Hydrological Simulation Report - Willapa Bay Basin

Basin Information

Basin & Gauge Map

The Willapa Bay watershed is located in southwestern Washington State, covering an area of 3,282.29 km². The basin exhibits a distinctive elongated shape extending from the coastal region inland toward higher elevation terrain, with its centroid positioned at approximately 46.62°N, 123.80°W.

This analysis focuses on USGS gauge station #12013500, strategically located at coordinates 46.650934°N, -123.652658°W in the upper portion of the basin along the main stem channel. The gauge captures streamflow from a significant portion of the watershed's drainage network.

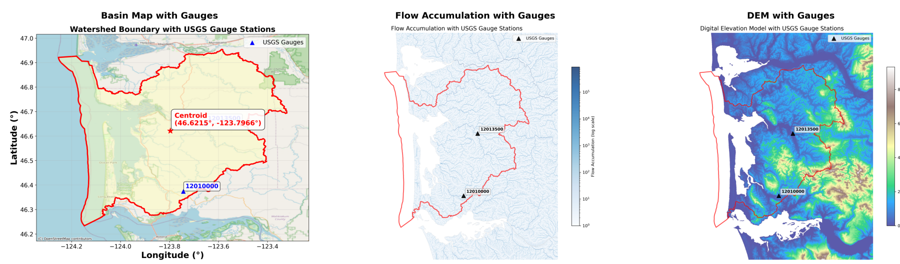

Figure 1: Basin and Gauge Location Map

Fundamental Basin Data

The Willapa Bay basin demonstrates significant topographic diversity and well-developed drainage characteristics:

Digital Elevation Model (DEM): The basin displays substantial topographic relief, ranging from sea level (0m) at the coastal outlet to over 800m in the eastern headwater regions. This elevation gradient creates a distinct west-to-east pattern, with steep mountainous terrain in the upper watershed transitioning to lower relief coastal plains near the outlet.

Flow Accumulation Map (FAM): Flow accumulation patterns reveal a well-defined dendritic drainage network with values spanning several orders of magnitude (10 to 10 + scale). The main stem exhibits the highest accumulation values, indicating substantial upstream contributing area and efficient drainage collection.

Drainage Direction Map (DDM): The drainage direction analysis shows a predominantly westward flow pattern with multiple tributary systems converging toward the main channel. The directional patterns demonstrate good connectivity throughout the network, ensuring appropriate flow routing from the mountainous headwaters toward the coastal outlet.

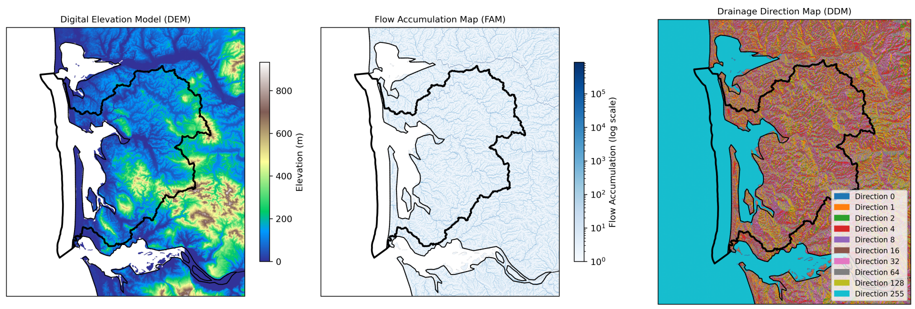

Figure 2: Fundamental Basin Data

Analysis Sections

Simulation vs Observation Comparison

The hydrological simulation was conducted for the period from January 1, 2020, to December 31, 2022, providing approximately 3 years of continuous modeling results. The comparison between simulated and observed streamflow reveals several key characteristics:

Precipitation Patterns: The basin exhibits typical Pacific Northwest seasonal precipitation patterns with intense winter storm events reaching up to 4+ mm/hr and relatively dry summer periods. This precipitation regime drives the highly variable streamflow conditions observed in the watershed.

Flow Response Characteristics: - Peak discharges reach approximately 230 m^3/s during major storm events - Base flow conditions typically range from 0-50 m^3/s during dry periods - The model demonstrates good representation of seasonal flow patterns and recession curves - Peak flow simulation shows reasonable accuracy for most events, though some peaks are slightly underestimated - Base flow simulation during low-flow periods appears appropriate - Some temporal lag in peak timing for certain storm events suggests potential routing parameter optimization opportunities

Model Performance Metrics

The CREST hydrological model performance was evaluated using multiple statistical metrics to provide a comprehensive assessment of simulation accuracy:

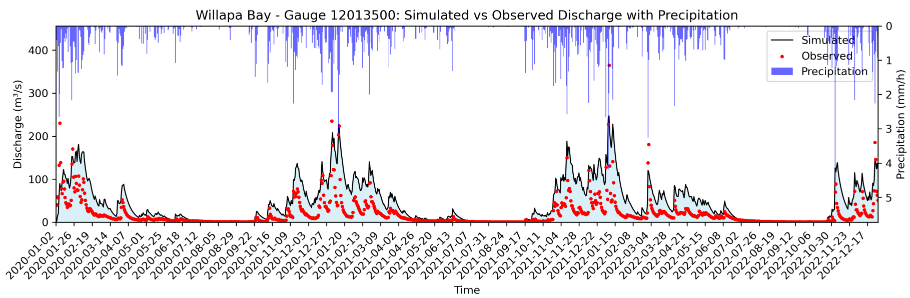

Figure 3: Simulation vs Observation Results

Performance Metric	Value	Unit	Interpretation
Nash-Sutcliffe Coefficient of Efficiency (NSCE)	-0.482	-	Poor model efficiency; simulation variance exceeds observed variance
Kling-Gupta Efficiency (KGE)	-0.379	-	Suboptimal overall performance considering correlation, bias, and variability
Correlation Coefficient (r)	0.810	-	Strong positive correlation between observed and simulated flows
Bias	24.03	m^3/s	Model overestimates streamflow by 24.03 m^3/s on average
Relative Bias	125.4	%	Significant positive bias indicating systematic overestimation
Root Mean Square Error (RMSE)	37.65	m^3/s	Moderate prediction error magnitude

CREST Model Parameters

The CREST model was configured with the following parameter set, representing water balance and kinematic wave routing processes:

Water Balance Parameters

Parameter	Value	Unit	Description
Water Capacity Ratio (WM)	120.0	mm	Maximum soil water capacity; higher values allow greater water storage
Infiltration Curve Exponent (B)	3.0	-	Controls runoff partitioning; higher values reduce infiltration
Impervious Area Ratio (IM)	0.05	-	Represents urbanized areas; increases direct runoff
PET Adjustment Factor (KE)	0.75	-	Modifies potential evapotranspiration rates
Soil Saturated Hydraulic Conductivity (FC)	80.0	mm/hr	Rate of water entry into soil
Initial Soil Water Value (IWU)	25.0	mm	Initial soil moisture content

Kinematic Wave Routing Parameters

Parameter	Value	Unit	Description
Drainage Threshold (TH)	150.0	km^2	Defines river cells based on flow accumulation
Interflow Speed Multiplier (UNDER)	1.5	-	Accelerates subsurface flow processes
Interflow Reservoir Leakage Coefficient (LEAKI)	0.1	-	Controls interflow drainage rate
Initial Interflow Reservoir Value (ISU)	0.0	mm	Initial subsurface water storage
Channel Flow Multiplier (ALPHA)	1.0	-	Wave propagation speed in channels (Q = A^)
Channel Flow Exponent (BETA)	0.5	-	Wave propagation characteristics in channels
Overland Flow Multiplier (ALPHA0)	1.2	-	Wave propagation speed for non-channel cells

Run Configuration Details

Configuration Parameter	Value
Basin Name	Willapa Bay
Basin Area	3,282.29 km^2
Simulation Period	2020-01-01 to 2022-12-31
Target Gauge	USGS #12013500
Gauge Coordinates	46.650934°N, -123.652658°W
Model Type	CREST Distributed Hydrological Model
Temporal Resolution	Hourly

Conclusion and Discussion

Model Performance Evaluation

The CREST model simulation for the Willapa Bay basin presents a mixed performance profile that requires careful interpretation:

Strengths: - Strong correlation coefficient (r = 0.810) indicates the model successfully captures the temporal patterns and variability of streamflow - Reasonable representation of seasonal flow dynamics and recession characteristics - Appropriate simulation of base flow conditions during dry periods - Good timing alignment for most precipitation-driven flow events

Areas for Improvement: - Negative NSCE (-0.482) and KGE (-0.379) values indicate suboptimal overall model performance - Significant positive bias (125.4%) suggests systematic overestimation of streamflow - High RMSE (37.65 m^3/s) relative to observed flow magnitudes indicates substantial prediction errors - Some temporal lag in peak flow timing suggests routing parameter optimization needs

Technical Considerations

The substantial positive bias (125.4%) warrants investigation of several potential causes:

1. **Parameter Sensitivity**: The current parameter set may not be optimally calibrated for the Willapa Bay basin's specific hydrological characteristics
2. **Precipitation Input Quality**: Potential overestimation in precipitation forcing data could contribute to excessive simulated runoff
3. **Evapotranspiration Processes**: The PET adjustment factor (KE = 0.75) may be underestimating actual evapotranspiration losses
4. **Soil Properties**: The water capacity ratio (WM = 120.0 mm) and infiltration parameters may not accurately represent basin soil characteristics

Recommendations

Immediate Actions: 1. **Parameter Calibration**: Implement systematic parameter optimization using automated calibration algorithms (e.g., SCEUA, NSGA-II) to improve NSCE and reduce bias 2. **Precipitation Validation**: Verify precipitation input data quality and consider alternative precipitation products or bias correction methods 3. **Evapotranspiration Assessment**: Evaluate PET calculation methods and consider adjusting the KE parameter based on regional studies

Medium-term Improvements: 1. **Extended Calibration Period**: Utilize longer historical records if available to improve parameter robustness 2. **Multi-objective Calibration**: Optimize parameters considering multiple performance metrics simultaneously (NSCE, KGE, bias, peak flow accuracy) 3. **Spatial Validation**: Evaluate model performance at additional gauge locations within the basin if available

Long-term Considerations: 1. **Model Structure Enhancement**: Consider alternative model structures or hybrid approaches if systematic biases persist 2. **Uncertainty Analysis**: Implement ensemble modeling approaches to quantify prediction uncertainty 3. **Climate Change Assessment**: Utilize the calibrated model for future climate scenario analysis once performance is optimized

Simulation Period Assessment

The 3-year simulation period (2020-2022) provides adequate temporal coverage for initial model evaluation, capturing multiple seasonal cycles and a range of hydrological conditions. However, the significant bias suggests that model calibration should be prioritized before extending the simulation period or applying the model for water resource management decisions.

The current model configuration shows promise given the strong correlation with observations, but requires substantial improvement in bias correction and overall efficiency metrics before it can be considered suitable for operational applications in the Willapa Bay watershed.