Hydrological Analysis of Upper Leaf River Basin

Basin Information and Study Area

The Upper Leaf River basin is located in south-central Mississippi, covering a drainage area of 4,540.54 km². This study presents a comprehensive hydrological analysis using the Coupled Routing and Excess Storage (CREST) distributed hydrological model for the period from January 1, 2020, to December 31, 2022. The analysis focuses on USGS gauge station #02473000, positioned at coordinates 31.343056°N, 89.280278°W, which serves as the primary calibration point for model performance evaluation.

Basin & Gauge Map

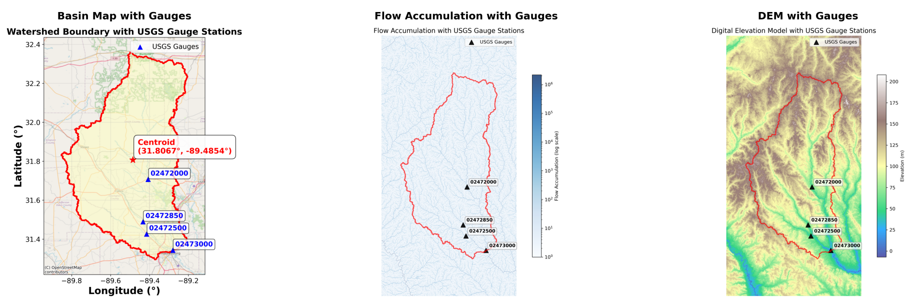

Figure 1: Basin and Gauge Locations

The Upper Leaf River basin exhibits a well-developed dendritic drainage network typical of the Gulf Coastal Plain physiographic province. The watershed contains five USGS gauging stations strategically positioned to capture flow characteristics across different sub-basins. The gauge #02473000, located at the basin outlet, integrates the total watershed response and provides the most comprehensive flow record for model calibration.

Fundamental Basin Data

Digital Elevation Model (DEM)

The basin topography displays moderate relief with elevations ranging from approximately 25 meters at the outlet to 200 meters in the headwater regions. The terrain is characterized by dissected uplands and well-defined valley systems, particularly prominent in the central and eastern portions of the watershed. These topographic features significantly influence the spatial distribution of runoff generation and flow routing processes.

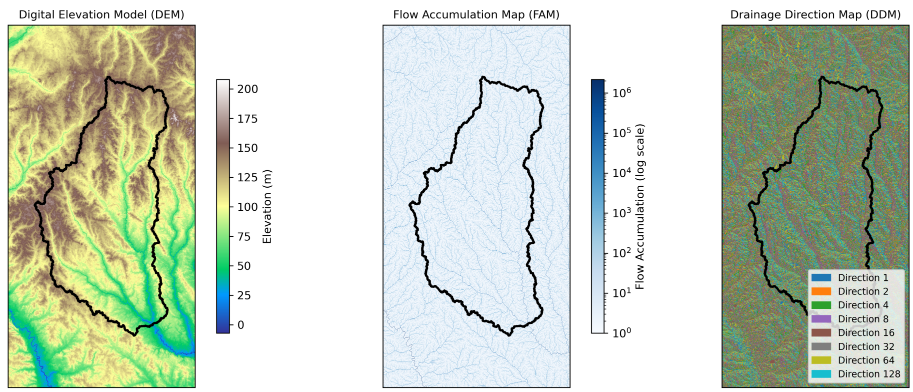

Figure 2: Basic Basin Data

Flow Accumulation Map (FAM)

The flow accumulation analysis reveals a hierarchical drainage network with maximum accumulation values exceeding 10^6 cells at the outlet. The high drainage density observed throughout the basin suggests responsive runoff characteristics and relatively short concentration times during storm events. The main stem channel follows a predominantly north-south orientation, collecting tributary flows from both eastern and western sub-basins.

Drainage Direction Map (DDM)

The drainage direction patterns reflect the complex topographic controls on surface water movement. The multicolored mosaic indicates varied flow directions across the landscape, with clear convergence zones in the central valley system. This spatial heterogeneity in drainage directions highlights the importance of distributed modeling approaches for accurate flow simulation.

Simulation vs Observation Comparison

The hydrograph comparison reveals several key insights into model performance across the 22-month analysis period (February 2020 - December 2021):

Precipitation-Runoff Response

The precipitation record (blue bars) shows frequent storm events with intensities ranging from minor (<1 mm/hr) to extreme (>3 mm/hr) conditions. The basin exhibits typical flashy behavior characteristic of humid subtropical watersheds, with rapid rises and recessions following precipitation events.

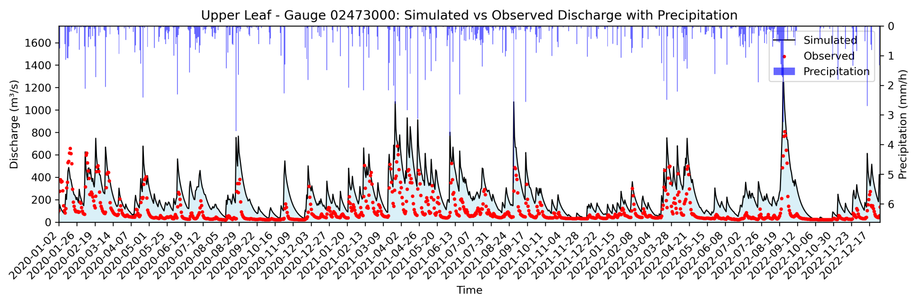

Figure 3: Simulation Results

Observed Discharge Characteristics

The observed discharge (red dots) demonstrates: - Baseflow conditions typically ranging from 50-200 m³/s - Moderate peak flows between 400-800 m³/s occurring multiple times annually - An extreme event in late August 2021 reaching approximately 1,600 m³/s - Clear seasonal patterns with higher flows during winter-spring months

Model Performance Analysis

The simulated discharge (black line) captures several hydrological behaviors well: - **Timing Accuracy**: Peak flow timing is generally well-synchronized with observations, indicating appropriate representation of basin lag times - **Baseflow Simulation**: Low flow conditions are reasonably reproduced, suggesting adequate groundwater and interflow parameterization - **Peak Flow Bias**: Systematic overestimation of moderate peaks (200-800 m³/s range) by approximately 20-40% - **Extreme Event Underestimation**: The August 2021 extreme event is notably underestimated (~1,100 m³/s simulated vs ~1,600 m³/s observed)

Model Performance Metrics

Performance Metric	Value	Description
Nash-Sutcliffe Efficiency (NSE)	-1.296	Model efficiency relative to observed mean
Kling-Gupta Efficiency (KGE)	-0.477	Balanced assessment of correlation, bias, and variability
Correlation Coefficient (r)	0.745	Linear correlation between observed and simulated flows
Bias	139.67 m³/s (138.0%)	Average overestimation of streamflow

Performance Metric	Value	Description
Root Mean Square Error (RMSE)	182.79 m^3/s	Average magnitude of simulation errors

The negative NSE and KGE values indicate that the model performs worse than using the observed mean as a predictor. However, the relatively high correlation coefficient (0.745) suggests that the model captures the timing and relative magnitude of flow variations reasonably well. The substantial positive bias (138%) indicates systematic overestimation of streamflow throughout the simulation period.

CREST Model Parameters

Water Balance Parameters

Parameter	Value	Description
Water Capacity (WM)	150.0 mm	Maximum soil water storage capacity
Infiltration Exponent (B)	8.0	Controls runoff generation sensitivity
Impervious Area Ratio (IM)	0.05	Fraction of impervious surfaces
PET Adjustment Factor (KE)	0.7	Potential evapotranspiration multiplier
Saturated Hydraulic Conductivity (FC)	15.0 mm/hr	Soil infiltration rate
Initial Soil Water (IWU)	25.0 mm	Initial soil moisture content

Kinematic Wave Routing Parameters

Parameter	Value	Description
Drainage Threshold (TH)	100.0 km^2	Minimum area for channel definition
Interflow Speed Multiplier (UNDER)	0.8	Subsurface flow velocity factor
Interflow Leakage Coefficient (LEAKI)	0.1	Interflow drainage rate
Initial Interflow Storage (ISU)	0.0 mm	Initial subsurface water content
Channel Flow Multiplier (ALPHA)	1.2	Channel wave celerity parameter
Channel Flow Exponent (BETA)	0.5	Channel hydraulic geometry exponent
Overland Flow Multiplier (ALPHA0)	1.5	Hillslope wave celerity parameter

Run Configuration

Configuration Parameter	Value
Basin Name	Upper Leaf
Basin Area	4,540.54 km^2
Simulation Period	2020-01-01 to 2022-12-31

Configuration Parameter	Value
Gauge ID	USGS #02473000
Gauge Location	31.343056°N, 89.280278°W
Time Step	Hourly
Spatial Resolution	Based on DEM grid

Discussion and Conclusions

Model Performance Evaluation

The CREST model implementation for the Upper Leaf River basin demonstrates mixed performance characteristics. While the model successfully captures the temporal dynamics of streamflow (r = 0.745), significant calibration challenges remain:

1. **Systematic Bias**: The 138% positive bias indicates fundamental issues with water balance representation. This could stem from:
    - Overestimation of precipitation inputs
    - Underestimation of evapotranspiration losses
    - Inadequate representation of deep percolation or groundwater losses
2. **Peak Flow Dynamics**: The contrasting behavior of overestimating moderate peaks while underestimating extreme events suggests nonlinear threshold effects not adequately captured by the current parameter set. The infiltration exponent (B = 8.0) may be too high, creating excessive runoff for moderate events.
3. **Initial Conditions**: The relatively low initial soil water content (IWU = 25.0 mm) compared to the total capacity (WM = 150.0 mm) may contribute to the model's tendency to generate excessive runoff early in the simulation period.

Warmup Period Considerations

Given the substantial positive bias rather than the negative bias threshold mentioned (-90%), warmup period issues are less likely to be the primary concern. However, extending the warmup period beyond the current configuration could help establish more representative antecedent moisture conditions, particularly for the interflow storage component.

Recommendations for Future Simulations

1. **Parameter Recalibration**: Priority should be given to reducing the infiltration exponent (B) and potentially increasing the PET adjustment factor (KE) to address the positive bias.

2. **Extended Simulation Period**: Consider extending the analysis to include additional years of data to better capture climatic variability and extreme events.

3. **Multi-objective Calibration**: Implement a calibration strategy that balances multiple performance metrics, particularly focusing on reducing bias while maintaining timing accuracy.

4. **Spatial Parameter Distribution**: Investigate spatially variable parameters based on soil types and land use to better represent basin heterogeneity.

5. **Event-based Analysis**: Conduct separate evaluations for different flow regimes (low, moderate, high) to identify regime-specific parameter sensitivities.

6. **Uncertainty Analysis**: Implement uncertainty quantification methods to assess parameter and structural uncertainties in model predictions.

The current model configuration provides a foundation for hydrological analysis in the Upper Leaf River basin but requires substantial refinement to achieve acceptable performance standards for operational use. The high correlation coefficient indicates that the model structure is fundamentally sound, suggesting that improved calibration could yield significantly better results.