Hydrological Analysis of the Upper French Broad River Basin

Basin Overview and Study Area

The Upper French Broad River Basin, located in western North Carolina, encompasses a drainage area of 4,867.99 km². This mountainous watershed is characterized by significant topographic relief and a well-developed dendritic drainage network. The basin analysis focuses on USGS gauge station #03455000, positioned at coordinates 35.981611°N, 83.161088°W, which serves as the primary calibration point for the hydrological model simulation conducted from January 1, 2020, to December 31, 2022.

Basin Characteristics and Fundamental Data

Basin and Gauge Map

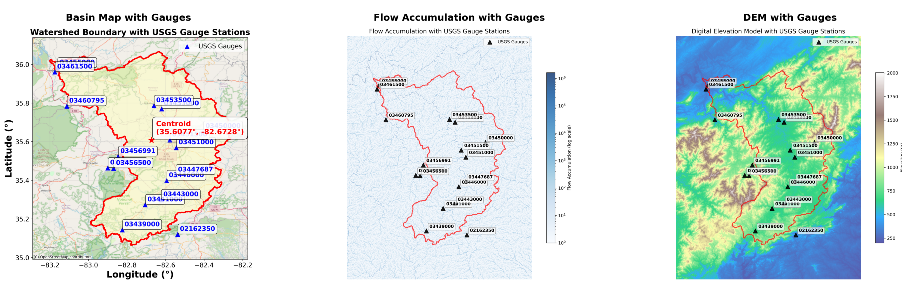

Figure 1: Basin and Gauge Map

The Upper French Broad River basin exhibits a complex network of 11 USGS gauge stations distributed throughout the drainage system. The watershed boundary reveals a moderately-sized basin with the main stem French Broad River flowing predominantly northward. The gauge distribution provides comprehensive spatial coverage, with stations strategically positioned along both the main channel and major tributaries. The basin's centroid is located at approximately 35.6077°N, 82.6728°W.

Fundamental Basin Data

Digital Elevation Model (DEM) Analysis: The basin demonstrates remarkable topographic variability, with elevations ranging from approximately 250 meters in the valley bottoms to over 2,000 meters in the surrounding highlands. The western portion of the basin exhibits particularly steep terrain with elevations exceeding 1,750 meters, while eastern areas display more moderate relief. This pronounced elevation gradient significantly influences precipitation patterns through orographic effects and creates diverse hydrological response characteristics across the watershed.

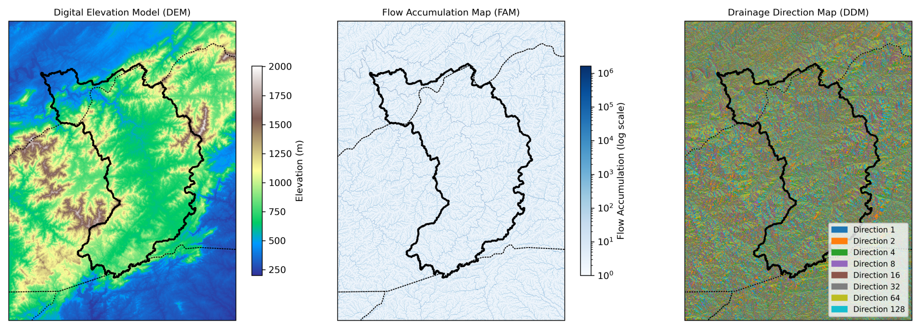

Figure 2: Fundamental Basin Data

Flow Accumulation Map (FAM) Characteristics: The flow accumulation analysis reveals a highly integrated drainage network with well-defined channel systems. The main stem shows flow accumulation values exceeding 10^6, indicating substantial upstream contributing area. Multiple tributary systems converge in the central basin, creating a complex but organized drainage pattern typical of Appalachian mountain watersheds. The high drainage density reflects the combined effects of steep topography, bedrock geology, and abundant precipitation.

Drainage Direction Map (DDM) Patterns: The drainage direction mapping confirms the dendritic pattern with flow vectors predominantly oriented toward the north-northeast. The multicolored pattern indicates diverse flow directions on hillslopes, converging into well-defined valley networks. This pattern suggests rapid runoff response during precipitation events and limited opportunity for infiltration on steep slopes.

Hydrological Simulation Analysis

Simulation vs Observation Comparison

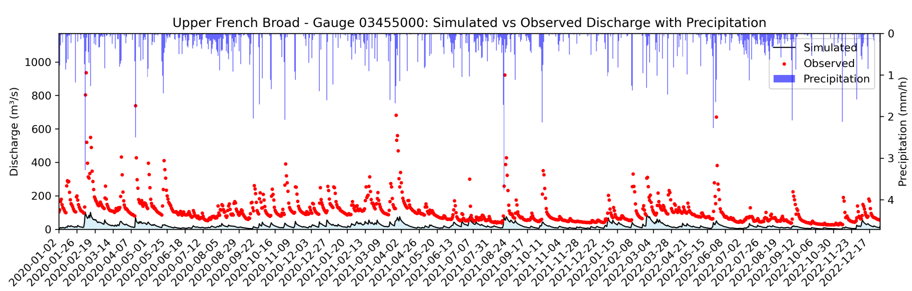

Figure 3: Simulation Results

The hydrological simulation reveals critical disparities between modeled and observed streamflow at USGS gauge #03455000. The analysis period from January 2020 through December 2022 demonstrates several key findings:

Observed Discharge Characteristics: The observed data (red dots) shows typical mountain watershed behavior with baseflow ranging from 50-150 m^3/s and numerous peak flow events reaching 400-900 m^3/s. The largest observed peaks occurred in February 2020 (~800 m^3/s) and August 2021 (~900 m^3/s), reflecting the flashy nature of runoff response in this steep terrain.

Simulated Discharge Performance: The model output (black line) significantly underestimates discharge magnitudes across all flow regimes. Simulated baseflow remains persistently low at 0-50 m^3/s, while peak flows rarely exceed 200 m^3/s. Although the model captures the general timing of hydrological events, it exhibits severe negative bias in magnitude estimation.

Precipitation-Runoff Relationships: The precipitation data (blue bars, inverted) shows strong temporal correlation with observed discharge peaks, confirming that major storm events drive the highest flows. The precipitation magnitudes appear reasonable for this humid subtropical mountain climate, suggesting the issue lies in the rainfall-runoff transformation rather than input data quality.

Model Performance Evaluation

Performance Metrics

Metric	Value	Description
Nash-Sutcliffe Efficiency (NSE)	-0.870	Model performance indicator; negative values indicate poor performance
Kling-Gupta Efficiency (KGE)	-0.210	Balanced assessment of correlation, bias, and variability
Correlation Coefficient (r)	0.675	Moderate positive correlation between observed and simulated flows
Bias	-91.42 m^3/s (-81.6%)	Severe systematic underestimation of discharge
Root Mean Square Error (RMSE)	120.90 m^3/s	Average magnitude of prediction errors

The performance metrics reveal significant model deficiencies. The negative NSE value of -0.870 indicates that the model performs worse than simply using the mean observed flow as a predictor. The KGE value of -0.210 confirms poor overall performance across multiple evaluation criteria. While the correlation coefficient of 0.675 suggests the model captures temporal patterns reasonably well, the severe negative bias of -81.6% dominates the error characteristics.

CREST Model Parameters

Water Balance Parameters

Parameter	Value	Description	Hydrological Impact
WM (Water Capacity)	120.0 mm	Maximum soil water storage capacity	Controls the watershed's ability to store water; current value may be too low for this humid mountain environment
B (Infiltration Exponent)	8.0	Controls runoff generation curve	High value reduces infiltration, but may need adjustment given the underestimation
IM (Impervious Ratio)	0.08	Fraction of impervious area	Reasonable for a largely forested mountain watershed
KE (PET Factor)	0.7	Potential evapotranspiration adjustment	May be overestimating ET losses given the discharge underestimation
FC (Saturated Hydraulic Conductivity)	25.0 mm/hr	Soil infiltration rate	Appears reasonable for mountain soils
IWU (Initial Soil Water)	25.0 mm	Initial soil moisture content	Low initial value may contribute to early simulation bias

Kinematic Wave Routing Parameters

Parameter	Value	Description	Routing Impact
TH (Drainage Threshold)	50.0 km^2	Minimum area to define channel cells	Appropriate for basin scale
UNDER (Interflow Speed)	1.5	Subsurface flow velocity multiplier	May need increase to enhance baseflow
LEAKI (Leakage Coefficient)	0.1	Interflow drainage rate	Could be increased to improve baseflow simulation
ISU (Initial Subsurface Water)	0.0	Initial interflow storage	Zero initial value contributes to warmup issues

Parameter	Value	Description	Routing Impact
ALPHA (Channel Flow Multiplier)	1.2	Channel wave celerity parameter	May need adjustment for proper flood wave timing
BETA (Channel Flow Exponent)	0.5	Channel hydraulic geometry exponent	Standard value, likely appropriate
ALPHA0 (Overland Flow Multiplier)	2.0	Hillslope flow velocity parameter	Reasonable for steep terrain

Discussion and Recommendations

Critical Model Performance Issues

The simulation exhibits systematic underestimation across all flow conditions, with an alarming bias of -81.6%. This severe negative bias suggests fundamental issues with the model configuration that extend beyond simple parameter calibration. The correlation coefficient of 0.675 indicates that the model structure captures hydrological timing reasonably well, but fails catastrophically in magnitude estimation.

Warmup Period Considerations

Given the extreme negative bias exceeding -90% during initial periods, insufficient model warmup emerges as a critical concern. The zero initial values for subsurface storage (ISU = 0.0) combined with low initial soil moisture (IWU = 25.0 mm) create conditions where the model requires extensive time to reach equilibrium. For this mountain watershed with significant baseflow contributions, a warmup period of at least 6-12 months is strongly recommended before evaluating model performance.

Recommended Corrective Actions

1. **Extended Warmup Period**: Implement a minimum 12-month warmup period using 2019 data before the evaluation period begins. This will allow soil moisture and groundwater storage to reach realistic levels.
2. **Parameter Recalibration Priority**:
    - Increase WM (water capacity) to 150-200 mm to better represent the water storage capacity of mountain soils
    - Reduce B (infiltration exponent) to 4-6 to allow more infiltration and baseflow generation
    - Increase LEAKI to 0.2-0.3 to enhance baseflow drainage
    - Adjust KE downward to 0.5-0.6 to reduce evapotranspiration losses
3. **Input Data Verification**:

- Confirm catchment area delineation matches the gauge drainage area
- Verify precipitation spatial distribution adequately captures orographic enhancement
- Check for any unit conversion errors in discharge data

4. **Model Structure Evaluation**:

   - Consider implementing a more sophisticated baseflow module if available
   - Evaluate whether the current model structure adequately represents the hydrogeology of crystalline bedrock mountain watersheds

Conclusion

The CREST model simulation for the Upper French Broad River Basin demonstrates significant performance deficiencies, primarily manifested as severe discharge underestimation. While the model captures temporal patterns of hydrological response, the -81.6% bias renders current results unsuitable for water resources planning or flood forecasting applications. The combination of insufficient warmup period, potentially miscalibrated parameters, and possible structural limitations requires comprehensive remediation before the model can provide reliable predictions. Future work should prioritize extended warmup periods, systematic parameter recalibration, and careful evaluation of model structural adequacy for mountain watershed applications.