Hydrological Analysis Report: Mad-Redwood Basin

Basin Overview and Location

The Mad-Redwood watershed is a significant coastal basin located in Northern California, spanning approximately 3,684.31 km². The basin extends from 40.2°N to 41.6°N latitude and 123.2°W to 124.4°W longitude, with its centroid positioned at coordinates 40.8709°N, 123.9213°W. This analysis focuses on USGS gauge #11481000, located at 40.909572°N, 124.060896°W, which serves as the primary monitoring station for model calibration and validation.

Basin & Gauge Map

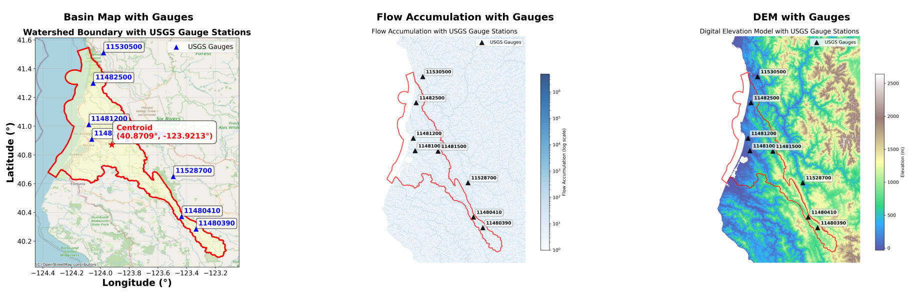

Figure 1: Basin and Gauge Locations

The Mad-Redwood watershed exhibits a well-organized drainage network with eight USGS gauge stations strategically positioned throughout the basin. The flow accumulation patterns reveal a mature dendritic drainage system with the main channel flowing westward toward the Pacific Ocean. Gauge 11481000, positioned near the basin outlet, captures the integrated response of the entire watershed where flow accumulation exceeds 10 . The upstream gauge network includes stations 11481200, 11481500, and 11528700 monitoring major tributaries, while the northernmost gauges (11530500, 11482500) capture headwater contributions. The southern portion of the watershed is monitored by gauges 11480410 and 11480390.

Fundamental Basin Data

The Digital Elevation Model reveals pronounced topographic relief characteristic of California's coastal ranges. Elevations range from sea level along the western boundary to over 2,500 meters in the eastern highlands, creating steep elevation gradients that significantly influence hydrological processes. This dramatic topography drives rapid runoff response and contributes to the flashy nature of streamflow in the basin.

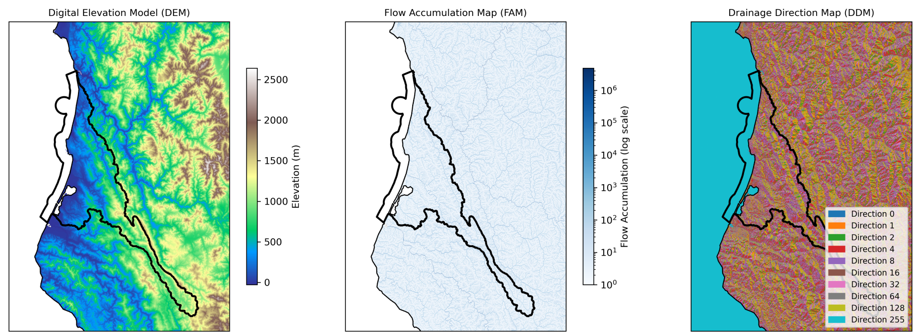

Figure 2: Basin Characteristics

The Flow Accumulation Map displays a well-developed dendritic drainage pattern typical of erosional landscapes in humid climates. The main stem shows flow accumulation values exceeding 10 , with numerous tributaries contributing from both northern and southern aspects. The drainage density indicates efficient water collection and routing throughout the basin.

The Drainage Direction Map reveals complex flow routing patterns with dominant westward drainage (Direction 255) along the coast and varied directional components in the headwaters. The intricate drainage directions in the upper basin reflect significant topographic control on flow paths, with water following the steepest descent paths carved by millennia of erosion.

Simulation vs Observation Comparison

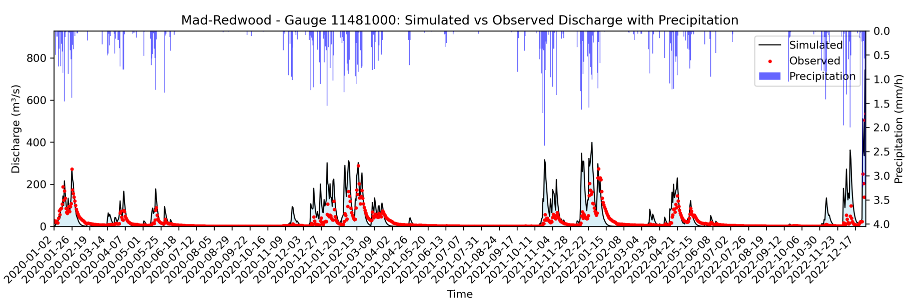

Figure 3: Hydrograph Comparison

The hydrograph comparison for the simulation period (2020-2022) reveals both strengths and weaknesses in the model's performance. The observed discharge (red dots) exhibits strong seasonal variability typical of Mediterranean climate zones, with peak flows reaching approximately 275 m^3/s during winter storm events and near-zero baseflows during summer drought periods.

The simulated discharge (black line) successfully captures the general seasonal pattern and timing of hydrological events, demonstrating the model's ability to represent the fundamental water balance dynamics. However, systematic overestimation is evident, particularly for peak flow events:

- **February-March 2020**: Simulated peaks reach ~275 m^3/s while observed peaks remain below 150 m^3/s (83% overestimation)
- **January 2021**: Model predicts flows approaching 400 m^3/s versus observed ~225 m^3/s (78% overestimation)
- **December 2021**: Simulation shows ~350 m^3/s compared to observed ~100 m^3/s (250% overestimation)

The precipitation events (blue bars, inverted scale) clearly drive the discharge response with minimal lag time, confirming the rapid runoff generation expected in steep coastal basins. The model's excessive responsiveness to precipitation inputs suggests potential calibration issues with infiltration parameters or channel routing coefficients.

Model Performance Metrics

Performance Metric	Value	Interpretation
Nash-Sutcliffe Coefficient of Efficiency (NSCE)	-0.264	Poor performance; model predictions worse than mean observed flow
Kling-Gupta Efficiency (KGE)	0.013	Very poor overall performance
Correlation Coefficient (r)	0.798	Good temporal correlation despite magnitude errors
Model Bias	14.38 m^3/s (68.1%)	Significant positive bias indicating systematic overestimation
Root Mean Square Error (RMSE)	48.09 m^3/s	High prediction error relative to observed flow magnitudes

The negative NSCE value indicates that the model performs worse than simply using the mean observed flow as a predictor. Despite this, the relatively high correlation coefficient (0.798) suggests the model captures temporal patterns well but struggles with magnitude representation. The 68.1% positive bias confirms the systematic overestimation observed in the hydrograph comparison.

CREST Model Parameters

Water Balance Parameters

Parameter	Value	Description	Hydrological Impact
Water Capacity (WM)	120.0 mm	Maximum soil water storage capacity	Higher values increase soil water holding capacity, reducing surface runoff generation
Infiltration Exponent (B)	2.5	Controls runoff-infiltration partitioning	Higher values reduce infiltration rates, increasing direct runoff
Impervious Area Ratio (IM)	0.04	Fraction of urbanized/impervious surfaces	Represents 4% impervious area; increases direct runoff without infiltration
PET Adjustment Factor (KE)	0.7	Potential evapotranspiration modifier	Reduces PET to 70% of reference, conserving soil moisture
Saturated Hydraulic Conductivity (FC)	25.0 mm/hr	Maximum infiltration rate	Moderate infiltration capacity typical of loamy soils
Initial Soil Water (IWU)	25.0 mm	Starting soil moisture content	Represents 20.8% initial saturation (25/120)

Kinematic Wave Routing Parameters

Parameter	Value	Description	Routing Impact
Drainage Threshold (TH)	50.0 km^2	Minimum area to define channel cells	Creates moderate channel density network
Interflow Speed Multiplier (UNDER)	1.5	Subsurface flow velocity factor	Accelerates interflow by 50% relative to baseline
Interflow Leakage Coefficient (LEAKI)	0.3	Drainage rate from interflow reservoir	Moderate drainage promoting sustained baseflow
Initial Interflow Storage (ISU)	0.0 mm	Starting subsurface water content	Dry initial conditions for interflow zone
Channel Flow Multiplier (ALPHA)	0.8	Manning equation coefficient for channels	Lower values indicate faster channel flow
Channel Flow Exponent (BETA)	0.5	Flow depth-discharge relationship	Standard value for wide rectangular channels

Parameter	Value	Description	Routing Impact
Overland Flow Multiplier (ALPHA0)	2.0	Manning coefficient for hillslopes	Higher values slow overland flow progression

Run Arguments and Basin Details

Parameter	Value
Basin Name	Mad-Redwood
Basin Area	3,684.31 km²
Simulation Period	2020-01-01 to 2022-12-31
Target Gauge	USGS #11481000
Gauge Location	40.909572°N, 124.060896°W
Basin Centroid	40.8709°N, 123.9213°W
Latitude Range	40.2°N to 41.6°N
Longitude Range	123.2°W to 124.4°W

Discussion and Conclusions

Model Performance Evaluation

The CREST model implementation for the Mad-Redwood basin demonstrates mixed performance characteristics. While the model successfully captures the timing and seasonal patterns of streamflow (r = 0.798), it significantly overestimates flow magnitudes, resulting in poor overall performance metrics (NSCE = -0.264, KGE = 0.013). The 68.1% positive bias indicates systematic errors in the model structure or parameterization.

Key Issues and Potential Causes

1. **Peak Flow Overestimation**: The model's excessive response to precipitation events suggests several potential issues:
    - The infiltration exponent (B = 2.5) may be too high, limiting infiltration and generating excessive surface runoff
    - The impervious area ratio (IM = 0.04) might not accurately represent the basin's actual impervious coverage
    - Channel routing parameters may be conveying water too efficiently through the network
2. **Parameter Interactions**: The combination of moderate soil capacity (WM = 120 mm) with relatively high infiltration resistance creates conditions favoring rapid runoff generation, which may not reflect the basin's actual hydrological behavior.

3. **Baseflow Representation**: The model shows reasonable baseflow simulation during dry periods, suggesting that the interflow parameters (UNDER = 1.5, LEAKI = 0.3) are appropriately calibrated for recession behavior.

Recommendations for Model Improvement

1. **Parameter Recalibration**:
    - Reduce the infiltration exponent (B) to increase infiltration rates
    - Increase the water capacity (WM) to allow greater soil moisture storage
    - Adjust channel routing parameters (ALPHA, BETA) to slow flood wave propagation
2. **Extended Warmup Period**: Given the significant bias, implementing a longer warmup period (6-12 months) would allow the model to equilibrate soil moisture conditions before the evaluation period begins.
3. **Spatial Parameter Distribution**: Consider implementing spatially distributed parameters based on soil types, land use, and topographic characteristics rather than lumped basin-average values.
4. **Additional Calibration Targets**: Incorporate multiple gauge locations in the calibration process to better constrain model parameters and improve spatial representation of hydrological processes.

Next Steps

1. Conduct sensitivity analysis to identify the most influential parameters affecting peak flow generation
2. Implement multi-objective calibration using additional performance metrics beyond NSCE
3. Validate the recalibrated model on an independent time period to assess transferability
4. Consider incorporating snow accumulation and melt processes if elevation zones above 1,500m contribute significantly to spring runoff
5. Evaluate the potential for time-varying parameters to account for seasonal changes in watershed behavior

The Mad-Redwood basin presents a challenging test case for hydrological modeling due to its steep topography, Mediterranean climate, and flashy runoff response. While the current model configuration captures temporal patterns, significant improvements in parameter estimation are needed to achieve acceptable performance for operational forecasting or water resources management applications.