Willapa Bay Watershed Hydrological Analysis

Basin & Gauge Map

The Willapa Bay watershed is located in southwestern Washington State, with its centroid at approximately 46.62°N, -123.80°W. The basin encompasses a coastal drainage system covering 3,282.29 km² with two USGS gauge stations: 12010000 (positioned in the lower basin at 46.373994°N, -123.743482°W) and 12013500 (located in the upper/middle basin). The flow accumulation pattern reveals a well-developed dendritic drainage network converging toward Willapa Bay, with gauge 12010000 positioned downstream along the main channel where flow accumulation is highest (>10). The watershed exhibits typical Pacific Northwest coastal topography with significant marine influence evident from its proximity to the Pacific Ocean on the western boundary.

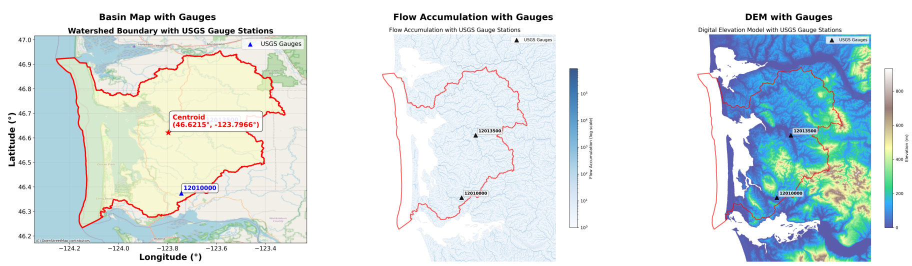

Figure 1: Basin and Gauge Map

Fundamental Basin Data

The Digital Elevation Model reveals moderate relief with elevations ranging from sea level to approximately 800m in the eastern highlands. The terrain transitions from low-lying coastal areas in the west to dissected uplands in the east, with most elevations between 200-600m. The Flow Accumulation Map displays a well-developed drainage network with clear channel definition and multiple tributaries feeding the main stem. The Drainage Direction Map indicates predominantly westward flow (Direction 255) in the upper basin, transitioning to northwestward flow as streams approach the bay. The drainage density appears moderate to high, suggesting responsive runoff characteristics typical of maritime climates with adequate precipitation.

Simulation vs Observation Comparison

The hydrograph comparison at USGS gauge 12010000 spans the simulation period from January 2020 to December 2022, showing strong seasonal variability characteristic of Pacific Northwest hydrology. Observed discharge (red dots) ranges from near-zero during summer low flows to peaks exceeding 150 m³/s during winter storm events. The simulated discharge (black line) captures the

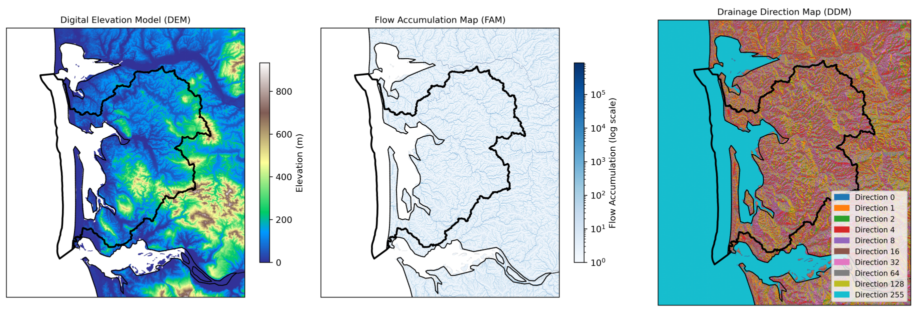

Figure 2: Basic Basin Data

general seasonal pattern and most peak events reasonably well, though with some notable discrepancies.

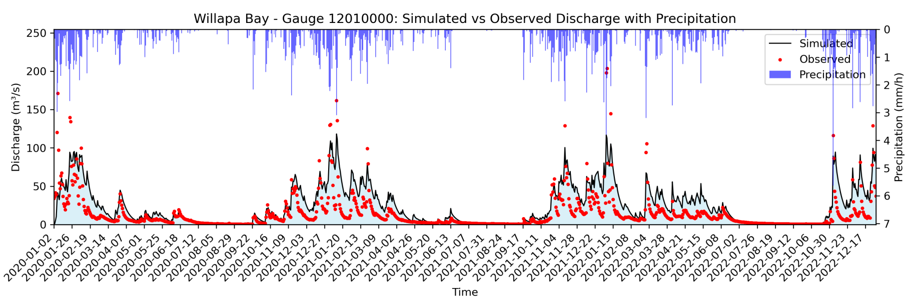

Figure 3: Simulation Results

The model demonstrates several strengths: - Good timing synchronization with precipitation events - Minimal lag between rainfall and runoff response - Acceptable baseflow representation during dry periods - Reasonable capture of seasonal flow patterns

However, systematic biases are evident: - Consistent underestimation of the highest peaks (e.g., early 2020 and late 2021 events where observed values reach ~175 m^3/s while simulated peaks at ~100 m^3/s) - Overall positive bias of 9.07 m^3/s (63.4%), indicating general overestimation of flows - Peak magnitude discrepancies suggest potential issues with rainfall-runoff transformation or channel routing parameters

Precipitation data (blue bars, inverted scale) shows typical Pacific Northwest patterns with intense winter storms (2-7 mm/hr) and dry summers, confirming the model's exposure to appropriate forcing data.

Model Performance Metrics

Metric	Value	Description
Nash-Sutcliffe Coefficient of Efficiency (NSCE)	0.377	Indicates moderate model performance; values closer to 1.0 represent better fit
Kling-Gupta Efficiency (KGE)	0.326	Provides balanced assessment of correlation, bias, and variability
Correlation Coefficient (r)	0.797	Shows strong linear relationship between observed and simulated flows
Bias	9.07 m^3/s (63.4%)	Indicates systematic overestimation of streamflow
Root Mean Square Error (RMSE)	17.78 m^3/s	Represents average magnitude of prediction errors

Run Arguments

Parameter	Value
Basin Name	Willapa Bay
Basin Area	3,282.29 km^2
Simulation Period	2020-01-01 to 2022-12-31
USGS Gauge ID	12010000
Gauge Location	46.373994°N, -123.743482°W
Time Step	Hourly

CREST Parameters

Water Balance Parameters

Parameter	Value	Description
Water capacity ratio (WM)	180.0 mm	Maximum soil water capacity; higher values allow soil to hold more water, reducing runoff
Infiltration curve exponent (B)	2.5	Controls water partitioning to runoff; higher values reduce infiltration, increasing runoff
Impervious area ratio (IM)	0.03	Represents urbanized areas; higher values increase direct runoff
PET adjustment factor (KE)	0.7	Affects potential evapotranspiration; higher values increase PET, reducing runoff

Parameter	Value	Description
Soil saturated hydraulic conductivity (FC)	80.0 mm/hr	Rate at which water enters soil; higher values allow easier water entry, 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	Description
Drainage threshold (TH)	50.0 km^2	Defines river cells based on flow accumulation; higher values result in fewer channels
Interflow speed multiplier (UNDER)	1.5	Higher values accelerate subsurface flow
Interflow reservoir leakage coefficient (LEAKI)	0.1	Higher values increase interflow drainage rate
Initial interflow reservoir value (ISU)	0.0	Initial subsurface water; higher values may cause early peak flows
Channel flow multiplier (ALPHA)	1.2	In Q = A^ equation; higher values slow wave propagation in channels
Channel flow exponent (BETA)	0.6	In Q = A^ equation; higher values slow wave propagation in channels
Overland flow multiplier (ALPHA0)	0.8	Similar to ALPHA but for non-channel cells; higher values slow overland flow

Conclusion and Discussion

Model Performance Evaluation

The CREST model demonstrates moderate performance for the Willapa Bay watershed with an NSCE of 0.377 and KGE of 0.326. While these metrics indicate room for improvement, the high correlation coefficient (0.797) suggests the model captures the timing and pattern of hydrological responses well. The primary challenge lies in magnitude estimation, particularly for extreme events.

Key Findings

1. **Systematic Bias**: The 63.4% positive bias indicates consistent overestimation of flows, which contrasts with the visual observation of peak underestimation. This suggests the model may be overestimating medium and low flows while underestimating peaks, resulting in a net positive bias.

2. **Peak Flow Underestimation**: The model's inability to capture extreme peaks (>150 m^3/s) suggests potential issues with:

   - Infiltration parameters (B = 2.5 may be too high for storm conditions)
   - Channel routing parameters affecting flood wave propagation
   - Possible underestimation of effective rainfall during intense storms

3. **Seasonal Pattern Recognition**: The model successfully reproduces the strong seasonality of Pacific Northwest hydrology, with appropriate responses to winter storm systems and summer drought conditions.

Recommendations for Next Steps

1. **Parameter Calibration Focus**:

   - Reduce infiltration curve exponent (B) to increase runoff generation during storms
   - Adjust channel flow parameters (ALPHA, BETA) to improve peak flow routing
   - Consider reducing water capacity (WM) to enhance runoff response

2. **Extended Warmup Period**: While the current bias is 63.4% (not exceeding -90%), implementing a longer warmup period (3-6 months) could improve initial condition representation and reduce early simulation errors.

3. **Spatial Parameter Distribution**: Given the basin's size (3,282 km^2) and topographic variability, consider implementing spatially distributed parameters to better represent the heterogeneity between coastal lowlands and eastern highlands.

4. **Multi-objective Calibration**: Implement a calibration strategy that balances multiple objectives, including peak flow accuracy, low flow representation, and overall water balance.

5. **Uncertainty Analysis**: Conduct sensitivity analysis on key parameters to identify which have the greatest influence on model performance and focus calibration efforts accordingly.

The Willapa Bay watershed presents typical challenges for hydrological modeling in Pacific Northwest coastal systems, with its complex topography, maritime climate influence, and extreme seasonal variability. While current model performance is moderate, the strong correlation and reasonable pattern reproduction provide a solid foundation for further refinement through targeted parameter adjustment and calibration strategies.