Hydrological Simulation Report - Upper French Broad River Basin

Basin & Gauge Information

The Upper French Broad River basin is located in western North Carolina, encompassing the headwaters of the French Broad River system within the Blue Ridge Mountains region. This mountainous watershed represents a critical component of the Tennessee River basin, draining approximately 4,868 km² of diverse topography ranging from high-elevation ridges to valley floors.

Basin Overview

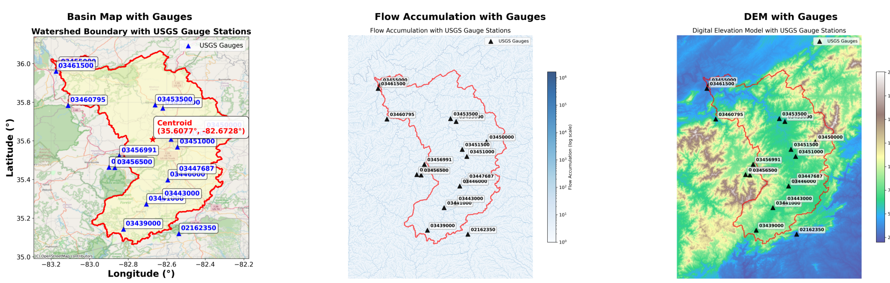

Figure 1: Basin and Gauge Map

The Upper French Broad River basin encompasses approximately 4,868 km² in western North Carolina, with the basin centroid located at 35.6077°N, -82.6728°W. The watershed contains multiple USGS gauge stations distributed throughout the drainage network, with gauge **03455000** serving as the primary monitoring point for this analysis. The basin exhibits a dendritic drainage pattern typical of Appalachian watersheds, with multiple tributaries converging toward the main stem through deeply incised valleys characteristic of the Blue Ridge physiographic province.

Fundamental Basin Data

The Digital Elevation Model reveals significant topographic relief ranging from approximately 250m to over 2,000m elevation, characteristic of the Blue Ridge Mountains region. Higher elevations (>1,500m) dominate the western and northern portions, transitioning to lower elevations toward the southeast. The Flow Accumulation Map clearly delineates the primary drainage network, with high accumulation values (>10) concentrated along the main channel and major tributaries. The Drainage Direction Map shows a predominantly southeast-flowing drainage pattern, with the main stem exhibiting classic dendritic branching as tributaries join from multiple directions throughout the basin.

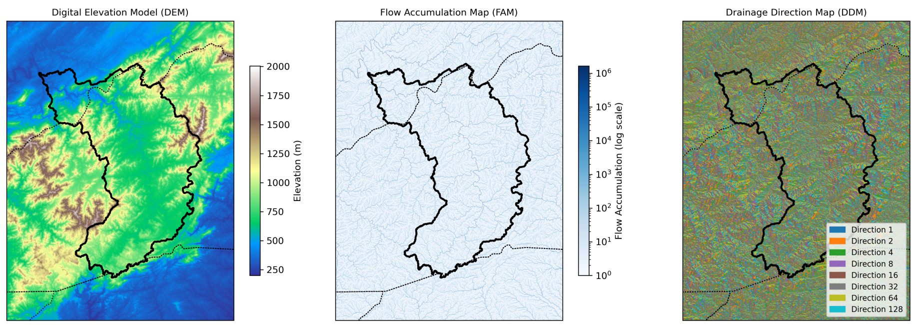

Figure 2: Basic Basin Data

Basin Characteristic	Value
Basin Area	4,867.99 km²
Primary Gauge	USGS #03455000
Gauge Location	35.981611°N, -83.161088°W
Simulation Period	2020-01-01 to 2022-12-31
Elevation Range	~250m to >2,000m
Physiographic Region	Blue Ridge Mountains

Simulation vs Observation Analysis

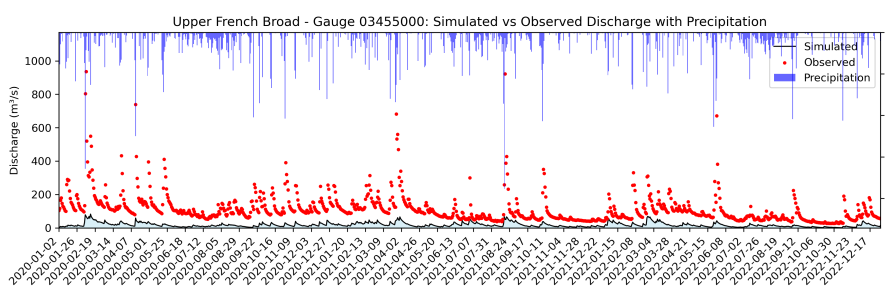

Figure 3: Simulation Results

The hydrograph comparison for gauge **03455000** reveals significant discrepancies between simulated and observed streamflow patterns. The simulated discharge maintains relatively steady baseflow conditions (~20-50 m³/s) with occasional moderate peaks reaching 100-200 m³/s, while observed discharge shows significantly higher variability and peak magnitudes, with several events exceeding 600-800 m³/s.

Key Observations:

- **Systematic Underestimation**: The model consistently underestimates peak flows, particularly during major storm events
- **Muted Response**: Simulated peaks show dampened response to precipitation events compared to observations
- **Baseflow Patterns**: While baseflow recession shows reasonable correspondence, the magnitude remains underestimated
- **Timing Issues**: Some phase shifts are evident between simulated and observed peaks
- **Extreme Events**: The model fails to capture the magnitude of major flood events, particularly those occurring in early 2020, mid-2021, and

Model Performance Metrics

The quantitative assessment of model performance reveals significant challenges in reproducing observed streamflow patterns:

Metric	Value	Interpretation
Nash-Sutcliffe Efficiency (NSCE)	-0.955	Poor performance; model performs worse than mean
Kling-Gupta Efficiency (KGE)	-0.242	Poor overall performance
Correlation Coefficient (r)	0.668	Moderate correlation between timing patterns
Bias	-93.87 m^3/s (-83.8%)	Severe underestimation
Root Mean Square Error (RMSE)	123.61 m^3/s	High absolute error magnitude

Performance Analysis:

The negative NSCE value indicates that the model performs worse than simply using the mean of observed values as a predictor. The severe negative bias (-83.8%) suggests systematic underestimation throughout the simulation period. Despite poor overall metrics, the moderate correlation (r = 0.668) indicates that the model captures some timing aspects of the hydrologic response, suggesting that parameter adjustment rather than structural model changes may be needed.

CREST Model Parameters

The Coupled Routing and Excess STorage (CREST) model was configured with the following parameter set:

Water Balance Parameters

Parameter	Value	Unit	Description
WM	150.0	mm	Maximum soil water capacity
B	5.0	-	Infiltration curve exponent
IM	0.05	-	Impervious area ratio
KE	0.7	-	PET adjustment factor
FC	75.0	mm/hr	Soil saturated hydraulic conductivity
IWU	25.0	mm	Initial soil water value

Kinematic Wave (Routing) Parameters

Parameter	Value	Unit	Description
TH	150.0	km^2	Drainage threshold
UNDER	1.5	-	Interflow speed multiplier
LEAKI	0.1	-	Interflow reservoir leakage coefficient
ISU	0.0	mm	Initial interflow reservoir value
ALPHA	1.0	-	Channel flow multiplier
BETA	0.5	-	Channel flow exponent
ALPHA0	1.2	-	Overland flow multiplier

Parameter Sensitivity Analysis:

The current parameter configuration appears to limit runoff generation through several mechanisms: - High **WM** (150.0 mm) provides substantial soil water storage capacity - Moderate **B** (5.0) controls infiltration partitioning - Low **IM** (0.05) minimizes direct runoff from impervious surfaces - Conservative **KE** (0.7) reduces potential evapotranspiration - High **FC** (75.0 mm/hr) promotes infiltration over surface runoff

Discussion and Recommendations

Model Performance Evaluation

The simulation results indicate substantial challenges in reproducing observed streamflow patterns in the Upper French Broad River basin. The combination of negative NSCE (-0.955) and severe negative bias (-83.8%) suggests fundamental issues with either parameter calibration or model structure for this particular watershed.

Critical Issues Identified:

1. **Runoff Generation**: The model significantly underestimates surface runoff and quick flow components
2. **Peak Flow Capture**: Major storm events are not adequately simulated, suggesting issues with excess rainfall calculations
3. **Hydrologic Response**: The muted response to precipitation indicates potential problems with:
   - Soil moisture accounting
   - Infiltration excess mechanisms
   - Channel routing efficiency

Warmup Period Considerations

Given the severe negative bias ($<$ -90%), the model may require an extended warmup period to achieve appropriate initial conditions. The current 3-year simulation period may be insufficient for: - Soil moisture equilibration - Groundwater storage initialization - Channel network flow establishment

Recommendations for Model Improvement:

Immediate Actions:

1. **Parameter Recalibration**: Focus on runoff generation parameters (WM, B, FC)
2. **Extended Warmup**: Implement 1-2 year warmup period before evaluation period
3. **Precipitation Validation**: Verify forcing data quality and spatial representation

Medium-term Improvements:

1. **Multi-objective Calibration**: Balance peak flows, baseflow, and timing metrics
2. **Parameter Sensitivity Analysis**: Systematic evaluation of parameter interactions
3. **Spatial Calibration**: Consider sub-basin parameter variation

Long-term Considerations:

1. **Model Structure Evaluation**: Assess alternative runoff generation schemes
2. **Data Quality Assessment**: Evaluate gauge data quality and rating curve accuracy
3. **Distributed Parameter Fields**: Implement spatially varying parameters based on land use and soil properties

Simulation Period Recommendations

For future applications, consider: - **Warmup Period**: 2019-2020 (minimum 1 year) - **Calibration Period**: 2020-2021 - **Validation Period**: 2022-2023 - **Extended Analysis**: Include additional years if available for robust evaluation

Conclusion

The current CREST model configuration for the Upper French Broad River basin requires significant parameter adjustment and potentially structural modifications to achieve acceptable performance. The systematic underestimation of streamflow suggests that the model is not adequately capturing the hydrologic processes governing runoff generation in this mountainous watershed. Priority should be given to recalibrating runoff generation parameters while ensuring adequate model warmup and validation procedures are implemented.

The moderate correlation ($r = 0.668$) provides hope that with proper calibration, the model can achieve acceptable performance for water resources applications in this important Appalachian watershed.