SMA PMF analysis of a Rocky Mountain System – Santa Fe, NM

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Abstract

The Santa Fe River drains from its headwaters in the Sangre de Cristo Mountains through the McClure and Nichols Reservoir system to the City of Santa Fe, New Mexico. The two-reservoir system is critical infrastructure for municipal water supply and for flood control and attenuation. In consideration of maintenance and stewardship of the reservoirs, and with recently updated Probable Maximum Precipitation (PMP) guidelines, a Probable Maximum Flood (PMF) hydrological analysis of the watershed was performed for maximum inflow assessments.

The contributing 22.6 square-mile Santa Fe River watershed can be characterized as mature subalpine forest with rugged and undeveloped terrain. Surficial soil types are rocky, decomposed bedrock with high infiltration rates, overlaying fractured igneous bedrock lenses. Snowmelt runoff is dominant for non-storm hydrology, with groundwater storage and saturation dependent on recent snowpack history. The foothills are subject to convective storms and orographic lifting with common high-intensity, localized precipitation events. High infiltration rates, groundwater storage fluctuation with snowmelt, and temporal precipitation distribution may indicate the importance of saturation-excess runoff mechanisms in addition to infiltration-excess runoff.

Proposed watershed response models for the PMF included Soil Moisture Accounting (SMA) method within HEC-HMS. Specifically, SMA allows for saturation-excess runoff mechanisms in addition to more traditional infiltration-excess mechanisms with both groundwater storage and transfer to surface flow included. SMA has been proposed by others in applications to mountainous foothill watersheds in the Colorado Front Range, similar in characteristics and processes with the project watershed.

These methods are applied to the specific characteristics of the Santa Fe River watershed for two different calibration storm events. SMA parameters are adjusted for each storm and then evaluated using PMP inputs to determine PMF results.

Introduction

The Santa Fe River drains from its headwaters in the Sangre de Cristo Mountain range through the McClure and Nichols Reservoir system to the City of Santa Fe, New Mexico. The reservoirs are critical infrastructure to the city water supply and can be operated to provide limited flood control and attenuation. Figure 1 provides an overview and local vicinity map of the Santa Fe River watershed under focus.

Since prior design efforts of the fusegate spillway at McClure Reservoir (Woodward-Clyde, 1995) and evaluation of the Nichols Dam (Scanlon and Associates, 1988), new methodologies for estimating Probable Maximum Precipitation (PMP) have been developed along with advances in computational resources, hydrologic modeling standards, and New Mexico protocols (NMOSE, 2008).

AECOM has performed an updated flood hydrology study for McClure and Nichols Reservoirs to determine the Probable Maximum Flood (PMF) for design and evaluation purposes. Recommendations from NMOSE (2008) were followed for the models, methodologies, and data inputs to the PMF evaluation; however, results indicated models did not capture the unique characteristics of the project watershed or underlying physical processes. Specifically, high values of hydraulic conductivity at the surficial soil layers absorbed incoming precipitation at a rate which resulted in no response at the basin outflow. As a response, methodologies targeted specifically to the geographic and geologic characteristics of the basin were examined.

Methodologies have recently been proposed with applications to mountainous foothill watersheds in the Colorado Front Range, similar in characteristics and processes with the project watershed (e.g., Woolridge *et al.*, 2020). The method utilizes the Soil Moisture Accounting (SMA) model to account for precipitation losses in the vegetation canopy, soil column, and groundwater layer(s). Specifically, SMA allows for saturation-excess runoff mechanisms in addition to more traditional infiltration-excess mechanisms with both groundwater storage and transfer to surface flow included. The SMA method described by Woolridge *et al.* (2020) is used for PMF determination herein and comparisons to alternative methodologies are provided.

This conference proceeding details data sources, analyses performed, results, and comparisons to previous design and evaluations. A description of the Santa Fe River watershed geometry and characteristics is provided, and a hydrological model framework is developed for simulation of runoff events. The SMA methods are described, and their parameters quantified for the project watershed. Calibration of the SMA method is performed using historical storm data and recommendations from the literature for two discrete events. Both calibrated SMA models are then evaluated with the governing PMP storm event and the PMF output is compared between calibrations.

Project Watershed Geometry and Characteristics

The Santa Fe River project watershed drains a total of 22.8 square miles (mi^2) measured from the headwaters to a location at the outlet of Nichols Reservoir. Elevations in the project watershed range from approximately 7,500 ft to 12,000 ft including snow-affected areas. The vegetation is primarily composed of mature ponderosa pine forests and mountain junipers, and the watershed is within national forest. Error! Reference source not found. illustrates the project watershed topography, reservoir locations, discharge and precipitation gage locations, and basin delineation.

Two Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) sites are located in the watershed; Elk Cabin (921) and Santa Fe (922). The Santa Fe River flow rates are gaged at U.S. Geological Survey (USGS) stations 08315480 and 08316000. In addition, both McClure and Nichols Reservoirs have USGS reservoir level gages (08315500 and 08316500, respectively).

The project watershed was disaggregated into four sub-basins as a function of main drainage pathway and size. The physical characteristics of each watershed are presented in Table 1. The four sub-basins correspond to areas draining: 1) to the inlet of McClure Reservoir; 2) laterally into McClure Reservoir from the south; 3) laterally into McClure Reservoir from the north; and 4) into Nichols Reservoir from the downstream extent of McClure Reservoir. Channel slope characteristics and additional stream delineation was performed using digital elevation model (DEM) data obtained from the USGS (2019) and stream pathway refinement analyses using the ArcHydro tools in ArcGIS.

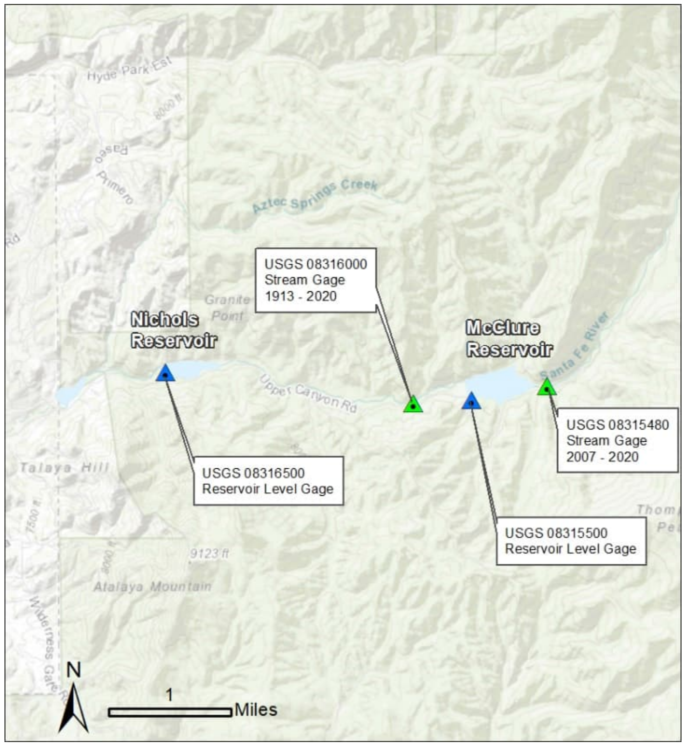

Figure 1. Vicinity map and gage locations

Soil classifications and distributions were obtained from the NRCS SSURGO database (USDA, 2020). Characteristic surficial soil types within the watershed are rocky, decomposed bedrock with high infiltration rates. Deeper geologic bedrock composition was determined through USGS (2020) and is primarily classified as fractured igneous rock.

The Santa Fe National Forest encompasses the project watershed and its primary land use. Almost the entirety of the watershed is pervious with little development outside of the two reservoir locations.

Table 1. Sub-basin Geometry Characteristics

Parameter	McClure Upper	McClure South	McClure North	Nichols
Latitude centroid (degrees)	35.738	35.677	35.706	35.685
Longitude centroid (degrees)	-105.789	-105.826	-105.827	-105.855
Drainage area (mi^2)	12.885	2.160	2.368	5.433
Longest flow path (mi)	9.894	2.115	3.465	4.547
Length to centroid (mi)	4.814	0.839	1.844	1.804
Longest slope (ft/mi)	453.76	795.12	478.90	351.44

Hydrologic Model Schematic

A model was created in HEC-HMS version 4.8 (USACE, 2021) to represent four contributing sub-basins, the McClure and Nichols Reservoirs, spillway capacity curves, dam geometries, and the Santa Fe River.

Elevation-storage curves were generated using USGS gage data for the McClure and Nichols Reservoirs in feet NAVD88 (08315500 and 08316500, respectively) and were extrapolated beyond gage readings using geospatial analysis of the most recent Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM).

The McClure Dam is earthen with a concrete spillway controlled with fusegates. Nichols Dam is also earthen with a concrete spillway terminating in earthen/rock. Stage-discharge relationships for the McClure Reservoir and Nichols Reservoir spillways were provided by Woodward-Clyde (1995) and Scanlon and Associates (1988), respectively. Stage-storage relationships for the reservoirs were determined using LiDAR geospatial analyses.

Muskingham-Cunge routing method was used for the Santa Fe River between the reservoirs. The Santa Fe River reach is 2.9 miles, has a slope of 0.021, and is approximately a trapezoidal channel geometry with bottom width of 30 ft and side slopes of 4 H:V with Manning's *n* of 0.045.

Figure 2. McClure Spillway Fusegates

Runoff Methodology

Infiltration-excess and saturation-excess runoff are two mechanisms that drive watershed response to precipitation input. Infiltration excess occurs when the precipitation rate exceeds the soil matrix infiltration rate, which is a function of soil properties and preceding moisture conditions. This mechanism may be explained as top-down excess runoff. Saturation-excess runoff may be referenced as bottom-up excess runoff, where groundwater reservoirs in the soil matrix are filled to capacity resulting in surface runoff. Infiltration-excess mechanisms are most appropriate when the soil type has relatively low hydraulic conductivity which is exceeded by the storm precipitation rate. Saturation-excess mechanisms coincide with relatively high hydraulic conductivity surficial soils that exceed storm precipitation rates with underlying lenses of restrictive materials.

Infiltration-Excess Method

Infiltration-excess runoff methods have been historically recommended for hydrological response modeling for dam applications (NMOSE, 2008). The SSURGO data compiled for the project watershed indicated approximately 75% fractured bedrock at the surface with hydraulic conductivity values approaching values of 50 in/hr and higher. These values exceed maximum rainfall rates that the project watershed has historically seen and thus would produce a zeroresponse runoff hydrograph for design storms. Calibration of infiltration-excess runoff to produce observed hydrographs response is possible (e.g., manipulation of the soil infiltration rate in the Green-Ampt method); however, this process may result in parameter values that are outside of normal ranges or fail to represent underlying physical processes. As such, a more physically descriptive methodology was identified for the project watershed characteristics before further calibration was considered.

Soil Moisture Accounting

Soil Moisture Accounting has recently been proposed as a method for the hydrological modeling of steep, mountainous watersheds with a prevalence of surficial fractured rock and apparent groundwater dynamics with saturation-excess runoff. Specifically, Woolridge and Niemann (2018), Woolridge (2019), and Woolridge *et al.* (2020) have performed studies using SMA on the Colorado Front Range, which share similar characteristics to the project watershed.
A schematic of the SMA methodology is provided in Figure 3. The method allows for the transmission of water infiltrated through the upper soil matrix into a series of groundwater reservoirs which either reflow to surface water or are transferred to deep groundwater storage. As shown in the schematic, rainfall is initially captured by the vegetation canopy with a portion leaving through evapotranspiration. Next, when the rainfall intensity exceeds the canopy storage, the rainfall interacts with the soil. The soil has a storage capacity before percolating to a groundwater layer which is a function of local characteristics. Deep percolation can occur to another groundwater storage layer, depending on the permeability of the layers. Subsurface streamflow occurs when the infiltrated water collects in this layer and flows downslope to the stream. Saturation excess runoff occurs when the subsurface layers are completely saturated from the low-permeability layer up to the ground surface.

HEC-HMS parameterizes the SMA method, and each of these parameter determinations is described in detail by Woolridge *et al.* (2020), which served as guidelines for quantification of a non-calibrated baseline. The parameters can be grouped into the types of data which are used to generate them, i.e., soil distribution and stratigraphy, hydrographic, or calibration.

Guidelines for hydrologic analysis for dams stress the difficulty of having a recorded record of a large storm approaching the magnitude of the PMP to use for calibration and that use of lesser storms may not be appropriate for PMP analysis. The SMA methodology includes input parameters that are only reasonably obtained through calibration, which was performed for two hydrographic events.

The project watershed was disaggregated into four sub-basins as a function of main drainage pathway and size. The physical characteristics of each watershed are presented in Table 1. The four sub-basins correspond to areas draining: 1) to the inlet of McClure Reservoir; 2) laterally into McClure Reservoir from the south; 3) laterally into McClure Reservoir from the north; and 4) into Nichols Reservoir from the downstream extent of McClure Reservoir. Channel slope characteristics and additional stream delineation was performed using digital elevation model (DEM) data obtained from the USGS (2019) and stream pathway refinement analyses using the ArcHydro tools in ArcGIS.

SMA soils parameters include the maximum infiltration rate, antecedent moisture, soil storage, tension storage, and soil percolation and are dependent on the SSURGO dataset (USDA, 2020) and geological bedrock (USGS, 2020).

Soil (%) is a measure of the estimate of the initial water stored, as a percent of the total storage, in the top layer of the soil. This parameter can have a value between 0% and 100% (completely dry or fully saturated).

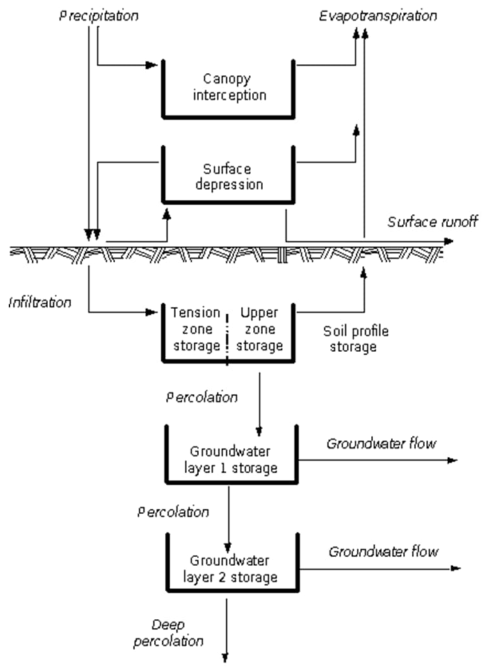

Figure 3. SMA Process Schematic

SMA Soils Parameters

Precipitation that is not intercepted in the canopy (or impervious areas) can infiltrate the soil. The soil is represented by two regions, the upper zone and the tension zone. The upper zone is defined as the portion of the soil that will lose water to Evapotranspiration (ET) and/or percolation to deeper soil layers. This represents water that fills the pores of the soil matrix. The tension zone is defined as the area that will lose water to ET only and represents water that is attached to soil particles. ET occurs from the upper zone first and tension zone last. For this study the model was run with a short time frame, so ET was neglected.

Groundwater 1 (GW1, %) represents the percentage of saturation at the start of the simulation in a shallow layer of groundwater in the watershed. This could be highly fractured rock, for example. The SMA methodology allows for horizontal interflow processes and can include either one or two of these layers. Water can percolate from the soil into the groundwater layer at a user specified rate. The outflow from a groundwater layer is into one “linear reservoir”, which can be thought of as all the aggregated impacts of groundwater storage affecting lateral flow. This parameter is estimated or determined from detailed moisture surveys. For this model, two layers were utilized as found to better simulate the slower release of flow from the watershed that is characteristic of the recession limb of the hydrographs shown in calibration data.

Groundwater 2 (GW2, %) represents the percentage of saturation at the start of a simulation in a second groundwater storage layer in the watershed, similar to GW1. What percolates from GW1 goes to GW2. Both GW1 and GW2 can range from 0% to 100% (completely dry to fully saturated).

Maximum Infiltration (in/hr) represents the maximum rate at which water can enter the soil column from the ground surface. If the available water for infiltration exceeds the calculated rate at the specified timestep, then the excess water contributes to surface runoff. This is a function of the soil type, horizon thickness, saturated hydraulic conductivity, and degree of vegetation.

Impervious (%) represents the percent of the watershed or sub-basin area that is impervious and contributes directly to runoff. For this basin, the value was determined as 0% for all basins based on NCLD (USGS, 2016b).

Soil Storage (in) is an estimated measure of the maximum depth of water that can be stored in the top layer of the soil, measured in inches. This is estimated to be equal to the available pore space in the soil times the maximum soil horizon depth.

Tension Storage (in) is the measure of the maximum depth of water that is held in the soil matrix and can only be removed through ET. The upper zone of the soil (Soil Storage – Tension Storage) is first made available for any ET demand. If all water from the upper zone is used by potential ET, then water from Tension Storage is drawn upon. This value is estimated by soil property and equations.

Soil Percolation (in/hr) is a measure of the rate at which water can percolate by gravity to lower groundwater layers.

Ground Water 1 Storage (in) is a measure of the total depth of water that can be held in the GW1 layer. This value is estimated by hydrograph estimation but is calibrated to arrive at a reasonable value.

Ground Water 1 Percolation (in/hr) is a measure of the rate of percolation by gravity that water transverses to a lower groundwater layer (GW2). This value is first estimated from standard literature and then adjusted during calibration.

Ground Water 1 Coefficient (hr) is an empirical value that describes the coefficient for the groundwater linear reservoir model. This value is estimated with calibration to a known stream gage.

Ground Water 2 Storage, **Ground Water 2 Percolation**, **Ground Water 2 Coefficient** are all similar to the previous ground water layer with similar functions. Different values are used to model slower, deeper moving interflow before returning to the stream channel. Any water that percolates out of GW2 is considered lost to the system into a deep aquifer.

SMA Soil Parameter Calculations

Maximum infiltration rate was determined through the application of the Green-Ampt infiltration methodology, which is mostly sensitive to the saturated hydraulic conductivity, K_S, matric pressure of the soil, Ψ_F, saturated moisture content, θ_S, and wetting-front depth. These values were processed from the SSURGO dataset obtained for the area. Significant variability in each map unit key was reported in the obtained soil report data, with many grouped soil families in one map unit classification, multiple horizons per soil type, and orders of magnitude variance within K_S values. Common to all sub-basins was the presence of rock layers, with notably high K_S values reported at approximately 50 in/hr. These values far exceed the recommended infiltration rate values of K_S for modeling as indicated by hydrologic flood modeling guidelines (e.g., Sabol, 2008).

The SSURGO dataset provides percentage composition of sand, silt, and clay for each soil depth horizon in a given soil classification. Using the top 18-inches of soil, pedotransfer functions of Saxton and Rawls (2006) were applied to determine values of K_S, Ψ_F, and θ_S for each soil type. Area weights were assigned for each soil classification and K_S values were log-averaged based on recommendations from Sabol (2008). All other spatially distributed parameters were calculated using a weighted average per sub-basin with a non-log scheme.

Bare-soil K_S data were adjusted for vegetation cover percentages, V_C, based on the adjustment ratio, C_K, of Sabol (2008): $C_K = (V_C - 10)/90 + 1.0$. Vegetation cover was determined based on normalized difference vegetation index calculations and was found to cover between 95 – 100% of the sub-basin area. The resulting K_S value was halved to account for unsaturated flow being able to infiltrate more efficiently than non-vegetated soil as recommended in Woolridge *et al.* (2020) and Bouwer (1964).

A recommended wetting-front depth value of 3 inches (Woolridge *et al.* 2020) for watershed characteristics similar to the project was used and infiltration rates were calculated for each soil type and sub-basin and used as the maximum infiltration rate values.

Antecedent moisture content was initially set at 30%, which is approximately field capacity values for local soils (NRCCA, 2010) and representative of conditions preceding large storms. Identified maximum storms in the project watersheds occur during summer and fall, where snowmelt has not saturated the soil. NMOSE (2008) notes that stream base flow is generally non-existent in New Mexico systems. However, the SMA methodology explicitly assumes subsurface interflow and/or baseflow and these are modeled for this PMP/PMF study. *Soil storage* was calculated using the maximum horizon depth from the SSURGO dataset multiplied by the porosity (θ_S) determined from Saxton and Rawls (2006) for each soil type.

Tension storage was calculated as the soil storage multiplied by the antecedent moisture adjustment.

Soil Percolation was assessed through aligning USGS National Geologic Map (USGS, 2020) and percolation rates from Domenico and Schwartz (1990). The geology within the watershed is composed of fractured plutonic (phaneritic) and metamorphic rock. Using weathered granite as an estimate of the crystalline rock type for the basin, the hydraulic conductivity was estimated as ½ the average between the values from Domenico and Schwartz 3.3*10-6 and 5.2*10-5 m/s (0.47 and 7.37 in/hr) or 1.96 in/hr.

SMA Hydrology Parameters

Main hydrology-derived parameters for the SMA methodology are *groundwater (1 and 2) coefficients*. Woolridge *et al.* (2020) describes this coefficient as it relates to the hydrograph recession for a calibration storm and procedures for quantification. A storm event from September 2013 was initially selected for *groundwater coefficient* determination and is one of the storms used for SMA calibration comparisons in later sections. The Woolridge *et al.* (2020) method was followed to remove the baseflow from the receding limb, fit an exponential decay function through regression analysis, determine a time coefficient, and then halve that value for the *groundwater coefficients*. These values were then adjusted based on calibration to known storm events.

SMA Calibration Parameters

The remaining parameters in the SMA methodology followed value ranges suggested by Woolridge *et al.* (2020) as initial points but were noted as calibration parameters. These include initial antecedent *groundwater moisture*, *groundwater storage*, *groundwater percolation*, and *canopy storage*. As described in later sections, two storms were identified to calibrate these parameters.

Canopy storage is a potentially important parameter for hydrologic modeling of mountainous watersheds. Areas of the watershed above the reservoirs are densely populated with evergreens consisting of ponderosa pine, white fir, and Douglas fir, similar in characteristics to the Woolridge *et al*. (2020) Colorado watersheds, specifically the Cache la Poudre (Traff *et al.*, 2015). No known throughfall or canopy interception studies are known to have been performed for the Santa Fe River watershed. The Cache la Poudre studies indicated a value of 0.167-inches of storage for a non-calibrated initial value.

SMA method allows for the use of *surface losses* based on depressions in the landform and other physical reasons. Due to the slopes of the whole basin, plus the fact that *surface losses* are orders of magnitude smaller than the infiltration losses, this additional loss was not modeled for this study. Literature review of some typical values state that the total depths could be in the hundredths of an inch (0.04 in) for steep watersheds like this one.

Direct Flow Transform

The Clark Unit Hydrograph (UH) methodology was applied for all sub-basins as recommended for by Woolridge *et al.* (2020) and is an approved methodology indicated by NMOSE (2008). Required parameters for HEC-HMS modeling are the time of concentration (hrs), T_C, storage coefficient (hrs), R, and the Time-area method. Sabol (2008) describes T_C and R relationships for Rocky Mountain regions: $T_C = 2.4A^{0.1}L^{0.25}L_{CA}^{0.25}S^{-0.2}$, $R = 0.37A^{-0.57}L^{0.80}T_C^{1.11}$.

The time-area relation method is local watershed/sub-basin specific. For the Santa Fe River watershed, Figure 4 provides a summary of the distributions computed using spatial analysis of the project watershed DEM. Travel time over each cell was set as a function of surface roughness (Manning's *n*) as taken from the NLCD database (USGS, 2016) and Chow (1959). The total travel time from each grid cell to the outlet was calculated as the sum of least-cost distance of the time raster. The cumulative distribution function of the time raster was calculated for the time-area curves.

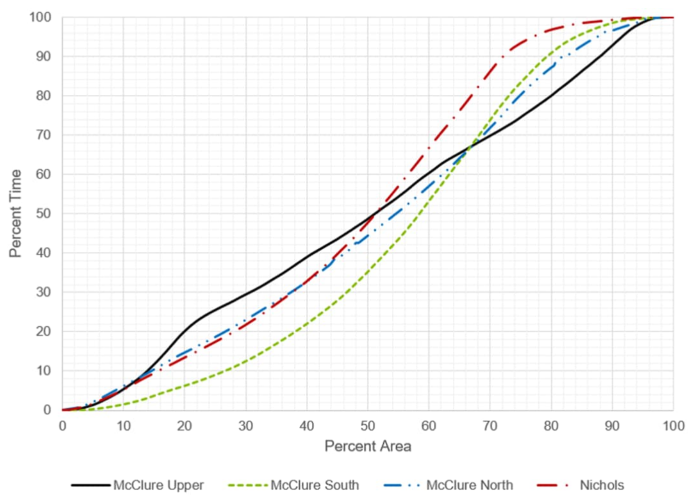

Figure 4. Time-Area-Method Distribution for Each Basin

Table 2. Clark UH Parameter Summary

Sub-basin	T_C *hrs*	R *hrs*
McClure Upper	2.39	1.42
McClure South	0.79	0.33
McClure North	1.21	0.76
Nichols	1.49	0.74

Calibration Storm Events

Two storm events were chosen for SMA parameter calibration. These storms were the largest events captured during local gage period-of-records and varied in intensity and duration. Model parameters were calibrated independently for each to match runoff response.

September 2013

A storm on September 9th – 16th, 2013, covered many parts of the State and resulted in two Presidential Disaster Declarations, extensive flooding, and record stream flows. Based on NOAA Atlas 14, Volume 1, Version 5, the Santa Fe area is depicted as having a 7-day total of rainfall that would equate to a 10-yr to 50-yr exceedance probability (or 10-yr to 50-yr average recurrence interval). Bulletin 17C analysis of local USGS gages (08315480, 08316000) indicate 10-yr and 50-yr flows of 177 cfs and 583 cfs, respectively. Waltemeyer (2008) methods used in USGS StreamStats indicate the peak 50-yr flow rate at the same location as the USGS stream gage (08315480) upstream of McClure is 359 cfs.

Locations of precipitation recording gages in the Santa Fe River watershed are sparse and discontinuous. Spatial variability of precipitation in the local region is significant.

The Elk Cabin (site 921) and Santa Fe (site 922) SNOTEL gages reliably recorded daily precipitation totals during the September 2013 storm event, but not reliable sub-daily data. Hourly time scale data were taken from nearby hourly precipitation rain gages as a proxy for the temporal distribution of hourly precipitation. One precipitation gage considered was at the Santa Fe Municipal Airport (KSAF) 12 miles west of Nichols Dam, while the other was station SFWN5 owned and operated by the U.S. Forrest Service located in the Santa Fe River watershed, south of the river.

The total amount of rain that fell over the worst 7 days at the SFWN5 site (3.56 in.) would relate to a 10-year event (3.62 in.). The airport 7-day total (3.72 in.) would relate to a 25-year event (3.81 in). Elk Cabin and Santa Fe SNOTEL sites recorded 5.3 inches and 7.2 inches, respectively, over the worst 7 days. These would equate to a 50-year and between a 50- and 100-year event, respectively.

The hourly incremental (blue solid) and cumulative (red dashed) precipitation at the SFWN5 from September 10-16, 2013, are plotted in Figure 5. While the storm event did not exhibit intense rainfall for shorter durations (24-hr or less) that could result in large runoff measurements at the stream gage, the rainfall (approximately 0.63 in. at SFWN5) that fell between Sept 10-11, 2013, had the effect of saturating the ground and soil profile, such that the 1.83 in. that occurred in the 24 hours from Sept 12 (at 1:00 pm MDT) to Sept 13 (12:00 pm MDT) was able to generate much more runoff just as the stream gage stopped recording. It is widely understood that various factors of a storm and watershed prevent direct equivalence of the estimated average recurrence interval of measured precipitation and the estimated recurrence interval of the peak stream flow from that storm event. However, an estimate of the peak flow and the recurrence interval is discussed in the next section.

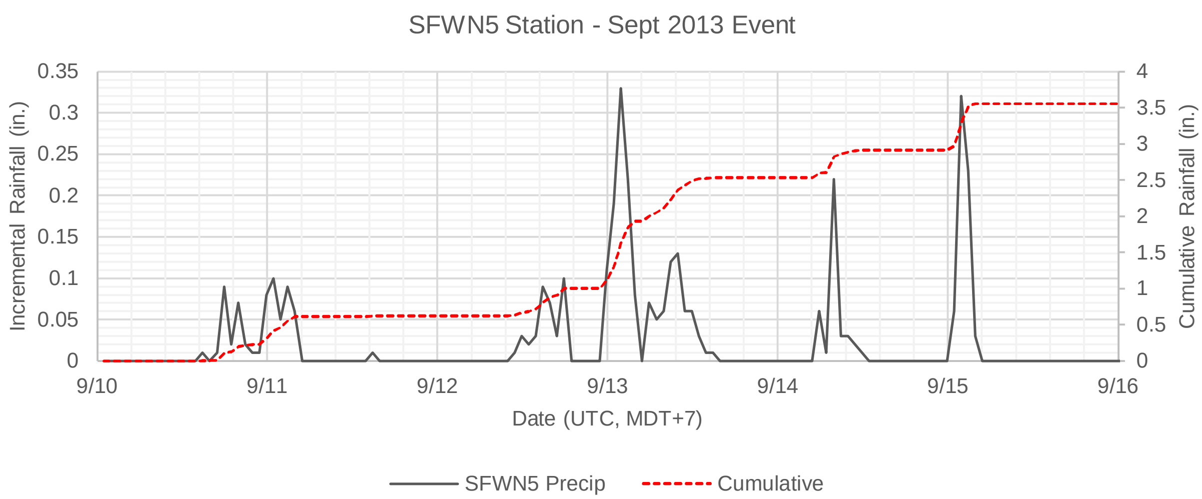

Figure 5. Hourly and Cumulative Precipitation at SFWN5

The USGS stream gage located upstream of McClure (08315480) did not record peak flows entering the reservoir throughout the full duration of the September 2013 runoff event. Figure 7 shows the recorded discharge of the river with the missing peak (greater than 90 cfs) occurring sometime between 9/13/2013 and 9/15/2013. The USGS reports a maximum daily average of 199 cfs for 9/13/2013 and codes it as “estimate” in the table of annual peak flows. While the peak flow from the 2013 storm was probably not a large magnitude, the volume of rain that occurred over the entire storm was substantial. Based on McClure Reservoir release estimates (USGS Gage 08315500), the instantaneous peak was likely between 250 and 350 cfs for the September 2013 event, which would put it on the order of a 50-yr event.

July 2021

July 2021 was a monsoonal wet month for the watershed and was chosen to model the saturation-excess process in the watershed as a different calibration method than the record storm.

According to the RAWS precipitation station (SFWN5), 4.71 inches of rain was measured for the entire month of July. Elk Cabin SNOTEL (921) recorded 5.7 inches and Santa Fe SNOTEL (922) recorded 7.9 inches. See Figure 6 for the hourly rainfall at the SFWN5 station located southwest of McClure reservoir.

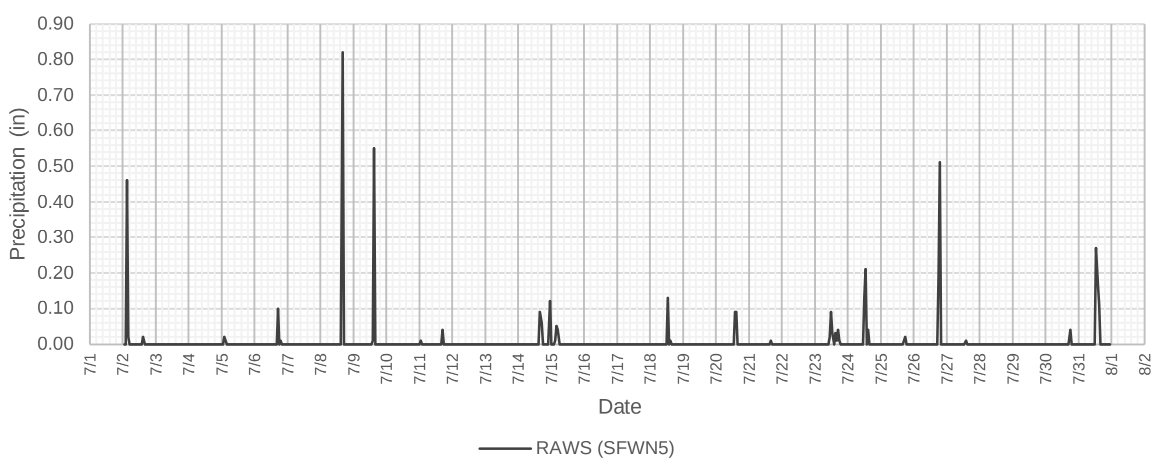

Figure 6. July 2021 Hourly Rainfall at SFWN5

Gridded rainfall estimates for the entire month of July were obtained using the newer Multiple Radar/Multiple Sensor (MRMS) precipitation data from NOAA's National Severe Storms Laboratory (NSSL). The 1-hour timestep, 1-km resolution gridded data combined RADAR data from NEXRAD quantitative precipitation estimation (QPE) rainfall, corrected by gages for bias, and filled in any gaps with data from other sources, such as radars, satellites, surface observations, rain gages, and numerical prediction models to produce useful modeling products.

SMA Model Calibration

Model parameters were adjusted to calibrate to the September 2013 and July 2021 storm events.

Parameters adjusted to have flows from the McClure Upper sub-basin match the assumed September 2013 peak and recorded runoff hydrograph. The calibrated model produced a peak flow of 259 cfs, which falls between the estimated peak 250 - 350 cfs range, based on changes in storage at the reservoir as discussed. Table 3 presents the values of the calibrated parameters. Main parameter adjustments were the initial soil and groundwater saturation, groundwater percolation, soil storage, tension storage, and soil percolation.

Significant effort was required to produce a peak that was in the assumed range of the 2013 runoff while also matching the recession limb of the hydrograph. Figure 7 shows a relatively steep rising limb for both modeled (blue) and observed (black) before the USGS gage stopped recording and picking back up on the recession limb. Other storm hydrographs from this USGS gage exhibit similar shapes – steep rising limbs and slow falling limbs. This is indicative of the interflow in the soils and fractured rocks throughout the mountain watershed that release their water at a slower pace than the much more immediate overland surface flow into the stream channel.

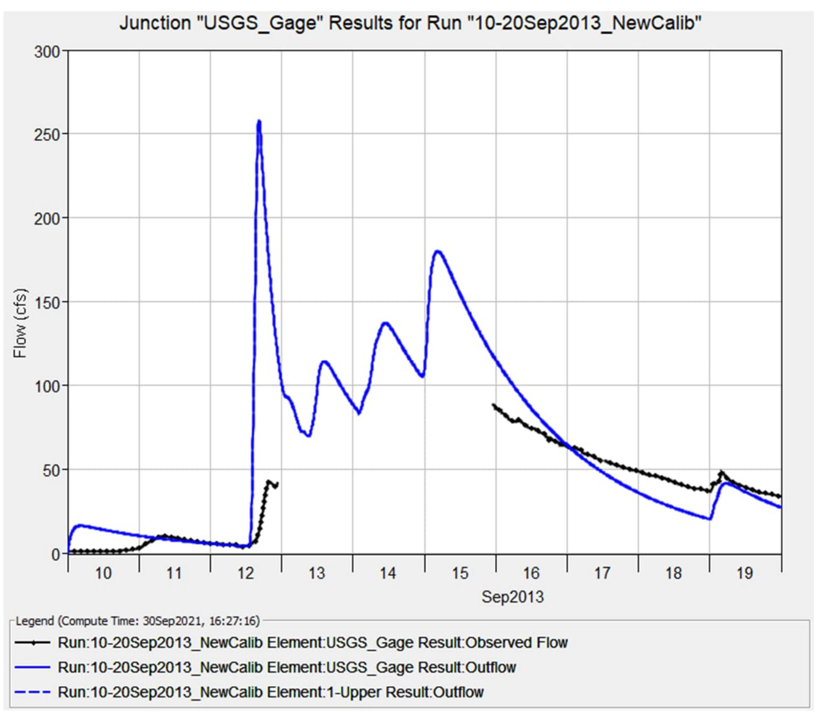

Figure 7. USGS Gage (08315480) 2013 Storm Response and Calibrated Model Response

Parameters were then adjusted to have the flows from the McClure Upper sub-basin match the July 2021 runoff hydrograph. Figure 8 illustrates the model output (blue) compared with the observed runoff (black).

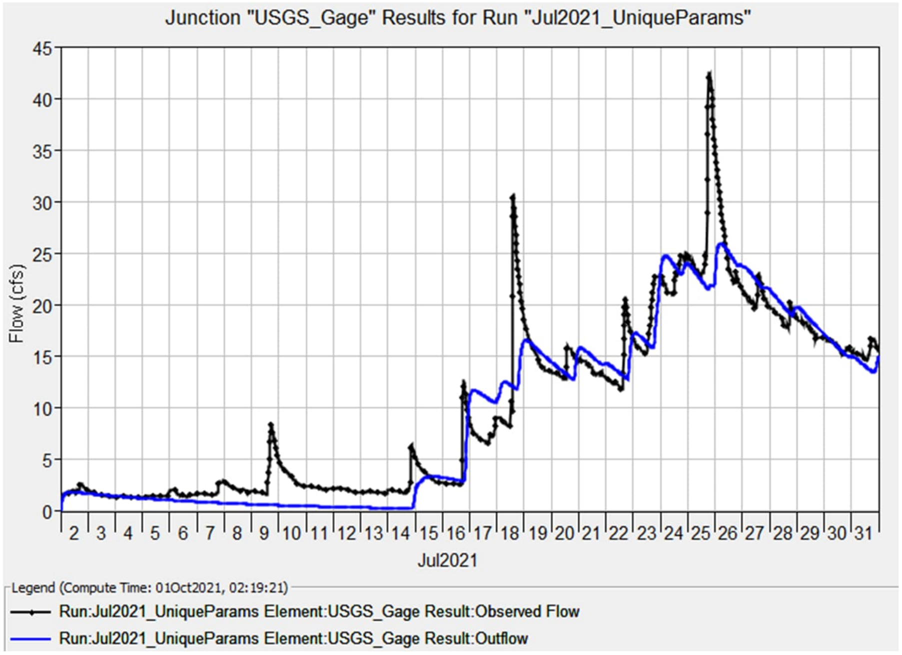

Figure 8. USGS Gage (08315480) 2021 Storm Response and Calibrated Model Response

A comparison of the previous SMA parameters from the September 2013 event and those derived from July 2021 are shown in Table 3. It is noted that of these 14 parameters, especially the groundwater and initial water content ones (Soil %, etc), different combinations could have generated hydrographs that to some degree match up closer to observed data. However, many parameters are within similar ranges between the two storm events.

Table 3. Comparison of 2013 and 2021 Calibration Parameters

Basin / Calib.	Soil %	GW 1 %	GW 2 %	Maximum Infiltration *in/hr*	Impervious %	Soil Storage *in*	Tension Storage *in*
1 / Sep 2013	32	15	15	2.232	0	9.15	7.11
1 / July 2021	23.8	15.8	15.6	2.976	0	9.59	7.11

Basin / Calib.	Soil Percolation *in/hr*	GW 1 Storage *in*	GW 1 Percolation *in/hr*	GW 1 Coefficient *hr*	GW 2 Storage *in*	GW 2 Percolation *in/hr*	GW 2 Coefficient *hr*
1 / Sep 2013	1.96	0.9	0.3	2	0.5	0.5	8
1 / July 2021	0.76	0.26	2.98	13.6	1.2	0.53	10.9

PMP / PMF Evaluation

Calibrated models were used to simulate the PMF event at McClure and Nichols Reservoirs to compare estimates.

Probable Maximum Precipitation Development

The Colorado-New Mexico Regional Extreme Precipitation Study (REPS) toolbox was evaluated following NMOSE (2019) on the project watershed. It was noted that the McClure and Nichols watersheds fell into the REPS PMP Transposition Zone 6 (Colorado Rockies South) (Applied Weather Associates, 2018). NMOSE (2019) recommends various REPS PMP design storms for PMF evaluations based on Zone. MetPortal (MetStat, 2018) similarly recommends various PMP design storms. It was found that of nine PMP storms, the REPS 6-hr Local Storm event, centerloaded (50%) produced the greatest PMF for the watersheds independent of calibration methods used.

Probable Maximum Flood Results

Table 4 provides the results of the PMF evaluation for Inflow Basin 1 with the two calibration storms. The September 2013 storm exceeds the July 2021 storm by 21%.

Table 4. PMF Results

Dam	PMF	September 2013	July 2021
McClure	Inflow Basin 1	6,609	5,442

Discussion and Summary

A PMF analysis was conducted for the McClure and Nichols Dams using the guidelines for hydrologic modeling from NMOSE (2008) and other sources. A HEC-HMS model was created using the Soil Moisture Accounting loss methodology to account for saturation-excess runoff mechanisms with groundwater storage and transfer to surface flow. This model was calibrated to two runoff hydrographs, one driven by a singular storm cycle and one driven by monsoonal rain events. The calibrated models were then provided PMP input to gage PMF response.

Results indicate sensitivity of PMF results to model calibration. The September 2013 PMF response was greater than the July 2021 response, indicating a larger response to the calibration performed by storm event.

When using discontinuous or sparse gage records, finding calibration data that is suitable for SMA calibration can be difficult. However, the reliance of this method on calibration data can lead to complications. Ultimately, a conservative assumption was chosen and applied for all basins based on the September 2013 PMF response.

Future data collection and model calibrations on watersheds with similar geographic, geologic, and hydrographic characteristics may illuminate predictive trends in dependent parameter calibrations as functions of independent parameters. The information presented in this proceeding may be suitable datapoints for use in those empirical relationship developments.

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