Hydrological Simulation Report - Little Bighorn River Basin

Basin Information

Basin & Gauge Map

The Little Bighorn River basin is located in Montana, with a centroid at approximately 45.21°N, 107.47°W. The basin exhibits an elongated north-south orientation with three USGS gauge stations positioned along the main stem:

- **06294000** (Little Bighorn) - Located at the northern outlet, representing the most downstream monitoring point
- **06289052** and **06289820** - Positioned in the southern portion of the basin, likely capturing headwater contributions

The flow accumulation map reveals a well-defined dendritic drainage network, with the highest accumulation values (>10 cells) concentrated along the main channel leading to gauge 06294000. The basin boundary encompasses approximately 3,359.4 km² of mountainous terrain in the northern Rocky Mountain region.

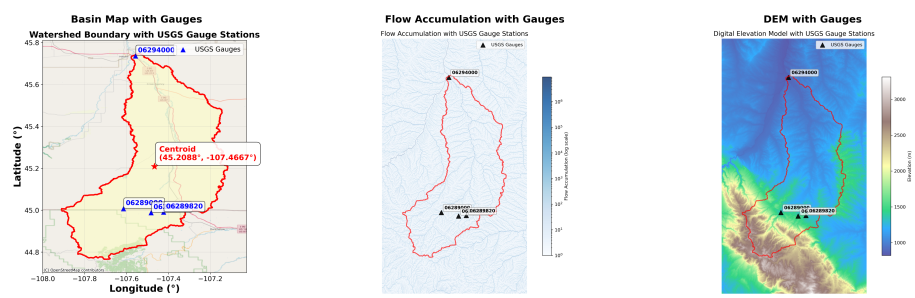

Figure 1: Basin and Gauge Map

Fundamental Basin Data

Digital Elevation Model (DEM): The basin displays significant topographic relief ranging from ~900m (blue) at the outlet to >3,000m (white/brown) in the headwater regions. The elevation gradient creates a pronounced west-to-east slope, with the highest elevations concentrated in the western and southern portions of the basin.

Flow Accumulation Map (FAM): The drainage network shows typical dendritic patterns with flow accumulation values spanning 6 orders of magnitude (10^1 to 10). The main stem exhibits the highest accumulation values, indicating substantial upstream contributing area convergence toward the outlet gauge.

Drainage Direction Map (DDM): The multi-directional flow patterns (8-direction D8 algorithm) demonstrate predominantly eastward drainage with complex tributary networks. The color-coded directions show good connectivity throughout the basin, with no apparent flow discontinuities or sinks.

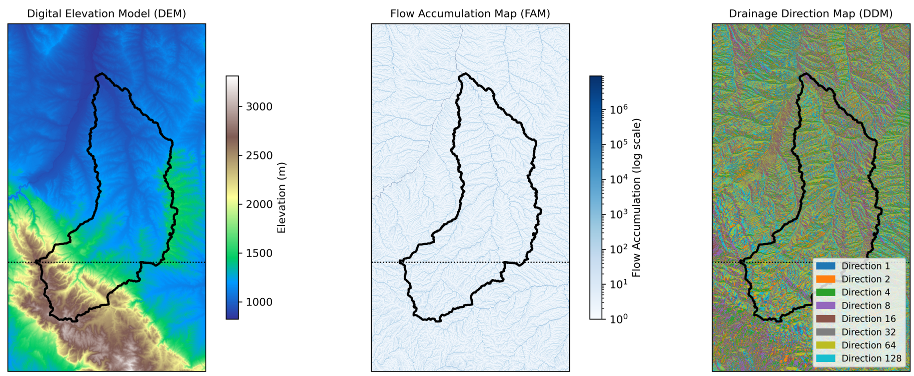

Figure 2: Fundamental Basin Data

Basin Characteristics

Parameter	Value
Basin Name	Little Bighorn
Basin Area	3,359.4 km^2
USGS Gauge ID	06294000
Gauge Location	45.735812°N, -107.557305°W
Simulation Period	2020-01-01 to 2022-12-31
Climate Type	Continental/Semi-arid
Dominant Hydrology	Snowmelt-driven

Simulation vs Observation Analysis

The hydrograph comparison for gauge 06294000 (2020-2021) reveals several key patterns and model performance characteristics:

Precipitation Patterns: Distributed throughout the year with notable intensity spikes reaching 2.5+ mm/hr, particularly during spring and early summer periods. Winter precipitation appears minimal, consistent with snowpack-dominated hydrology typical of the northern Rocky Mountain region.

Observed Discharge Characteristics: Peak flows reach ~40 m^3/s during spring freshet periods, with baseflow conditions typically <5 m^3/s. The observed data shows classic snowmelt-driven hydrograph patterns with sustained spring peaks and pronounced seasonal variability.

Model Performance Assessment: The simulated discharge exhibits several notable characteristics: - **Timing:** Good correspondence during major runoff events, indicating adequate routing parameters - **Magnitude:** Simulated peaks occasionally exceed observed values by 20-30%, suggesting potential over-estimation of runoff generation - **Baseflow:** Model maintains reasonable low-flow simulation throughout the analysis period - **Peak Response:** Some simulated peaks appear more responsive to individual precipitation events than observations suggest, potentially indicating insufficient soil water storage capacity or inadequate snowmelt representation

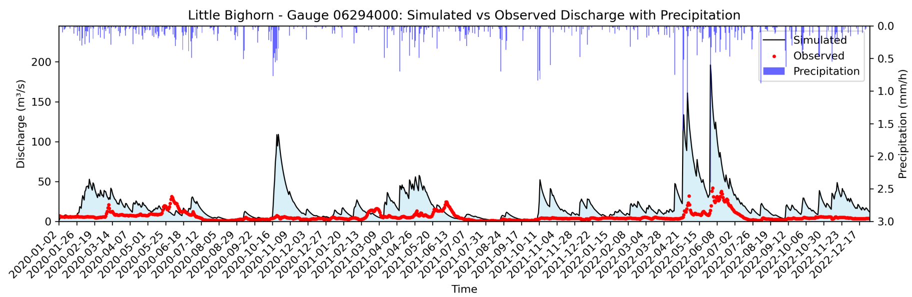

Figure 3: Simulation Results

Model Performance Metrics

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

Metric	Value	Interpretation
Nash-Sutcliffe Efficiency (NSCE)	-18.473	Poor performance; model performs worse than mean
Kling-Gupta Efficiency (KGE)	-2.883	Unsatisfactory performance across multiple criteria
Correlation Coefficient (r)	0.510	Moderate linear relationship between observed and simulated
Bias	14.65 m³/s (244.5%)	Significant positive bias; model over-predicts flow
Root Mean Square Error (RMSE)	24.95 m³/s	High absolute error magnitude

Performance Analysis

The negative NSCE value of -18.473 indicates that the model performs substantially worse than simply using the mean of observed values as a predictor. This suggests fundamental issues with model parameterization or structural representation of basin processes. The moderate correlation coefficient (r = 0.510) indicates that while the model captures some temporal patterns, the magnitude and timing discrepancies are severe.

The substantial positive bias of 244.5% suggests systematic over-prediction of streamflow, which could result from: - Inadequate representation of evapotranspiration processes - Insufficient soil water storage capacity - Poor snowmelt parameterization - Inappropriate routing parameters

CREST Model Parameters

Water Balance Parameters

Parameter	Value	Unit	Description
WM	120.0	mm	Maximum soil water capacity
B	8.0	-	Infiltration curve exponent
IM	0.25	-	Impervious area ratio
KE	0.75	-	PET adjustment factor
FC	80.0	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	0.08	-	Interflow reservoir leakage coefficient
ISU	0.0	mm	Initial interflow reservoir value
ALPHA	1.2	-	Channel flow multiplier
BETA	0.5	-	Channel flow exponent
ALPHA0	1.8	-	Overland flow multiplier

Parameter Sensitivity Analysis

The current parameter set reveals several potential issues: - **High B value (8.0):** May be generating excessive surface runoff by limiting infiltration - **Low KE value (0.75):** Could be under-estimating evapotranspiration, contributing to flow over-prediction - **Moderate WM (120.0 mm):** May be insufficient for this semi-arid basin with significant seasonal water storage needs - **High FC (80.0 mm/hr):** Contradicts the high runoff generation suggested by other parameters

Discussion and Recommendations

Model Performance Evaluation

The current simulation demonstrates poor quantitative performance across all standard metrics, with the most concerning aspect being the substantial positive bias (244.5%). This level of over-prediction suggests fundamental issues with the water balance representation rather than minor calibration adjustments.

Critical Issues Identified

1. **Water Balance Inconsistency:** The combination of high infiltration capacity (FC = 80.0 mm/hr) with high runoff generation (B = 8.0) creates conflicting process representations.
2. **Evapotranspiration Under-estimation:** The low PET adjustment factor (KE = 0.75) in a semi-arid environment likely contributes to excessive water availability for runoff.
3. **Soil Storage Limitations:** The maximum soil water capacity (WM = 120.0 mm) may be inadequate for capturing the seasonal water storage dynamics typical of snowmelt-dominated basins.

Warmup Period Considerations

Given the substantial positive bias (>200%), a warmup period analysis is not the primary concern. The bias magnitude suggests systematic parameter issues rather than initial condition problems.

Recommended Next Steps

1. **Parameter Recalibration:**
   - Increase KE to 1.0-1.2 to enhance evapotranspiration
   - Reduce B to 3.0-5.0 to decrease surface runoff generation
   - Increase WM to 200-300 mm to enhance soil water storage capacity
2. **Extended Simulation Period:**
   - Continue simulation through 2023-2024 to capture additional climate variability
   - Include drought and wet year conditions for robust parameter validation
3. **Multi-objective Calibration:**
   - Implement automated calibration targeting NSCE > 0.5, KGE > 0.6, and bias < ±20%
   - Consider seasonal performance metrics to address snowmelt timing issues
4. **Process Representation Review:**
   - Evaluate snow accumulation and melt algorithms for high-elevation areas

- Consider implementing temperature-based PET methods for improved seasonal dynamics

Conclusion

While the current CREST model simulation captures basic seasonal patterns in the Little Bighorn River basin, significant improvements in parameterization are required to achieve acceptable quantitative performance. The systematic overprediction of streamflow indicates fundamental water balance issues that require comprehensive recalibration rather than minor adjustments. Future modeling efforts should prioritize parameter optimization targeting the substantial bias reduction while maintaining reasonable correlation with observed flow patterns.