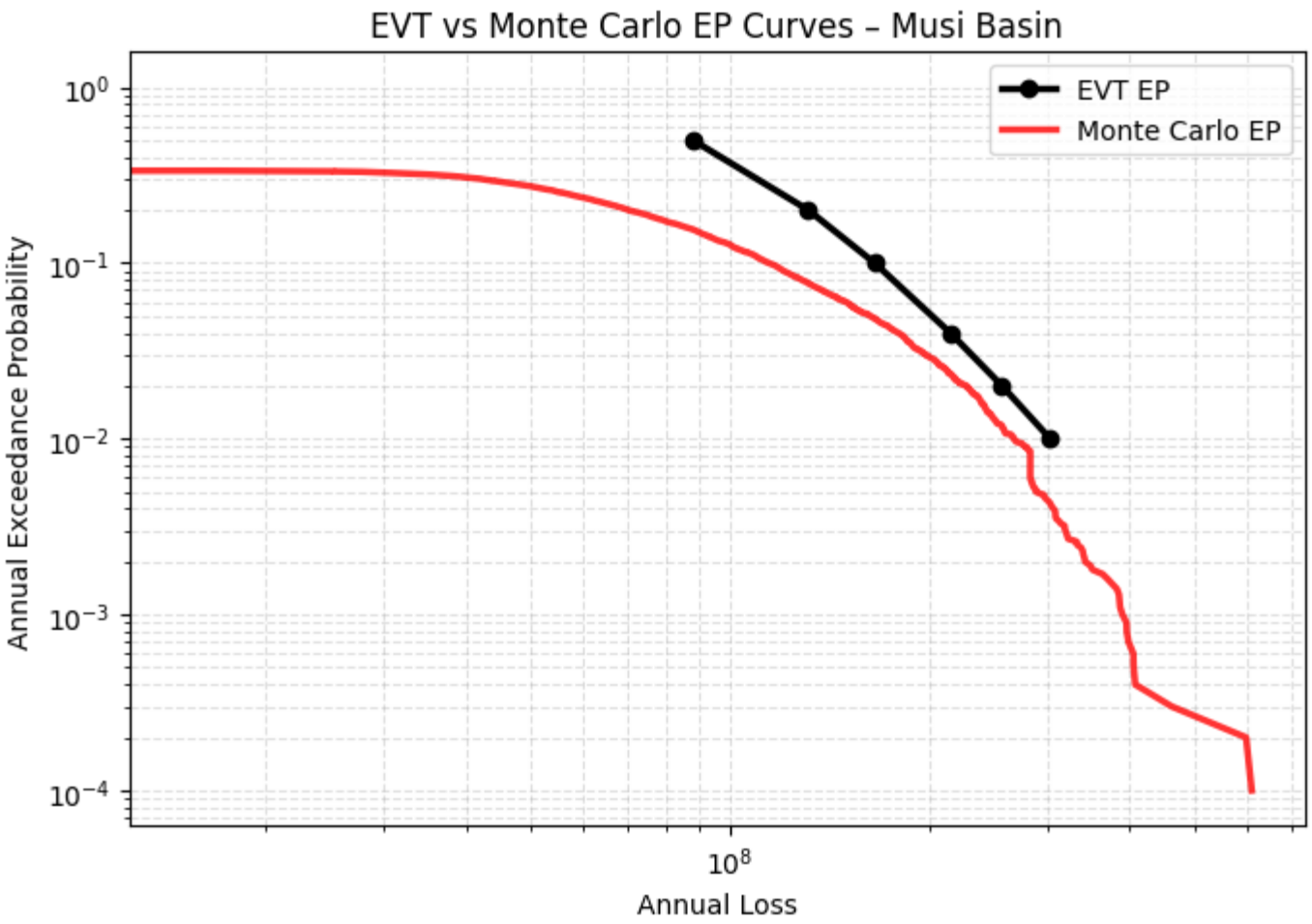
Average Annual Loss (AAL): 32,889,135.07

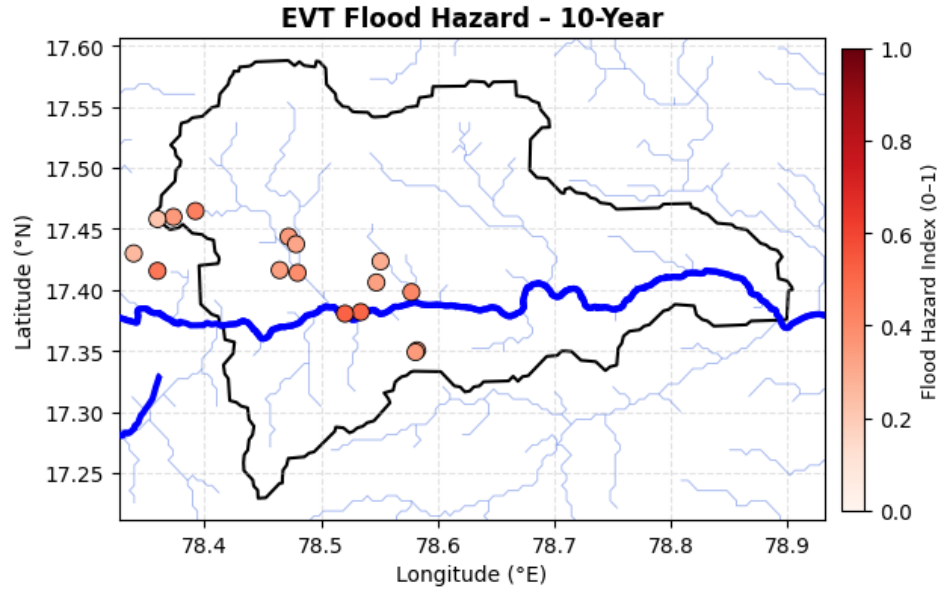


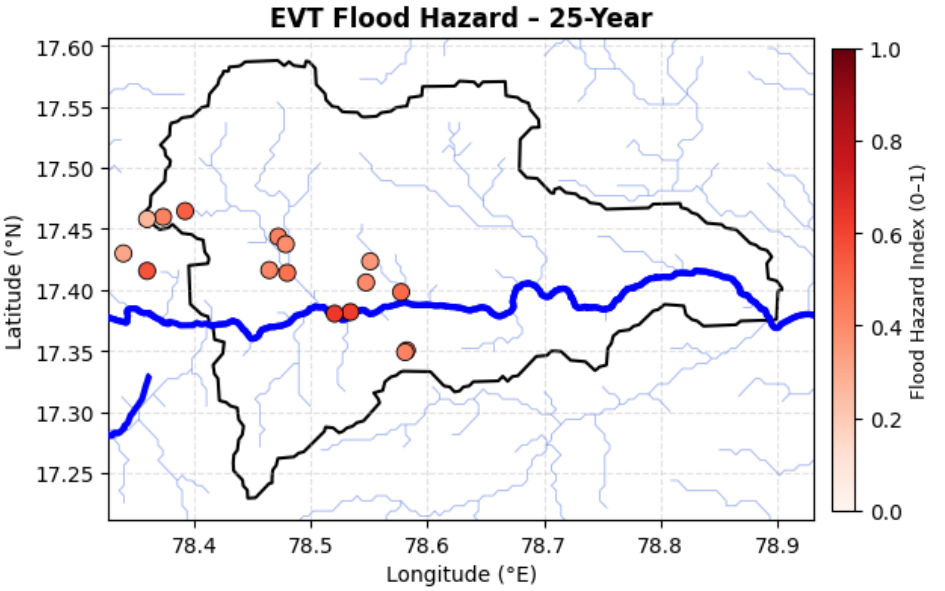

OEP vs AEP – Musi Basin Flood Risk
Annual Exceedance Probability
Return Period
Annual Loss
100 M
AAL
Frequent / Seasonal Flooding
Severe Monsoon Years
Extreme / Compound Events
AEP:
Multiple events per year
(Monsoon clustering)
OEP:
Single worst event
(Dominant extreme)
214 M
268 M
259 M
289 M
283 M
342 M
10-year
25-year
50-year
100-year
200-year
500-year
Aggregate EP (AEP)
Occurrence EP (OEP)
Extreme Tail Risk (>100y)

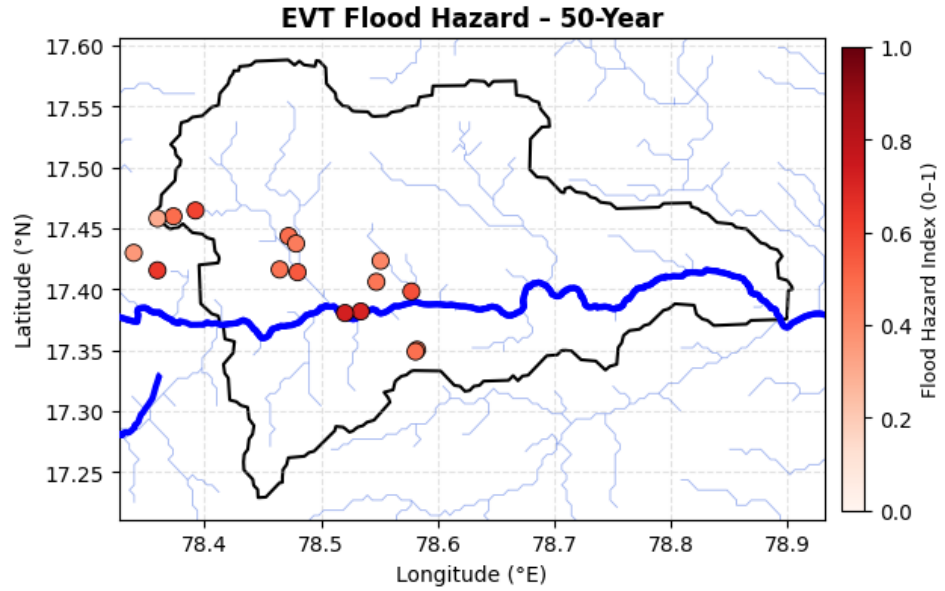

EVT vs Monte Carlo Portfolio Loss – Musi Basin
EVT-based Loss
Monte Carlo Loss
Portfolio Loss (Million)
Return Period (years)
300
250
200
150
100
50
0
10^1
10^2

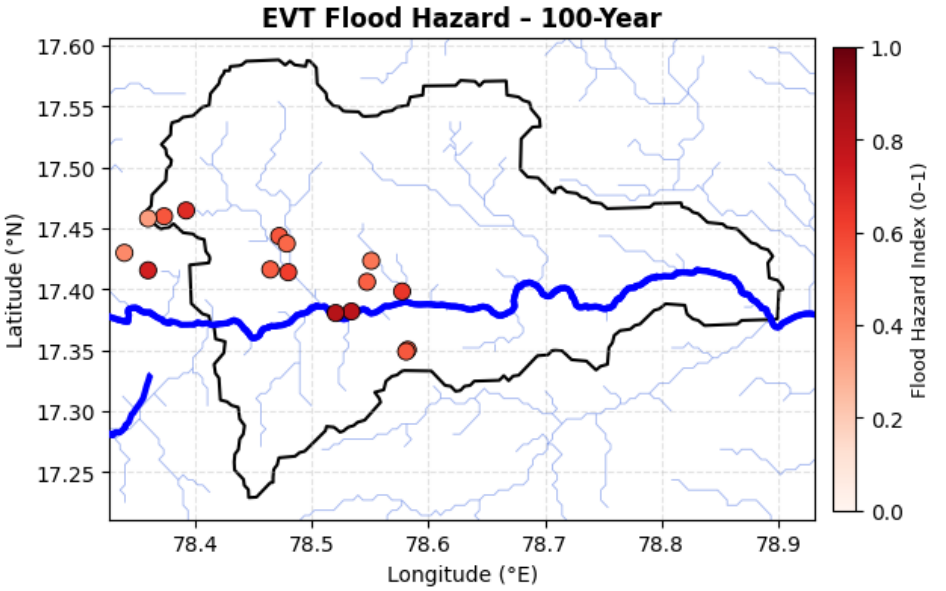

Monte Carlo vs EVT Loss Ratio
MC Loss / EVT Loss
Return Period (years)
1.0
0.8
0.6
0.4
0.2
0.0
10^1
10^2

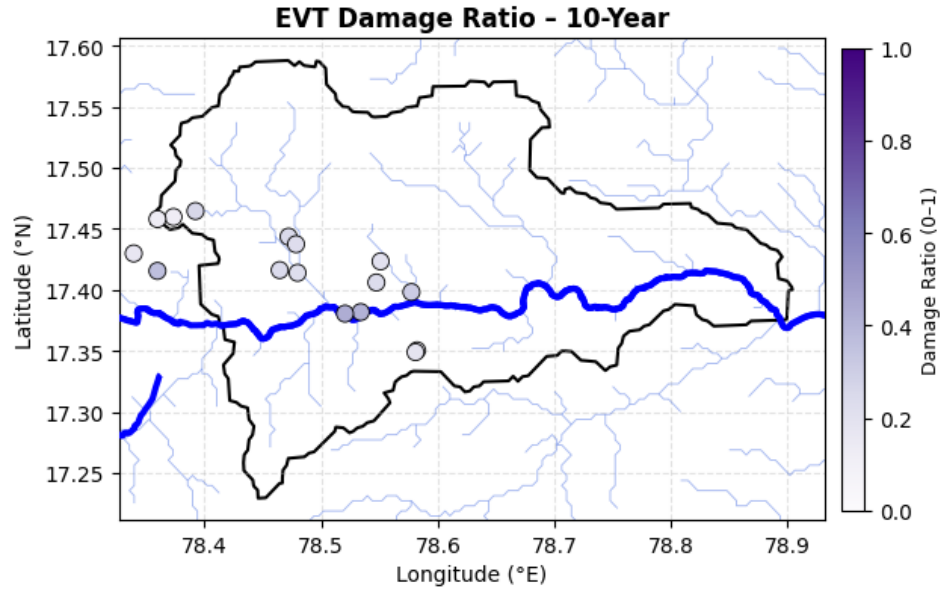

EVT vs Monte Carlo EP Curves – Musi Basin
EVT EP
Monte Carlo EP
Annual Exceedance Probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{8}
Annual Loss

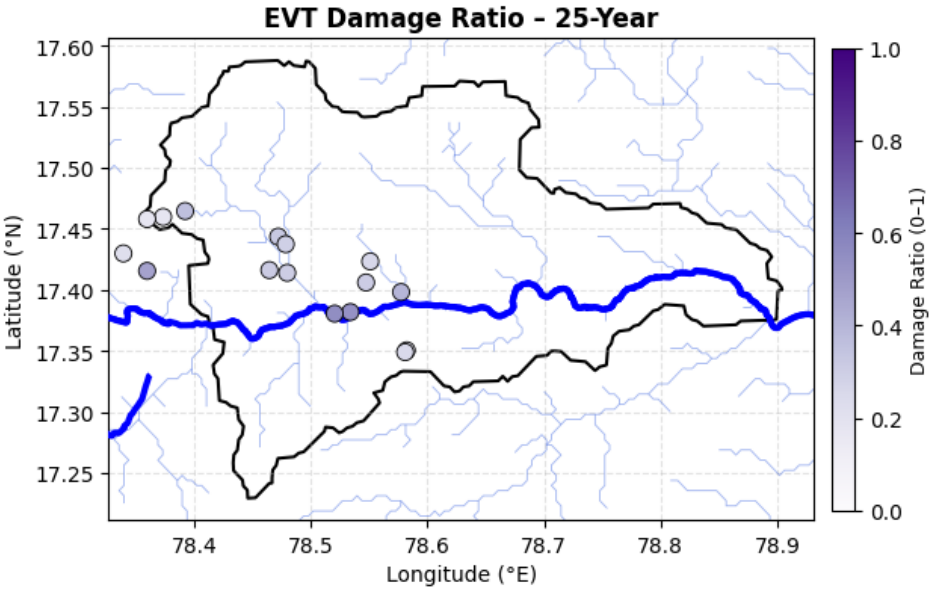

EVT Flood Hazard – 10-Year
Latitude (°N)
Longitude (°E)
Flood Hazard Index (0–1)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
1.0
0.8
0.6
0.4
0.2
0.0

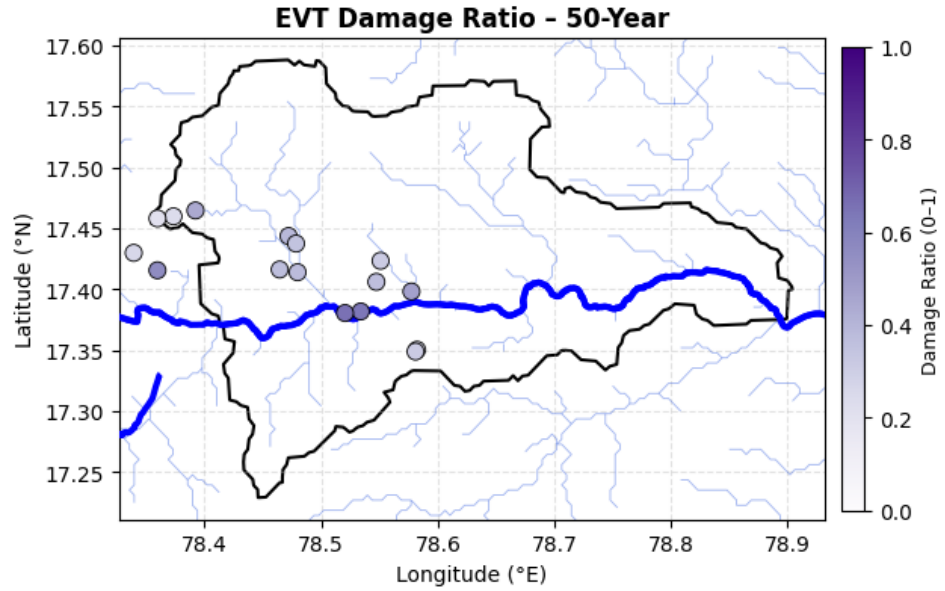

EVT Flood Hazard – 25-Year
Latitude (°N)
Longitude (°E)
Flood Hazard Index (0–1)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
1.0
0.8
0.6
0.4
0.2
0.0

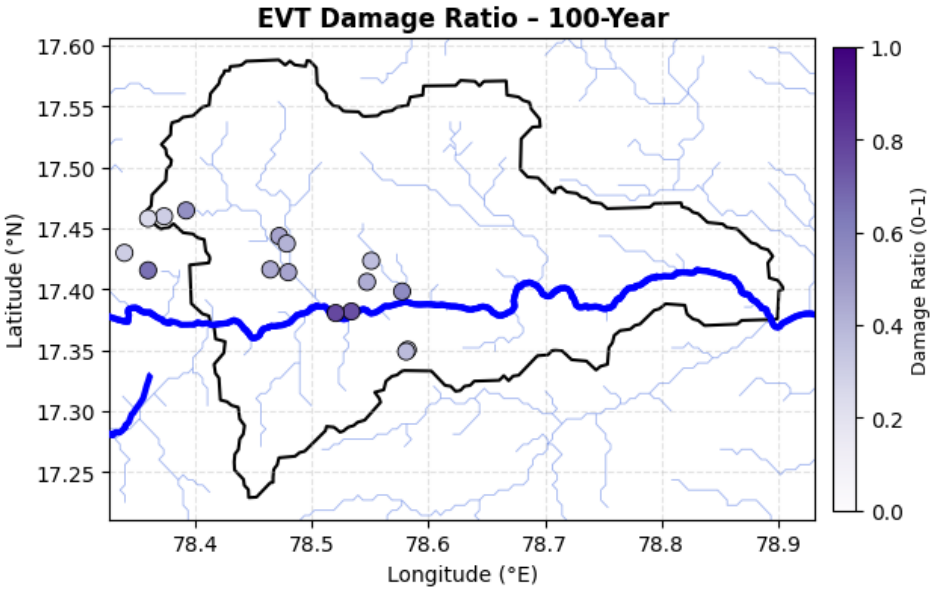

EVT Flood Hazard – 50-Year
Latitude (°N)
Longitude (°E)
Flood Hazard Index (0–1)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
1.0
0.8
0.6
0.4
0.2
0.0

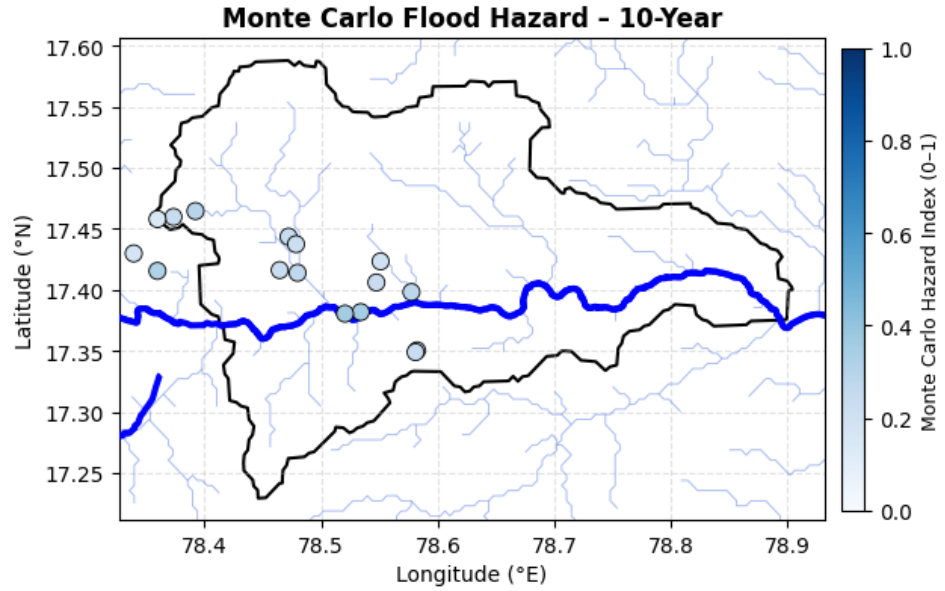

EVT Flood Hazard – 100-Year
Latitude (°N)
Longitude (°E)
Flood Hazard Index (0–1)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
1.0
0.8
0.6
0.4
0.2
0.0

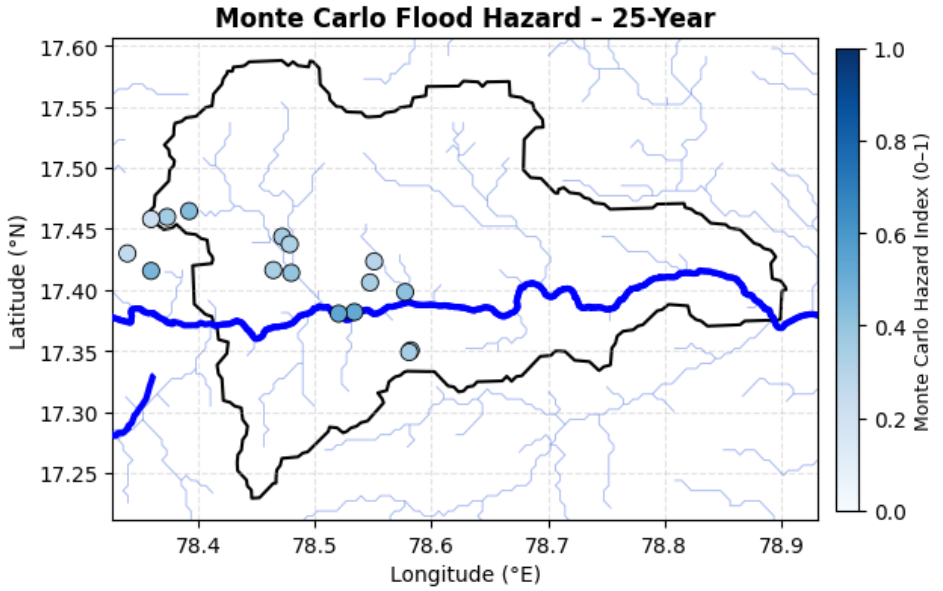

EVT Damage Ratio – 10-Year
Latitude (°N)
Longitude (°E)
Damage Ratio (0–1)

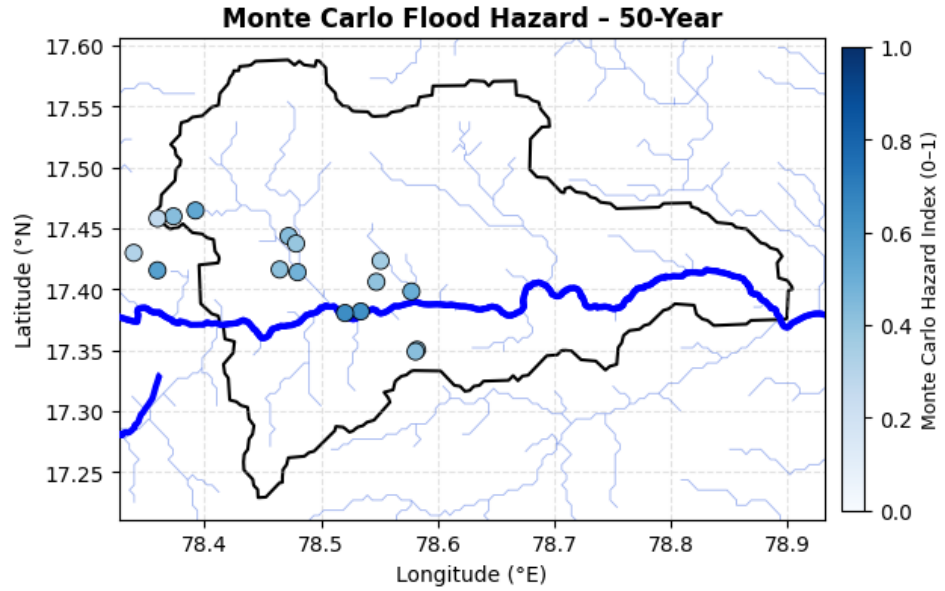

EVT Damage Ratio – 25-Year
Latitude (°N)
Longitude (°E)
Damage Ratio (0–1)

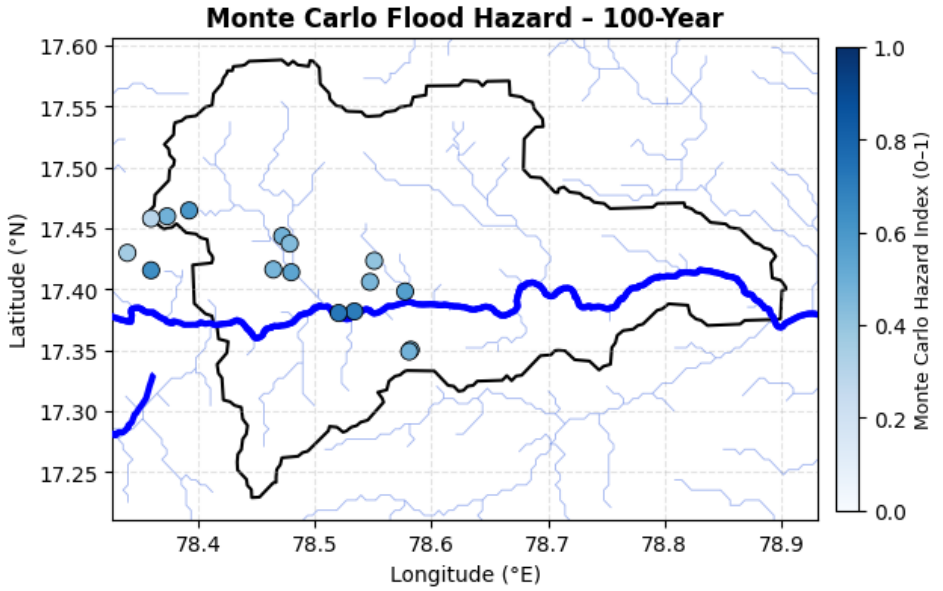

EVT Damage Ratio – 50-Year
Latitude (°N)
Longitude (°E)
Damage Ratio (0–1)

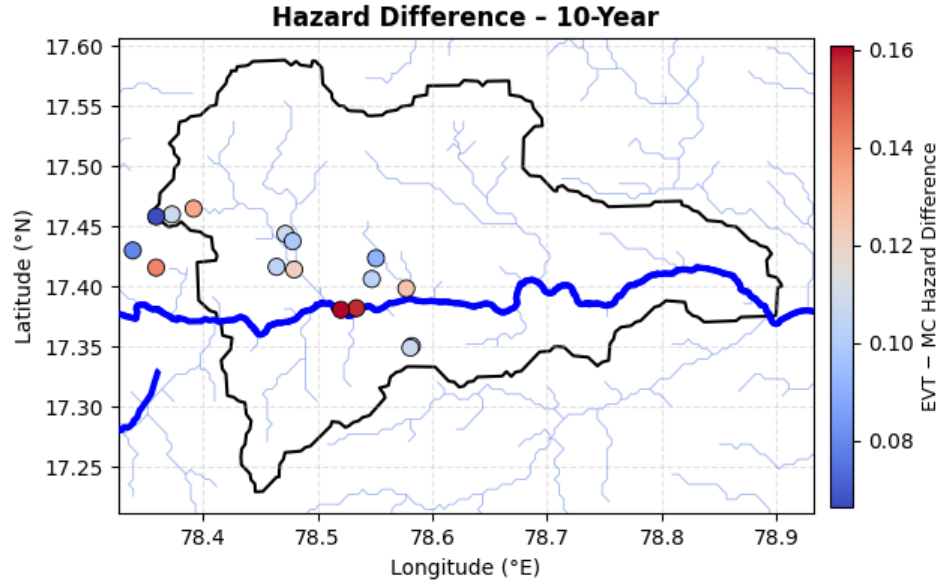

EVT Damage Ratio – 100-Year
Latitude (°N)
Longitude (°E)
Damage Ratio (0–1)

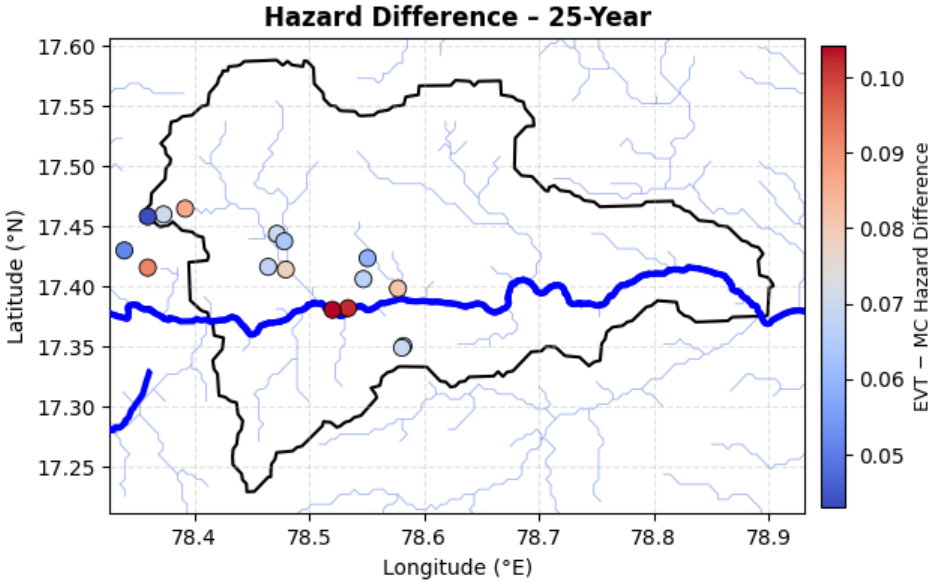

Monte Carlo Flood Hazard – 10-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Hazard Index (0–1)

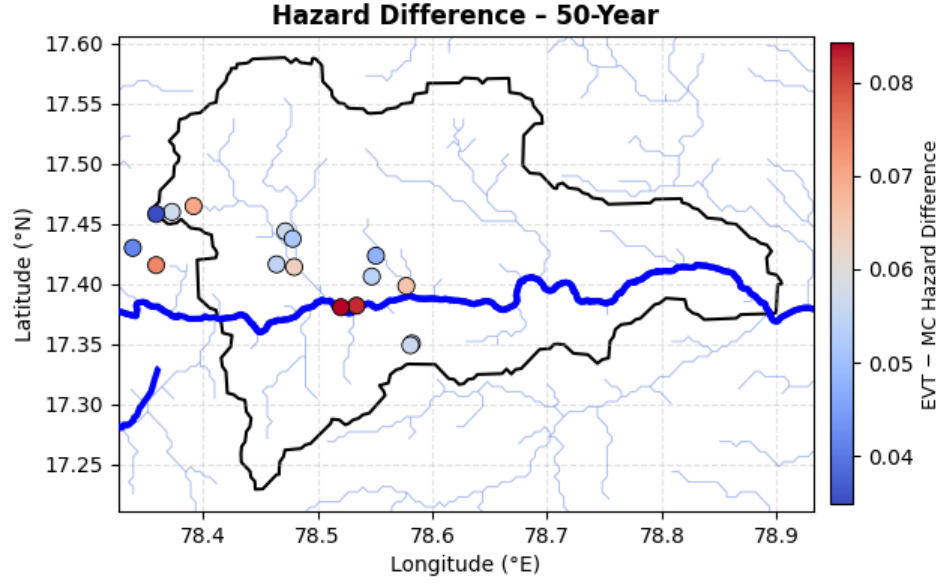

Monte Carlo Flood Hazard – 25-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Hazard Index (0–1)

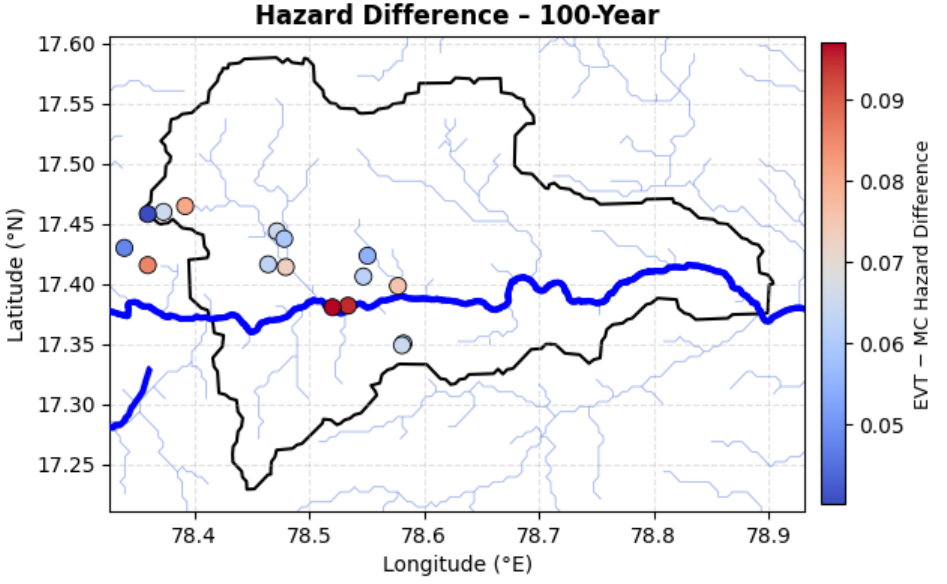

Monte Carlo Flood Hazard – 50-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Hazard Index (0–1)

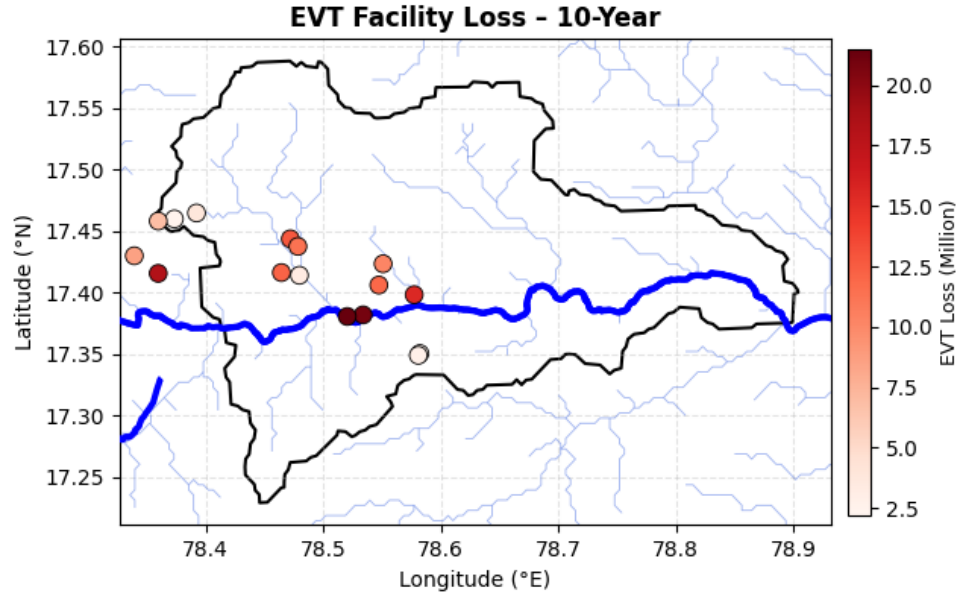

Monte Carlo Flood Hazard – 100-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Hazard Index (0–1)

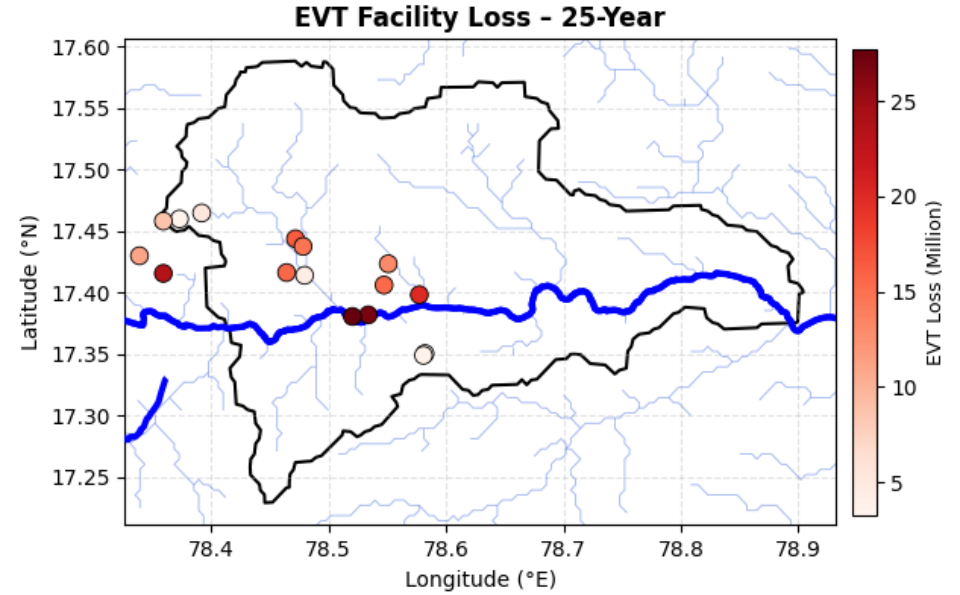

Hazard Difference – 10-Year
Latitude (°N)
Longitude (°E)
EVT − MC Hazard Difference

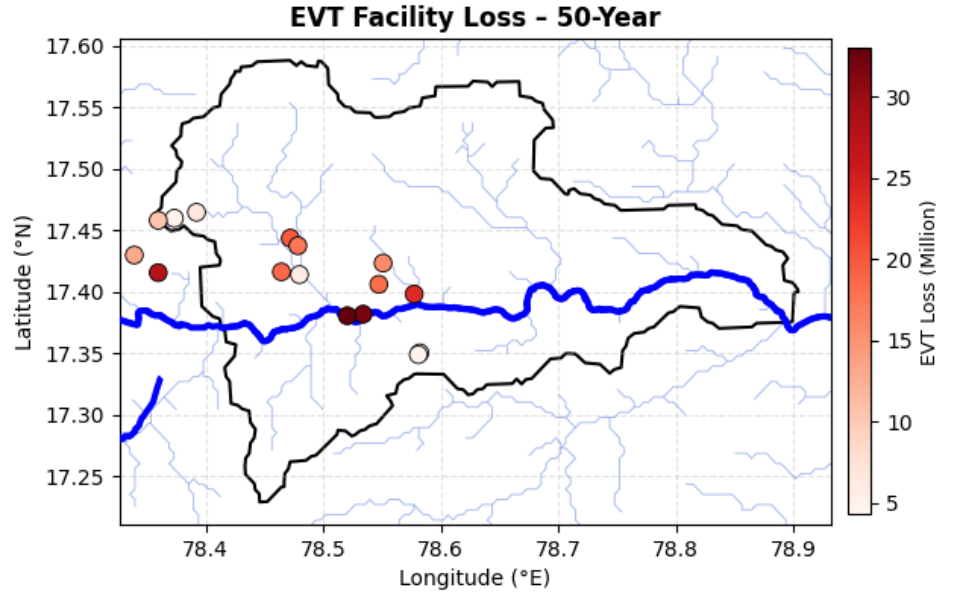

Hazard Difference – 25-Year
Latitude (°N)
Longitude (°E)
EVT − MC Hazard Difference

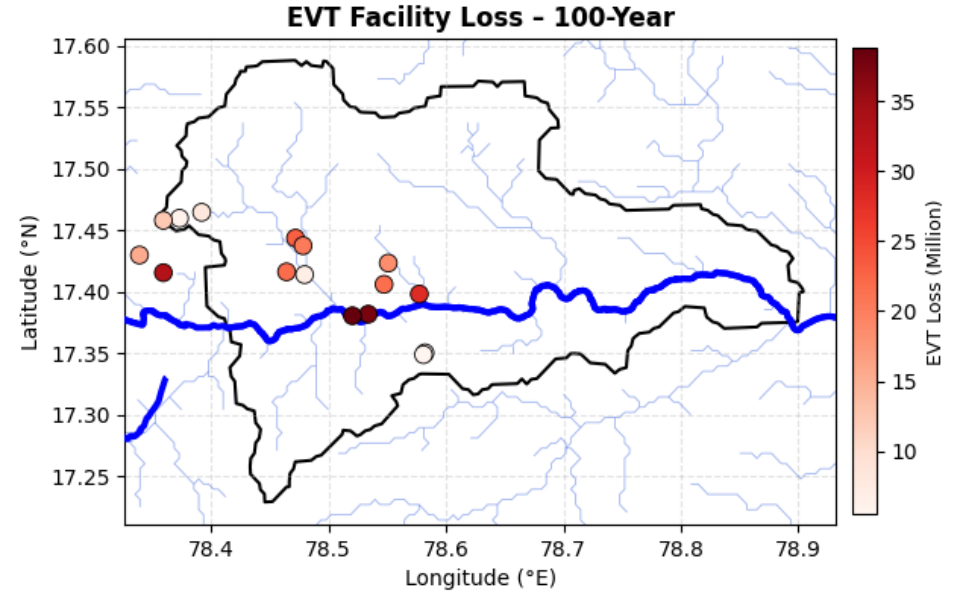

Hazard Difference – 50-Year
Latitude (°N)
Longitude (°E)
EVT − MC Hazard Difference

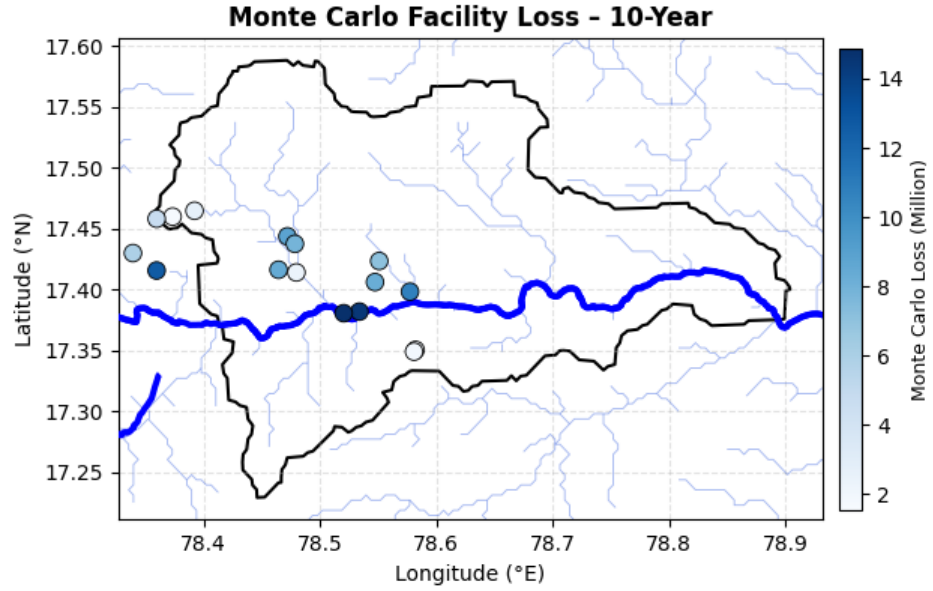

Hazard Difference – 100-Year
Latitude (°N)
Longitude (°E)
EVT − MC Hazard Difference

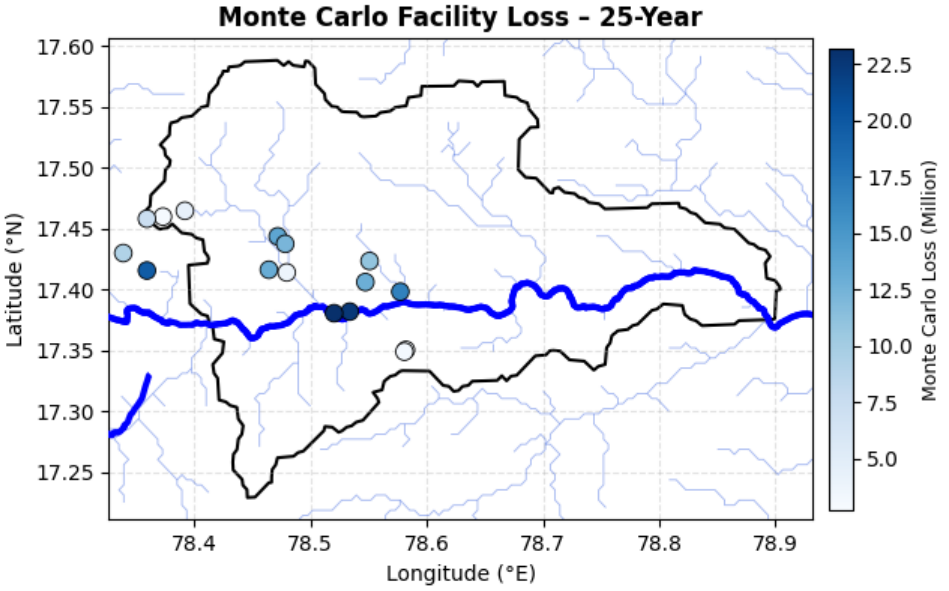

EVT Facility Loss – 10-Year
Latitude (°N)
Longitude (°E)
EVT Loss (Million)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5

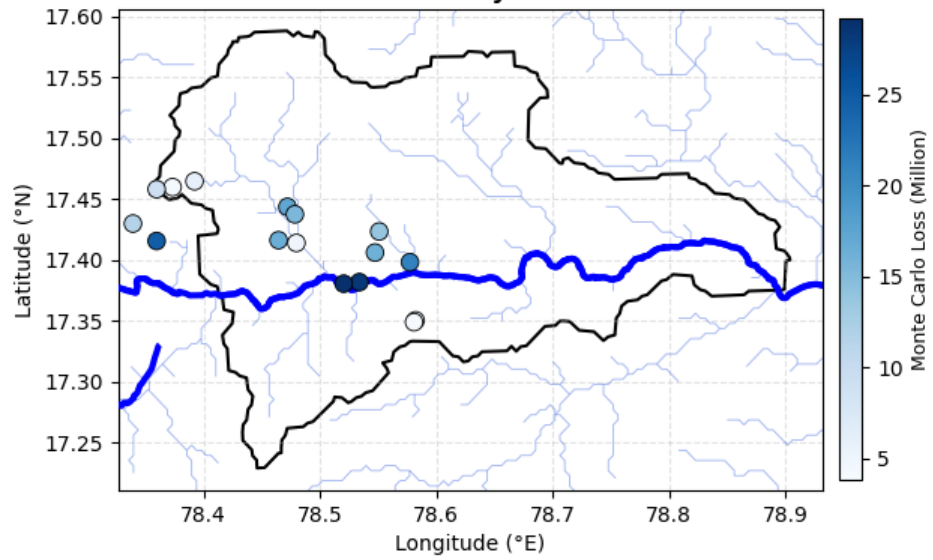

EVT Facility Loss – 25-Year
Latitude (°N)
Longitude (°E)
EVT Loss (Million)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
25
20
15
10
5

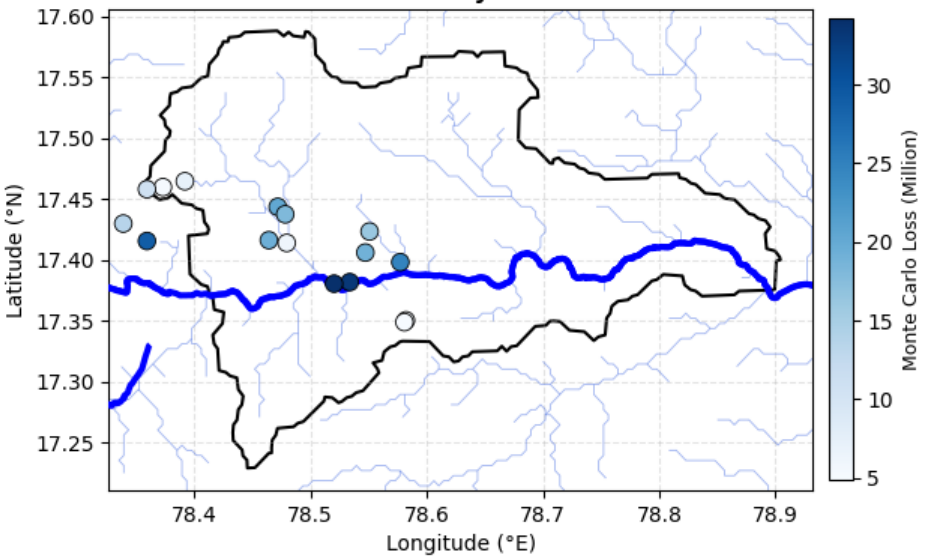

EVT Facility Loss – 50-Year
Latitude (°N)
Longitude (°E)
EVT Loss (Million)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
30
25
20
15
10
5

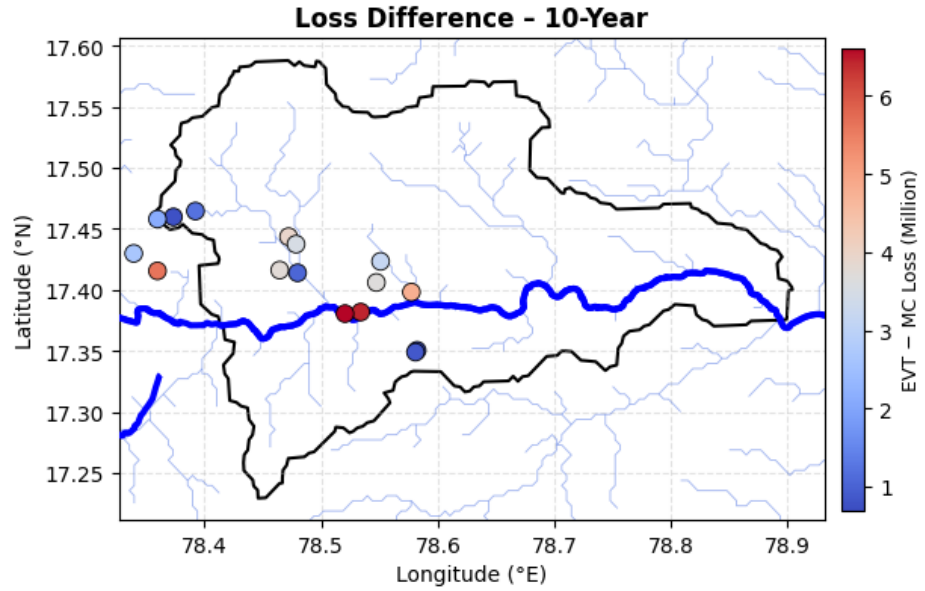

EVT Facility Loss – 100-Year
Latitude (°N)
Longitude (°E)
EVT Loss (Million)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
35
30
25
20
15
10

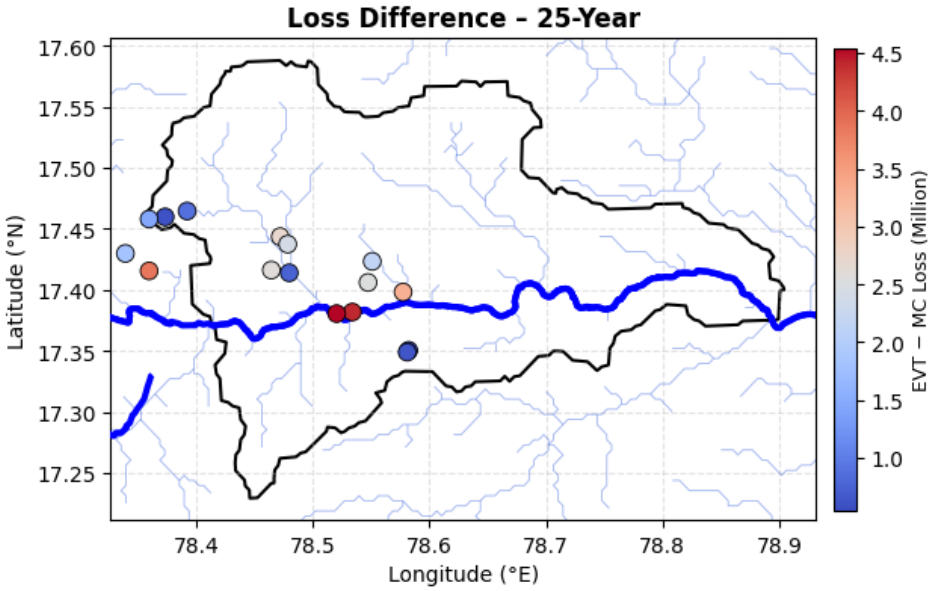

Monte Carlo Facility Loss – 10-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Loss (Million)

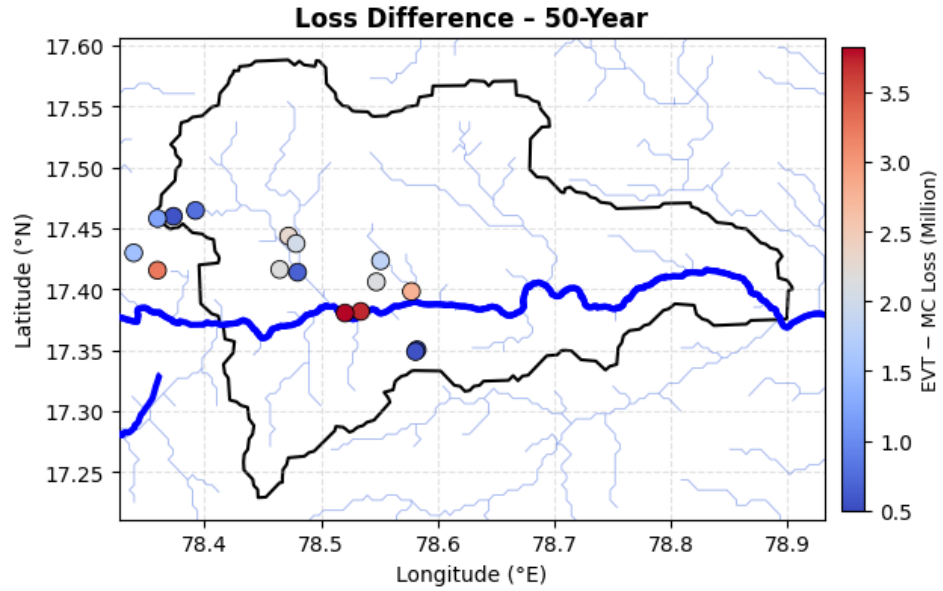

Monte Carlo Facility Loss – 25-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Loss (Million)

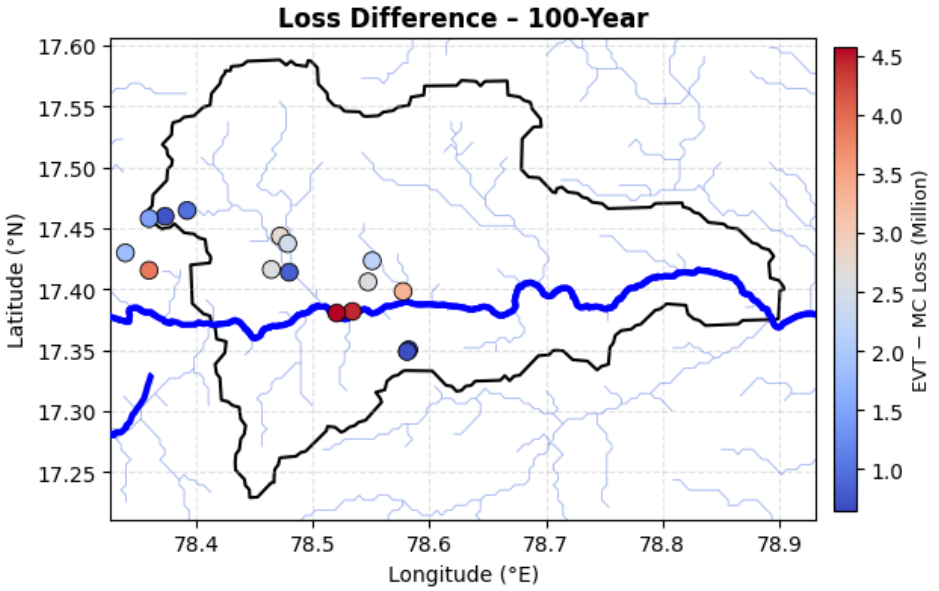

Monte Carlo Facility Loss – 50-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Loss (Million)

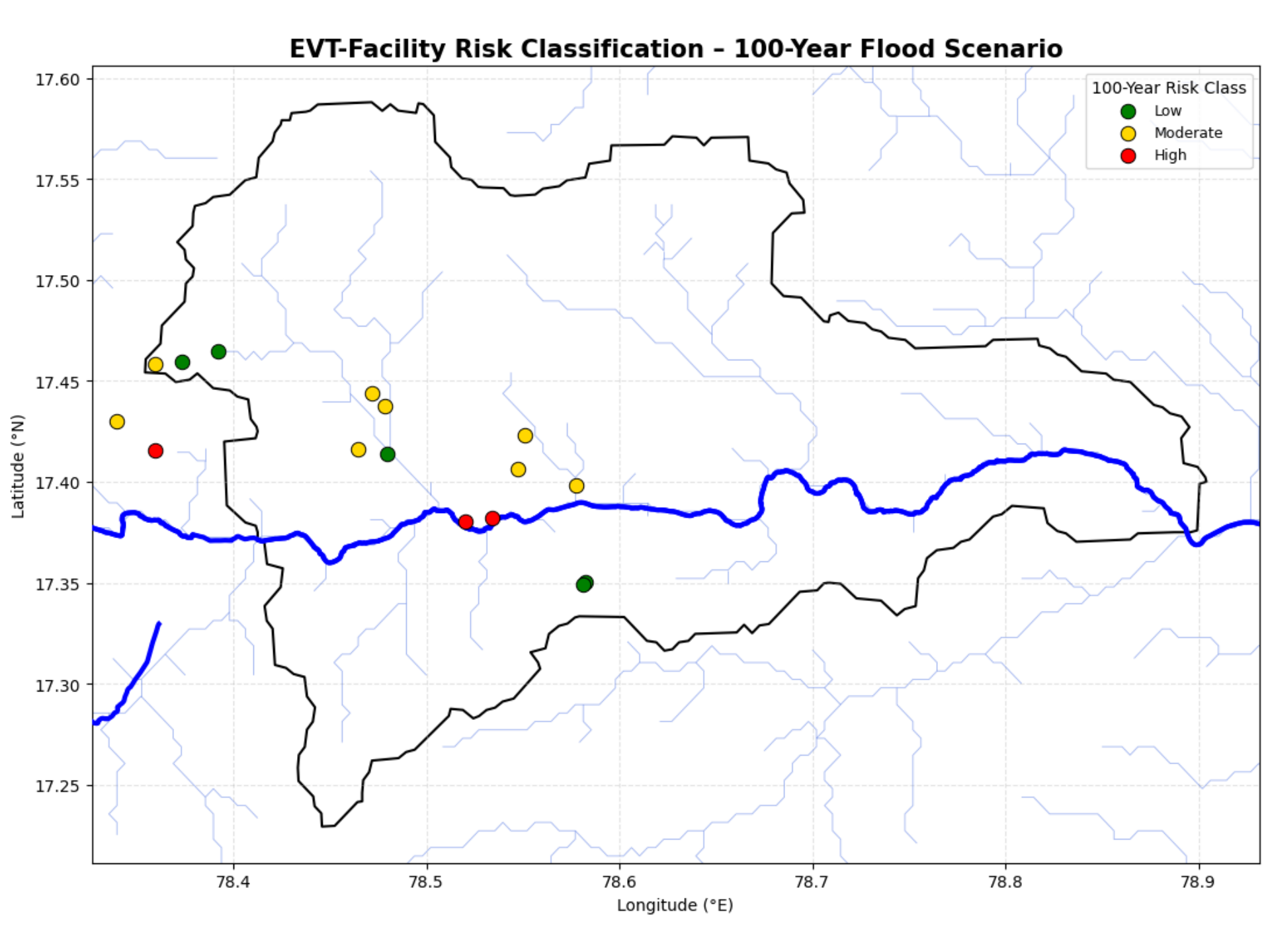

Monte Carlo Facility Loss – 100-Year
Latitude (°N)
Longitude (°E)
Monte Carlo Loss (Million)

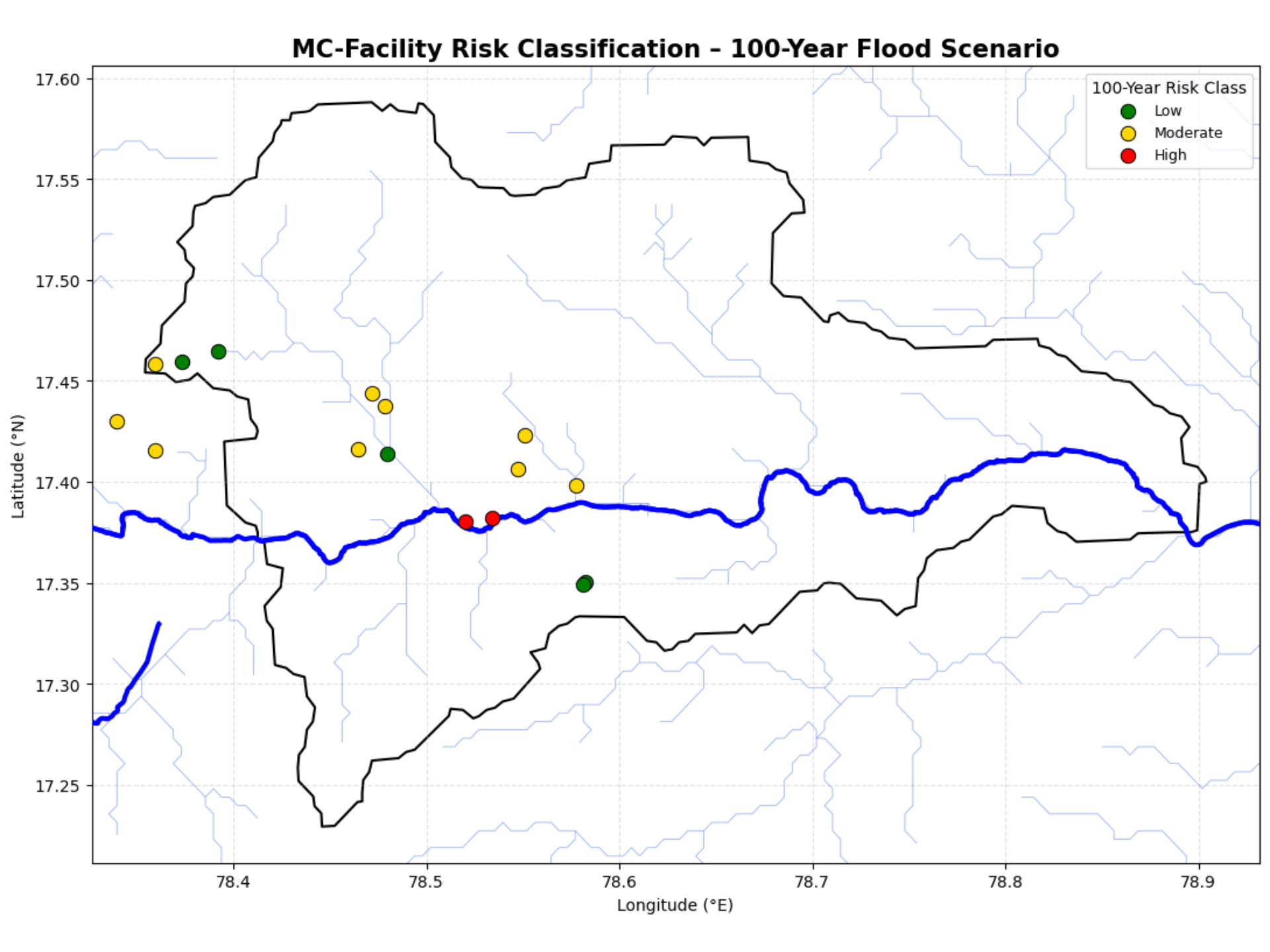

Loss Difference – 10-Year
Latitude (°N)
Longitude (°E)
EVT − MC Loss (Million)

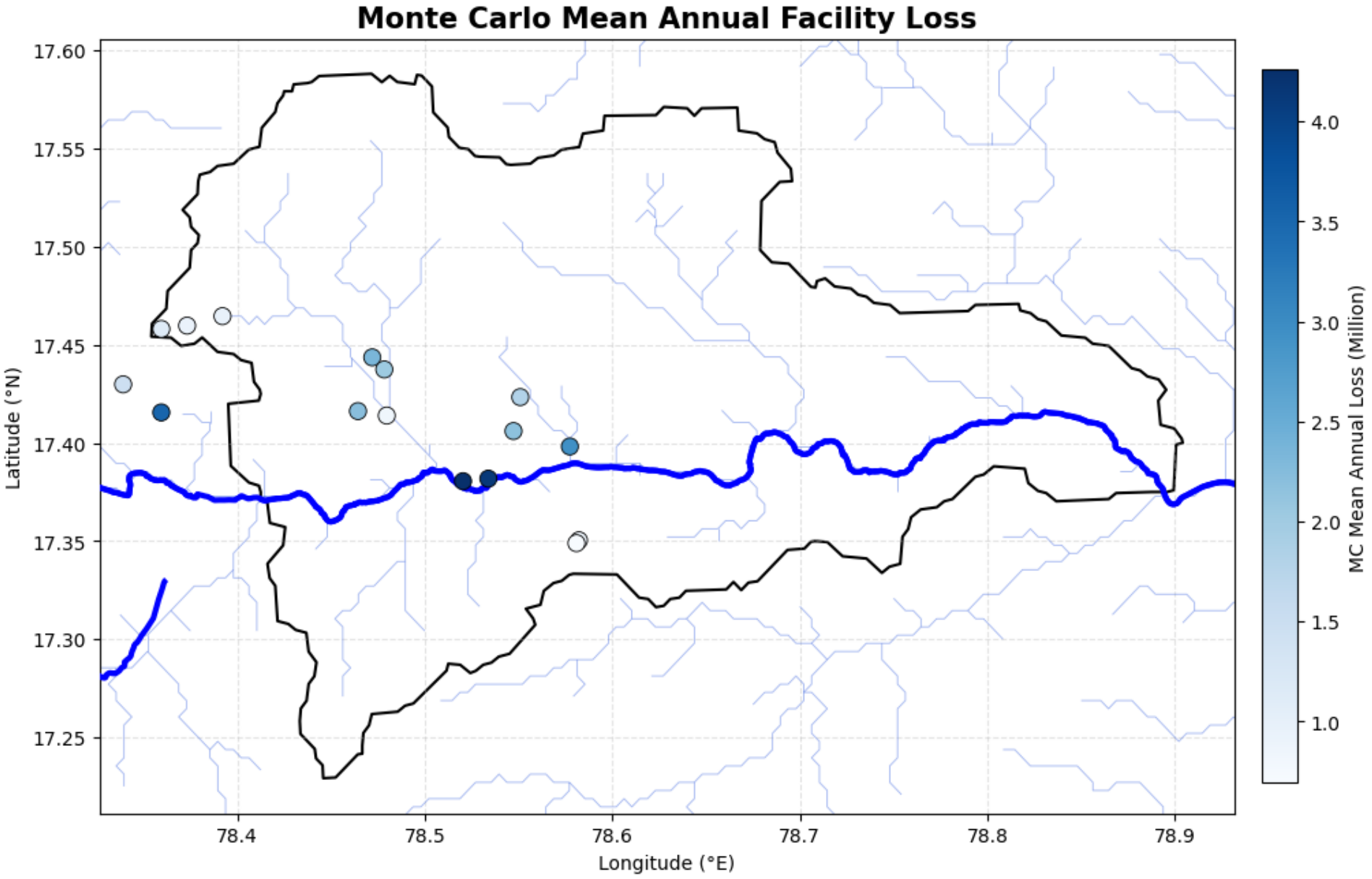

Loss Difference – 25-Year
Latitude (°N)
Longitude (°E)
EVT − MC Loss (Million)

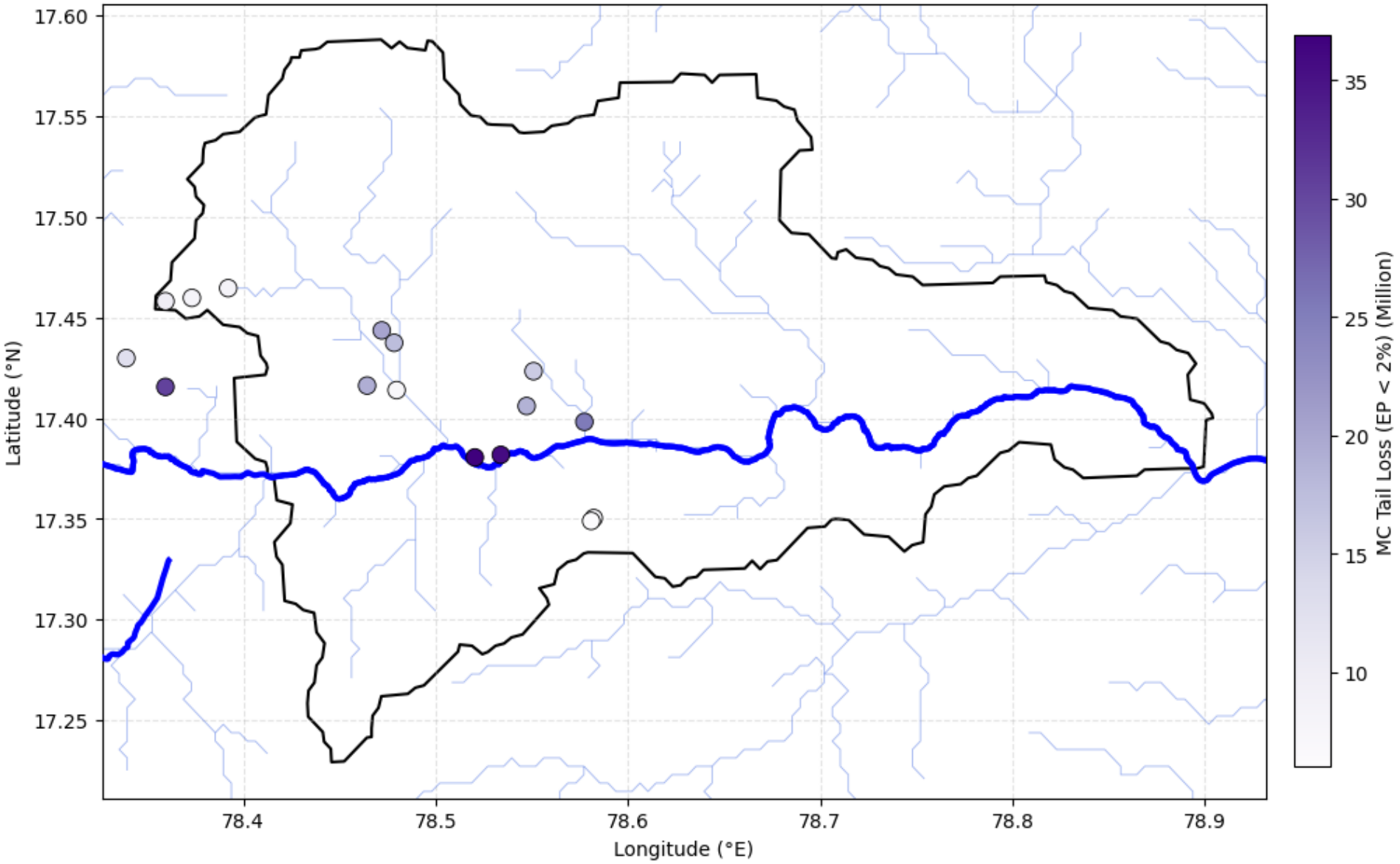

Loss Difference – 50-Year
Latitude (°N)
Longitude (°E)
EVT − MC Loss (Million)

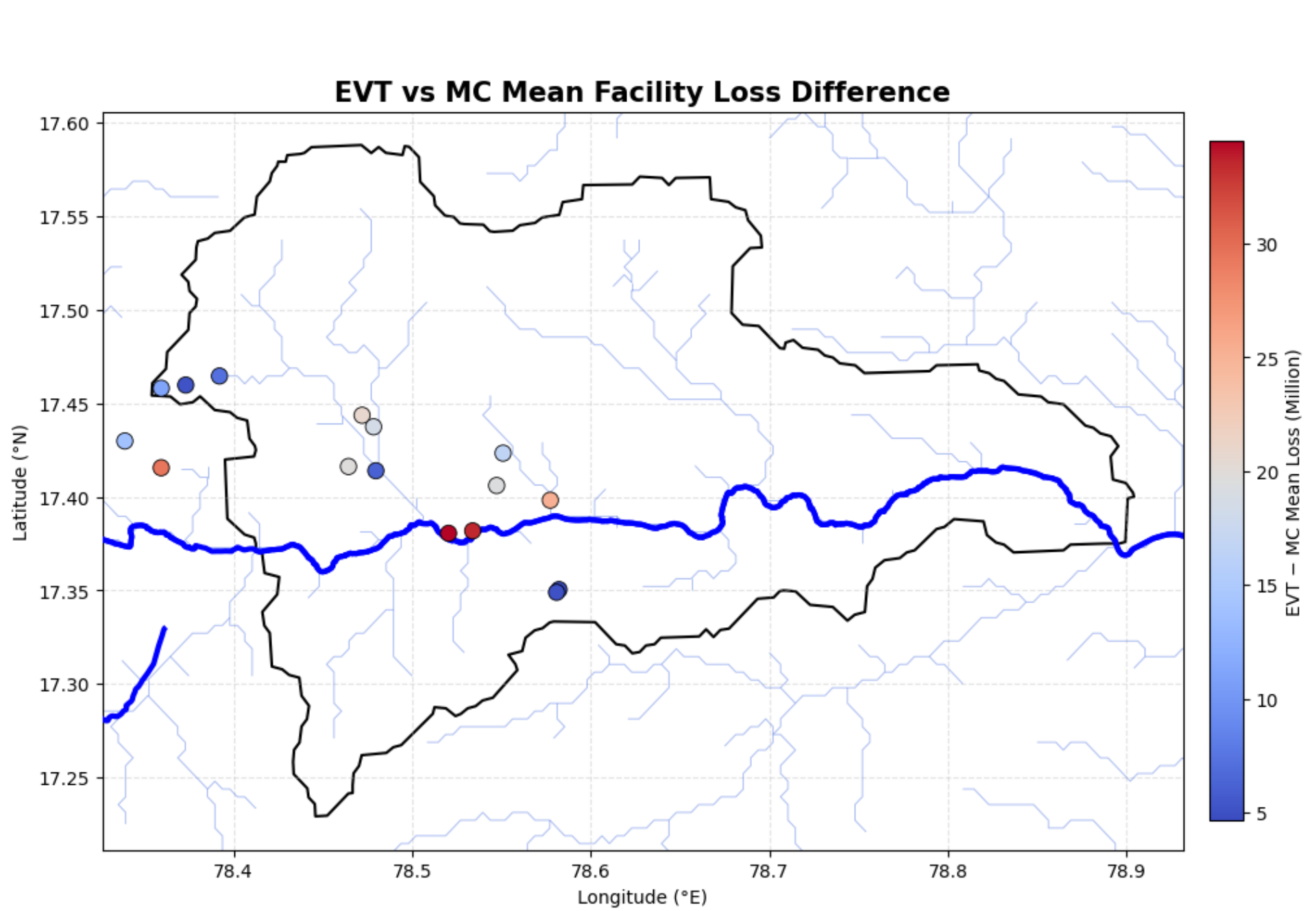

Loss Difference – 100-Year
Latitude (°N)
Longitude (°E)
EVT − MC Loss (Million)

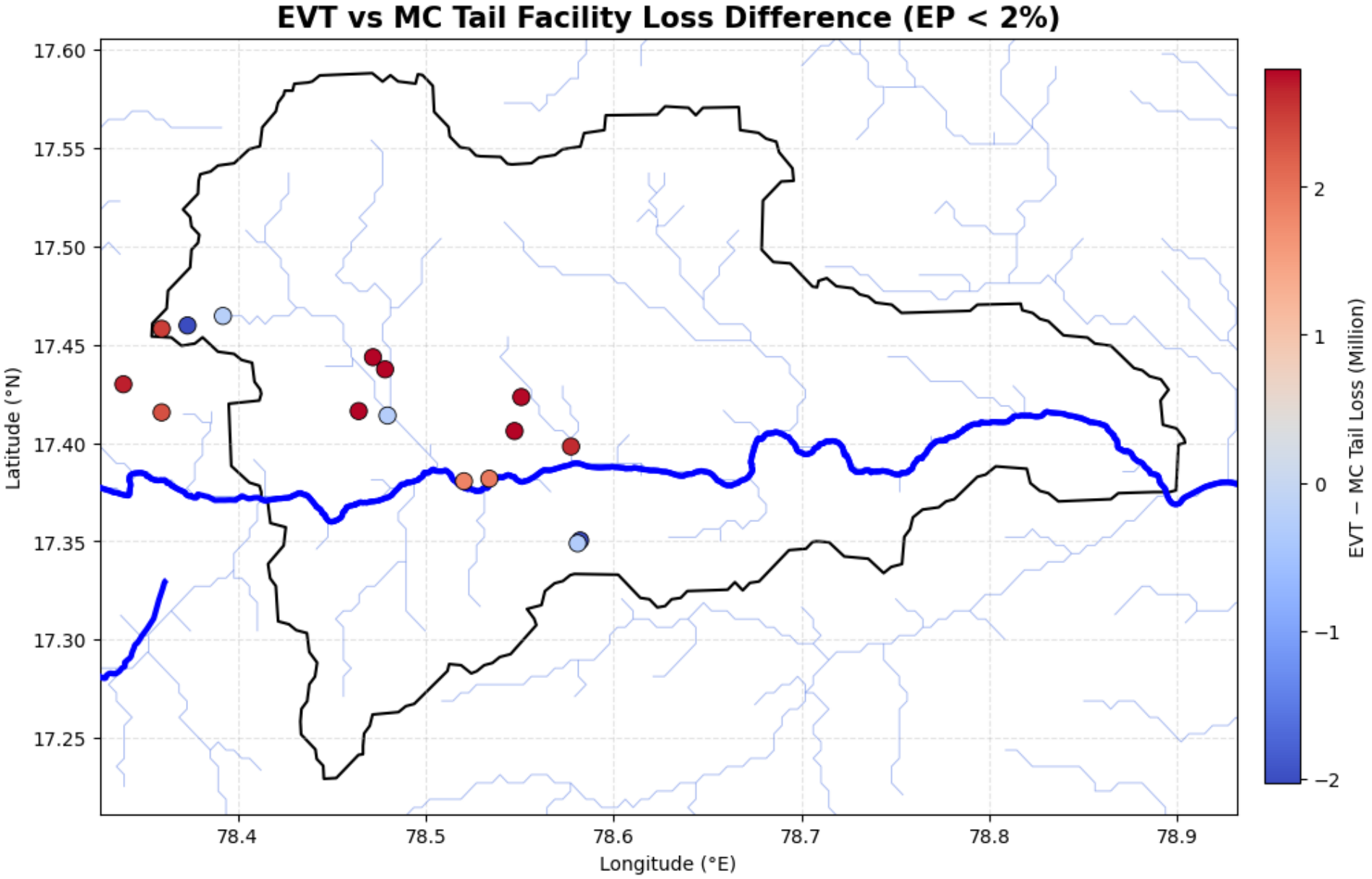

EVT-Facility Risk Classification – 100-Year Flood Scenario
100-Year Risk Class
Low
Moderate
High
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)

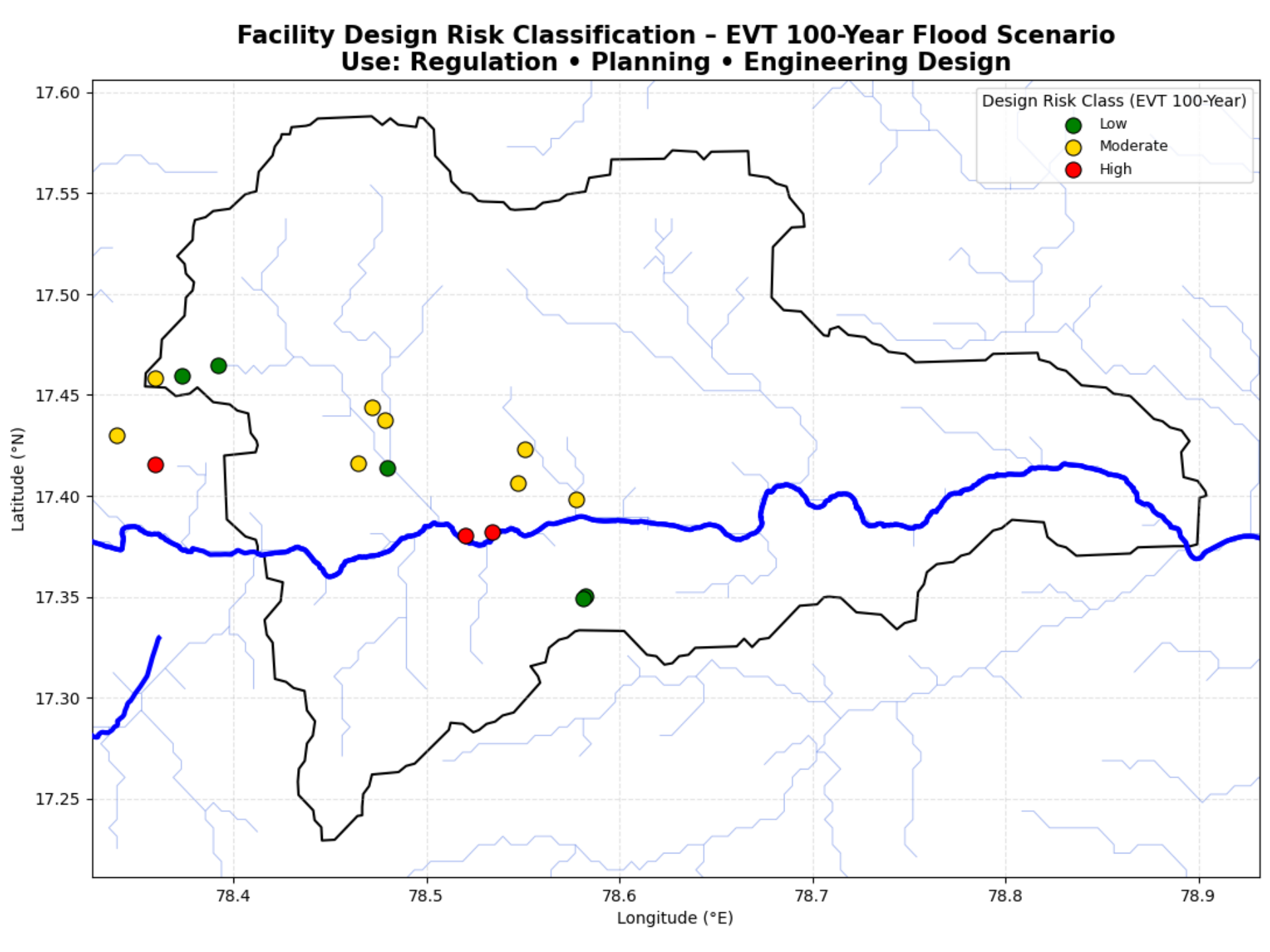

MC-Facility Risk Classification – 100-Year Flood Scenario
100-Year Risk Class
Low
Moderate
High
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)

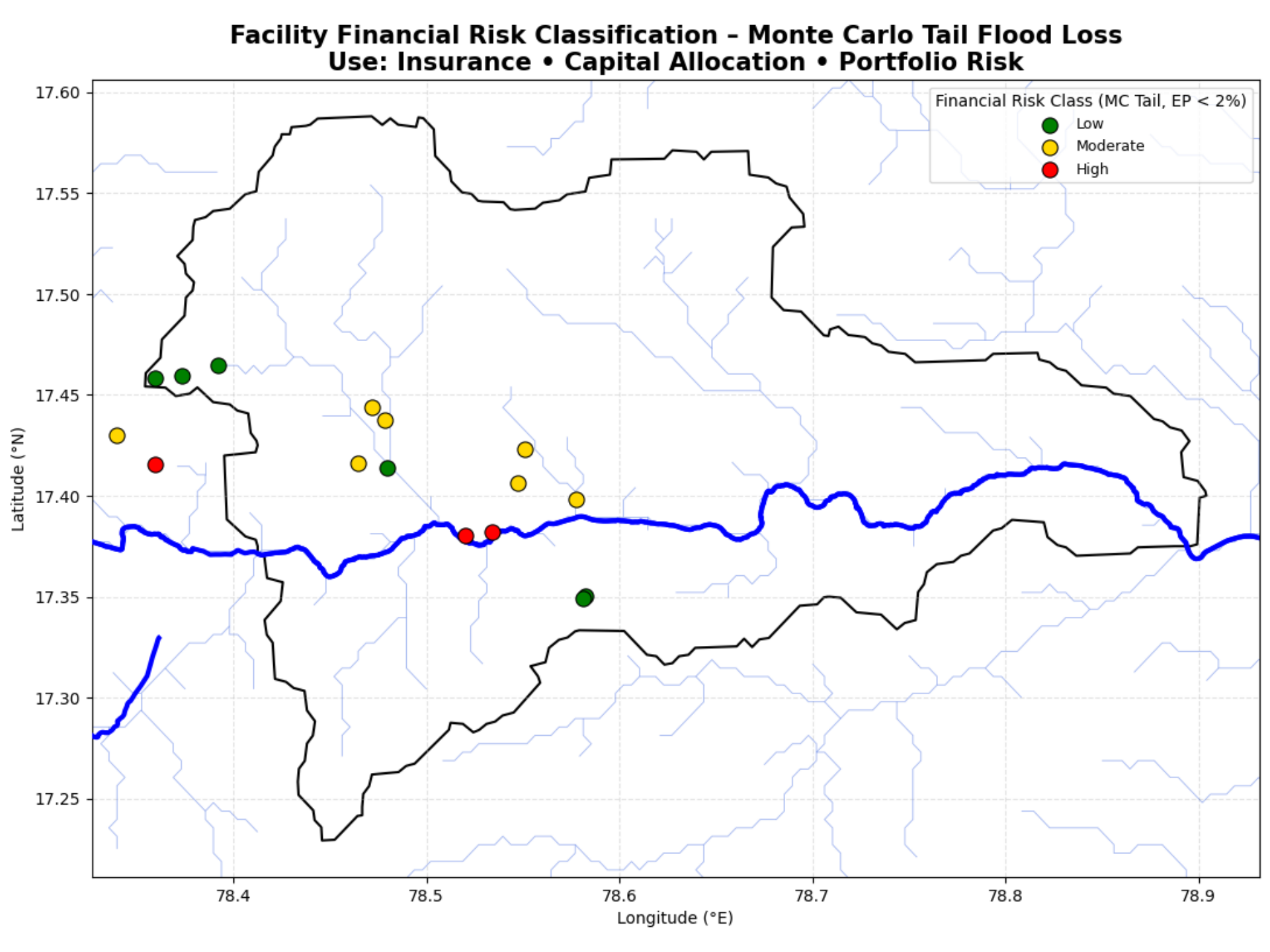

Monte Carlo Mean Annual Facility Loss
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
MC Mean Annual Loss (Million)


Monte Carlo Tail Facility Loss (EP < 2%)
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)
MC Tail Loss (EP < 2%) (Million)
35
30
25
20
15
10

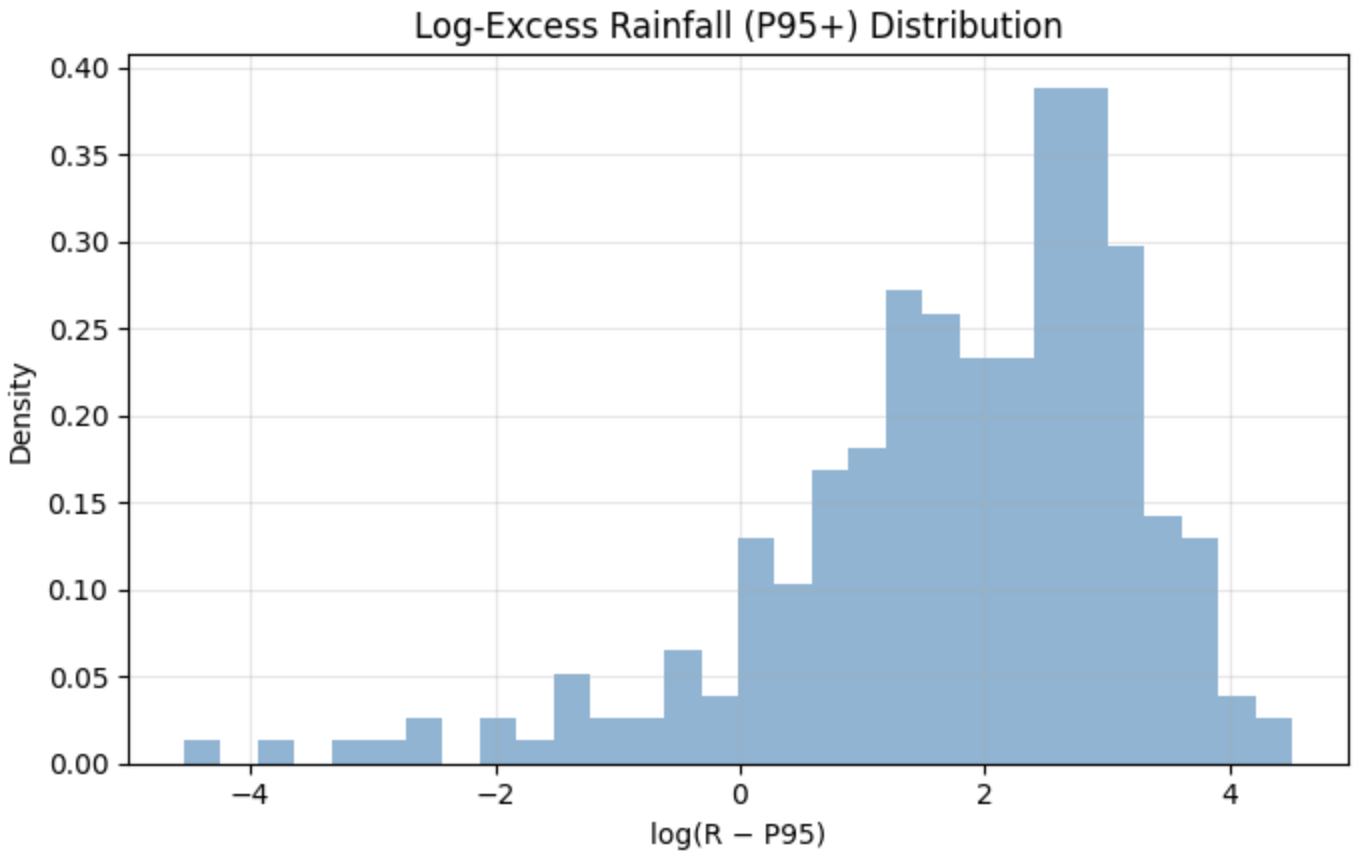

EVT vs MC Mean Facility Loss Difference
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)
30
25
20
15
10
5
EVT − MC Mean Loss (Million)

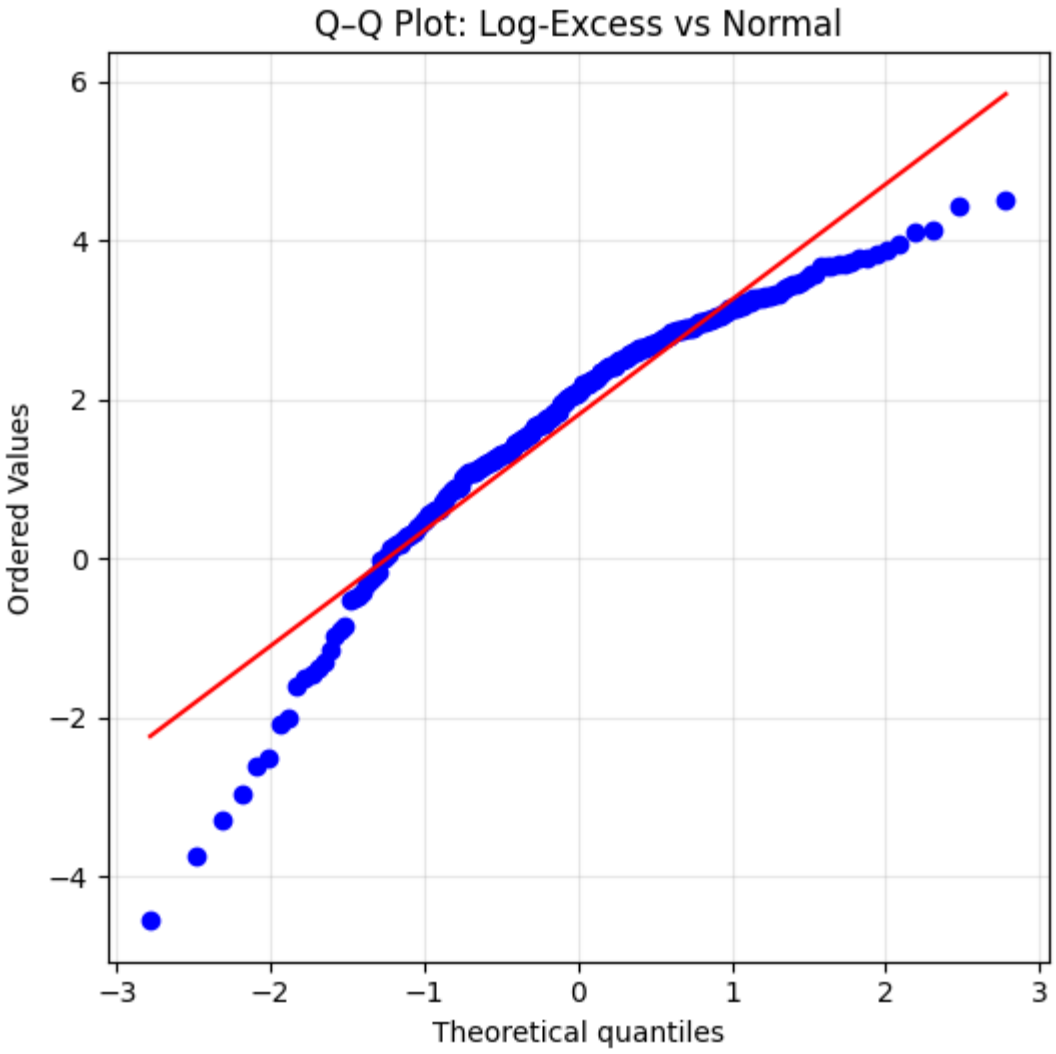

EVT vs MC Tail Facility Loss Difference (EP < 2%)
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
EVT − MC Tail Loss (Million)
2
1
0
−1
−2

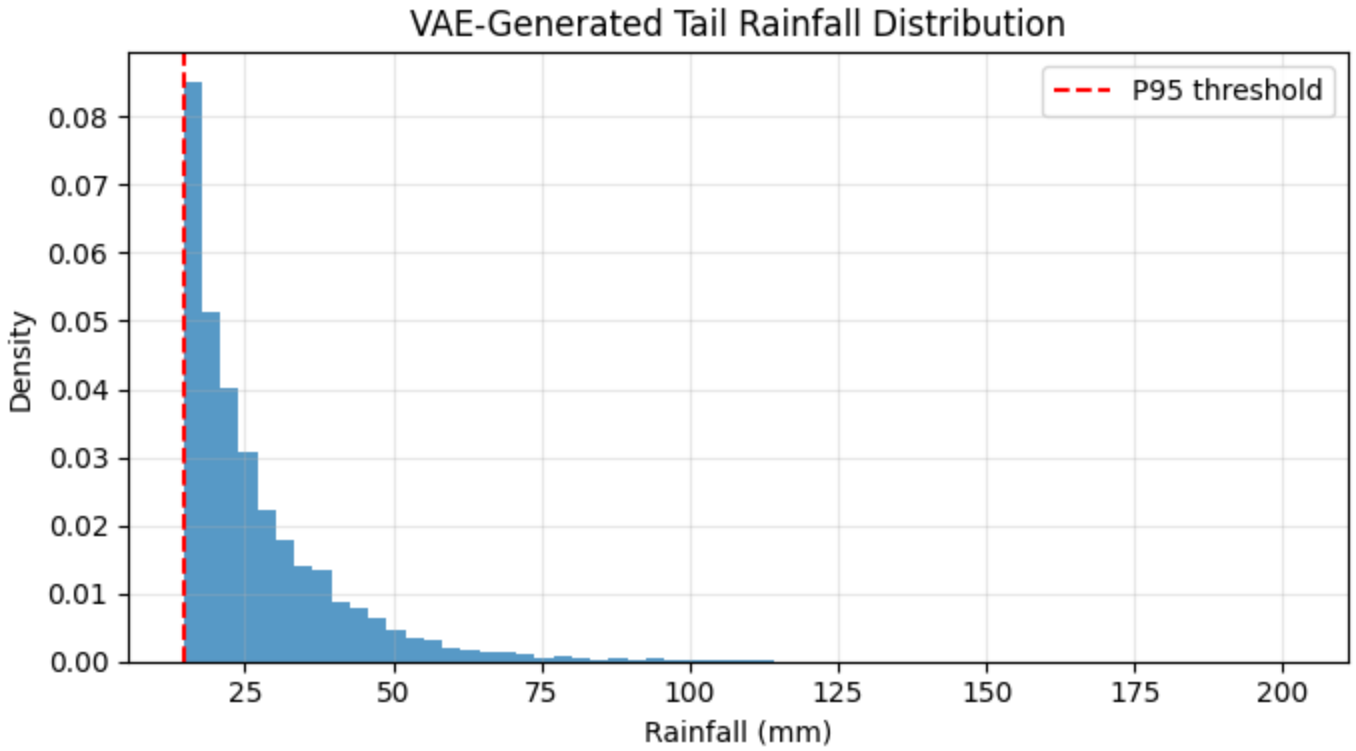

Facility Design Risk Classification – EVT 100-Year Flood Scenario
Use: Regulation • Planning • Engineering Design
Design Risk Class (EVT 100-Year)
Low
Moderate
High
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)

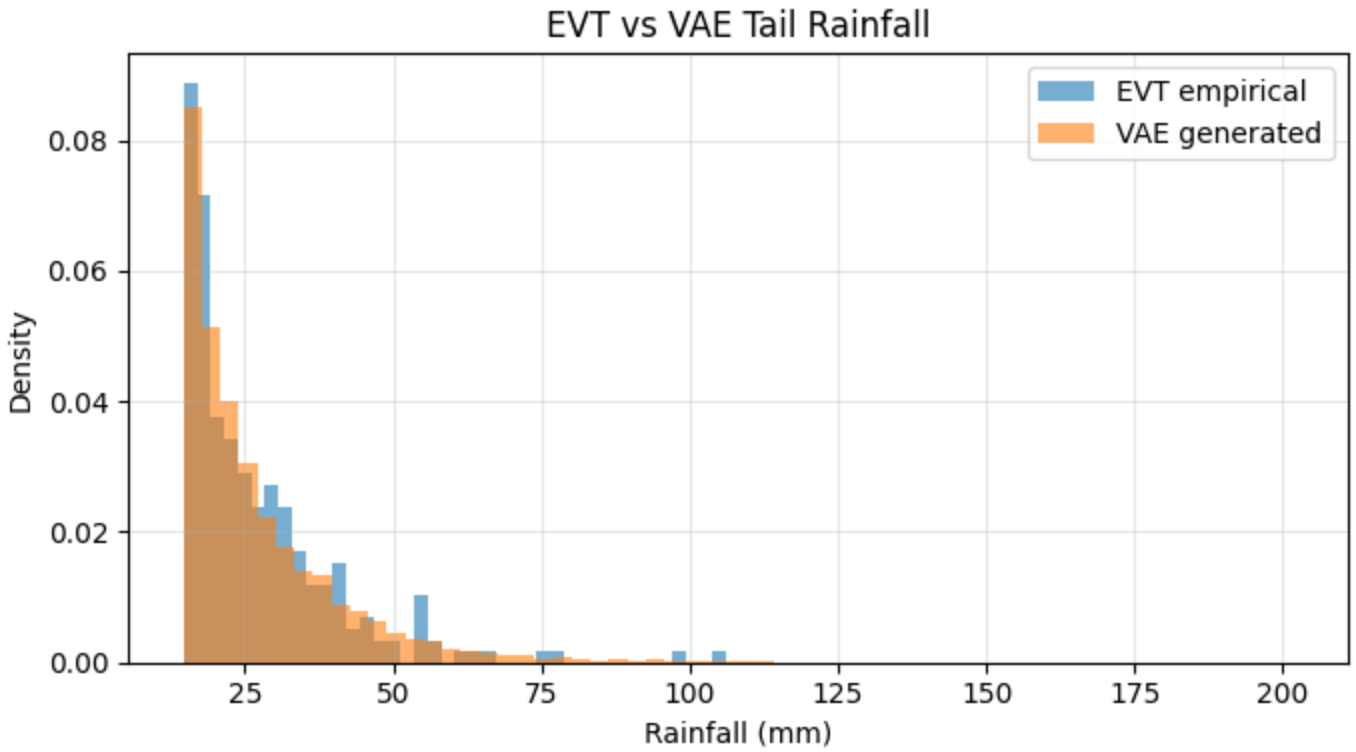

Facility Financial Risk Classification – Monte Carlo Tail Flood Loss
Use: Insurance • Capital Allocation • Portfolio Risk
Financial Risk Class (MC Tail, EP < 2%)
Low
Moderate
High
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Latitude (°N)
78.4
78.5
78.6
78.7
78.8
78.9
Longitude (°E)

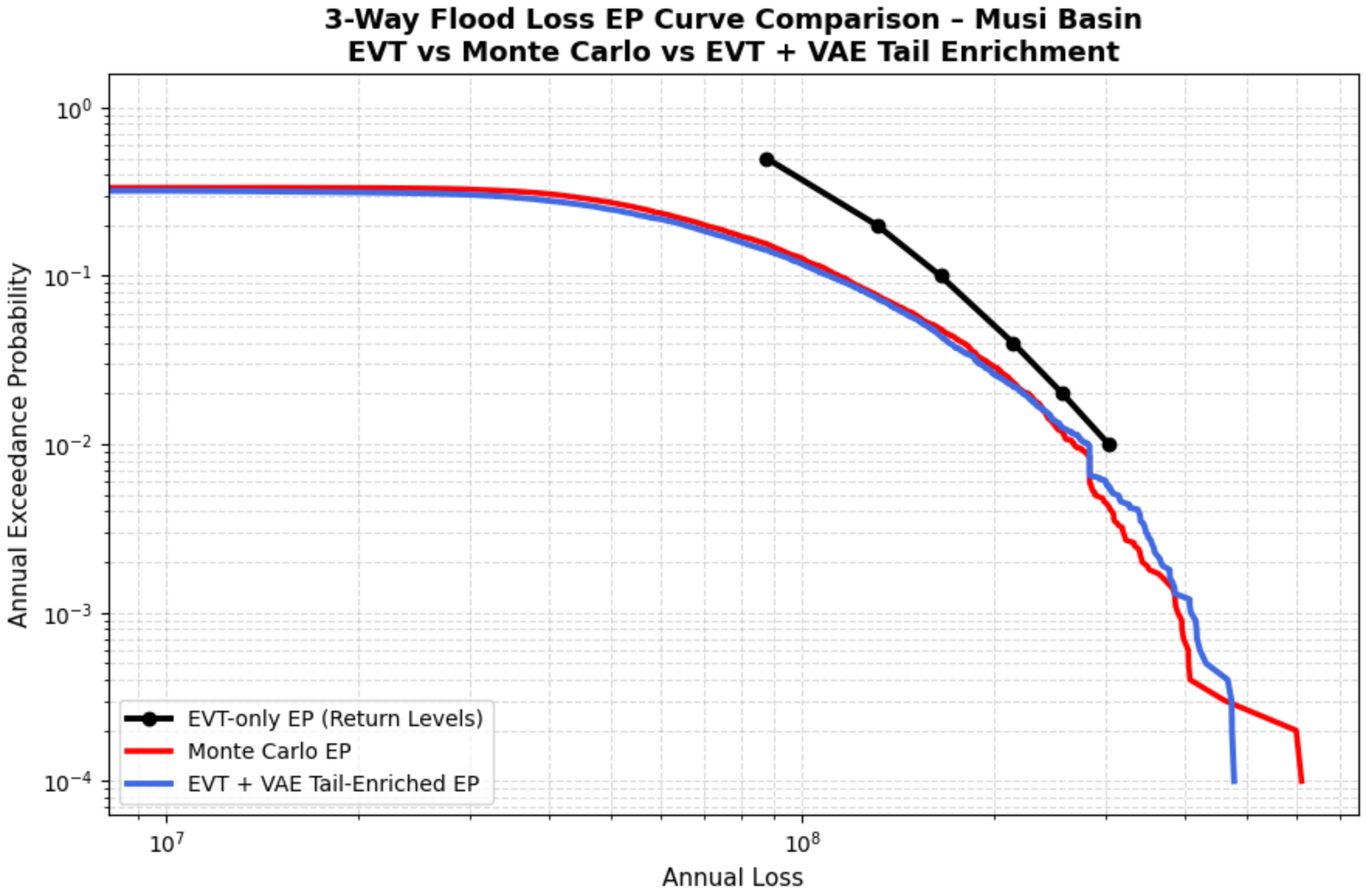
DGM-VAE

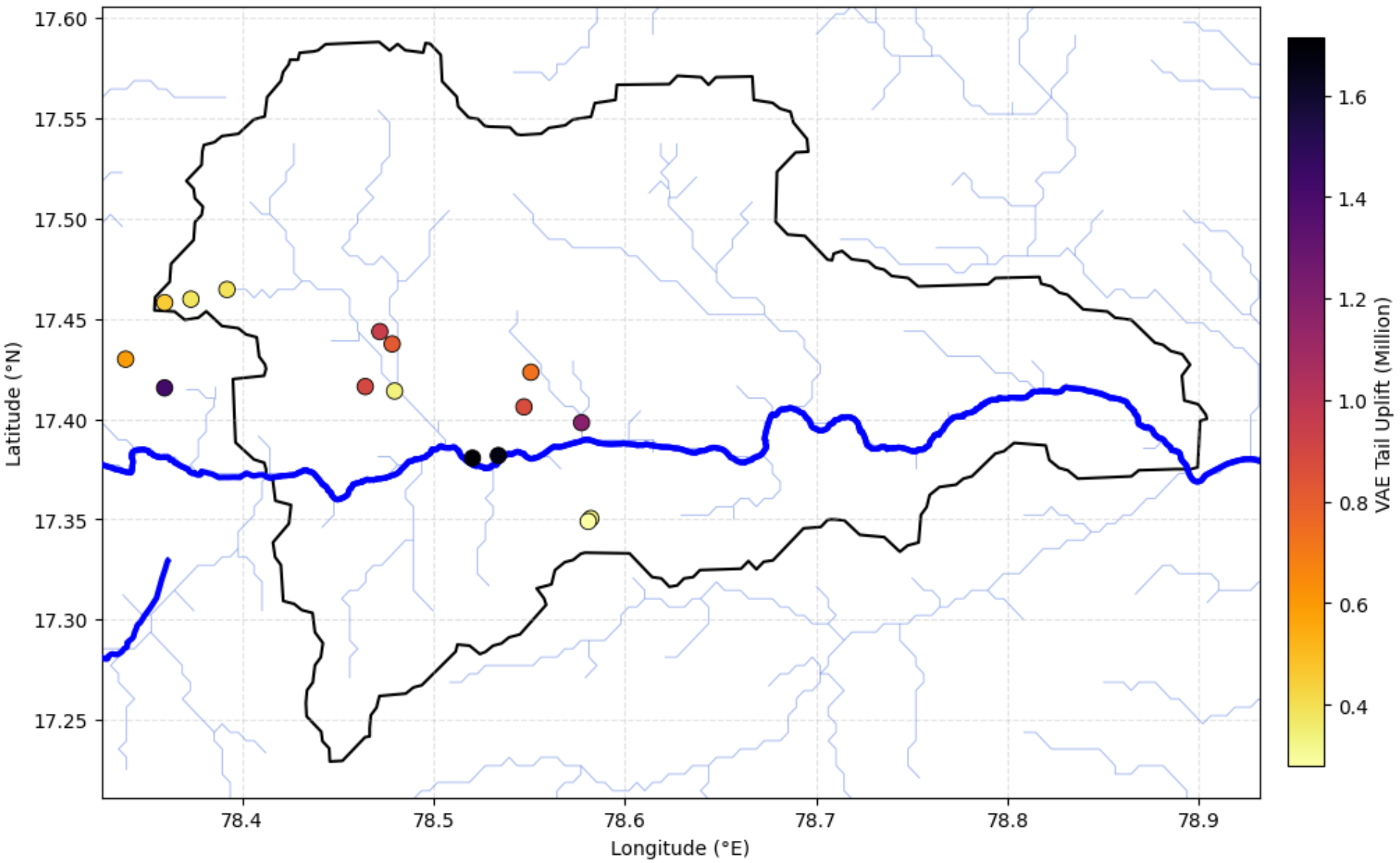

Log-Excess Rainfall (P95+) Distribution
Density
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
−4
−2
0
2
4
log(R − P95)

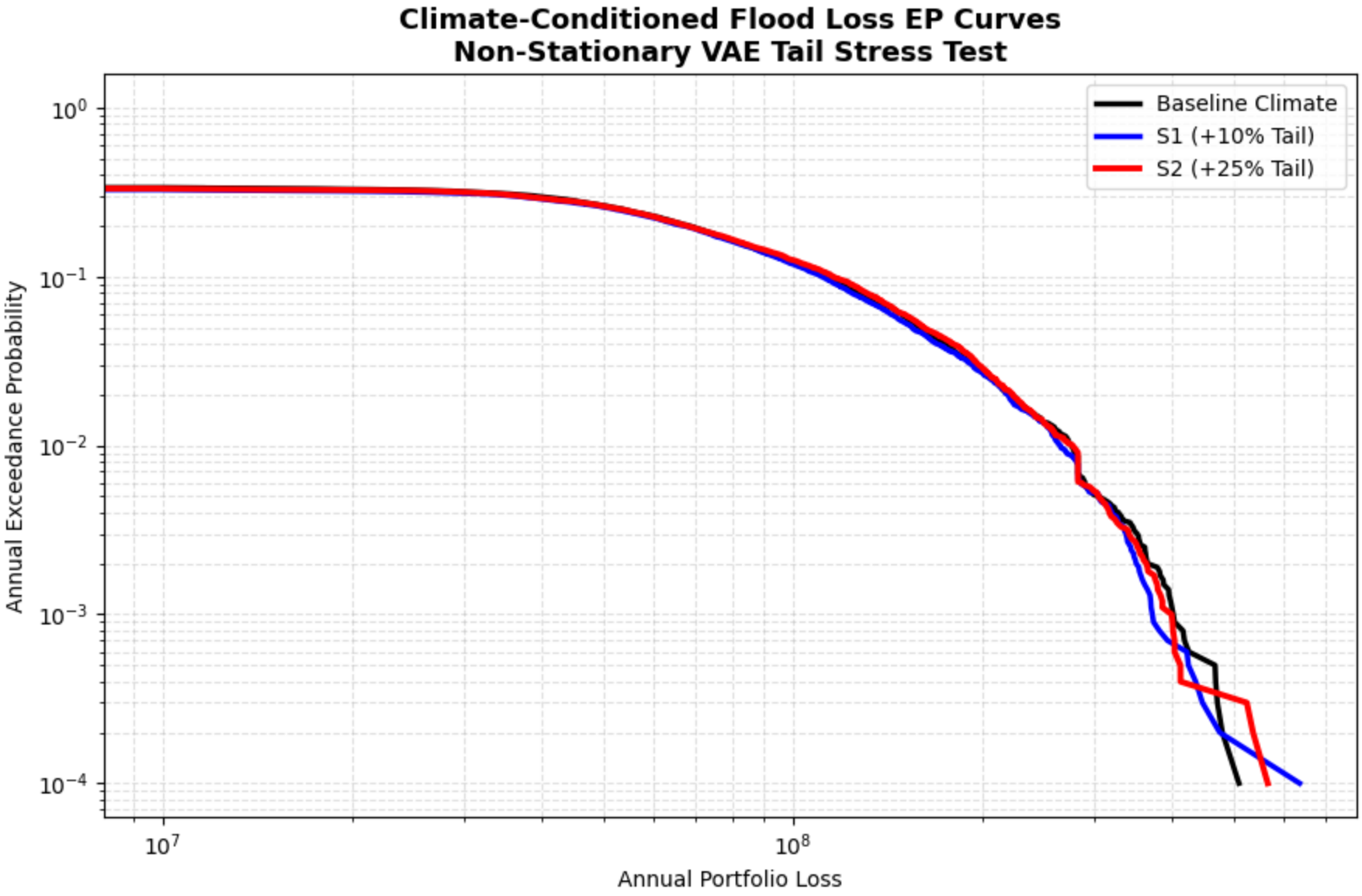

Q–Q Plot: Log-Excess vs Normal
Ordered Values
Theoretical quantiles
6
4
2
0
−2
−4
−3
−2
−1
0
1
2
3

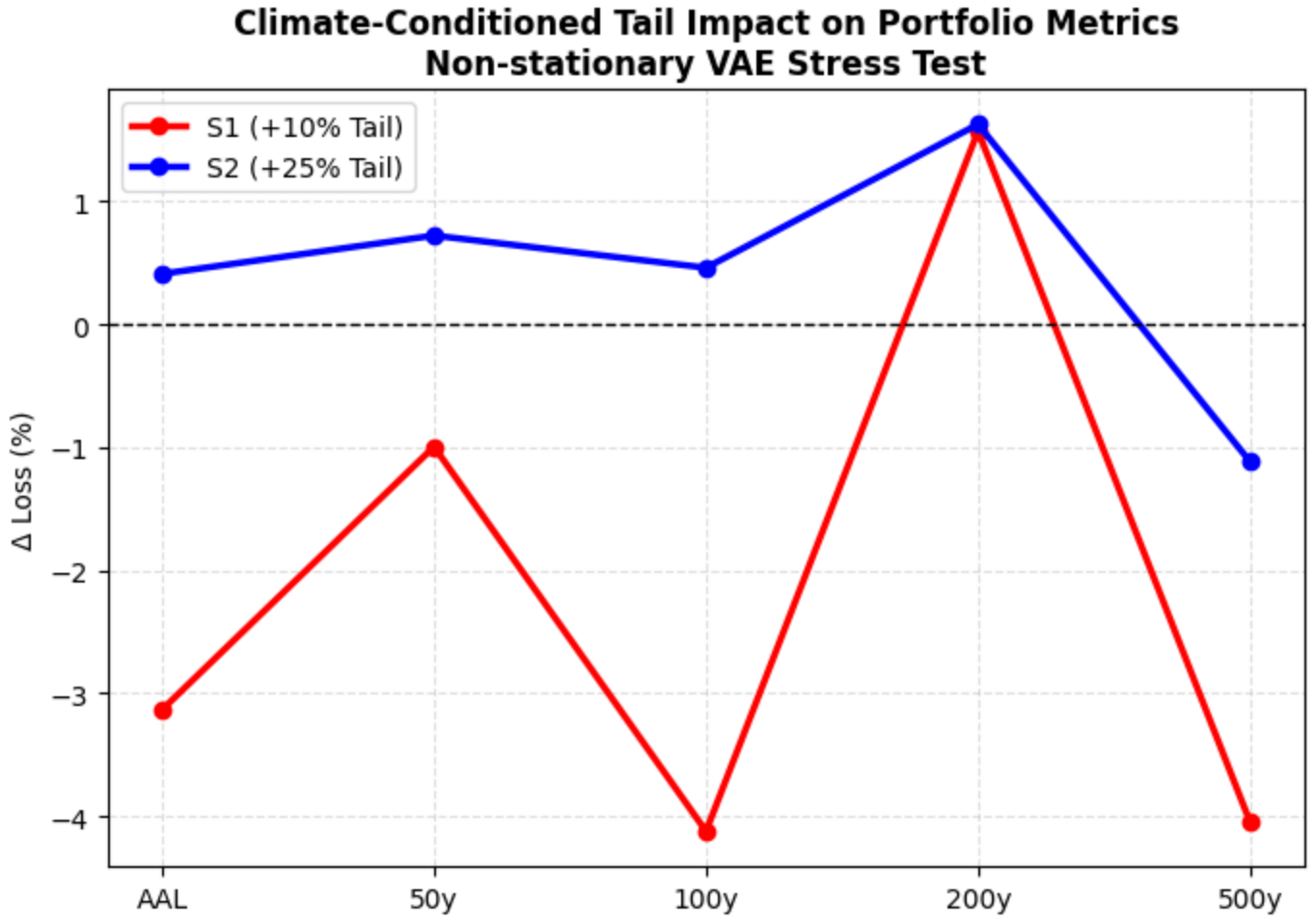

VAE-Generated Tail Rainfall Distribution
P95 threshold
Density
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
25
50
75
100
125
150
175
200
Rainfall (mm)

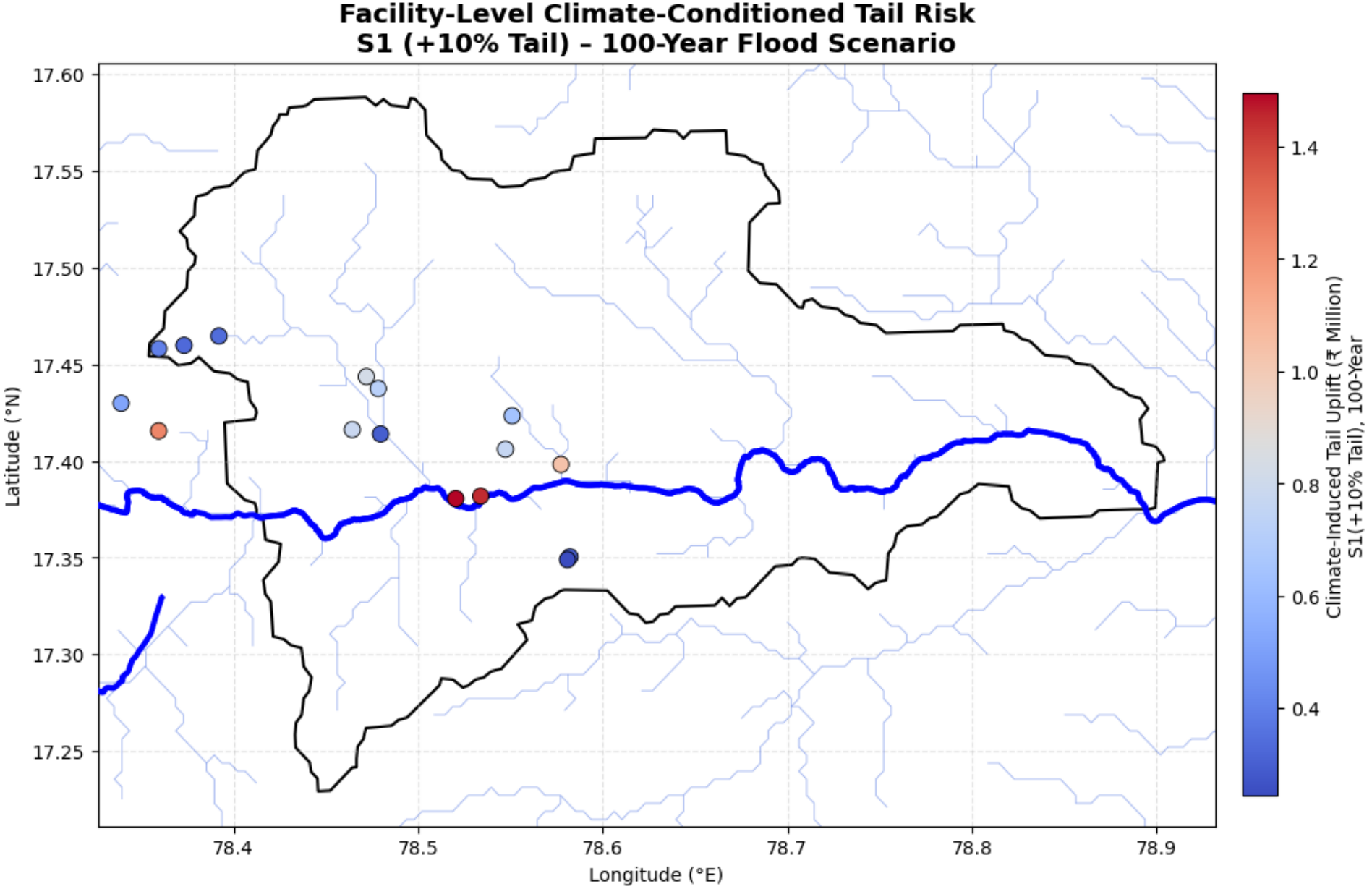

EVT vs VAE Tail Rainfall
EVT empirical
VAE generated
Density
0.00
0.02
0.04
0.06
0.08
25
50
75
100
125
150
175
200
Rainfall (mm)

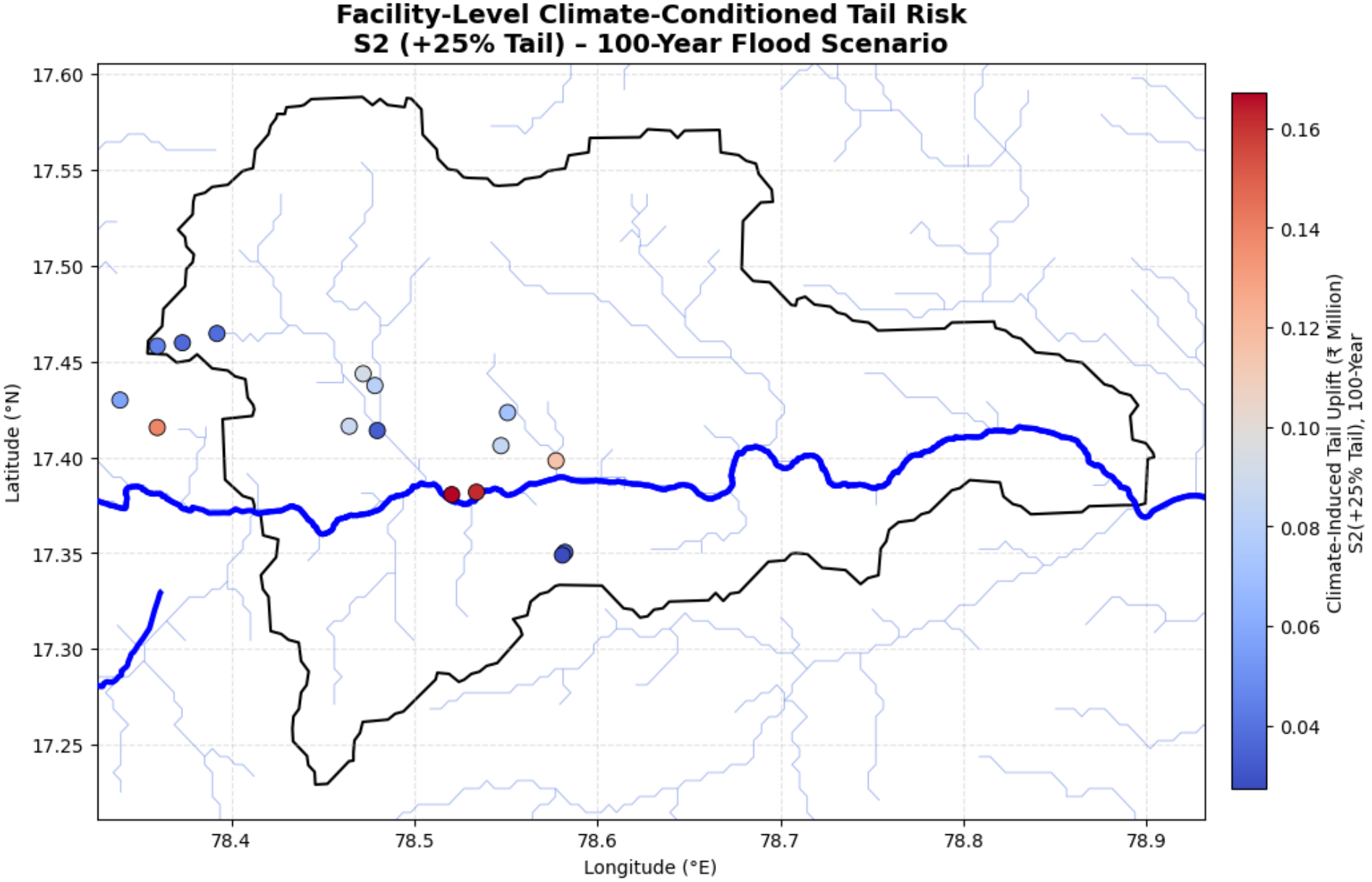

3-Way Flood Loss EP Curve Comparison – Musi Basin
EVT vs Monte Carlo vs EVT + VAE Tail Enrichment
Annual Exceedance Probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{7}
10^{8}
Annual Loss
EVT-only EP (Return Levels)
Monte Carlo EP
EVT + VAE Tail-Enriched EP

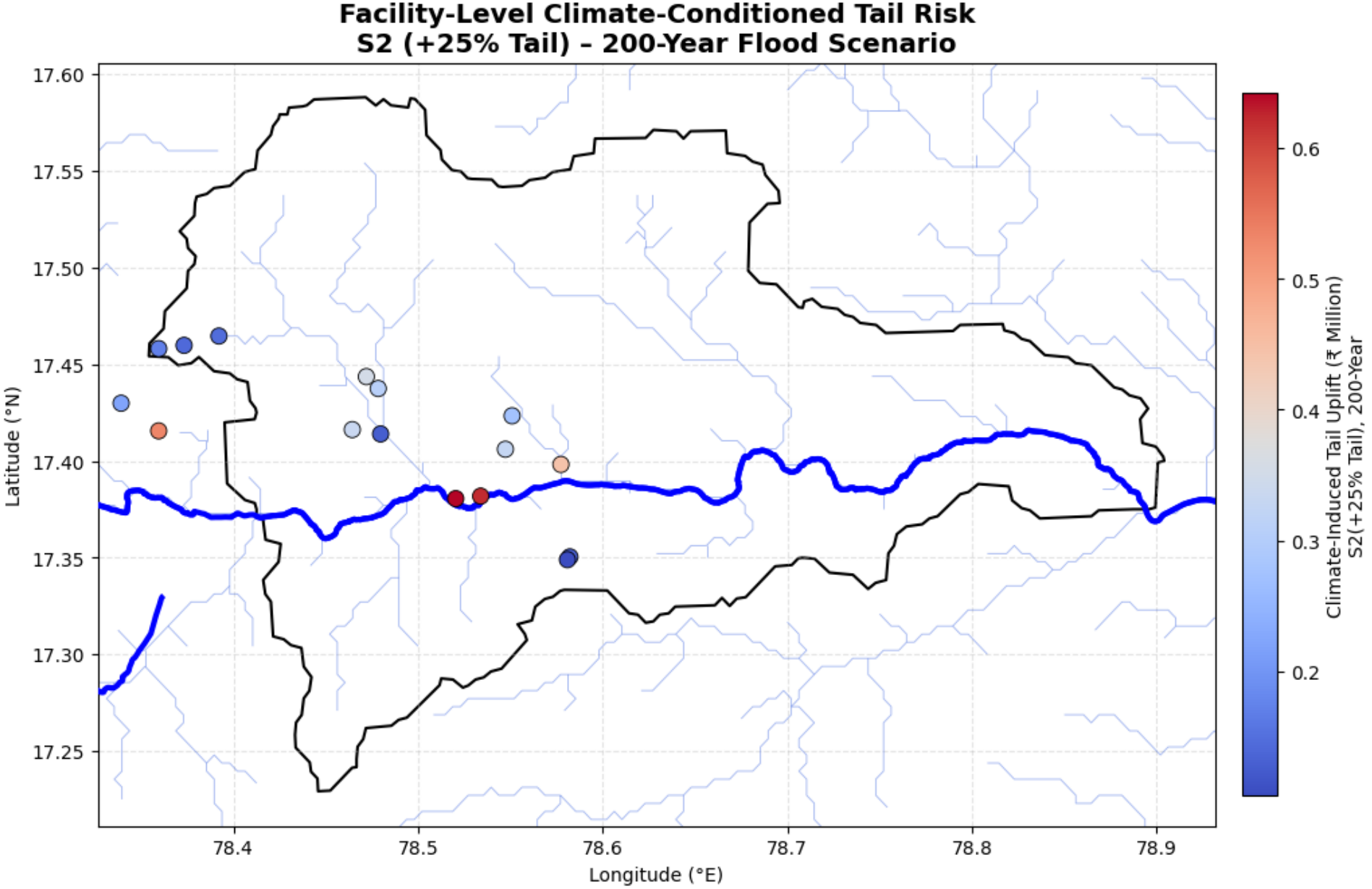

Facility-Level VAE Tail Risk Attribution
Color = Incremental Tail Loss from DGM
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
VAE Tail Uplift (Million)
1.6
1.4
1.2
1.0
0.8
0.6
0.4


Climate-Conditioned Flood Loss EP Curves
Non-Stationary VAE Tail Stress Test
Baseline Climate
S1 (+10% Tail)
S2 (+25% Tail)
Annual Exceedance Probability
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{7}
10^{8}
Annual Portfolio Loss

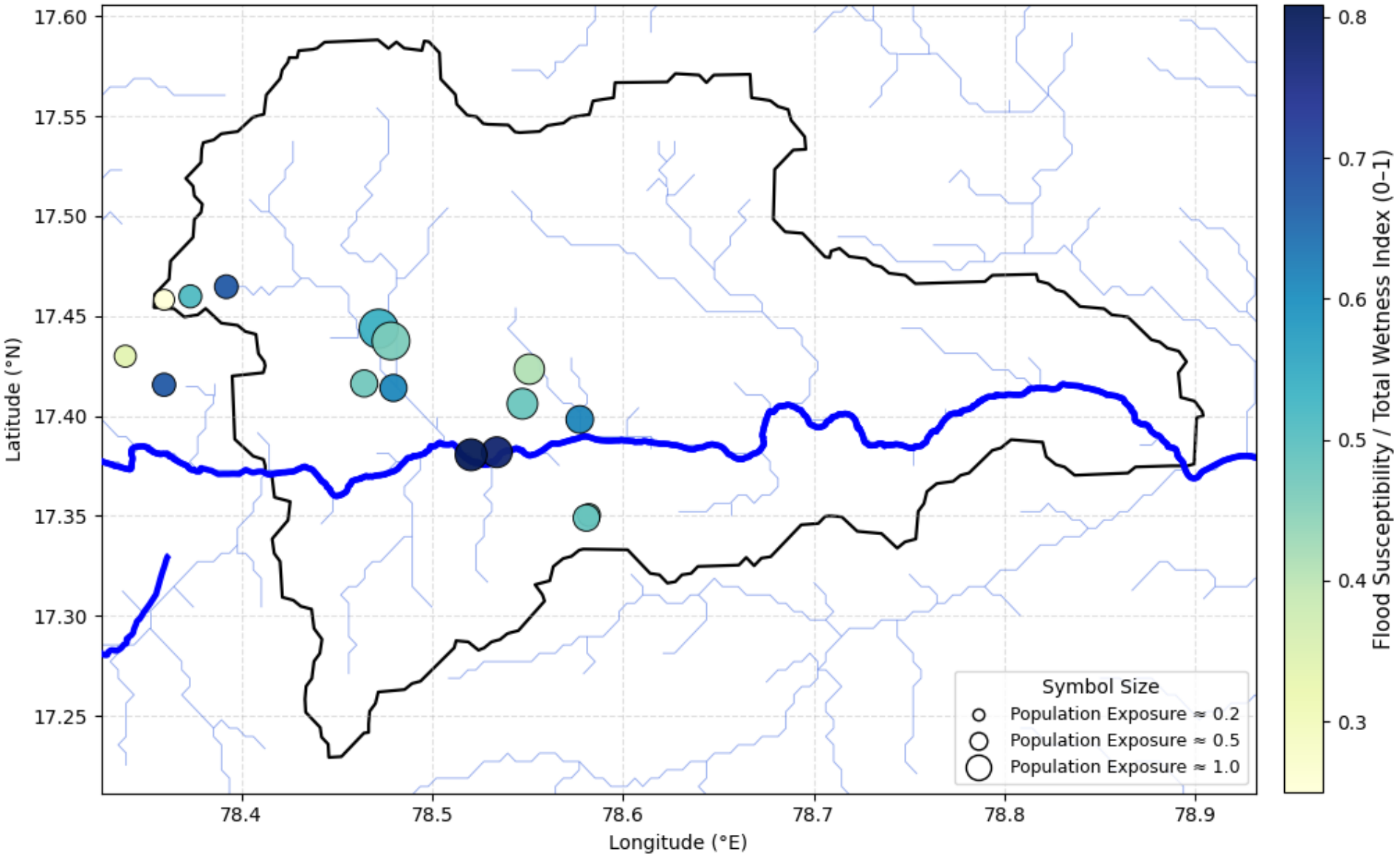

Climate-Conditioned Tail Impact on Portfolio Metrics
Non-stationary VAE Stress Test
S1 (+10% Tail)
S2 (+25% Tail)
Δ Loss (%)
1
0
−1
−2
−3
−4
AAL
50y
100y
200y
500y

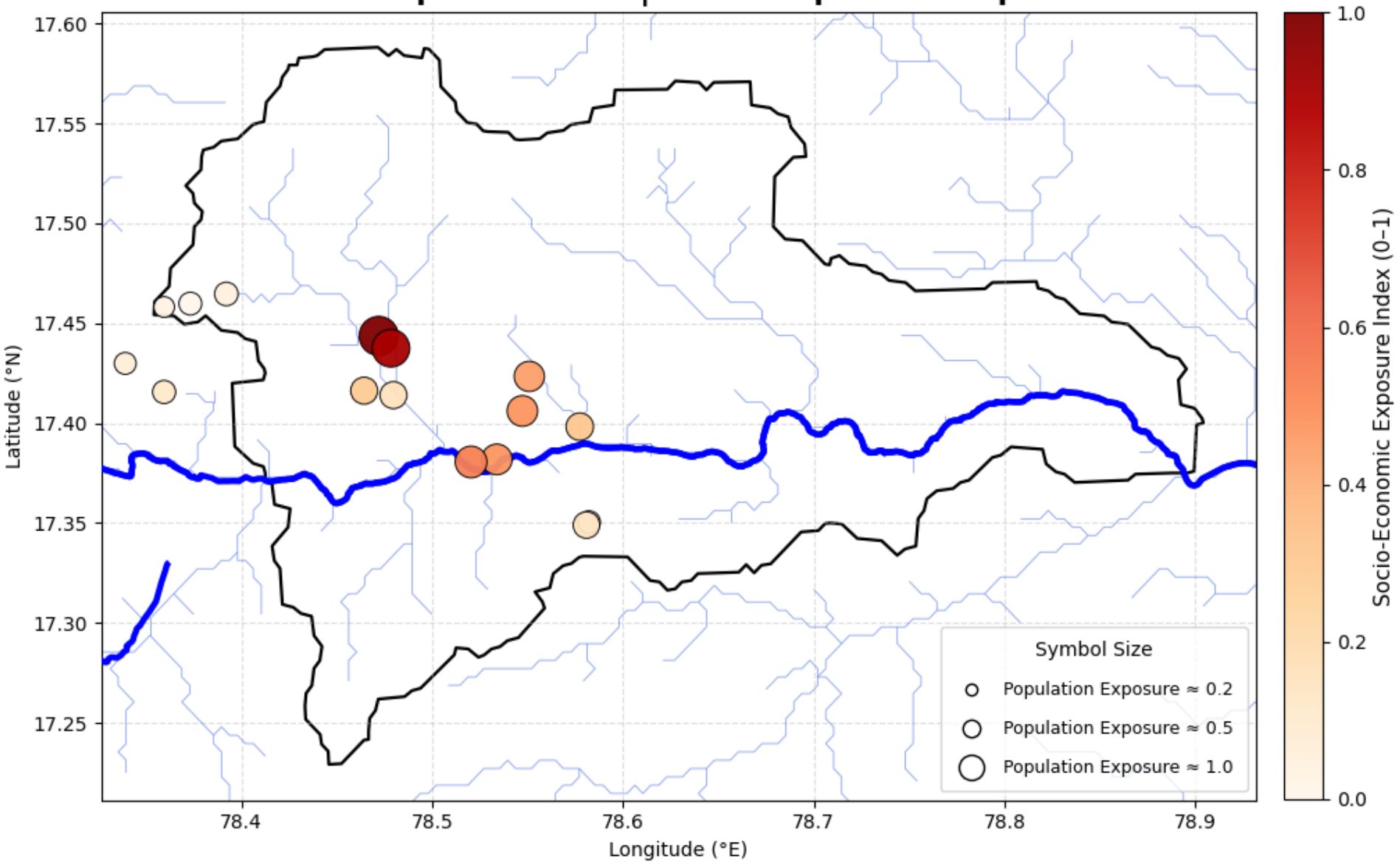

Facility-Level Climate-Conditioned Tail Risk
S1 (+10% Tail) – 100-Year Flood Scenario
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
Climate-Induced Tail Uplift (₹ Million)
S1(+10% Tail), 100-Year
1.4
1.2
1.0
0.8
0.6
0.4

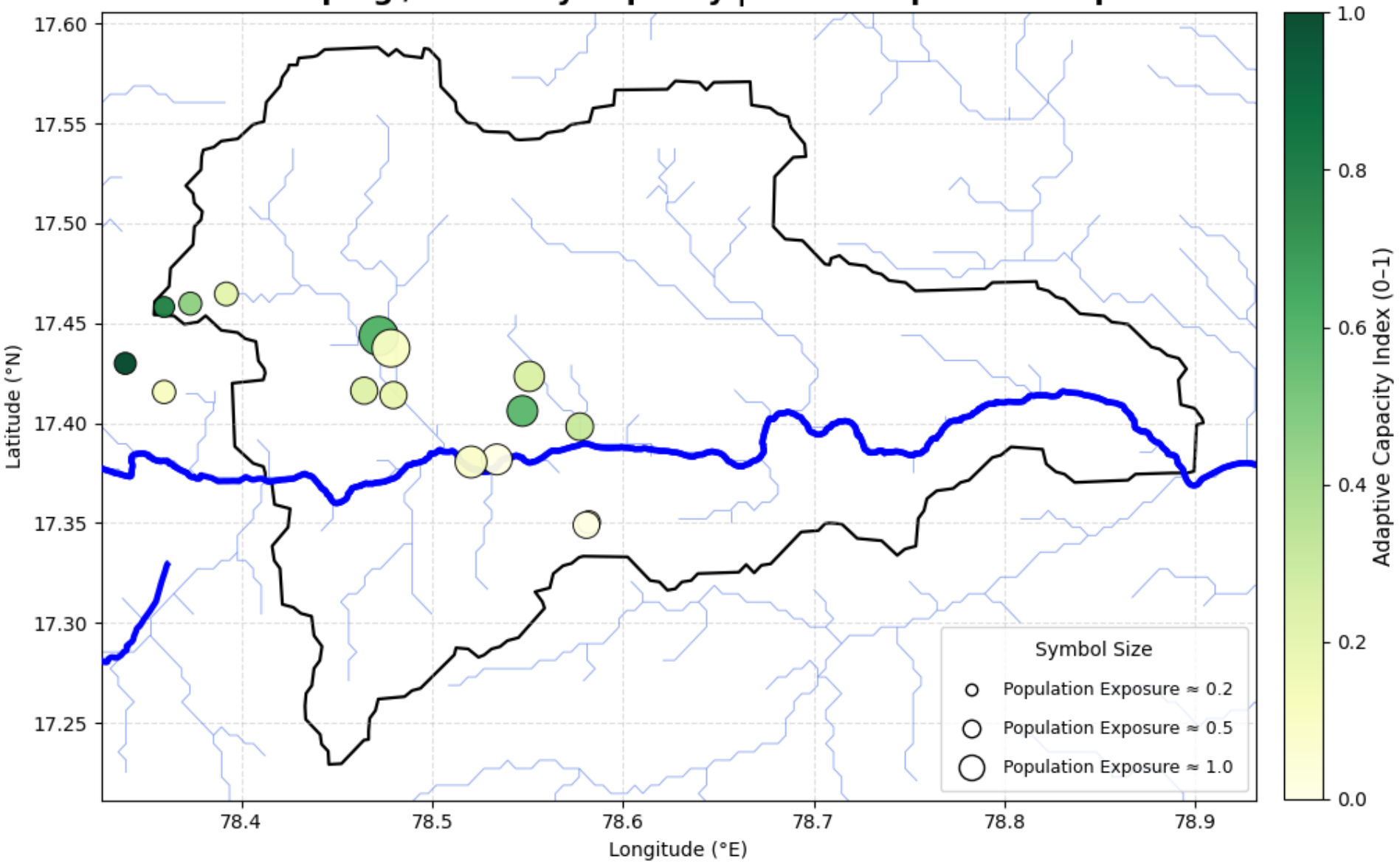

Facility-Level Climate-Conditioned Tail Risk
S2 (+25% Tail) – 100-Year Flood Scenario
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
Climate-Induced Tail Uplift (₹ Million)
S2(+25% Tail), 100-Year
0.16
0.14
0.12
0.10
0.08
0.06
0.04

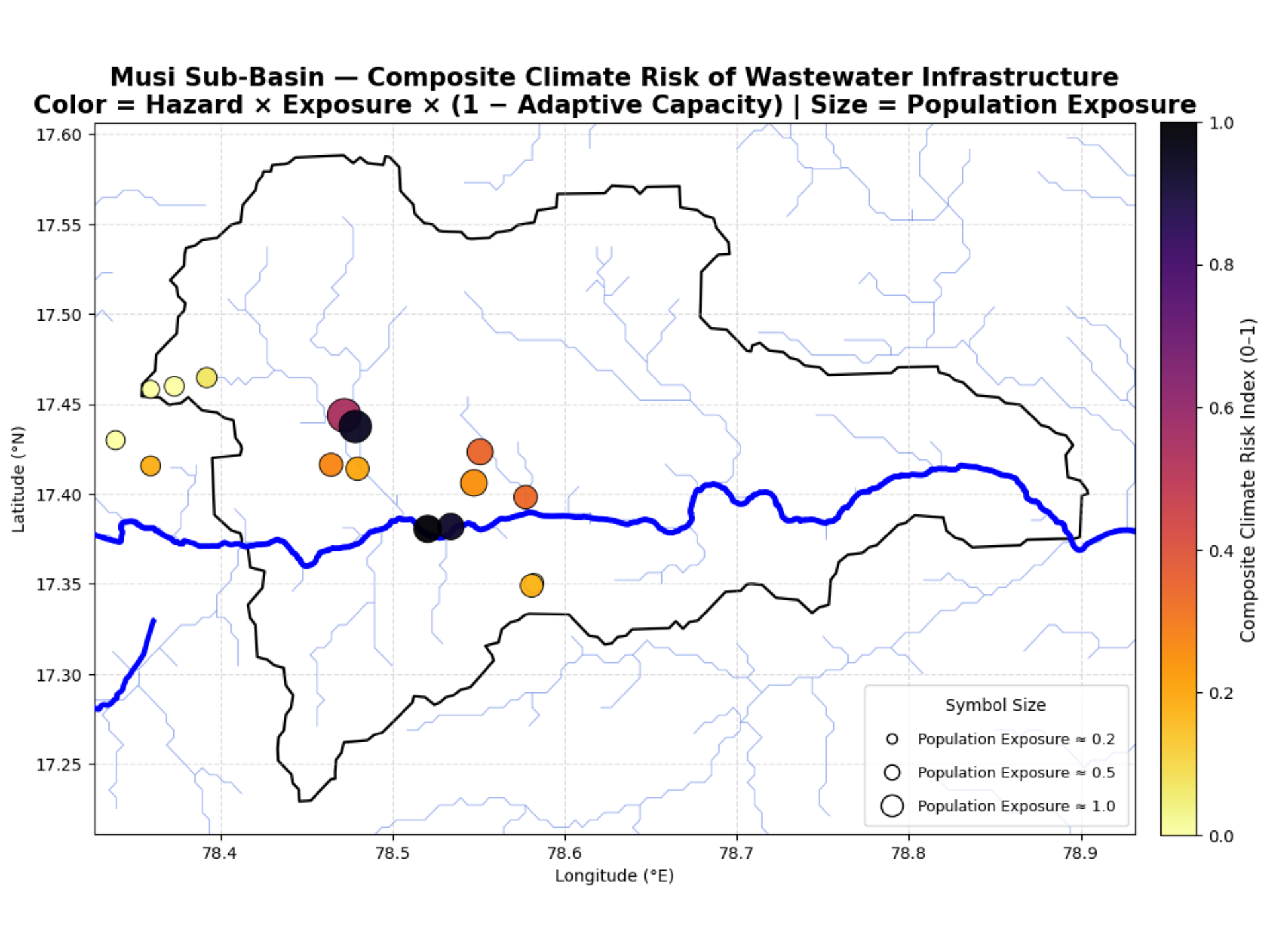

Facility-Level Climate-Conditioned Tail Risk
S2 (+25% Tail) – 200-Year Flood Scenario
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
Climate-Induced Tail Uplift (₹ Million)
S2(+25% Tail), 200-Year
0.6
0.5
0.4
0.3
0.2

indices


Musi Sub-Basin — Bio-Physical Flood Susceptibility Index
Color = Terrain Wetness & Drainage Susceptibility | Size = Population Exposure
Latitude (°N)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
Longitude (°E)
78.4
78.5
78.6
78.7
78.8
78.9
Flood Susceptibility / Total Wetness Index (0–1)
0.8
0.7
0.6
0.5
0.4
0.3
Symbol Size
Population Exposure ≈ 0.2
Population Exposure ≈ 0.5
Population Exposure ≈ 1.0


Musi Sub-Basin — Socio-Economic Exposure of Wastewater Infrastructure
Color = Exposure Index | Size = Population Exposure
Latitude (°N)
Longitude (°E)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
Symbol Size
Population Exposure ≈ 0.2
Population Exposure ≈ 0.5
Population Exposure ≈ 1.0
Socio-Economic Exposure Index (0–1)
1.0
0.8
0.6
0.4
0.2
0.0


Musi Basin – Adaptive Capacity of Wastewater Facilities
Color = Coping / Recovery Capacity | Size = Population Exposure
Latitude (°N)
Longitude (°E)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
Symbol Size
Population Exposure ≈ 0.2
Population Exposure ≈ 0.5
Population Exposure ≈ 1.0
Adaptive Capacity Index (0–1)
1.0
0.8
0.6
0.4
0.2
0.0


Musi Sub-Basin — Composite Climate Risk of Wastewater Infrastructure
Color = Hazard × Exposure × (1 − Adaptive Capacity) | Size = Population Exposure
Latitude (°N)
Longitude (°E)
17.60
17.55
17.50
17.45
17.40
17.35
17.30
17.25
78.4
78.5
78.6
78.7
78.8
78.9
Composite Climate Risk Index (0–1)
1.0
0.8
0.6
0.4
0.2
0.0
Symbol Size
Population Exposure ≈ 0.2
Population Exposure ≈ 0.5
Population Exposure ≈ 1.0

Musi Sub-Basin — VAE-Amplified Flood Tail Risk vs Composite Climate Risk