Hydrologic Model Comparison in Support of Water Resources Planning and Operations Studies

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Daniel Broman, Ph.D., P.E., Civil Engineer (Hydrologic)
Marketa McGuire, P.E., Civil Engineer (Hydrologic)

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The SUMMA model platform is attractive for supporting long-term planning studies in the future but will require further development before it is ready for applications.

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U	U				(303) 445-2551

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prepared by

Technical Service Center
Daniel Broman, Ph.D., P.E., Civil Engineer (Hydrologic)
Marketa McGuire, P.E., Civil Engineer (Hydrologic)

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DANIEL BROMAN Digitally signed by DANIEL BROMAN
Date: 2020.07.30 11:36:44 -06'00'

Prepared by: Daniel Broman, Ph.D., P.E.
Civil Engineer (Hydrologic), Bureau of Reclamation Technical Service Center

MARKETA MCGUIRE Digitally signed by MARKETA MCGUIRE
Date: 2020.07.30 12:44:22 -06'00'

Prepared by: Marketa McGuire, P.E.
Civil Engineer (Hydrologic), Bureau of Reclamation Technical Service Center

DREW LONEY Digitally signed by DREW LONEY
Date: 2020.07.30 12:40:43 -06'00'

Peer Review by: Drew Loney, Ph.D., P.E.
Hydrologist, Bureau of Reclamation Technical Service Center

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Executive Summary

Water resources planning and operations studies often require the simulation of streamflow through the implementation of hydrologic models to support investigations into projected future changes or to examine current and alternative water management operational policies. The Bureau of Reclamation (Reclamation) has identified limitations in the Variable Infiltration Capacity Model (VIC) to accurately simulate streamflow to support these investigations. This study presents a preliminary comparison between the VIC model and a new hydrologic model, the Structure for Unifying Multiple Modeling Alternatives (SUMMA) model. The SUMMA model is modular in that it allows for the selection of the most appropriate physical processes when developing a model to accurately simulate streamflow for a given study area.

This preliminary comparison demonstrated that SUMMA can reproduce the monthly cycle of streamflow as well as VIC for two river basins with distinct basin characteristics – a snowpack-runoff driven basin on the east side of the Rocky Mountains, Swiftcurrent Creek at Sherburne MT, and a high plains prairie-hydrology driven basin, Frenchman River at the International Boundary. This preliminary comparison also highlighted model platform and model functionality challenges with SUMMA which prevented a more detailed comparison from being performed. The original study design called for SUMMA to be configured so that the spatial extents and scale matched the VIC model, that the forcing data match the VIC model, and that the model would be calibrated using available naturalized flows. This design would have allowed for differences in streamflow between VIC and SUMMA to be diagnosed by investigating differences in water balance components – surface runoff, baseflow, snowpack storage, and evapotranspiration. In developing SUMMA, only the matching spatial configuration was realized – SUMMA used a different set of forcing data and was not calibrated – so this preliminary comparison only looked at streamflow.

The SUMMA model platform, which includes the pre-processing tools to configure the model, develop forcing data, develop model routing data, calibration tools to effectively calibrate models, and post-processing tools to visualize and evaluate model output – is currently in a state of development. Particularly with the pre-processing tools additional refinement is needed to ensure that a SUMMA model can be developed at the desired spatial scale with the desired set of forcing data. SUMMA Model functionality was adequate to allow for the simulation of streamflow, but slow run times, and slow input-output presented challenges in running SUMMA effectively in this study. SUMMA remains an attractive option to support water resources planning and operations studies, but improvements to both the model platform and model itself are needed before it can support these studies effectively. A more thorough model comparison, similar to original study design for this comparison should be conducted to thoroughly evaluate SUMMA's performance against vetted models, including VIC. Additional evaluation of SUMMA using it's modular construction and evaluating the use of different physical parameterizations to develop guidance for the selection of these parameterizations for different hydrologic conditions would greatly benefit its use in future studies as well. Reclamation through this comparison was able to successfully implement and run the SUMMA hydrologic platform, and this capability will be useful in future SUMMA model comparison projects as well as ultimately for water resources operations and planning studies.

1 Introduction

1.1 Background and Motivation

Within Reclamation, long-term planning studies, under the Basin Studies Program, and new programs including the SECURE Reservoir Operations program, are interested in examining water supply and demand imbalances, identifying water management challenges, and evaluating the effect of structural and non-structural changes at daily time scales. Water resources planning studies often require the simulation of streamflow through the implementation of hydrologic models to support investigations into projected future changes, or to examine current and alternative water management policies. Hydrologic models are used to simulate streamflow to examine the impact of environmental conditions, including the impact of climate change. These streamflow simulations are then used within water management models to examine how different streamflow conditions impact water management metrics. The complexity of the management model, and the questions being asked of the study determine the level of accuracy required of the streamflow simulations, with accuracy defined as how well the simulations match the timing and magnitude of a study-specific reference streamflow dataset. Past long-term planning studies under the Basin Studies Program, including the Colorado River Basin Water Supply and Demand Study (Reclamation, 2012), the Truckee Basin Study (Reclamation, 2015), the Klamath River Basin Study (Reclamation, 2016a), and the Sacramento and San Joaquin Rivers Basin Study (Reclamation, 2016b), have relied upon hydrologic models to develop streamflow for climate change and paleoclimate scenarios. In these studies, hydrologic models alone could not simulate streamflow at the required accuracy, and an additional step of bias-correction was required. Through bias-correction, streamflow simulations were adjusted so that when they were used within management models, the river system can be accurately simulated, and management metrics can be accurately evaluated. Bias-correction however, severs link with physical processes simulated within the hydrologic model and introduces uncertainty that make it challenging to accurately examine scenario changes at time scales less than one month. Hydrologic models that could more accurately simulate streamflow and negate the need for bias-correction, or at least greatly reduce the need, would allow for management metrics to be evaluated at finer time scales.

The Variable Infiltration Capacity (VIC) hydrologic model (Liang et al. 1994) has been used by Reclamation in numerous studies and has become the de-facto standard to simulate streamflow in support of long-term planning and operations studies. VIC tends to perform well in locations with snowpack-melt driven hydrology but can struggle to accurately simulate streamflow in locations with other hydrologic regimes. A limitation of VIC is that it is limited to a single set of physical representations for hydrologic processes. Several recent planning studies have found VIC unable to simulate streamflow at the desired level of accuracy. While these studies were ultimately successful in providing assessments of the impact of future change at a high level, the accuracy of the streamflow simulations prevented the studies from providing a more detailed assessment of the impact of future changes. In addition to challenges in simulating streamflow at the desired accuracy, advances in alternative hydrologic models has made future long-term support for VIC by its developers in the Computational Hydrology group at the University of Washington (UW) uncertain.

The National Center for Atmospheric Research (NCAR), Research Applications Laboratory (RAL), UW, and collaborators have been developing the Structure for Unifying Multiple Modeling Alternatives (SUMMA) hydrologic model (Clark et al. 2015). SUMMA is built with a modular structure that allows the user to select from a multiple of physical representations for different physical processes to develop a model best fit for the region of interest and at the level of complexity desired. The physical representations within the model all used the same numerical solver, allowing additional representations to be added to the model as needed. This modular structure and parameterization flexibility offer the potential for simulating streamflow at the accuracy required for a wide range of locations with different hydrologic regimes. SUMMA development is being supported by the Computational Hydrology group at UW, the same group currently supporting VIC. While SUMMA has been tested in research settings, it has to this point seen little use in applications.

The objectives of this study are to evaluate the performance of SUMMA against VIC for sub-basins within the Milk and St Mary River Basins in northern Montana. Reclamation is exploring alternatives to VIC to address both challenges in simulating streamflow at the required accuracy for planning and operations studies and the lack of long-term support for VIC.

2 Study Area

The focus of this study is the upper St Mary River watershed and the Milk River watershed in north central Montana, southeast Alberta, and southern Saskatchewan. The St Mary River has its headwaters in the northern Rocky Mountains and flows north from Montana into Alberta. The Milk River has its headwaters in the foothills of the northern Rocky Mountains, to the east of the St Mary River headwaters, flowing northeast into Alberta (the Western Crossing), through Alberta for 200 river miles, before flowing back into Montana (the Eastern Crossing), and ending at its confluence with the Missouri River just downstream of Fort Peck Dam.

The St Mary River is primarily a snowmelt-dominated basin with its headwaters at high elevations in the Rocky Mountains. The St Mary experiences a single seasonal peak in streamflow in the spring and early summer, driven by the melting of high-elevation snowpack. The magnitude and timing of this streamflow peak are largely controlled by the amount of accumulated high-elevation snowpack and climatic conditions controlling the start and rate of snowpack melt.

The Milk River is primarily a prairie river, with its headwaters at lower elevations in the foothills of the Rocky Mountains. The Milk experiences two seasonal peaks on streamflow – one in the early to mid spring driven by the rapid melting of low- to mid-elevation snowpack, and a second driven by a peak in precipitation in late spring or early summer. Redistribution of snow from wind, year-to-year variability in precipitation, and changes to contributing areas from slight changes in river elevations given the flat topography can all have large impacts on the magnitude and timing of the two streamflow peaks. Three major "northern" tributaries, Lodge Creek, Battle Creek, and Frenchman Creek, originating in Canada are prairie rivers, and contribute roughly 13% of the annual Milk River streamflow. Four major "southern" tributaries, Big Sandy Creek, Clear Creek, Peoples Creek, and Beaver Creek (near Hinsdale), originating in Montana are also prairie rivers and contribute roughly 18% of annual Milk River streamflow (Reclamation, 2012).

Hydrologic models have historically had good accuracy in simulating streamflow in snowmelt-dominated watersheds (Reclamation, 2012) like the St Mary, and have struggled to simulate streamflow in watersheds with prairie-like hydrology, like the Milk River and its tributaries. Physical parameterizations that represent snowpack storage and snowpack melt have been well developed in hydrologic models, allowing them to simulate streamflow in snowmelt-dominated watersheds. Physical parameterizations to represent processes in prairie watersheds, including the influence of intermittently connected lakes and wetlands, and snow redistribution have not been as fully developed. This has made simulating hydrology in the prairie tributaries of the Milk River Basin challenging given the seasonal behavior of extensive lakes and wetlands (Stichling and Blackwell, 1957). Broad areas of the watershed contain lakes and wetlands that are seasonally connected to the stream channel during the spring snowmelt period and become disconnected as lake and wetland levels fall. These small depressions, lack of a well-developed drainage network, and the arid climate of the region present challenges in even understanding the hydrological processes leading to streamflow (Mengistu and Spence, 2016). Pomeroy et al. (2005) summarize the hydrology of Saskatchewan, which encompasses the northeastern sector of the Milk River Basin.

Of note for understanding the primary hydrologic processes and developing skillful hydrology models are a) in the fall and winter, water is stored as snow, as well as ice in lakes and the subsurface; b) in the early spring, rapid snowmelt results in a majority of the runoff; c) in late spring and early summer, corresponding with the peak in annual precipitation, a majority of the remainder of streamflow occurs. Both landcover and soils have a larger than average impact on hydrological processes given limited precipitation and energy inputs. Pomeroy et al. (2007) also demonstrate the importance of snow and snow redistribution as an important hydrologic process impacting streamflow in this region. Snow redistribution, impacted by wind, and slight changes in topography and land cover impact the volume and location of snowpack, whose rapid melt in the early spring is responsible for the primary streamflow peak in prairie rivers. The challenges presented in modeling prairie processed watersheds require hydrologic models though conceptual or process-based representation account for hydrologic processes often not included in hydrologic models.

3 Study Design

The original study design compared SUMMA to VIC in a way that limited the differences between the two model setups to the models themselves and their physical process representations. This design involved –

- Developing the models on the same spatial scale with the same spatial units (hydrologic response units in SUMMA and grid cells in VIC)
- Using the same forcing dataset
- Using the same run period
- Calibrating using the same calibration software and calibration metrics
- Using the same routing model

Challenges with the SUMMA model platform and SUMMA model functionality prevented this comparison from following the original study design. SUMMA models were developed but with the following differences to the original design:

- Spatial scale differed from the VIC model
- Forcing dataset differed from the VIC model
- Models were not calibrated

The functionality challenges along with study time constraints allowed only an initial comparison to be made looking at routed streamflow. A more thorough comparison following the original study design would allow for a comparison of water balance components – surface runoff, baseflow, evapotranspiration, and snow water equivalent – that could diagnose differences seen in the routed streamflow between the models.

3.1 Model Descriptions

Three models were included in the model comparison – VIC, SUMMA, and the Sacramento-Soil Moisture Accounting (SacSMA) model. The SacSMA models for the Milk and St Mary Rivers were originally developed by the Missouri River Basin Forecast Center (MBRFC) and were used to support the St Mary and Milk Rivers Basin Study (Reclamation 2012). Routed streamflow simulations were included in this study as benchmark comparisons. A brief description of each model is presented below.

3.1.1 Variable Infiltration Capacity (VIC) Model

VIC is a physically based distributed hydrologic model that simulates the water budget and optionally the energy budget. VIC is configured spatially to run on grid cells with no sub-surface connections between grid cells. VIC uses a variable infiltration curve to partition surface water into surface runoff and baseflow. VIC is typically configured with three soil layers with a shallow aquifer.

3.1.2 Structure for Unifying Multiple Modeling Alternatives (SUMMA) Model

SUMMA is a physically based hydrologic model that simulates both the water and energy budget. The spatial configuration used by SUMMA is flexible. It uses hydrologic response units (HRUs) and grouped response units (GRUs) where GRUs are spatially contiguous units comprised of one or more HRUs. HRUs are not required to be contiguous and can represent spatial units like elevation bands of landcover classes. HRUs can exchange moisture, but there is no exchange of moisture between GRUs. The SUMMA modeling concept is built around the idea of modular physical parameterizations all using the same numerical solver. Multiple parameterizations for different physical processes are currently included allowing the use to select the process and best fit for the region of interest and at the level of complexity desired.

3.1.3 Sacramento Soil Moisture Accounting (SacSMA) Model

SacSMA is a physically based, semi-distributed hydrologic model that, in conjunction with the SNOW-17 model, are the primary models used by the National Weather Service's River Forecast Centers to develop streamflow forecasts. Additional routines are also included within the legacy National Weather Service River Forecast System (NWSRFS) and the current operational

Community Hydrologic Prediction System (CHPS) to simulate hydrologic and management processes including reservoir operations, channel loss, and to perform streamflow routing.
A more detailed description of the models used in the NWSRFS and CHPS systems can be found in the NWSRFS User Manual,
https://www.nws.noaa.gov/oh/hrl/nwsrfs/users_manual/htm/xrfsdocpdf.php.
To support the St. Mary River and Milk River Basins Study (Reclamation, 2012b), the Manual Calibration Program (MCP3) version of the SacSMA/SNOW17 model used by the Missouri Basin River Forecast Center was used to develop historical streamflow simulations from 1950 through 1999 for locations throughout the St Mary and Milk River Basins. These streamflow simulations were used along with historical observed streamflow as benchmark comparisons.

4 Findings

The findings section is divided into three sections with the first focused on the SUMMA and VIC model comparison, the second focused on technological transfer of the SUMMA platform including SUMMA model setup, model configuration and existing challenges, and the third focused on recommendation for future SUMMA model development, SUMMA platform development, and additional hydrology model comparisons.

4.1 SUMMA and VIC Model Comparison

SUMMA and VIC models were developed for two locations – Swiftcurrent Creek at Sherburne, MT (USGS ID 05016000), a snowmelt-dominated basin, and the Frenchman River at International Boundary (USGS ID 06164000), a prairie stream. SUMMA models were developed over the period 1980-2014 using NLDAS-2 forcing data, and the models were not calibrated. VIC models were developed over the period 1980-2014 using Daymet forcing data and calibrated using the OSTRICH software package. SUMMA is a flexible hydrologic model with options for different physical parameterizations. The selections made for this study are shown in Table 1.

Table 1 - SUMMA Model Parameterization Selections

Parameterization	Description	Selection
soilCatTbl	soil-category dateset	STATSGO dataset
vegeParTbl	vegetation category dataset	MODIS 20-category dataset
soilStress	choice of function for the soil moisture control on stomatal resistance	thresholded linear function of volumetric liquid water content
stomResist	choice of function for stomatal resistance	Ball-Berry
num_method	choice of numerical method	iterative
fDerivMeth	method used to calculate flux derivatives	analytical derivatives

LAI_method	method used to determine LAI and SAI	LAI/SAI taken directly from a monthly table for different vegetation classes
f_Richards	form of Richard's equation	mixed form of Richards' equation
groundwatr	choice of groundwater parameterization	a big bucket (lumped aquifer model)
hc_profile	choice of hydraulic conductivity profile	constant hydraulic conductivity with depth
bcUpprTdyn	type of upper boundary condition for thermodynamics	energy flux
bcLowrTdyn	type of lower boundary condition for thermodynamics	zero flux
bcUpprSoiH	type of upper boundary condition for soil hydrology	liquid water flux
bcLowrSoiH	type of lower boundary condition for soil hydrology	free draining
veg_traits	choice of parameterization for vegetation roughness length and displacement height	Raupach (1994) "Simplified expressions..."
canopyEmis	choice of parameterization for canopy emissivity	parameterized as a function of diffuse transmissivity
snowIncept	choice of parameterization for snow interception	maximum interception capacity an inverse function of new snow density
windPrfile	choice of wind profile through the canopy	logarithmic profile below the vegetation canopy
astability	choice of stability function	Louis (1979) inverse power function
canopySrad	choice of canopy shortwave radiation method	Beer's Law (as implemented in VIC)
alb_method	choice of albedo representation	constant decay rate (e.g., VIC, CLASS)
compaction	choice of compaction routine	semi-empirical method of Anderson (1976)
snowLayers	choice of method to combine and sub-divide snow layers	CLM option: combination/sub-dividion rules depend on layer index
thCondSnow	choice of thermal conductivity representation for snow	Jordan (1991)
thCondSoil	choice of thermal conductivity representation for soil	function of soil wetness
spatial_gw	choice of method for the spatial representation of groundwater	separate groundwater representation in each local soil column
subRouting	choice of method for sub-grid routing	time-delay histogram

Benchmark comparison includes streamflow simulations from the SacSMA/SNOW17 MCP3 model used to support Reclamation's 2012 St Mary River and Milk River Basins Study (Reclamation, 2012) and naturalized streamflow developed by the USGS and the State of Montana Department of Natural Resources and Conservation. The naturalized streamflow was developed using gauged streamflow from the USGS and corrected for diversions and water losses from agricultural and municipal and industrial water uses.

4.1.1 Frenchman River at International Boundary

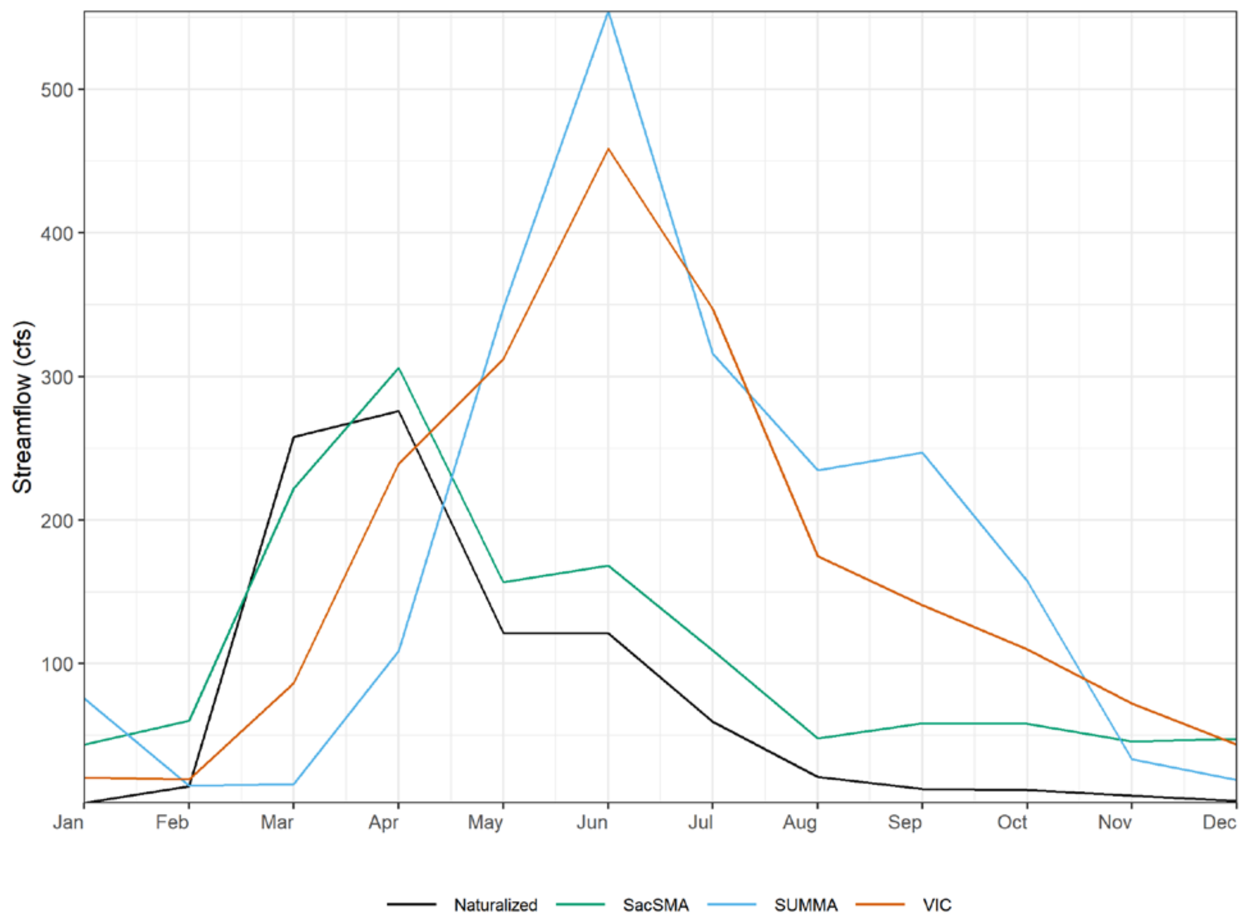

Figure 1: Mean monthly streamflow for Frenchman River at International Boundary (USGS 06164000) showing naturalized streamflows against SacSMA, SUMMA, and VIC simulations

Figure 1 shows mean monthly simulated and naturalized streamflow averaged over 1980-2014 for the Frenchman River at International Boundary. The Frenchman River is a tributary of the Milk River in the Prairie Potholes region, originating in Saskatchewan and joining the Milk River near Saco, Montana.

The SacSMA model captures the seasonal cycle of streamflow well, including the early spring and early summer peaks, but also simulates higher than observed streamflow during the summer through the following winter. The calibrated VIC simulations and the uncalibrated SUMMA simulations both show exhibit biases in the seasonal streamflow cycle, missing the early spring streamflow peak completely, and amplifying the early summer streamflow peak. Investigations into this behavior with VIC suggest the model is not melting out the snowpack until early summer, and this snowmelt, along with a peak in precipitation, are responsible for the over simulation of streamflow during this period. Seasonally connected wetlands and contributing area become disconnected from the river channel during the summer and fall as water levels drop and the land surface dries out. This behavior limits the area contributing to runoff, and as this process is not accounted for in VIC or SUMMA, leads to an over simulation of streamflow during this period.

4.1.2 Swiftcurrent Creek at Sherburne MT

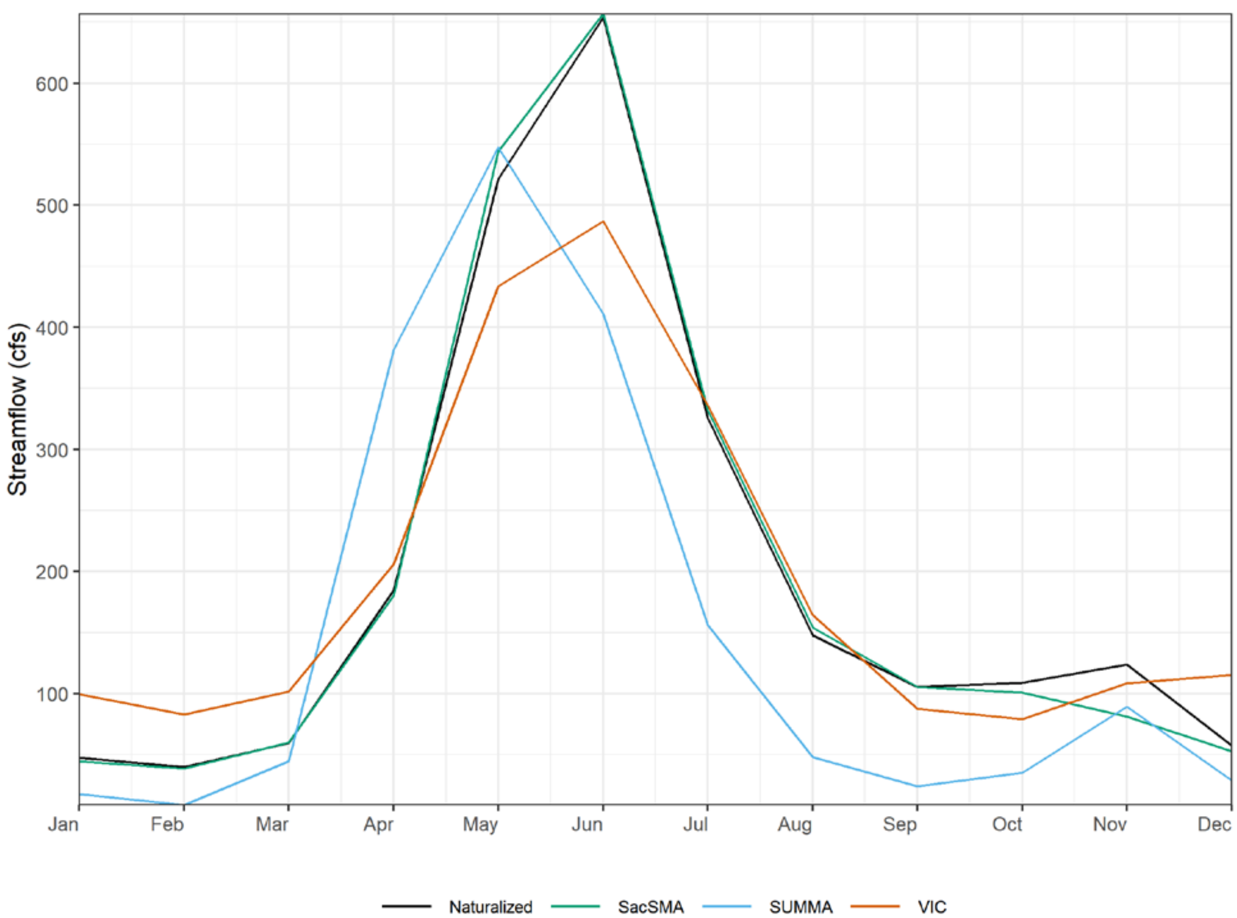

Figure 2: Mean monthly streamflow for Swiftcurrent Creek at Sherburne MT (USGS 05016000) showing naturalized streamflow against SacSMA, SUMMA, and VIC simulations

Figure 2 shows mean monthly simulated and naturalized streamflow averaged over 1980-2014 for Swiftcurrent Creek at Sherburne MT. Swiftcurrent Creek is a headwaters tributary of the St Mary River, originating in Glacier National Park, and joining the St Mary River at Lower St Mary Lake near Babb, MT. The watershed is snowmelt-dominated where streamflow typically peaks in late spring or early summer. All three models are able to generally capture the seasonal cycle of streamflow. SacSMA is well calibrated and matches almost exactly the observed streamflow. The calibrated VIC model has higher-than-observed flows through the winter, but its peak streamflow does not match the observations. The uncalibrated SUMMA model better matches the magnitude of peak streamflow seen in the observations, but its peak occurs a month early. SUMMA also under simulates streamflow in the late summer, fall, and winter, with streamflow almost nonexistent.

4.1.3 Discussion

Reclamation was able to develop SUMMA models and implement an end-to-end workflow in the SUMMA model platform for the two river basins. This model and workflow development was a significant advancement in making SUMMA able to serve applied projects and in developing Reclamation's capacity with the SUMMA modeling platform.

SUMMA and VIC perform better in simulating streamflow for Swiftcurrent Creek, a snowpack dominated basin, than in simulating streamflow for Frenchman River, with prairie-like hydrology. SUMMA captures the general seasonal cycle behavior in Swiftcurrent Creek and does a better job than VIC at capturing the peak streamflow. SUMMA however exhibits a bias in the timing of the peak, as well as in a earlier drop off in streamflow. Calibration of the SUMMA model would likely address at least some of these issues. In the Frenchman River, SUMMA and VIC exhibit similar biases with the timing of peak streamflow occurring much later compared to the two reference datasets and with much higher magnitudes. VIC was calibrated, and additional parameterizations, including the VIC frozen soils parameterization and VIC lakes model, were used in an attempt to improve streamflow simulations. These additional parameterizations did not resolve the major differences in timing and magnitude of streamflow between observations and model simulations. SUMMA was not calibrated, which makes it difficult to fully assess its ability to simulate streamflow accurately in this watershed. In addition, SUMMA contains options for many of its parameterizations, which present an additional option for 'calibration' SacSMA, which is more conceptual and less physically-based is able to simulate streamflow in this watershed with a reasonable level of accuracy and it is possible if SUMMA is configured in a more conceptual way that it could improve upon its currently poor simulations.

4.2 SUMMA Model Platform Assessment

The SUMMA hydrologic model has up to this point been used almost exclusively by the research community and is just now making the transition to a model useable to provide streamflow simulations for water management applications. The broader hydrologic model platform includes tools for subsetting model domains, developing model forcings, developing model parameters and attributes, performing model calibration, performing streamflow routing, and viewing and diagnosing model output. The nascent SUMMA platform is still very much under development, and this section describes the current platform and presents recommendations for future development.

The SUMMA model platform currently consists of tools to perform model setup, model runs, model analysis, model calibration, and model postprocessing. These tools currently allow a user to configure a SUMMA model on standard – e.g. HUC8 or 1/16 degree grid cell – spatial units, using GRUs and a single HRU. Additional work is required to fully take advantage of the HRU functionality. A tool exists to develop SUMMA model forcings, however also requires additional work to provide a full-featured tool that can generate SUMMA forcings that are ready to use. Tools exist to subset and develop inputs required by the routing model, but similar to the tools discussed require additional development before they are able to be used seamlessly.

The SUMMA model platform has grown substantially through the efforts of the SUMMA model developers directly and through a growing user community. A large set of tools exist to perform the tasks required when setting up a new hydrologic model, however these tools require additional development, testing, and documentation, to allow for a new model user to set up a SUMMA model.

4.2.1 Model Platform Repositories

Several code repositories have been created by SUMMA model developers to hold tools that allow users to configure, run, and analyze results from SUMMA.

NCAR has created a GitHub repository, *hydro_model_utils*[1], containing tools organized into five categories, analysis, calibration, postprocess, run, and setup, where beta versions of tools have been placed to begin to develop the set of tools required to effectively work with SUMMA. These tools are written in a variety of languages and formats and include Python scripts, R scripts, Jupyter notebooks, Perl scripts, and shell scripts. This repository is currently in development and does not contain an extensive set of tools to perform all the tasks required to develop a SUMMA hydrologic model.

The University of Virginia has developed a Python wrapper for SUMMA called pySUMMA[2]and a set of Jupyter notebooks that allow students to run SUMMA test cases presented in Clark et al. (2015b), change model parameterizations, and examine model sensitivity to changes in parameters and parameterizations. This repository has tools that are useful in training new SUMMA users, however it does not provide tools directly applicable to developing SUMMA hydrologic models. The University of Washington has developed a similar set of Jupyter notebooks[3] using pySUMMA for teaching hydrologic modeling. Both sets of notebooks have also been designed to work on CUAHSI HydroShare[4], and while they are instructive for educational purposes, they have not yet been developed to support SUMMA applications.

4.2.2 Model Compilation

SUMMA is written in FORTRAN 90 and needs to be compiled for use. SUMMA source code currently contains a MAKEFILE, but not a config file, meaning users must specify the correct file paths to all of SUMMA's library dependencies within the MAKEFILE. In order to overcome the current lack of a config file, a wiki page connected to the SUMMA GitHub repository[5] has working configurations where SUMMA was successfully compiled on a variety of systems. This reference is useful when debugging compilation errors and compiling SUMMA on new systems.

4.2.3 Meteorological Forcings

SUMMA requires meteorological forcings as inputs for each HRU. These forcings include precipitation rate, downward shortwave radiation, downward longwave radiation, air temperature, wind speed, air pressure, and specific humidity. The temporal resolution of the meteorological forcings must match the model run time step, which in SUMMA can be sub-daily, daily, or coarser.

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[1] https://github.com/NCAR/hydro_model_utils
[2] https://github.com/uva-hydroinformatics/pysumma
[3] https://github.com/UW-Hydro/hydroshare-pangeo-notebooks
[4] https://www.hydroshare.org/
[5] https://github.com/NCAR/summa/wiki/SUMMA-Makefile-Part-0-configuration

Often gridded meteorological datasets are available at a 24-hr (daily) resolution, requiring an approach to temporally disaggregate the forcings to a sub-daily resolution. The MT-CLIM routine (Bristow and Campbell, 1984; Glassy and Running, 1994; Kimball et al. 1997; Thornton and Running, 1999; Bohn et al., 2013) developed at the University of Montana has been integrated into the VIC model (through version 4) as a pre-processor to develop the sub-daily forcings required to run VIC. A stand-alone tool, MetSim [6], has been developed using the MT-CLIM routine to provide a way of generating sub-daily forcings for a wide variety of modeling applications. MetSim has become the standard tool for temporally disaggregating meteorological forcings for SUMMA, as well as producing timeseries estimates of variables from minimum daily temperature, maximum daily temperature, and total daily precipitation. This includes estimates of solar radiation (shortwave and longwave) (Thornton and Running, 1999), humidity (Kimball et al. 1997), and estimates of air pressure from surface elevation. MetSim is currently designed to work with gridded data sources defined by latitude and longitude dimensions. MetSim requires its own set of prep tools to develop the required inputs: a set of daily meteorological forcing files in ASCII, binary, or netCDF format, a domain file specifying the domain over which to run MetSim, and a state file containing daily timeseries of meteorological forcings for the 90 days prior to the desired initial time step. The meteorological forcing files have differing requirements depending on the format chosen. ASCII or binary input files require that only the required variables be present in the files, minimum and maximum temperature, precipitation, and optionally wind speed. Support for ASCII and binary input files were added to allow legacy VIC forcing files to be used as input and users starting from a source meteorological forcing dataset are advised to instead use netCDF input files. netCDF input files require variables with a standard naming convention, in standard units, and on a standard calendar (leap days included). MetSim also requires a domain file which specifies the spatial extent of the MetSim run and contains attribute information about each grid cell including a mask field indicating whether to generate forcings for the cell, elevation, and optionally, climatological monthly storm event duration, and climatological monthly storm time to storm peak. Bohn et al. (2019) have developed a domain file compatible with MetSim for the southern Canada-CONUS-Mexico domain at a 1/16° resolution, corresponding to the Livneh et al. (2016) (L16) meteorological forcing dataset. Metsim also requires a state file containing 90 days of meteorological data preceding the meteorological data over which Metsim is being run (or 90 days of climatology) to provide it with initial states for estimation and disaggregation. A Jupyter notebook[7] template exists to build this file but requires modification to read in the required meteorological data from source.

4.2.4 Model Parameters, Attributes, and Initial States

SUMMA requires model parameters, attributes, and initial states. As stated in the model documentation[8], *"Although SUMMA's distinction between attributes and parameters is somewhat arbitrary, attributes generally describe characteristics of the model domain that are time-invariant during the simulation, such as GRU and HRU identifiers, spatial organization, an topography*." SUMMA attributes include information about the spatial configuration of the model including numerical indices of HRUs and GRUs, longitude, latitude, elevation, area, watershed characteristics, and topology information. These attributes are specified once and do not get overwritten. SUMMA attributes used in this study were derived from the current NASA Land Information System (LIS; Kumar et al. 2006, Peters-Lidard et al., 2007). SUMMA parameters can be specified in multiple locations and are processed in the order described in Figure 3. The basin parameter file and local parameter file contain spatially consistent

[6] https://github.com/UW-Hydro/MetSim
[7] https://gist.github.com/arbennett/5f608ee32a2dd023d64c32106e88472b
[8] https://summa.readthedocs.io/en/latest

parameter values as well as valid minimum and maximum values. SUMMA also uses parameter tables from the Noah-MP land surface model (Niu et al., 2011), including its VEGPARM.TBL, SOILPARM.TBL, and GENPARM.TBL. The trial parameters file can be used to overwrite values in the basin parameter file, local parameter file, and Noah-MP parameter tables by specifying hru and or gru specific parameter values.

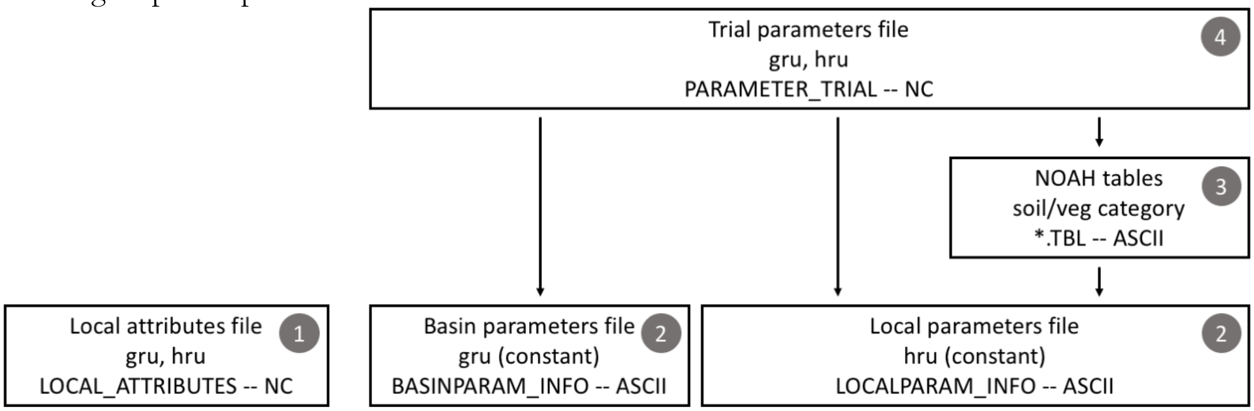

Figure 3: Order in which SUMMA model attributes and parameters are specified and processed

Tools exist to develop or modify the parameter and attribute files. but additional development work is required to allow for the development of SUMMA models with GRU spatial units consisting of multiple HRUs with different parameters and attributes.

4.2.5 Model Calibration

SUMMA has been coupled to OSTRICH, a software package with automated calibration routines. An initial coupling of SUMMA to OSTRICH has been developed that allows for the calibration of model parameters at the GRU level. HRU parameter calibration routines are still in development. A base set of calibration metrics have also been coded to be used by OSTRICH, however a more formal evaluation and guidance is needed to ensure that the correct set of metrics are used for calibration.

4.2.6 Streamflow Routing

SUMMA has been coupled to mizuRoute (Mizukami et al. 2016), a routing model developed by NCAR, to generate routed streamflow. mizuRoute requires as inputs a netCDF of generated surface flows and a flow network file defining the spatial flow network. Tools exist to subset existing flow network files based on the NHD+ flow network, however they are not currently fully functioning. Tools to develop new network files using a different source dataset currently do not exist.

5 Conclusions and Next Steps

SUMMA remains an attractive option for future hydrologic studies given its long-term support and flexibility. Challenges with the SUMMA model platform and SUMMA model functionality, along with study time constraints, prevented the original study design from being completed. This preliminary comparison between SUMMA and VIC, along with an assessment of the SUMMA model platform, offered a good initial assessment of SUMMA as a hydrologic model. Additional development work is required before this model will be ready to support long-term planning studies.

A model comparison following the original study design for this comparison should be completed. SUMMA should be compared to models, such as VIC and SacSMA whose performance is well understood and documented, to build confidence in its ability to support studies. A thorough assessment of SUMMA's parameterizations and which physical parameterization selections are most appropriate given the study should be undertaken.

The modular nature of SUMMA and its flexibility in being able to select the most appropriate parameterization when developing a hydrologic model is one of its great strengths and guidance should be developed to help inform these selections. SUMMA's spatial discretization and flexibility to configure spatially contiguous GRUs as well as non-contiguous HRUs (e.g. along elevation bands) is another of SUMMA's strengths. The SUMMA modeling platform should be further developed to allow a user to fully take advantage of this functionality. Finally, model documentation for SUMMA should be expanded to include the overall SUMMA model platform and document available tools and best practices for end-to-end SUMMA model development. This documentation should discuss how to spatially configure SUMMA, how to develop forcing data, how to perform calibration, how to develop routed streamflow, and how to evaluate model output and performance.

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