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WUCA Water Utility Climate Alliance

IMPROVING THE VEGETATION REPRESENTATION IN HYDROLOGIC MODELS ALTERS HYDROCLIMATE PROJECTIONS

A Summary of Impacts in Several Western U.S Basins

AS CLIMATE CHANGE DRIVES AIR TEMPERATURES UPWARD, HOW LAND COVER AND VEGETATION IS REPRESENTED IN HYDROLOGIC MODELS IS INCREASINGLY IMPORTANT IN ACCURATELY ESTIMATING RUNOFF VOLUMES.

INTRODUCTION

A hotter future from climate change is a near certainty. Accurately modeling evapotranspiration (ET), which is directly related to temperature, is crucial to adequately capture the impact of warming on streamflow. The Variable Infiltration and Capacity (VIC) hydrologic model is widely used for water resource assessments (Reclamation, 2014); however, many parameters in the model were estimated more than 20 years ago and never updated. Scientists have recently enhanced the vegetation in VIC using modern satellite observations (Bohn and Vivoni 2019), improving ET estimates (Bohn and Vivoni 2016), and modifying the modeled response to climate change. Currier et al. (2023) examined the influence of this updated vegetation for the Colorado River Basin, here we highlight the effect of these changes across the Western U.S.

MORE REALISTIC VEGETATION

The original vegetation dataset was created before the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data were available, and erroneously specified nearly 100% vegetation cover throughout the Western U.S. and treated arid mountain forests as if they were densely vegetated (Figure 1). Updating this dataset with improved observations from the last 20 years results in more realistic vegetation representation of nearly barren deserts and sparse forest canopies.

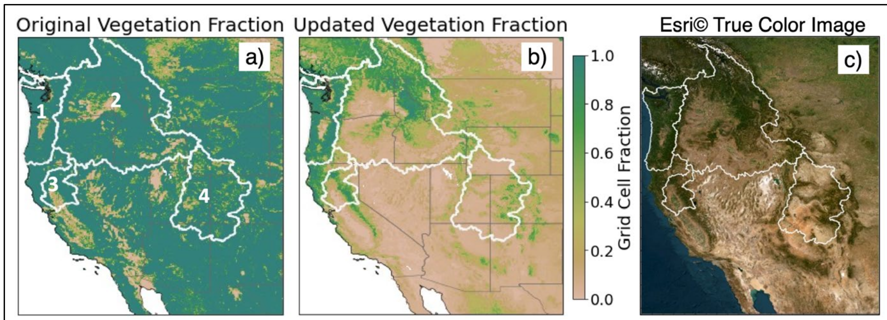


Figure 1. Vegetation fraction from the original (a) and updated (b) vegetation parameters with a satellite image for visual comparison (c). White outlines delineate hydrologic basins of interest: 1) Western Pacific Northwest 2) Columbia River Basin 3) Sacramento 4) Upper Colorado.

MODEL CALIBRATION CONSIDERATIONS

Key Limitation: Updating vegetation parameters significantly modifies the physical hydrology of the model. The net effect may require the model to be recalibrated in many basins.

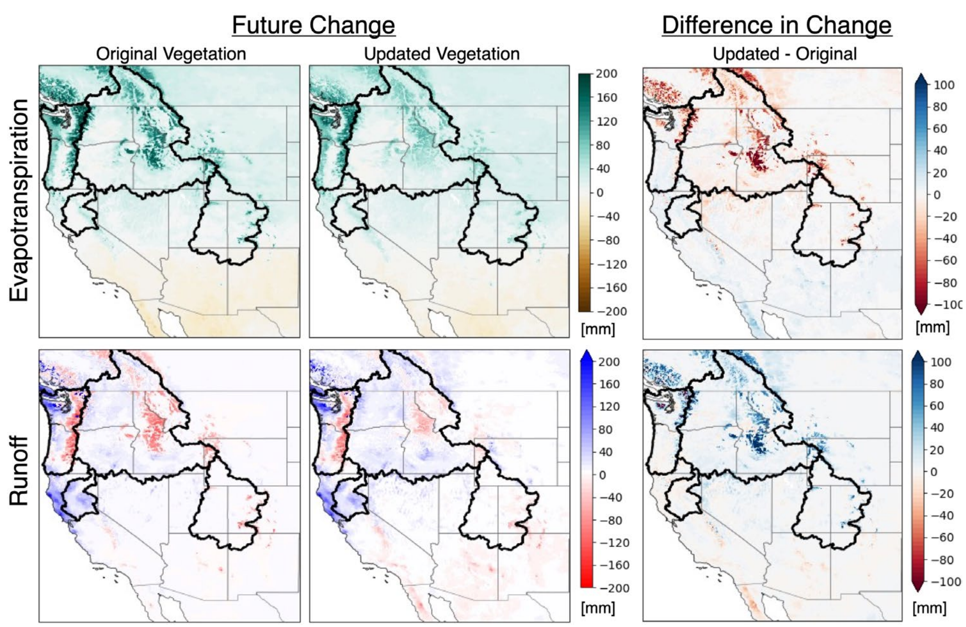
This update modifies the physical hydrology in the model including both historical streamflow and climate sensitivity. With the updated vegetation, more water is lost from a basin through evaporation relative to vegetation transpiration, less water is lost from intercepted rain and snow in the forest canopy, and more wind and sun can reach the snowpack underneath the forest. The net effect of these and other changes is that less water is lost to the atmosphere and in many basins, it may be necessary to recalibrate the model. Because of this, it is important not to rely on the percent increase/decrease in streamflow shown; these values primarily highlight the significance that vegetation parameters play in runoff modeling across the West. In Colorado, we found recalibration improved historical streamflow but did not eliminate the sensitivity to vegetation change (Currier et al., 2023).

IMPACTS TO STREAMFLOW FROM CHANGING VEGETATION PARAMETERS COMPARED TO IMPACTS FROM CHANGING CLIMATE

Key Finding: In some regions, the influence of updating the vegetation parameters in VIC on future changes in runoff and ET is larger than the magnitude of the original climate change signal.

This is particularly true in water limited basins, for which ET takes up a larger portion of total precipitation. While the total change in ET and runoff in a future climate looks very similar in the two model configurations, the difference between them is as large as the original mean climate change signal in some places (Figure 2). For example, in the Upper Colorado, the average future change in runoff using the original vegetation parameters is -19 mm and +22 mm using the updated parameters, a difference of 41 mm.

Figure 2. The mean end-of-century change in annual ET (top) and runoff (bottom) using the original (left), the updated (center) vegetation, and the difference between them (right). This highlights that changing vegetation parameters alters the climate change signal for runoff by decreasing the change in ET.



MODELED SEMI-ARID BASINS ARE MOST AFFECTED BY CHANGING VEGETATION PARAMETERS

Across the west, vegetation parameters have varying degrees of impact on basin wide flows. We see the largest effect in semi-arid basins such as the Upper Colorado and the Columbia River Basin. Figure 3 shows the modeled monthly runoff over these basins with original and updated vegetation parameters in both historical climate and future climate based on a subset of twelve Localized Constructed Analog (LOCA) downscaled climate projections from the Coupled Model Intercomparison Project (CMIP) Phase 5 (CMIP5) for the Representative Concentration Pathway (RCP) 4.5 emissions scenario. In these results the historical period spans from 1960-2005 and the future period is from 2070-2100. The climate models used include ten models selected by the California Technical Advisory Group plus two additional models which were found to perform well across the western U.S. In the Upper Colorado and Columbia River Basin, the new vegetation dataset results in a significant increase in flows and a shift to earlier runoff if the model is not recalibrated. Results in the Sacramento basin and the wetter Western Pacific Northwest (PNW) indicate relatively small differences between the original and updated vegetation parameters.

Key Finding: Changing vegetation parameters in VIC has the largest effect on basin wide runoff in semi-arid regions.

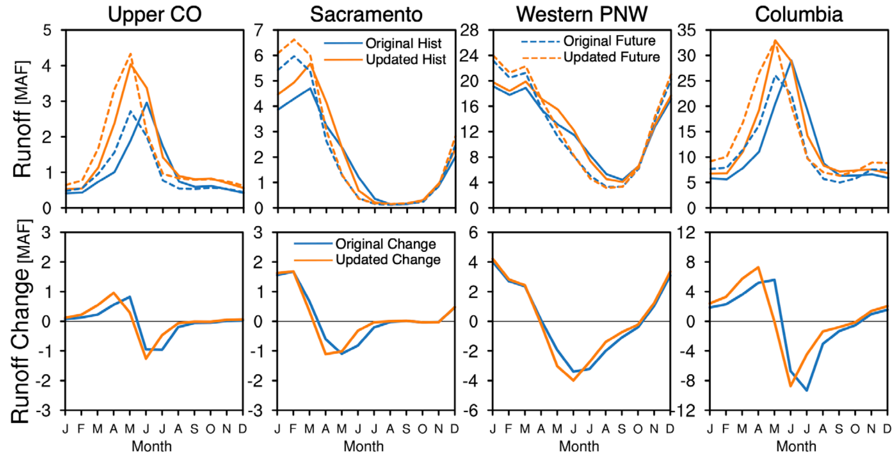


Figure 3. Modeled monthly hydrographs (top) for historical (solid) and future (dashed) periods in the four basins delineated in Figure 1, and monthly climate change signal (Future – Historical) for the monthly hydrographs (bottom). VIC runs used original (blue) and updated (orange) vegetation parameters.

Perhaps most importantly, less vegetation in semi-arid basins results in less increase in ET in the future, and greater modeled runoff in future climate projections (Table 1). Simulations of future streamflow using the original vegetation dataset resulted in a 3.0% decline in the Upper Colorado. In contrast, a 2.6% increase in future streamflow is simulated using the new vegetation datasets. Similarly in the Columbia River Basin, the updated model simulates a 4.2 % increase compared to a prior insignificant change. Semi-arid basins are most susceptible to this change because ET plays a larger role in the total water budget for these basins, and as a result, small percent changes in ET can cause large percent changes in runoff. Because the increase in temperature is one of the most reliable future climate projections, it is critical that modeled ET is as accurate as possible, and more importantly, that the sensitivity of ET to temperature is as accurate as possible in the model used. For more detailed information, Currier et al. (2023) describes these differences in the Colorado River Basin.

Key finding: In the two semi-arid basins (Upper Colorado and Columbia River Basin), less vegetation results in smaller increases in ET, leading to overall increases in modeled runoff in future climate projections (Table 1).

		Upper Colorado	Sacramento	Western PNW	Columbia
P	LOCA	4.2 %	4.7 %	3.6 %	6.1 %
ET	VIC_{Orig}	5.3 %	3.0 %	9.7 %	9.9 %
	VIC_{Update}	4.6 %	3.3 %	9.3 %	7.7 %
Runoff	VIC_{Orig}	-3.0 %	7.0 %	0.8 %	0.1 %
	VIC_{Update}	2.6 %	6.2 %	1.1 %	4.2 %

Table 1. End-of-century percent change from historical in annual total Precipitation (P), Evapotranspiration (ET), and Runoff for the four basins examined. Table 1 highlights differences in regional changes in ET and Runoff using original (VIC_{Orig}) and updated (VIC_{Update}) vegetation parameters in VIC.

CONCLUSION

Scientists have recently updated the representation of vegetation in VIC based on modern satellite imagery. Building upon the work of Currier et al. (2023), which examined the influence of these changes in the Colorado River Basin, this document illustrates the impact of these vegetation changes over the Western U.S. The largest impacts to runoff were found in semi-arid regions, where ET plays a large role in the water budget. In many semi-arid regions, decreases in vegetation cover in the new dataset reduce ET in the future thereby resulting in relatively increased runoff. Understanding the impact of warming is critical, with recent studies suggesting that warming has resulted in the loss of an entire Lake Mead of water from the Colorado River Basin (Bass et al., 2023).

The percent change in streamflow values presented here are intended to highlight how important the representation of vegetation is for modeling runoff. These values are not meant to be prescriptive for planning purposes as the soil parameters in VIC have not been recalibrated to these vegetation changes. Such calibration would be recommended to assess specific future basin changes.

The original VIC vegetation dataset was used in key hydrologic studies including canonical downscaled CMIP Phase 3 and CMIP5 hydrology projections (Reclamation, 2014; Vano et al, 2020). The results presented here do not invalidate the results of previous work. However, these results do highlight that past results may have higher levels of uncertainty than previously thought due to limitations in the representation of physical hydrology in some basins. When working on semi-arid regions, managers may want to consider using or performing updated hydrologic simulations.

REFERENCES

Bass, B., Goldenson, N., Rahimi, S., & Hall, A. 2023: Aridification of Colorado River Basin's snowpack regions has driven water losses despite ameliorating effects of vegetation. Water Resources Research, 59, e2022WR033454. https://doi.org/10.1029/2022WR033454

Bohn, T.J., and E.R. Vivoni, 2016: Process-based characterization of evapotranspiration sources over the North American monsoon region, *Water Resour. Res*, 52, 358-384.

Bohn, T.J., and E.R. Vivoni, 2019: MOD-LSP, MODIS-based parameters for hydrologic modeling of North American land cover change, Sci. Data, 6, 144.

Currier, W. R, A. Wood, N. Mizukami, B. Nijssen, J. Hamman, E. Gutmann, 2023: Vegetation representation influences projected streamflow changes in the Colorado River Basin. *J. Hydrometeorology*, in press.

Reclamation, 2014: Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections: Release of Hydrology Projections, Comparison with preceding information, and summary of User Needs', prepared by the U.S. Department of the Interior, Bureau of Reclamation, Technical Services Center, Denver, Colorado. 110pp.

Vano, J., J. Hamman, E. Gutmann, A. Wood, N. Mizukami, 2020: Comparing Downscaled LOCA and BCSD CMIP5 Climate and Hydrology Projections. Technical Memorandum, 96p.