PNNL-39348

VIC-Global Parameter Dataset Sensitivity with the Variable Infiltration Capacity Model

Evaluating the importance of dynamic land surface parameters when using the VIC-Global parameter dataset

May 2026

Mingjie Shi
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U.S. DEPARTMENT of ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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under Contract DE-AC05-76RL01830

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Abstract

Accurate prediction of runoff is essential to water resources management, flood risk assessment, and ecosystem protection. However, many hydrological models still have relatively substantial limitations when representing the influence of land use and land cover (LULC) on runoff generation and routing. Changes in LULC, such as deforestation, urban expansion, agricultural intensification, and wetland loss, have been shown to alter the water balance at the land surface through fundamental hydrologic processes (e.g., interception, infiltration, evapotranspiration, and soil storage). However, it remains an open question what the exact magnitude and timing of these impacts are for the spatial and temporal scales commonly used in engineering applications. In this analysis we focus on one aspect of recent LULC change for assessing human impacts, which is urbanization. Specifically, we seek to determine the impacts of urbanization on the magnitude and timing of surface runoff and baseflow in HUC-12 basins in Clark County, Nevada which has experienced rapid urbanization. We use the Variable Infiltration Capacity (VIC) hydrology model with a widely used off-the-shelf dataset of land surface parameters, VIC-Global, both of which have been commonly used in the past for water and energy balance modeling for large scale hydrologic studies. We examine two scenarios where the first scenario removes all urbanized land cover and parameterizes those areas of the basins as barren or open shrubland. The second scenario tests the opposite case where all areas of the basins are classified as urban regardless of their present classification. The results from the VIC model show there is a low sensitivity for daily surface runoff between scenarios. The daily baseflow values indicate similar low sensitivity to the classification change during specific periods, but then have substantial differences during other period when large precipitation events are occurring. This is likely due to the assumed parameter values for the urban land cover classification made by the VIC-Global dataset. Using a static land cover parameterization is reasonable for large domain hydrology models that are being used for near-term planning horizons (<30 years). However, longer planning horizons where feedbacks between the atmosphere and land surface are important, especially in transient climate situations, considerations for how to update land surface parameters should be incorporated.

Summary

This report evaluates the sensitivity of runoff and baseflow to land use and land cover (LULC) using the Variable Infiltration Capacity model (VIC v5) in an urbanizing region centered around Las Vegas, located in Clark County, Nevada. Six HUC-12 basins intersecting Clark County were selected based on substantial increases in urban fraction (>15%) between 1993 and 2012. Meteorological forcing was provided by the TGW dataset and aggregated from gridded fields to basin-scale, area-weighted time series. The VIC-Global parameter datasets which is 1/16° resolution were similarly aggregated to basin averages. Two idealized land-cover experiments were designed to isolate the hydrologic effects of urbanization: a 0% urban scenario in which all urban land fractions were converted to a uniform 50/50 mix of open shrubland and barren land, and a 100% urban scenario in which all basin land cover was converted to urban. Soil properties and atmospheric forcings were held constant, and simulations were uncalibrated. Results indicate that increasing urban fraction tends to decrease surface runoff and baseflow peaks. This is counterintuitive to the conceptual understanding of water partitioning at the land surface and is likely due to the values used by the VIC-Global parameter dataset to represent the urban land cover classification. The results from our simulations show that baseflow differences between the two scenarios are generally small; large daily discrepancies occur rarely (0.8% of days) and are concentrated in winter months and a few high-precipitation years. Examination of VIC-Global parameter tables suggests limited contrast between urban and some non-urban classes (e.g., grassland), which may reduce model sensitivity to LULC changes in this framework. The findings highlight that a clear understanding of the use case for the runoff results should be made. Using the VIC model along with the VIC-Global parameter dataset for capturing the complexities of urban hydrology is likely not a recommended use case. Credible assessment of urbanization impacts may require more explicit urban process representation (e.g., VIC-Urban) and/or localized parameterization beyond default land-cover libraries. In addition, our analysis only uses one region of the U.S. for evaluating the sensitivities and additional basins should be evaluated in future efforts for more rigorous results.

Key findings and recommendations from this analysis are:

- The values available through Schaperow et al. (2021a) are not completely consistent with those described in Schaperow et al. (2021b) for the associated land cover classes and should be verified before use.
- Using the VIC-Global parameter dataset is generally adequate for large domain hydrology model setup and simulations of near-term planning horizons; however, for smaller domains in highly urbanized areas, the assumptions made in the Schaperow et al. (2021b) publication regarding urban parameter values are likely not adequate for accurate water balance representation at the land surface.
- There is low sensitivity (~0.5%) for the results of the VIC surface runoff based on land cover classification in the six basins we evaluated. However higher sensitive is possible with other regions and classification changes.
- The basins in this case study do not represent all LULC changes, or even all urbanization scenarios in the CONUS, therefore we recommend additional investigations on appropriate VIC parameter values and configurations for urban landscapes which will provide more accurate water balance partitioning at the land surface.

Acknowledgments

This research was supported by the Framework for Optimizing Reliable Energy Systems and Infrastructure Given High-Uncertainty Trajectories (FORESIGHT) Initiative, under the Laboratory Directed Research and Development (LDRD) Program at Pacific Northwest National Laboratory (PNNL). The computational work was performed using PNNL Institutional Computing at Pacific Northwest National Laboratory. PNNL is a multi-program national laboratory operated for the U.S. Department of Energy (DOE) by Battelle Memorial Institute under Contract No. DE-AC05-76RL01830.

Acronyms and Abbreviations

CONUS – Contiguous United States

GODEEEP – Grid Operations for Decarbonization, Energy and Environmental Equity Platform

LULC – Land Use Land Cover

TGW – Thermodynamic Global Warming

USGS – U.S. Geological Survey

VIC – Variable Infiltration Capacity

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1.0 Introduction

Runoff generation is a fundamental component of the hydrological cycle, determining water supply, flood risk, soil erosion, and ecosystem functioning. Accurate simulation of runoff is critical for water resources management, infrastructure design, and climate adaptation. Land use and land cover (LULC) exert a first-order control on how rainfall is partitioned into infiltration, evapotranspiration, storage, and surface or subsurface flow (Bosmans et al., 2017). Changes in LULC, such as deforestation, agricultural expansion, urbanization, and wetland drainage, could substantially modify both the magnitude and timing of runoff (Niehoff et al., 2002; Zhou et al., 2023). At the hillslope scale, LULC affects hydrological processes through multiple mechanisms. Vegetation structure and type influence interception, root-zone water storage, and transpiration, altering soil moisture dynamics that control runoff generation (Wagener et al., 2013). Land management practices, including tillage, compaction, and irrigation, modify soil hydraulic properties and infiltration capacity. Urban development replaces permeable surfaces with impervious cover, increases drainage density, and shortens flow concentration times, typically leading to higher peak flows and flashier hydrographs (Filoso et al., 2017; Paul & Meyer, 2001). Conversely, reforestation and conservation agriculture can enhance infiltration and storage, reducing surface runoff and attenuating floods (Blanco-Canqui et al., 2020).

Existing hydrological models typically capture LULC effects only partially or implicitly. Conceptual hydrological models often rely on lumped or semi-distributed parameterizations that are calibrated to historical streamflow (Wagener et al., 2009). In these cases, the influence of LULC highly depends on calibrated parameters, which are then assumed to be stationary. These models may reproduce past hydrographs but can become unreliable when LULC conditions change, limiting their suitability for scenario analysis or impact assessment (Merz et al., 2011).

Process-based distributed models offer more explicit representation of land surface processes, but they often use simplified land cover classes and static maps that mask fine-scale heterogeneity in vegetation, soils, and impervious surfaces (Bierkens et al., 2015; Clark et al., 2015). Thus, parameterization of key LULC-sensitive affected processes, such as infiltration–excess runoff, preferential flow, and root-zone dynamics, are only accurate for short simulation periods with relatively stable land cover and management (Merz et al., 2011). However, static LULC parameterizations have been used for research aiming at reproducing historical streamflow at an outlet; in these cases, calibration can yield “effective” parameter values that summarize aggregate basin behavior and provide acceptable performance (Efstratiadis et al., 2010). Moreover, the use of static parameters to simulate streamflow over large domains, including the Columbia River Basin, have been shown to produce representative historical streamflow (Chegwidden et al., 2019).

Time-varying (dynamic) parameterizations are often sought for basins experiencing rapid LULC change, because models that treat LULC effects as fixed parameters or highly simplified land-surface classes that cannot respond realistically as vegetation, impervious cover, and soil disturbance evolve over time (Grangeon et al., 2022; Rakovec et al., 2016). Dynamic parameters or time-varying LULC inputs are also favored for scenario analysis and impact attribution, where internal consistency and transferability across periods matter more than reproducing a single historical record (Lan et al., 2020).

Based on the current literature, there are still unresolved research questions about the guidelines for implementing dynamic hydrologic model parameters for capturing the effects of LULC changes on runoff in large domain hydrologic models. To further understand these effects on runoff, we performed a parameterization experiment to quantify changes in runoff and baseflow in basins in Clark County Nevada (Las Vegas region), where land cover types have been changing due to urbanization for several decades. Our objective is to assess the extent to which LULC could affect runoff in a highly urbanized region using the Variable Infiltration Capacity (VIC) hydrology model (Liang et al., 1996) when the VIC-Global parameter dataset (Schaperow et al., 2021b) is used “out-of-the-box”. Section 2 of the report describes the VIC model setup and parameterization. Section 3 summarizes the results of the model testing while Section 4 provides key conclusions from this analysis.

2.0 Methods

2.1 The VIC Model Background

In this study, we used the Variable Infiltration Capacity model, version 5 (herein VIC). VIC is a semi-distributed, grid-based macroscale hydrologic and land-surface model, which is developed to simulate both the water and energy balance of the land surface over large domains, from large river basins to continental and global scales. The model represents the land surface as model grids, where each grid cell is modeled independently in terms of water and energy processes (i.e., without river routing and grid-to-grid routing processes). Within each grid cell, VIC accounts for subgrid heterogeneity in several ways. Vegetation is represented by different vegetation types (e.g., forest, grassland, crops, etc.), each with its own properties, such as leaf area index, rooting depth, and vegetation roughness length. Each vegetation class is associated with a fractional area of the grid cell. VIC can also represent elevation variability using elevation bands, particularly relevant in mountainous regions where snow and temperature change with altitude. Below the surface, the soil column is divided into multiple layers, with configurable thickness, hydraulic, and thermal properties. These layers respond differently to hydrologic forcing, with the shallow layer reacting quickly to precipitation and evaporation, and deeper layers providing seasonal storage and baseflow. However, VIC has limited capability to be parameterized for representing urban areas (Wang et al., 2020; Wang et al., 2024).

VIC partitions precipitation into rainfall and snowfall based on air temperature thresholds. Snowfall accumulates in a snowpack, and the model tracks snow water equivalent and snowpack temperature, along with the associated energy exchanges due to melt, refreezing, and heat fluxes. Rainfall interacts with the soil through an infiltration scheme (i.e., the variable infiltration capacity formulation). Runoff generation in VIC has two components: surface runoff and baseflow. Surface runoff occurs when precipitation exceeds the infiltration capacity or when the top soil layer becomes saturated. Baseflow is produced from the deepest soil layer using an empirical recession-type relationship, controlled by parameters that define a threshold soil moisture content, a maximum baseflow rate, and a nonlinear response to storage. The total runoff from a grid cell is the sum of surface runoff and base flow (Liang et al., 1996).

2.2 Model Setup for Testing

The VIC model used for this study was originally developed under the PNNL internal agile investment GODEEEP (Grid Operations for Decarbonization, Energy and Environmental Equity Platform) supporting the development of hydropower projections (Bracken et al. 2025). The GODEEEP-hydro VIC model leveraged a 1/16th degree gridded spatial resolution set up parameterized with the VIC-Global parameter dataset for the vegetation and soil parameters (Schaperow et al., 2021b) and recalibrated using TGW (Jones et al. 2023) as weather forcing (Bracken et al. 2025). For this analysis modifications to the GODEEEP-hydro VIC model were made to convert from a 1/16th degree gridded setup to a spatial configuration of lumped areas organized by basin boundaries defined by the U.S. Geological Survey. The parameterization of the model also used the VIC-Global information, which provides parameters at a 1/16th resolution from 60°S to 85°N providing a near-global parameter dataset (Schaperow et al., 2021b). The aggregation of parameters from 1/16th grid to basin spatial scale is detailed in Section 2.4.

To test the sensitivity of runoff to LULC, we focused on VIC simulations for Clark County, Nevada (34–38° N, 113–116° W) (**Figure 1a**). We used land cover data from Li et al. (2021), which characterizes urbanization variations over time, to select basins to evaluate that have experienced substantial urbanization (**Figure 1b**). Basins were defined using 12-digit Hydrologic Unit Code (HUC-12) boundaries from the USGS Watershed Boundary Dataset (USGS, 2024).

We selected Clark County, Nevada (which contains Las Vegas) as a representative urbanizing region due to the rapid urban growth that has occurred during the last 35 years following population increases of approximately 200% from 1991-2025 (U.S. Census Bureau, 2025). All HUC-12 basins intersecting Clark County were identified, and we retained only those that have more than 15% change in urban land cover between 1992-2012 based on Li et al. (2021) land cover dataset (**Figure 1b**).

The VIC model for this analysis is configured to simulate at 6-hour timesteps from 1993-2012 and based on the available forcing data described in Section 2.3. The vegetation and soil parameters were fixed for the simulation period and were based on the values provided in the VIC-Global database. The source dataset for the VIC parameters is described in more detail in Section 2.4. Spatial aggregation of the vegetation and soil parameters from the 1/16th gridded values to lumped values for each HUC-12 basin is described in Section 2.5.

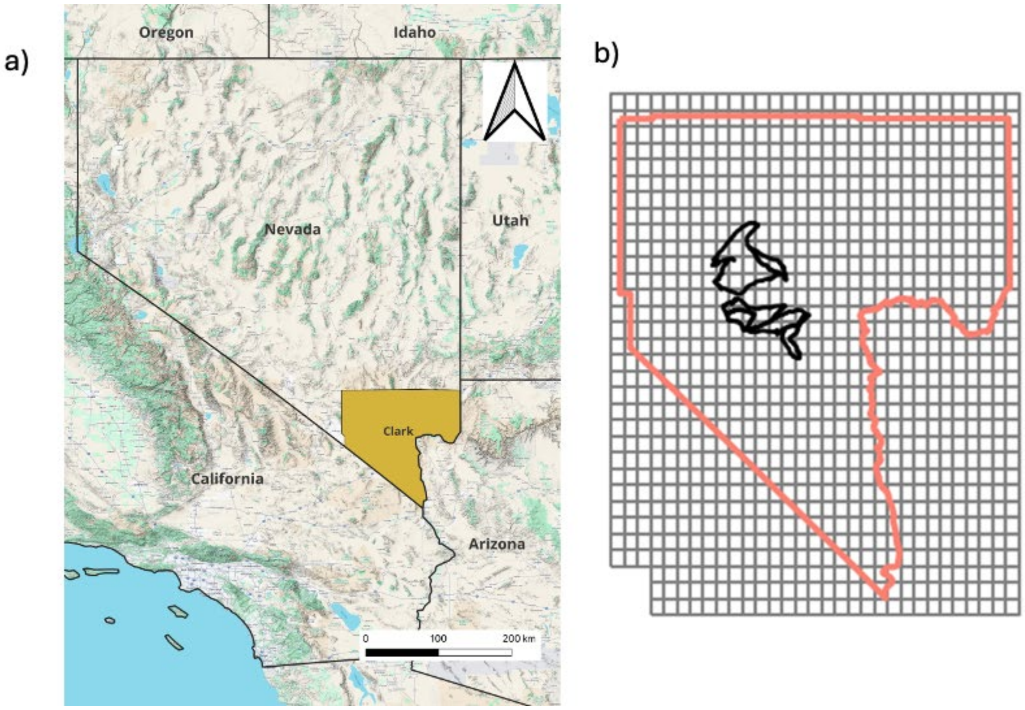

Figure 1. Area used in the LULC runoff analysis: a) Clark County, Nevada within the western U.S., and b) VIC grid cell coverage over Clark County along with HUC-12 basins that were used to compare runoff results.

2.3 The Atmospheric Forcing data

Meteorological forcings were taken from the TGW (Thermodynamic Global Warming) dataset for the contiguous United States (CONUS), which provides bias-corrected, thermodynamically modified historical weather fields. TGW forcings are available on a ~12 km grid and include precipitation, shortwave and longwave radiation, near-surface air temperature, wind speed, and humidity at 6-hour timesteps (Jones et al., 2023). As part of prior GODEEEP-hydro project, these forcings had been regridded to a 1/16° (~6–7 km) spatial resolution (Bracken et al., 2025). For this study, we further aggregated them from the 1/16° grid to basin-scale averages for the period 1993-2012 (**Figure 2**). For all forcing variables, we computed basin-area-weighted averages (Figure 2). The fraction of each grid that intersects the HUC-12 is calculated first (**Figure 2**) and then the grid value is multiplied by the fractional value to get the area-weighted estimate for all grids intersecting the basin.

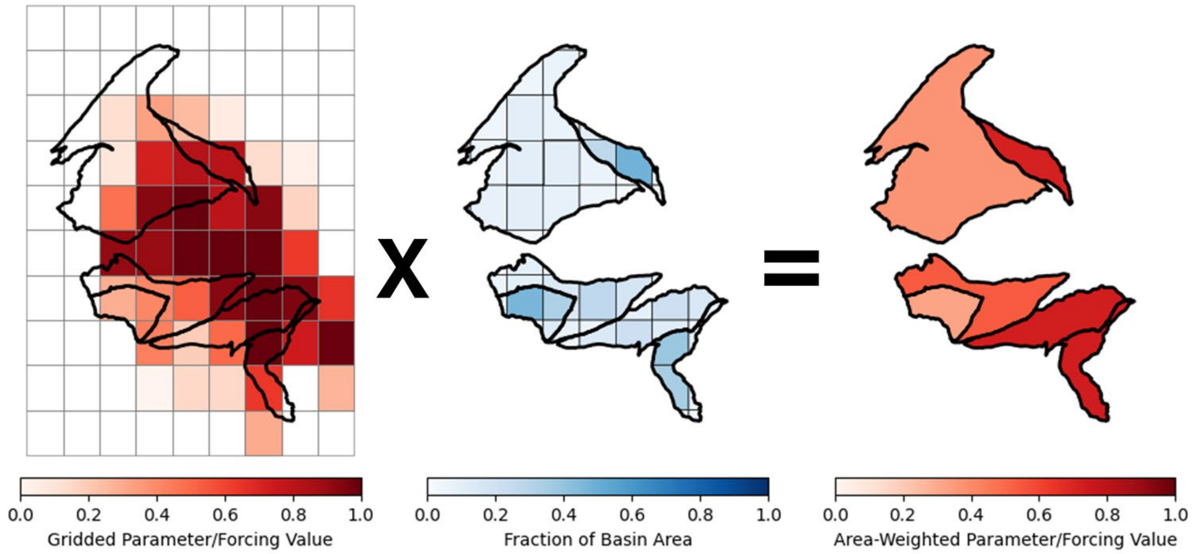

Figure 2. Example of process to aggregate the VIC-Global parameters for vegetation and soil from 1/16th gridded spatial scale to lumped HUC-12 spatial resolution. Example of process to aggregate the VIC-Global parameters for vegetation and soil from 1/16th gridded spatial scale to lumped HUC-12 spatial resolution.

2.4 Spatial aggregation model parameters

The land cover classification and fraction for the six basins used in our analysis are shown in **Figure 3.** The land cover factions are from VIC-Global and are consistent with the fractions reported by Li et al. (2021) The primary land cover classifications for our basins are “urban”, “barren”, “open shrubland”, and “grassland.” Four of the basins have urban as the highest land cover fraction value (~70%), suggesting the dense coverage of cities and concrete surfaces in those basins. The other two basins have approximately 30% of the land cover classified as urban. The land cover classifications are shown in Table A.1￼￼

Translation between the land cover classifications and the VIC parameters was performed using parameter values from the VIC-Global dataset, a near-global, high-resolution parameter dataset prepared for VIC at 1/16° resolution (Schaperow et al., 2021a). We used the VIC-Global vegetation parameter fields as a starting point, but modified the root zone fractions to match the rooting depth distribution reported in Schaperow et al. (2021b), because the default VIC-Global values differed from the assumptions discussed in Schaperow et al.(2021a).

Similar to the forcing variables, we spatially aggregated the parameter fields over each selected HUC-12 basin using an area-weighted average approach (**Figure 2**). -Global soil and vegetation parameters were also assumed uniform within individual grid cells, defined on the 1/16° grid, and were similarly aggregated to area-weighted basin-scale averages.￼that have ordinal values and the area-weighted basin-scale average is not meaningful, other aggregation approaches were used and are detailed in Table A.2.

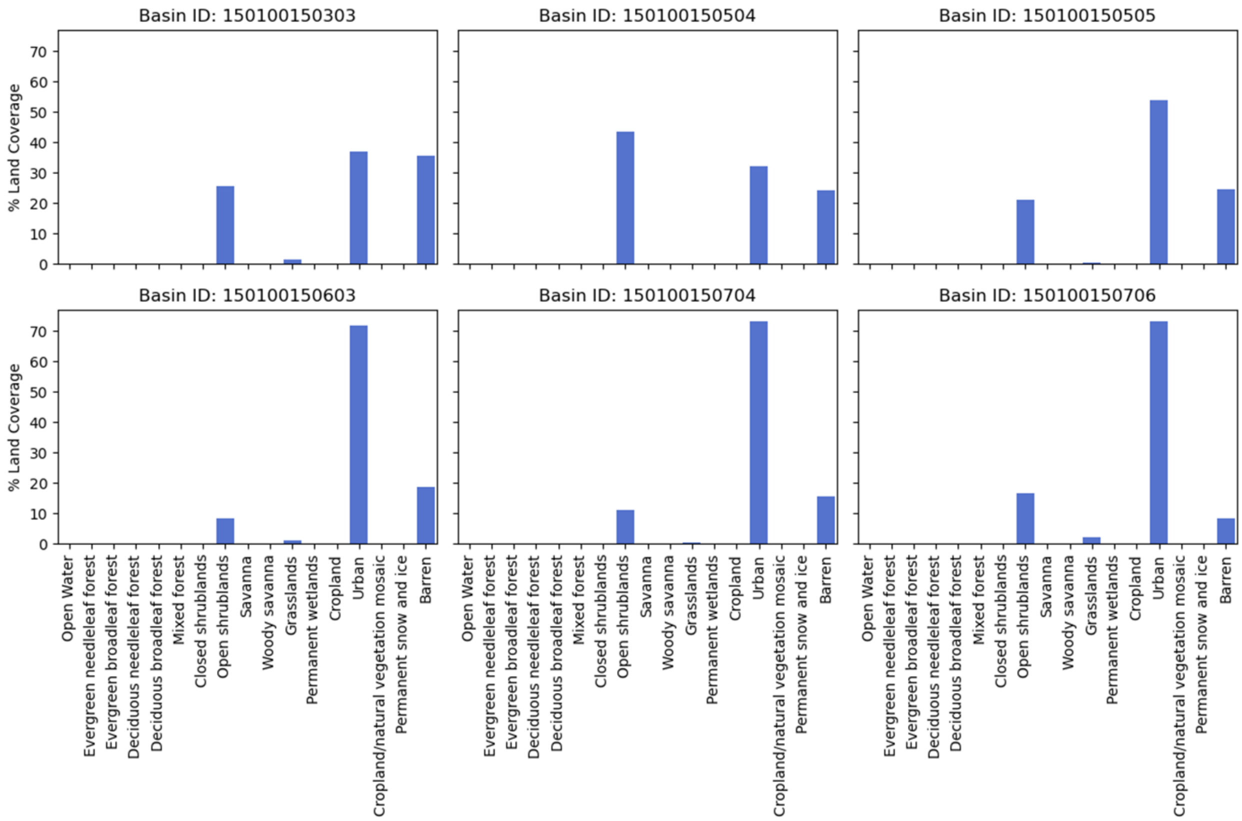

Figure 3. The selected basins for model testing in Clark County and the fractions of different land cover types (Schaperow et al., 2021b).

2.5 Urbanization in Basins and Land Cover Change Experiments

We focused on basins that have been experiencing substantial urbanization and combined the basin definitions with a time-varying land cover dataset (Li et al., 2021). For each HUC-12 basin intersecting Clark County, we calculated the change in urban fraction between reference years 1993 and 2012. To illustrate the sensitivity of LULC changes we selected six basins where the urban fraction increased by more than 15 % over this period based on the Li et al. (2021) dataset (**Figure 4**). The land cover data indicated that, in these basins, non-urban land is predominantly open shrubland and barren land.

We designed idealized land cover experiments to bracket the hydrologic impacts of urbanization at the basin scale, using two extreme scenarios:

- **0 % urbanized scenario (No Urban Land):** all grid cells classified as urban in VIC-Global within the basin were reclassified as a 50/50 mixture of open shrubland and barren land (uniform across basins).
- **100 % urbanized scenario (All Urban Land):** all land cover within each basin was reclassified as urban, replacing shrubland and barren land with urban cover.

For both scenarios, all other VIC parameter fields (soil properties, non-vegetation parameters) and all meteorological forcings remained unchanged. Only vegetation and land cover fractions were modified. While this experiment could have been setup for any HUC-12 in the U.S., we wanted to evaluate the sensitivity of our results for areas which are experiencing rapid urbanization and could represent sources of uncertainty for the VIC results.

For each of the six selected basins and for each land cover scenario (0 % and 100 % urban), we ran VIC over a 20-year period using the TGW forcings. Simulations were uncalibrated; we used the VIC-Global parameter values (with the modified root zone fractions and land-cover fractions described above) without tuning to streamflow. The two scenarios provide a controlled comparison of how basin-integrated runoff and related hydrologic variables respond to extreme changes in urban extent, isolating the effect of vegetation/impervious cover from other factors. The sensitivity of both surface runoff and baseflow is estimated between the two scenarios using the average difference in daily values for each basin divided by the percent change in urban land cover classification. A full sensitivity analysis was not performed since only the maximum (All Urban Land) and minimum (No Urban Land) were included in the analysis.

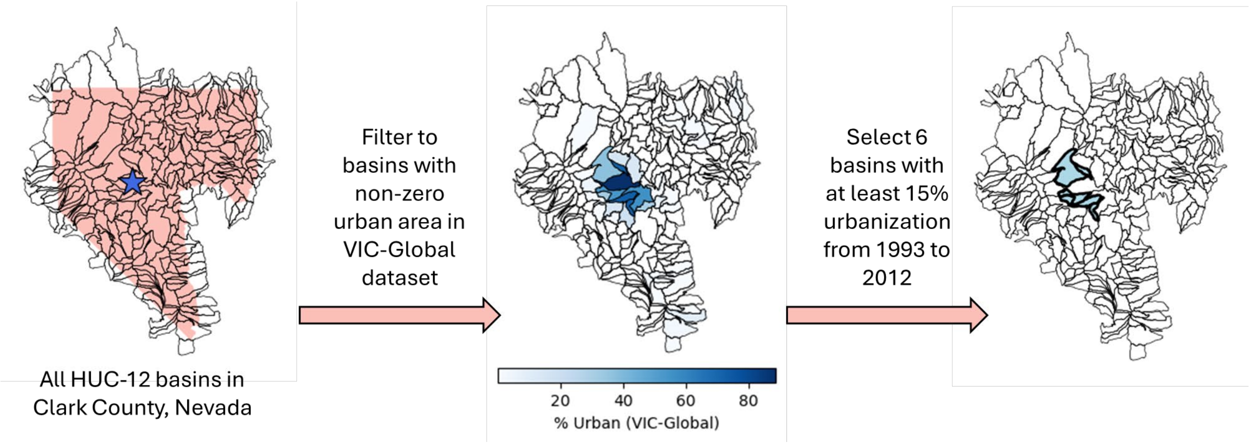

Figure 4. Down selection of basins in Las Vegas to the six that are ultimately used for VIC simulations based on the urban land cover fraction change of greater than 15% between 1992-2012 using the Li et al., 2021 dataset.

3.0 Results

3.1 VIC Parameter Differences

We assessed the VIC-global parameters by land cover type (**Figures 5 and 6**) based on the domain of our experiment (Figure 1b). There are two categories of parameter types that are set based on the land cover classification. These groups are parameters which vary only by classification (**Figure 5**) and parameters which vary by a combination of land cover classification and a secondary variable (**Figure 6**). The parameters that are only dependent on the land surface classification are overstory (overstory), architectural resistance of vegetation type (rarc), minimum stomatal resistance of vegetation type (rmin), measurement height of wind speed (wind_h), minimum incoming shortwave radiation at which transpiration will occur (RGL), wind attenuation (wind_atten), and trunk fraction (trunk_ratio). **Figure 6** shows VIC parameters that vary both by land surface classification and either season (blue shaded columns) or root zone in the VIC model (orange shaded columns). The time-dependent parameters include leaf-area index (LAI), albedo, vegetation roughness length (veg_rough), vegetation displacement height (displacement), and canopy cover fraction (fcanopy). The remaining parameters which depend on the land surface classification are root depth (root_depth) and root fraction (root_fract).

From our investigation of the VIC-Global parameter dataset we found the parameters that only depend on the land cover classification do not change values between classifications of urban, grassland, and barren (**Figure 5**). Schaperow et al. (2021b) notes this is the case in the data documentation which states "…barren land, permanent wetlands, snow and ice, urban land, and water bodies to take the parameters of "grasslands" from the LDAS vegetation parameter file."

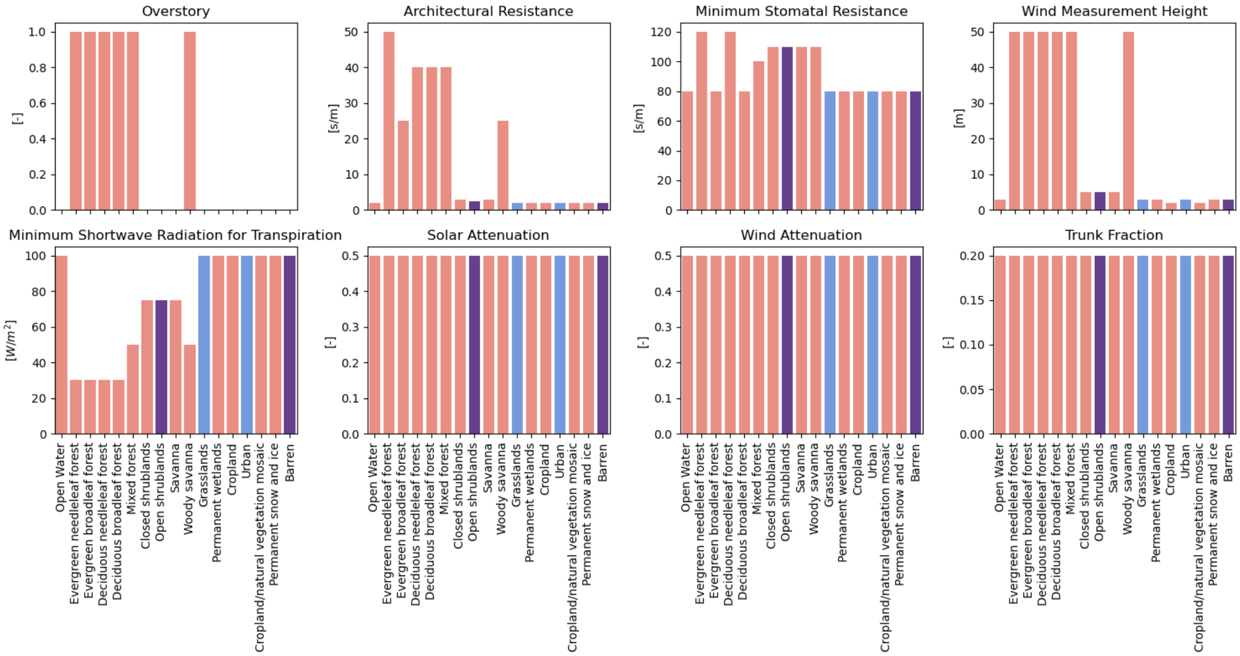

Figure 5. VIC-global parameters that only vary land cover classification. The parameters are overstory (overstory), architectural resistance of vegetation type (rarc), minimum stomatal resistance of vegetation type (rmin), measurement heigh of wind speed (wind_h), minimum incoming shortwave radiation at which transpiration will occur (RGL), wind attenuation (wind_atten), and truck fraction (trunk_ratio). The light blue columns show that grasslands and urban classification are the same as discussed by Schaperow et al. (2021b). The dark blue columns are the barren and open shrublands classifications. The barren classification is similar to the urban/grassland values while the parameters values for the open shrublands classification are different.

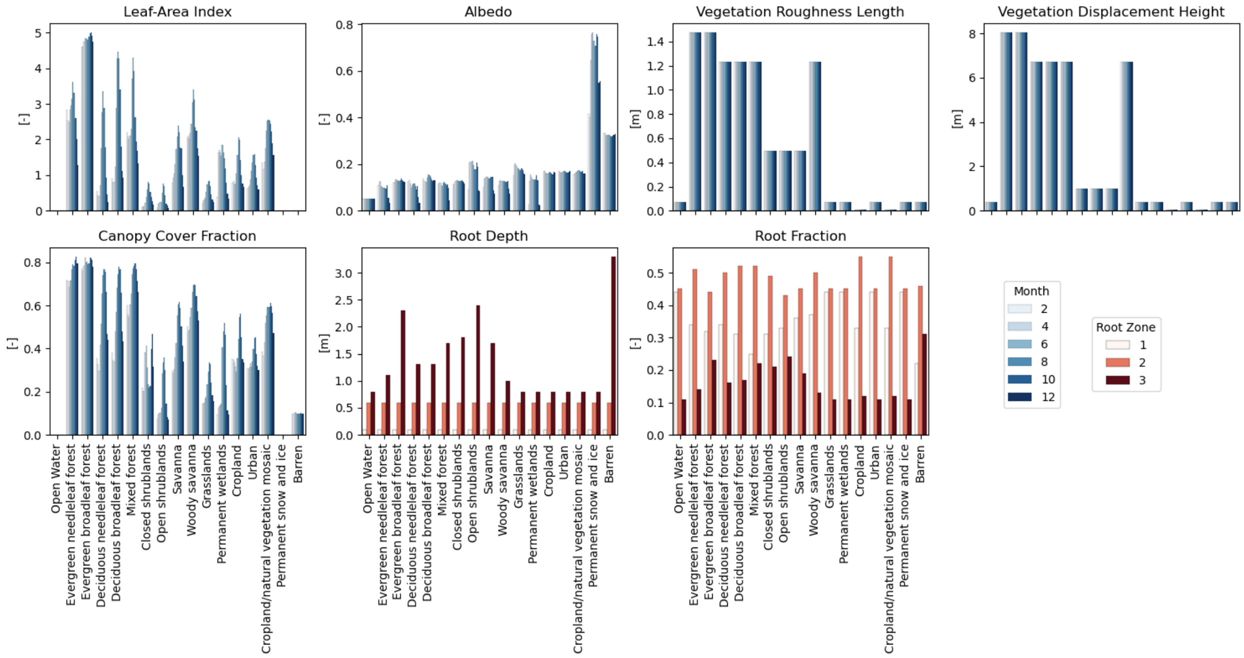

Figure 6. VIC-global parameters that vary by land cover classification and month of year (blue shaded columns) or soil layer (orange shaded columns). The panels are representing leaf area index (LAI), surface albedo, vegetation roughness length (veg_rough), vegetation height displacement (displacement), and canopy cover fraction (fcanopy) across time, and rooting depth (root_depth) and root fraction (root_fract) across soil layers.

3.2 Runoff and Baseflow

There are noticeable differences between scenarios for runoff and baseflow peaks. The No Urban Land consistently shows higher peak values (**Figures 7 and 8**). There is not a statistically significant difference between No Urban Land and All Urban Land for the surface runoff results (**Figure 7**); however there is a significant difference between scenarios for the baseflow results (**Figure 8**) using daily values for the 1993-2012 simulation period. The total runoff (sum of surface runoff and baseflow) are also significantly different which is due to the baseflow values comprising the largest fraction of the daily total runoff value.

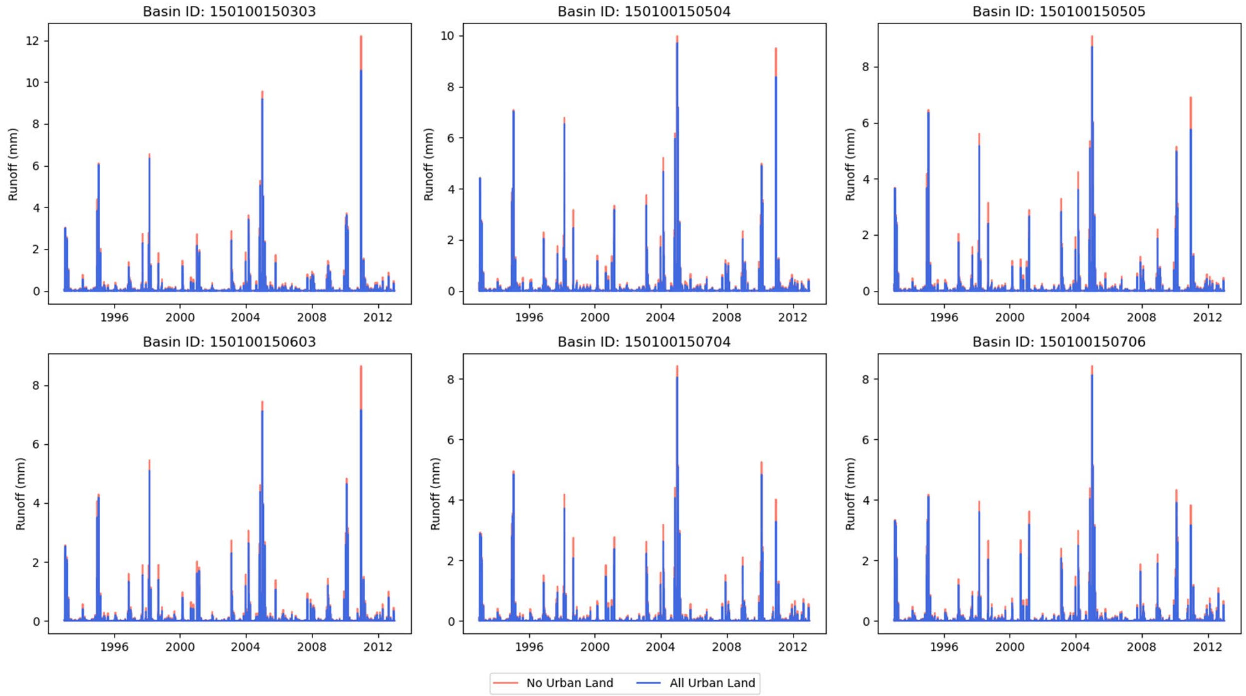

Figure 7. VIC simulated daily surface runoff that occurs between 0 and 100% in the six basins for period 1993-2012.

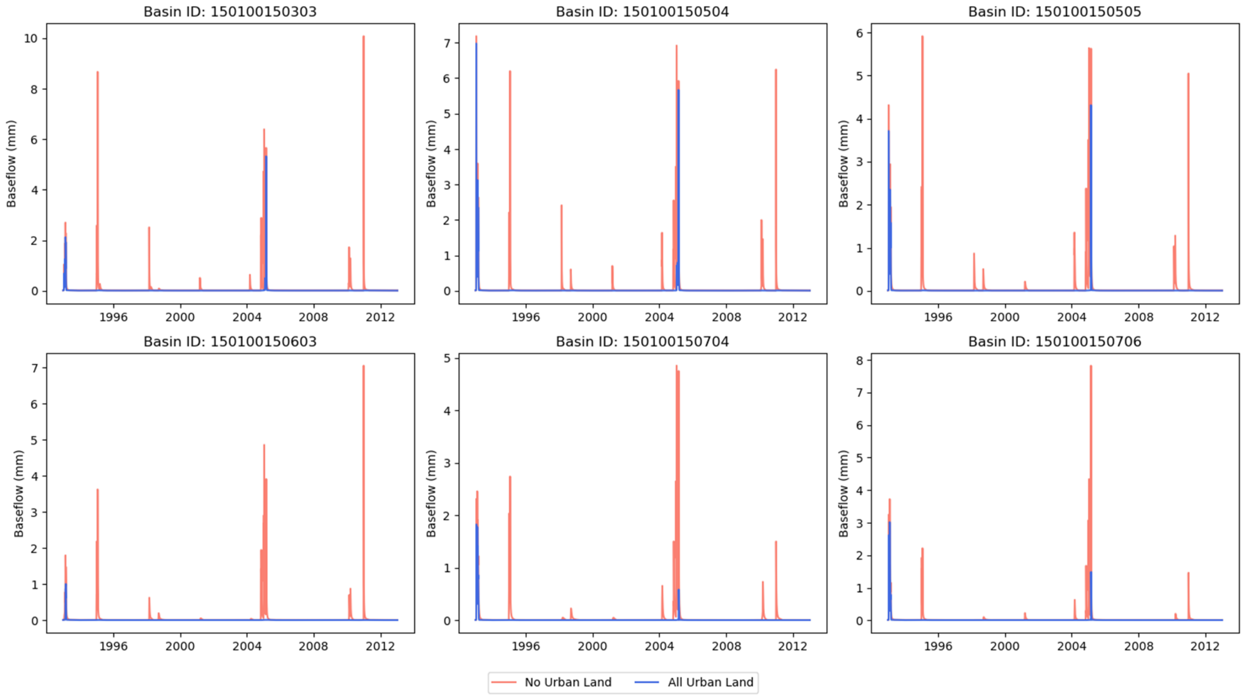

Figure 8. VIC simulated daily baseflow that occurs between 0 and 100% in the six basins for the period 1993-2012.

A comparison of surface runoff changes between each scenario is shown in **Figure 9**. The All Urban Land and No Urban Land scenarios plot close to the identity line and are similar in daily values for each basin. These results suggest that changing the land cover classification between scenarios has minimal effect on the surface runoff values. In contrast, the comparison of baseflow values between scenarios shows several distinct patterns which deviate from the identity line (**Figure 10**). There are several days that follow the identity line. However there are several days that have varying baseflow values for the No Urban Land but have no baseflow for the All Urban Land scenario indicated by the vertical points in **Figure 10**. The other pattern shown in **Figure 10** is a hysteresis-like pattern for basins 150100150504, 150100150704, and 150100150706. The daily baseflow values that follow closely to the identity line indicating the baseflow is less sensitive to land cover classification change. The average sensitivity between scenarios is approximately 0.5% for surface runoff. In contrast, the days that have zero baseflow for the All Urban Land scenario indicate a substantial effect between the scenarios. The most perplexing response are the days that create the hysteresis-type pattern. For those basins the same baseflow value for the All Urban Land simulation results in a large range of different No Urban Land baseflow values. The overall sensitivity for baseflow between scenarios is approximately 4%.

The daily baseflow output indicates that scenario differences are uncommon (0.8% of days) and exhibit a strong seasonal signal, occurring between Oct and January with 85% in December and January and 55% in January alone. These large differences are concentrated in a small number of winters, i.e., 2005, 1995, 2004, and 2010 (98% of cases), which align with years of pronounced winter precipitation peaks. The vertical patterns of points (when urban land baseflow equals to zeros) reflect these episodic winter events clustered in a few years, producing repeated occurrences of similarly large daily differences over short time windows. A plausible explanation is the values used by the VIC-Global parameter dataset for areas classified as urban land cover type are not representing an accurate response in the partitioning of water at the land surface. Potential sources of error are the evaporation and transpiration water balance components estimated from the VIC model.

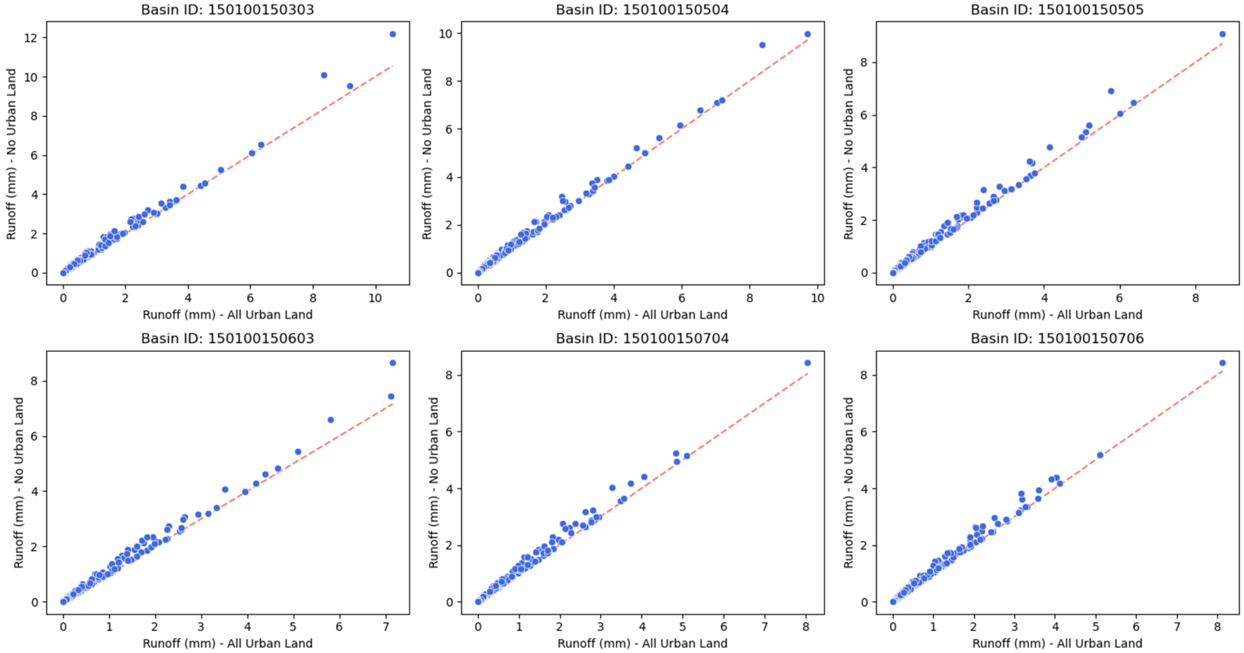

Figure 9. VIC simulated daily surface runoff that occurs between 0 and 100% in the six basins. The All Urban Land is shown on the horizontal axis while the No Urban Land is shown on the vertical axis. The identity line is shown in red.

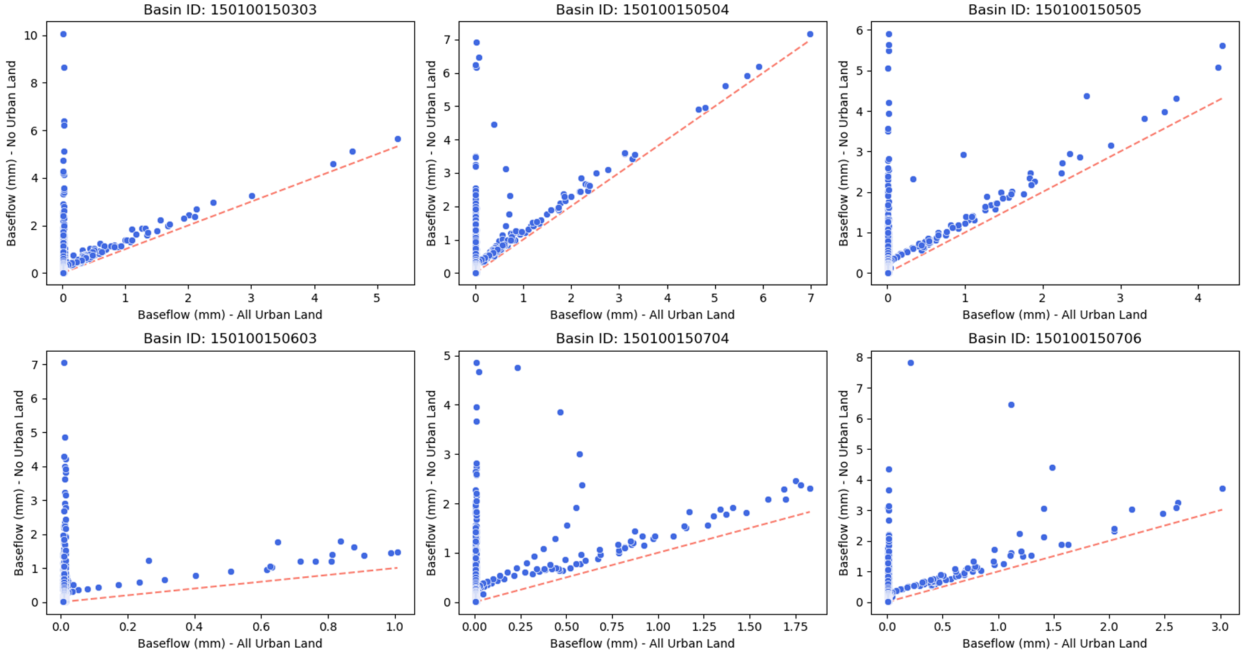

Figure 10. VIC simulated daily baseflow that occurs between 0 and 100% in the six basins. The All Urban Land is shown on the horizontal axis while the No Urban Land is shown on the vertical axis. The identity line is shown in red.

4.0 Conclusions

As suggested by existing studies, LULC is driving runoff changes globally (Zhou et al., 2023). To explicitly assess the impacts of LULC change on the hydrologic cycle, this study used a LULC dataset from Li et al. (2021) select basins included in the GODEEP-hydro VIC model to evaluate land cover parameterization sensitivity. The VIC model along with the VIC-Global parameter dataset was used to quantified the sensitivity of surface runoff and baseflow to LULC. Because VIC has limited capability to parameterize and represent urban areas, where most of the key parameters relevant to runoff were not calibrated, the simulations exhibited limited sensitivity of surface runoff (**Figure 7**); however there are substantial baseflow differences due to LULC change (**Figure 8**). The VIC-Global parameter dataset has identical values for grasslands, urban, and barren land for parameters that only depend on the land cover classification (**Figure 5**); however it should be noted that parameter values for soil types were not varied between the All Urban and No Urban simulations. There are some differences with shrubland parameters compared to urban (**Figures 6**). The parameters that depend on season or depth in the soil column have varying values for all four land cover classifications.

The surface runoff values had only minor differences between land cover scenarios (**Figures 7 and 9**). Confirming the sensitivity of the VIC surface runoff to land cover classification is low for the experiment we have performed. In contrast, the baseflow results show differences between urban and no-urban scenarios for specific periods (**Figures 8 and 10**). These differences are associated with precipitation partitioning variations likely caused by the assumption with the VIC-Global parameters that uses the same values for both urban and grassland classifications. More sophisticated landscape representations that explicitly couple urban processes with VIC could improve hydrological simulations by accounting for how diverse surface conditions (impervious area fraction, drainage infrastructure, and modified evapotranspiration) affect surface runoff and baseflow, particularly in rapidly urbanizing regions. Attempts to correct for urban hydrology differences have been made (Wang et al., 2024) however these formulations still use the concept of “urban” grids within VIC which does not directly translate into the aggregated basin approach we used in this analysis. Thus, to comprehensively understand the impacts of LULC on the hydrological cycle, we suggest detailed and localized parameterization of VIC or using model versions with explicit considerations of urban processes.

In large domain hydrology models where the total fraction of land cover changes are small or less dramatic as compared to the experiment we present in this report, the overall effects of a static land cover assumption over a relatively near-term planning horizon (<30 years) are likely to be negligible when estimating total streamflow. Moreover, when considering all the sources of hydrologic model uncertainty within this planning horizon (e.g., structural, data, etc.) the static land surface assumption is also likely not going to be a substantial driver of the uncertainty in the results (Frans et al., 2013). While including dynamic land surface for longer planning horizons (>50 years) could be important especially when evaluating atmosphere-land surface feedbacks in transient climate scenarios; however for shorter planning horizons over large modeling domains the climate is the primary driver of runoff compared to LULC changes (Frans et al., 2013).

Key findings and recommendations from this analysis are:

- The values available through Schaperow et al. (2021a) are not completely consistent with those described in Schaperow et al. (2021b) for the associated land cover classes and should be verified before use.

- Using the VIC-Global parameter dataset is generally adequate for large domain hydrology model setup and simulations of near-term planning horizons; however, for smaller domains in highly urbanized areas the assumptions, made in the Schaperow et al. (2021b) publication regarding urban parameter values are likely not adequate for accurate water balance representation at the land surface.

- There is low sensitivity (~0.5%) for the results of the VIC surface runoff based on land cover classification change and static soil parameters in the six basins we evaluated. However higher sensitivity is possible with other regions and classification changes.

- The basins in this case study do not represent all LULC changes, or even all urbanization scenarios in the CONUS, therefore we recommend additional investigations on appropriate VIC parameter values and configurations for urban landscapes which will provide more accurate water balance partitioning at the land surface.

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Appendix A – Parameters

Table A.1. Vegetation Classes from VIC-Global

Vegetation Class Identifier (veg_class)	Definition
1	Open water
2	Evergreen needleleaf forest
3	Evergreen broadleaf forest
4	Deciduous needleleaf forest
5	Deciduous broadleaf forest
6	Mixed forest
7	Closed shrubland
8	Open shrubland
9	Savanna
10	Woody savanna
11	Grasslands
12	Permanent wetlands
13	Croplands
14	Urban
15	Crop/Natural vegetation mosaic
16	Perennial snow and ice
17	Barren

Data from: Figure 3 in Schaperow et al. (2021)

Table A.2. Spatial Aggregation of VIC-Global parameters from 1/16-degree to basin.

Parameter	Definition	Dimensions	Aggregation Approach	Notes
layer	Moisture layer	nlayer	None	Not dependent on lat, lon coordinates
mask	Whether or not grid cell is masked	lat, lon	Set basin value to 1	Maximum value of 1
lons	Longitude of grid cell		Area-weighted average	
lats	Latitude of grid cell			
infilt	Variable infiltration curve parameter			
Ds	Fraction of Dsmax where non-linear baseflow begins			
Dsmax	Maximum velocity of baseflow			
Ws	Fraction of maximum soil moisture where non-linear baseflow occurs			
c	Exponent used in baseflow curve,			
elev	Average elevation of grid cell			
avg_T	Average soil temperature, used as the bottom boundary for soil heat flux solutions			
dp	Soil thermal damping depth (depth at which soil temperature remains constant through the year)			
off_gmt	Time zone offset from GMT. This parameter determines how VIC interprets sub-daily time steps relative to the model start date and time			
rough	Surface roughness of bare soil			
snow_rough	Surface roughness of snowpack			
annual_prec	Average annual precipitation			
July_Tavg	Average July air temperature, used for treeline computations			
cellnum	Grid cell number			
run_cell	1 = Run Grid Cell, 0 = Do Not Run			Maximum value of 1; Integer value
gridcell	Grid cell number			Integer value
fs_active	If set to 1, then frozen soil algorithm is activated for the grid cell. A 0 indicates that frozen soils are not			Maximum value of 1; Integer value

	computed even if soil temperatures fall below 0C			
Nveg	Number of vegetation tiles in the grid cell		Number of unique vegetation classes in basin	Integer value
overstory	Flag to indicate whether or not the current vegetation type has an overstory	lat,lon, veg_class	Set to 1 (True) for veg_class 2-6, 10 and set to 0 (False) for veg_class 1, 7-9, 11-17	Integer value
Cv	Fraction of grid cell covered by vegetation tile	lat, lon, veg_class	Area-weighted average	
rarc	Architectural resistance of vegetation type			
rmin	Minimum stomatal resistance of vegetation type			
wind_h	Height at which wind speed is measured			
RGL	Minimum incoming shortwave radiation at which there will be transpiration			
rad_atten	Radiation attenuation factor			
wind_atten	Wind speed attenuation through the overstory			
trunk_ratio	Ratio of total tree height that is trunk (no branches)			
expt	Exponent n (=3+2/lambda) in Campbell's eqn for hydraulic conductivity			
Ksat	Saturated hydrologic conductivity	lat, lon, nlayer		
phi_s	Soil moisture diffusion parameter			
init_moist	Initial layer moisture content			
depth	Thickness of each soil moisture layer			
bubble	Bubbling pressure of soil			
quartz	Quartz content of soil			
bulk_density	Bulk density of soil layer			
soil_density	Soil particle density			
Wcr_FRACT	Fractional soil moisture content at the critical point (~70% of field capacity)			
Wpwp_FRACT	Fractional soil moisture content at the wilting point			
resid_moist	Soil moisture layer residual moisture content in units of residual moisture content volume / total layer volume			
AreaFract	Fraction of grid cell covered by each elevation band	lat, lon, snow_band		
elevation	Mean (or median) elevation of elevation band			

pfactor	Fraction of cell precipitation that falls on each elevation band			
root_depth	Root zone thickness (sum of depths is total depth of root penetration)	lat, lon, veg_class, root_zone	Maximum value for each root_zone	
root_fract	Fraction of root in the current root zone			Ensure all root_fract sum to 1
LAI	Leaf-area index of vegetation type	lat, lon, veg_class, month	Maximum value for each veg_class/month	If veg_class = 1 (open water) or veg_class = 16 (perennial snow and ice), set LAI = 0
albedo	Shortwave albedo for vegetation type			
veg_rough	Vegetation roughness length			
displacement	Vegetation displacement height			
fcanopy	Partial vegetation cover fraction			If veg_class = 1 (open water) or veg_class = 16 (perennial snow and ice), set fcanopy = 0
Definitions of variables from: https://vic.readthedocs.io/en/master/Documentation/Drivers/Image/Params/				

**Pacific Northwest
National Laboratory**

902 Battelle Boulevard
P.O. Box 999
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