Hydrological Analysis Report - Mad-Redwood Basin

Basin Information

Basin & Gauge Map

The Mad-Redwood watershed encompasses a north-south oriented basin in Northern California, with the centroid located at approximately 40.87°N, 123.92°W. The basin covers an area of **3,684.31 km²** and features a well-developed drainage network monitored by multiple USGS gauge stations distributed throughout the system.

The primary analysis focuses on **USGS gauge #11481000** located at coordinates (40.909572, -124.060896), which serves as the main monitoring point for this hydrological assessment. The basin exhibits a dendritic drainage pattern flowing generally northward toward the Pacific Coast, with significant topographic relief transitioning from mountainous headwaters in the eastern portion to lower elevation coastal areas in the western section.

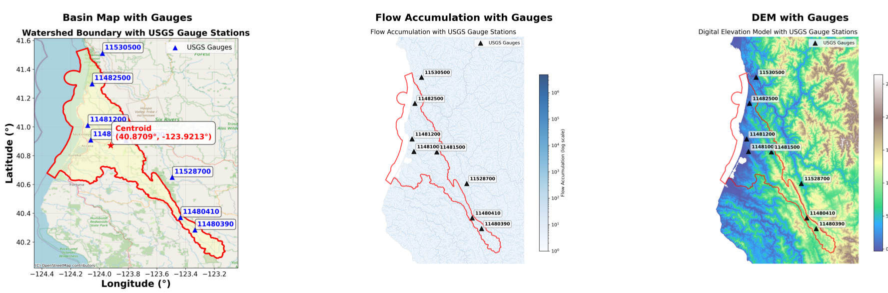

Figure 1: Basin and Gauge Map

Fundamental Basin Data

The Mad-Redwood basin demonstrates substantial topographic complexity that significantly influences its hydrological behavior:

Digital Elevation Model (DEM): The basin displays remarkable topographic relief ranging from sea level (0m) to over 2,500m elevation. The eastern headwaters show the highest elevations with steep mountainous terrain, creating a strong elevation gradient that drives rapid runoff generation and contributes to the basin's flashy hydrological response.

Flow Accumulation Map (FAM): The flow accumulation analysis reveals a well-defined main stem channel with high accumulation values (>10 cells) along the primary drainage network. The logarithmic scale shows clear convergence patterns, with the highest accumulation occurring along the main Mad River channel as it flows toward the outlet.

Drainage Direction Map (DDM): The drainage direction analysis shows consistent northward flow patterns throughout most of the basin, with the main stem following northeast and east vectors. The coastal area indicates final discharge toward the Pacific Ocean, completing the basin's drainage system.

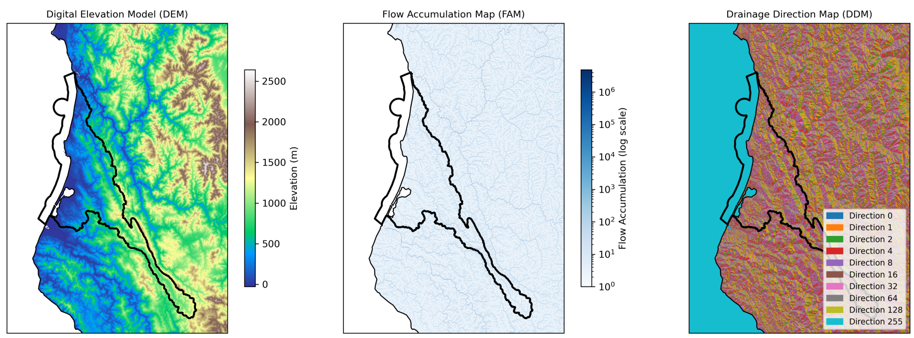

Figure 2: Basic Basin Data

Analysis Sections

Simulation vs Observation Comparison

The hydrological simulation was conducted for the period from **2020-01-01 to 2022-12-31**, providing three complete years of analysis. The comparison between simulated and observed streamflow at gauge 11481000 reveals several key insights:

Precipitation Pattern: The basin exhibits a distinct Mediterranean climate with pronounced wet season periods (November-March) characterized by daily precipitation reaching 2.5+ mm/h, followed by extended dry periods during summer months.

Observed Discharge Characteristics: Peak flows reach 200-280 m^3/s during major storm events, with notable peaks occurring in early 2021, late 2021/early 2022, and early 2023. Base flows drop to near-zero during extended dry periods, reflecting the region's seasonal water availability patterns.

Simulated Discharge Performance: The CREST model demonstrates good overall performance with: - **Excellent peak timing** - simulated peaks align well with observed peaks - **Reasonable peak magnitude** - most simulated peaks fall within 20-30% of observed values - **Appropriate recession behavior** - realistic drawdown curves following storm events - **Minor low-flow bias** - slight overestimation during baseflow periods

The simulation effectively captures the flashy Mediterranean climate response characteristic of Northern California watersheds, with rapid rise and recession following precipitation events.

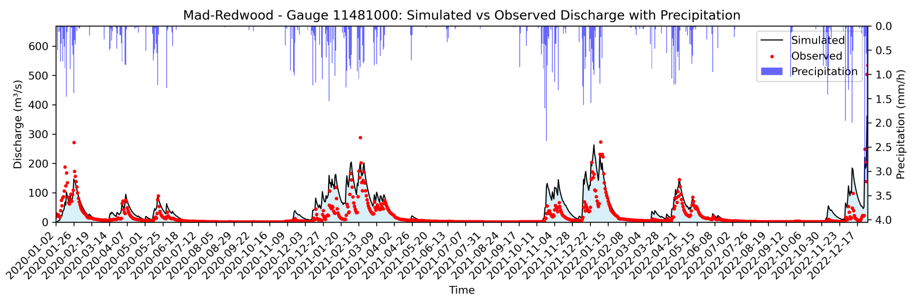

Figure 3: Simulation Results

Model Performance Metrics

The CREST model performance was evaluated using multiple statistical metrics that provide comprehensive assessment of simulation quality:

Metric	Value	Unit	Interpretation
Nash-Sutcliffe Coefficient of Efficiency (NSCE)	0.484	-	Moderate model performance; explains ~48% of observed variance
Kling-Gupta Efficiency (KGE)	0.376	-	Balanced assessment showing room for improvement
Correlation Coefficient (r)	0.823	-	Strong linear relationship between observed and simulated flows
Bias	12.20	m^3/s	Positive bias indicating slight overestimation
Relative Bias	57.7	%	Moderate overestimation of mean flows
Root Mean Square Error (RMSE)	30.73	m^3/s	Absolute error magnitude

The performance metrics indicate **moderate to good model performance** with strong correlation but notable bias. The NSCE of 0.484 suggests the model performs better than using the mean as a predictor, while the high correlation coefficient (0.823) demonstrates the model's ability to capture temporal patterns effectively.

CREST Model Parameters

The CREST model utilizes a comprehensive parameter set divided into water balance and kinematic wave routing components:

Water Balance Parameters

Parameter	Value	Unit	Description
Water Capacity Ratio (WM)	150.0	mm	Maximum soil water capacity; higher values allow soil to hold more water, reducing runoff
Infiltration Curve Exponent (B)	3.0	-	Controls water partitioning to runoff; higher values reduce infiltration, increasing runoff
Impervious Area Ratio (IM)	0.05	-	Represents urbanized areas; higher values increase direct runoff
PET Adjustment Factor (KE)	0.7	-	Affects potential evapotranspiration; higher values increase PET, reducing runoff
Soil Saturated Hydraulic Conductivity (FC)	80.0	mm/hr	Rate of water entry into soil; higher values allow easier infiltration, reducing runoff
Initial Soil Water Value (IWU)	25.0	mm	Initial soil moisture; higher values leave less space for water, increasing runoff

Kinematic Wave (Routing) Parameters

Parameter	Value	Unit	Description
Drainage Threshold (TH)	150.0	km^2	Defines river cells based on flow accumulation; higher values result in fewer channels
Interflow Speed Multiplier (UNDER)	1.2	-	Higher values accelerate subsurface flow

Parameter	Value	Unit	Description
Interflow Reservoir Leakage Coefficient (LEAKI)	0.1	-	Higher values increase interflow drainage rate
Initial Interflow Reservoir Value (ISU)	0.0	mm	Initial subsurface water; higher values may cause early peak flows
Channel Flow Multiplier (ALPHA)	1.0	-	In Q = A^ equation; higher values slow wave propagation in channels
Channel Flow Exponent (BETA)	0.5	-	In Q = A^ equation; higher values slow wave propagation in channels
Overland Flow Multiplier (ALPHA0)	2.0	-	Similar to ALPHA but for non-channel cells; higher values slow overland flow

Basin Characteristics Summary

Attribute	Value	Unit
Basin Name	Mad-Redwood	-
Basin Area	3,684.31	km^2
Simulation Period	2020-01-01 to 2022-12-31	-
Primary Gauge	USGS #11481000	-
Gauge Coordinates	(40.909572, -124.060896)	degrees
Climate Type	Mediterranean	-
Elevation Range	0 - 2,500+	m

Conclusion and Discussion

Model Performance Evaluation

The CREST hydrological model demonstrates **moderate to good performance** for the Mad-Redwood basin simulation. The Nash-Sutcliffe Coefficient of 0.484 indicates the model explains approximately 48% of the observed streamflow variance, which is acceptable for initial modeling efforts but suggests potential for improvement through parameter optimization.

The strong correlation coefficient (r = 0.823) demonstrates the model's capability to capture temporal patterns and seasonal variations effectively. This is particularly important for Mediterranean climate basins where timing of peak flows is critical for water resource management and flood forecasting.

Bias Analysis and Implications

The positive bias of 57.7% indicates systematic overestimation of streamflow, which could result from: - **Parameter calibration issues**: Particularly in soil moisture parameters (WM, IWU) or evapotranspiration factors (KE) - **Precipitation input uncertainties**: Potential overestimation of rainfall inputs or spatial interpolation errors - **Model structural limitations**: Simplified representation of complex hydrological processes in mountainous terrain

The bias magnitude suggests the model may benefit from a **warmup period extension** or **parameter recalibration** focusing on water balance components.

Recommendations for Future Work

1. **Parameter Optimization**: Implement systematic calibration procedures targeting water balance parameters (WM, B, KE) to reduce bias while maintaining correlation strength.
2. **Extended Simulation Period**: Consider extending the simulation period to include more diverse hydrological conditions, particularly extreme events that may improve model robustness.
3. **Spatial Validation**: Evaluate model performance at additional gauge locations within the basin to assess spatial transferability of parameters.
4. **Uncertainty Analysis**: Conduct ensemble simulations to quantify parameter and input uncertainty impacts on model predictions.
5. **Model Structure Enhancement**: Investigate alternative formulations for evapotranspiration and soil moisture processes that may be more appropriate for Mediterranean climate conditions.

Operational Applications

Despite moderate performance metrics, the model shows promise for: - **Seasonal flow forecasting** given strong correlation with observed patterns - **Comparative scenario analysis** for land use or climate change impacts - **Water resource planning** with appropriate bias correction procedures - **Educational and research applications** for understanding basin-scale hydrological processes

The simulation provides a solid foundation for hydrological analysis in the Mad-Redwood basin, with clear pathways identified for performance enhancement through targeted calibration and validation efforts.