

QUANTIFYING SNOWMELT CONTRIBUTION TO STREAMFLOW AND WATER BALANCE UNCERTAINTIES IN A SNOW-DOMINANT WATERSHED USING NOAH-MP, SNODAS, AND SNOWMODEL



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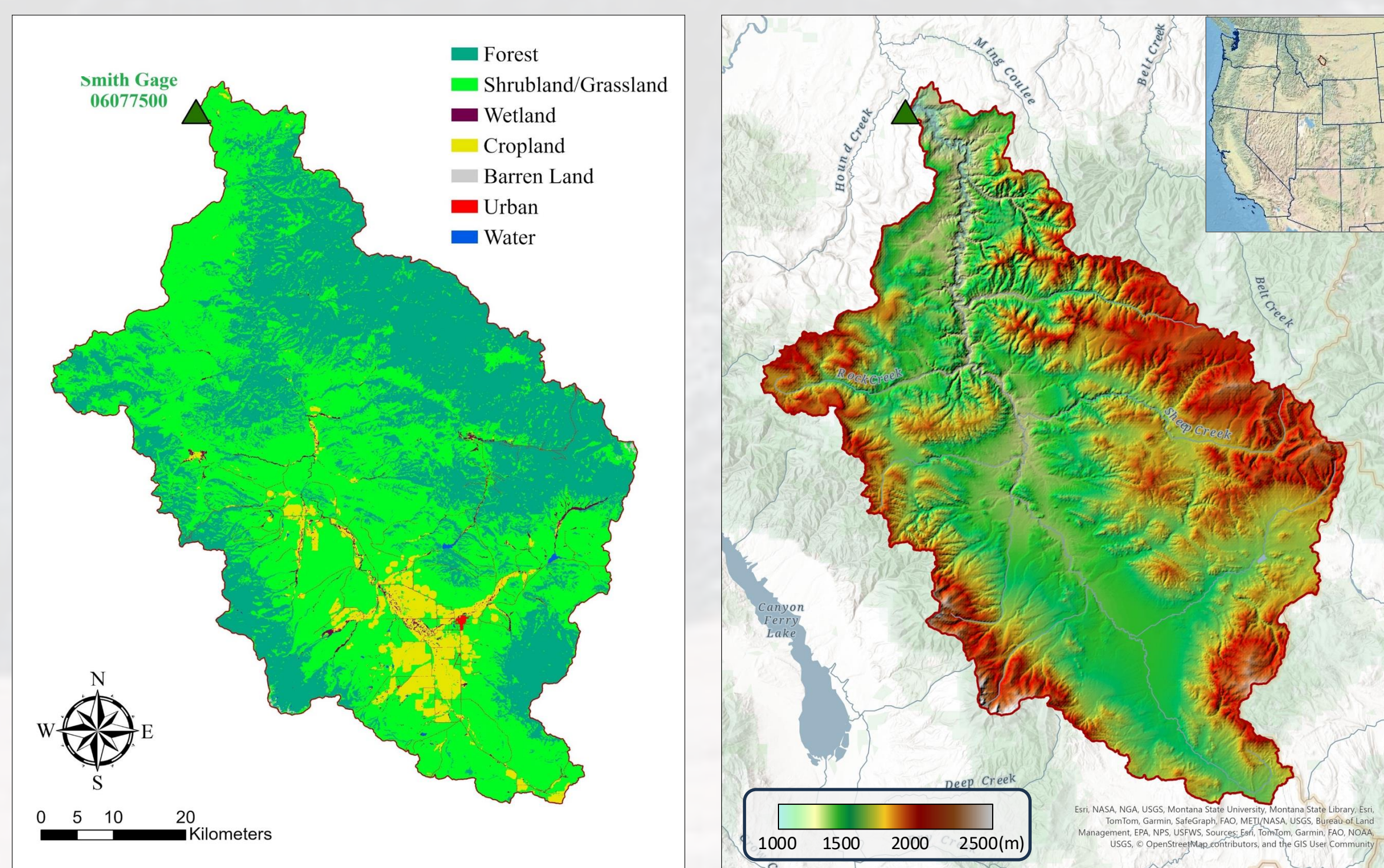
Farhaan Cooverji^{1*}, Eunsang Cho², Bailing Li^{3,4}, Carrie Vuyovich³, Jennifer M. Jacobs⁵, Eunsam Cho³, Samuel E. Tuttle⁶, Eric A. Sproles⁷ *Email: uhw2@txstate.edu

¹Department of Geography and Environmental Studies, Texas State University, San Marcos, TX, USA; ²Ingram School of Engineering, Texas State University, San Marcos, TX, USA; ³Hydrological Sciences Laboratory, NASA Goddard Space Flight Center, Greenbelt, MD, USA; ⁴Earth System Science Interdisciplinary Center, University of Maryland, College Park, MD, USA; ⁵Department of Civil and Environmental Engineering, University of New Hampshire, Durham, NH, USA; ⁶Department of Earth and Environmental Sciences, Syracuse University, Syracuse, NY, USA; ⁷Montana State University, Earth Sciences, Bozeman, MT, USA

Motivation and Background

- Regional water supply in the western United States heavily relies on seasonal snowpack and meltwater
- Understanding the regional water balance, its contributing hydrologic variables, and the contribution of snowmelt to streamflow in a snow-dominant watershed can provide valuable insights into quantifying available water resources
- Prior studies have utilized numerous methods to quantify snow-generated streamflow, yet some uncertainty regarding the fate of solid precipitation on land. To estimate the snowmelt portion of runoff for the western United States:
 - Barnett et al. (2005), and Kapnick and Delworth (2013) used Snowfall/Total Runoff
 - Serreze et al. (1999) used SWE/ Precipitation
 - Doesken and Judson (1996), and Kapnick and Delworth (2013) used Snowfall/Total Precipitation.
 - Mankin et al. (2015) used Snowmelt/Total Precipitation
 - Stewart et al. (2004) used Melt season runoff/ Total runoff
 - Li et al. (2017) used hydrologic model simulations and snowmelt tracking algorithms
- This study utilizes modeled and ground observation variables to address the following research objectives:
 - Explore key variables of the water balance within the watershed
 - Explore the differences in modeled sublimation values
 - Quantify snowmelt-induced streamflow within the watershed using relevant variables from the water balance

Study Area



- Study Area: Conducted in the Smith River Watershed, Montana, USA, for a five-year period of October 1, 2016, to September 30, 2021 (WY2017 - WY2021)
- The watershed was delineated based on a USGS gage (06077500) near Eden, Montana, and spans an area of 4112.6 sq. km or 1587.9 sq. miles

Data

Dataset	Resolution	Variables used	Relevant information
Western Land Data Assimilation System (Noah-MP WLDAS)	1 x 1 km	Precipitation, Groundwater storage, Soil Moisture, Evapotranspiration, Sublimation, Runoff	Noah-MP forced by NLDAS-2
Snow Data Assimilation System (SNODAS)	1 x 1 km	SWE, Sublimation, Snowfall	Modeling data assimilation system developed by NOHRSC
United States Geological Survey gage (USGS)	-	Streamflow	Ground observation gages
Landsat-based irrigation reanalysis dataset (LANID)	HUC12	Irrigation water usage	Utilizes OpenET/SSEBop to calculate E _t , E _o , irrigated areas, consumptive use, and effective precipitation
SnowModel (personal simulation)	0.5 km	Sublimation, Snowfall	NLDAS-2 forcing

RESULT 1: Regional Water Balance

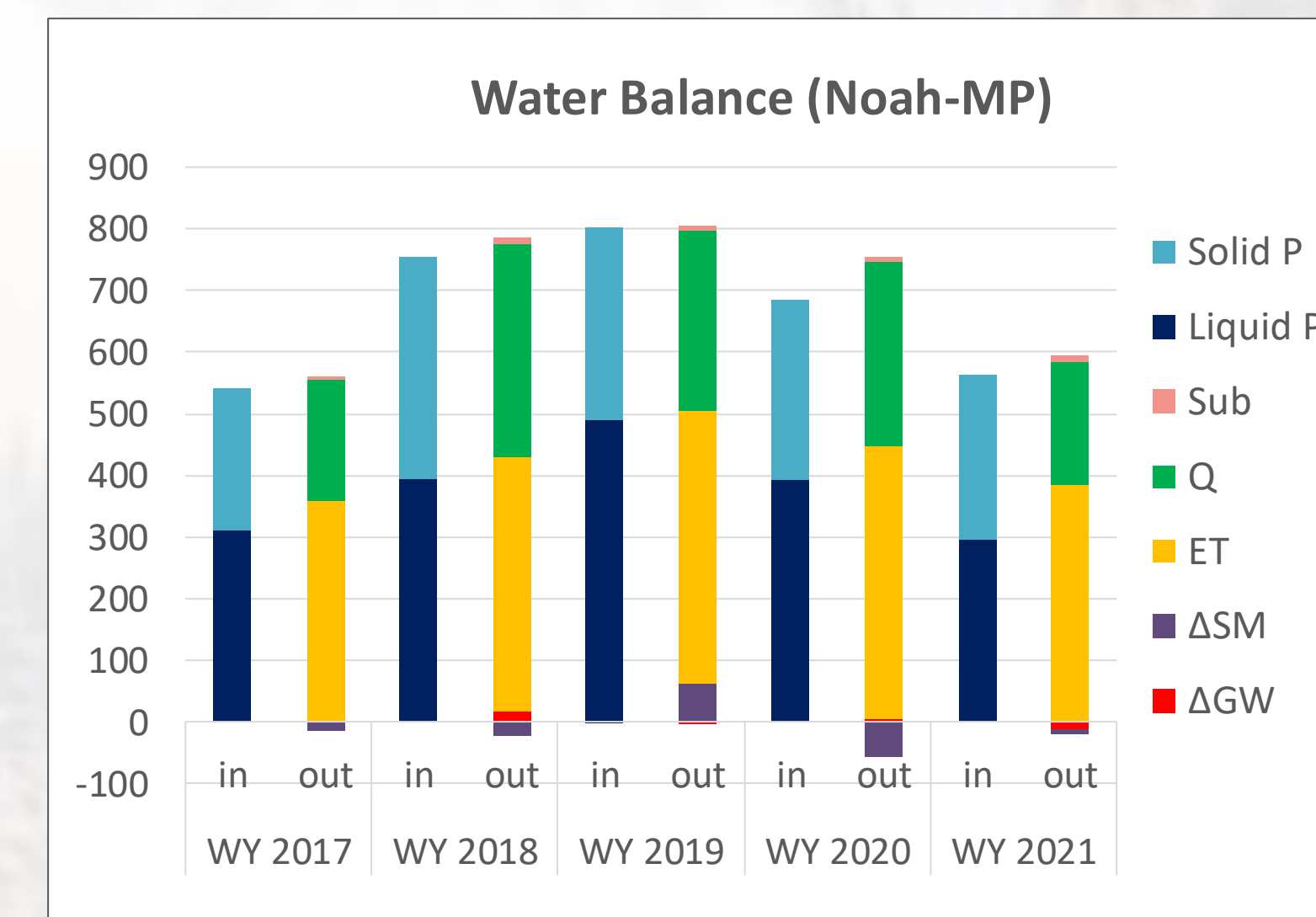
- We generated a water balance table comparing the values of modelled and ground observation variables, namely Precipitation (*P*), Evapotranspiration (*ET*), Sublimation (*Sub*), Groundwater Storage (ΔGW), Soil Moisture (ΔSM), and Streamflow (*Q*)

1. Noah-MP watershed-averaged water balance

- Method: The following formula was used for the water balance: $P(in) = ET + Sub + \Delta GW + \Delta SM + Q(out)$

WY	Solid P	Liquid P	Total P	ET	Sub	ΔGW	ΔSM	Q	Difference (in - out)
WY 2017	230	312	543	350	5	2	-12	199	0.3
WY 2018	359	395	754	404	9	17	-22	346	-0.1
WY 2019	313	489	802	436	7	0	61	291	6
WY 2020	291	393	684	435	8	4	-55	300	-7
WY 2021	267	297	564	375	10	-11	-9	199	-0.7

(All values in mm)



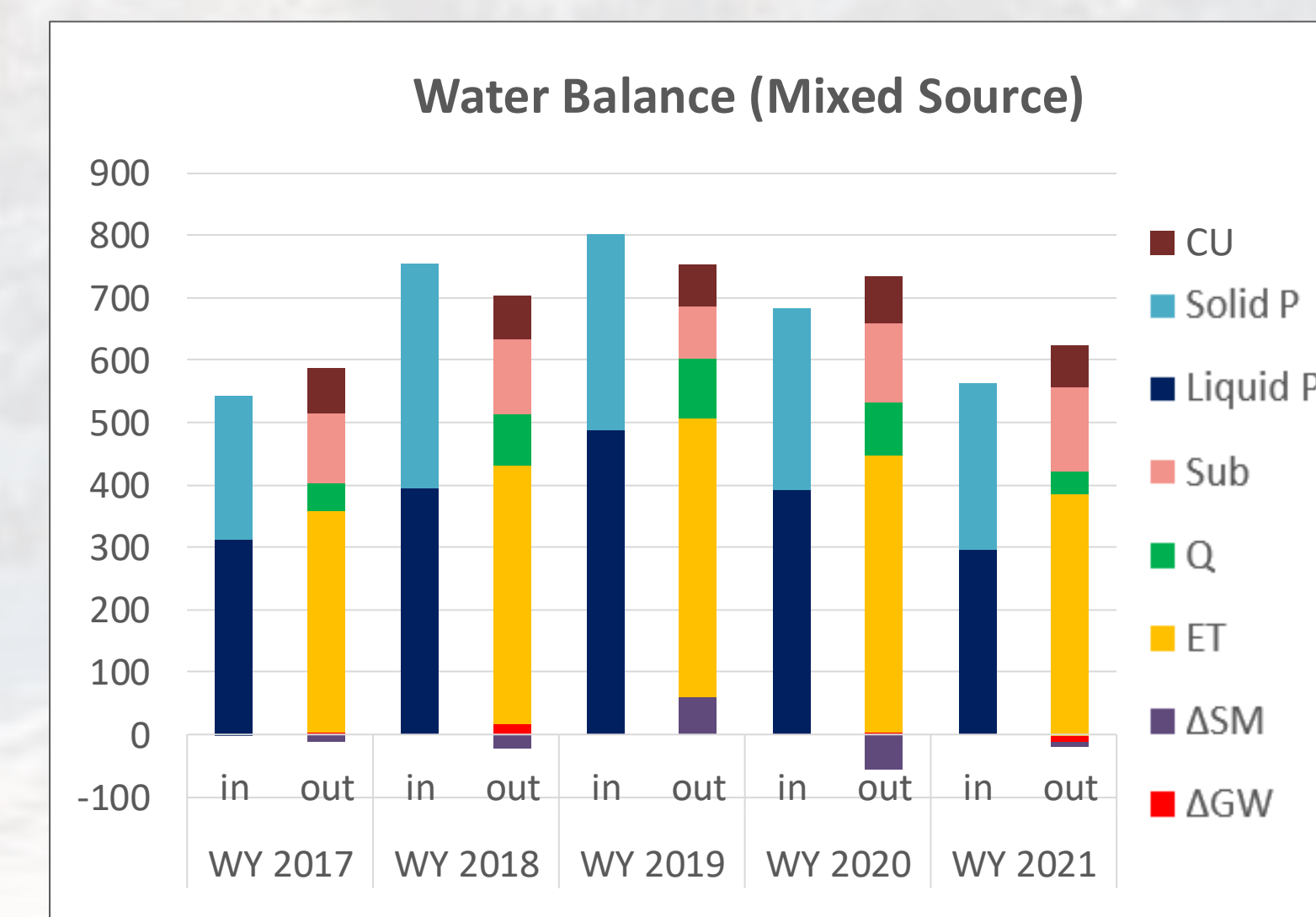
2. Mixed Source and Consumptive Use watershed-averaged water balance

- We used modeled SNODAS sublimation (*Sub*), USGS gage streamflow (*Q*), and LANID irrigation consumptive use (*CU*) values for this water balance version. The rest of the variables were derived from Noah-MP

- Method: Mixed source formula: $P(in) = ET + Sub + \Delta GW + \Delta SM + Q + CU(out)$

WY	Solid P	Liquid P	Total P	ET	Sub	ΔGW	ΔSM	Q	CU	Difference (in - out)
WY 2017	230	312	543	350	112	2	-12	44	75	-26
WY 2018	359	395	754	404	119	17	-22	82	71	83
WY 2019	313	489	802	436	84	0	61	97	67	55
WY 2020	291	393	684	435	126	4	-55	86	75	12
WY 2021	267	297	564	375	134	-11	-9	36	67	-29

(All values in mm)



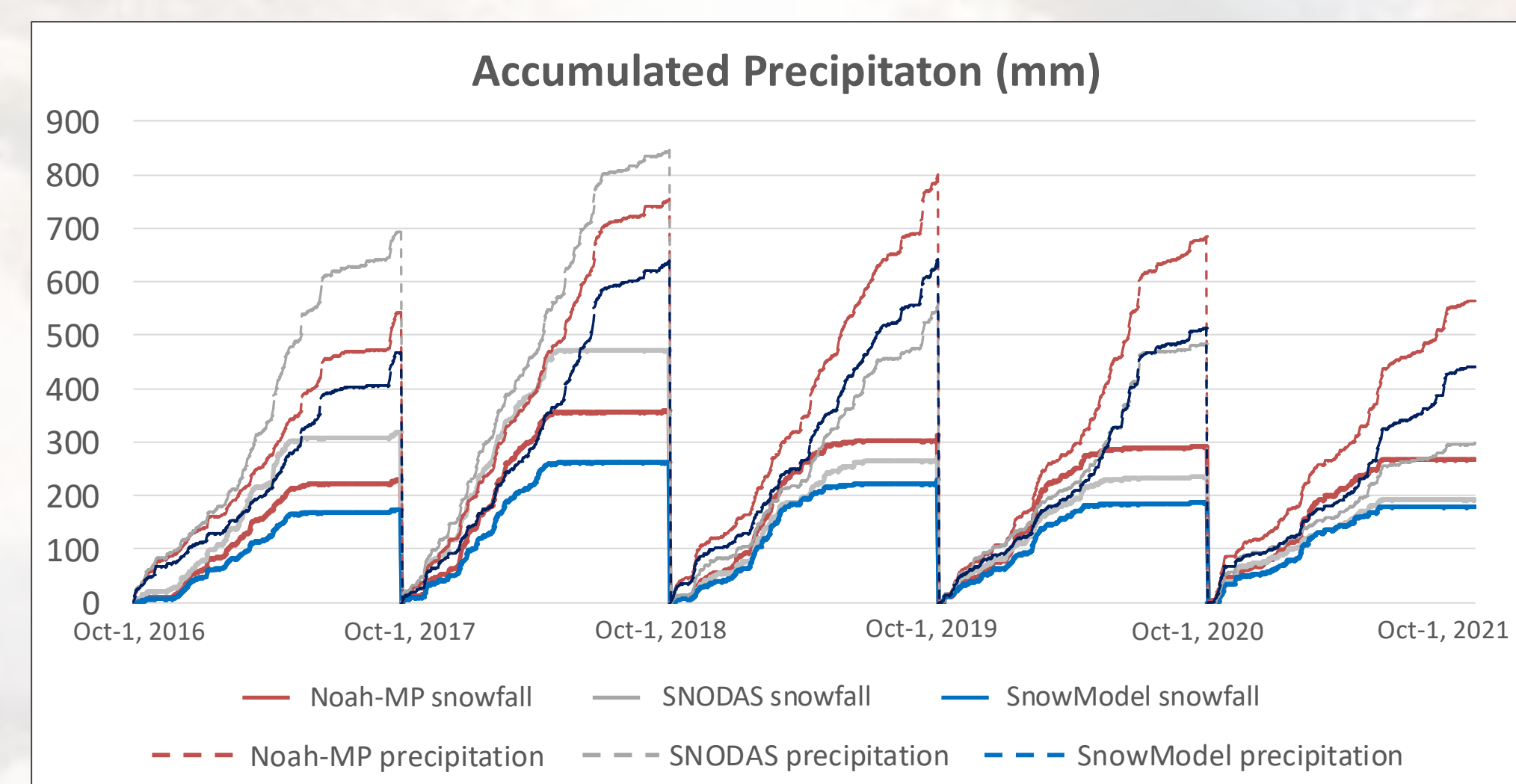
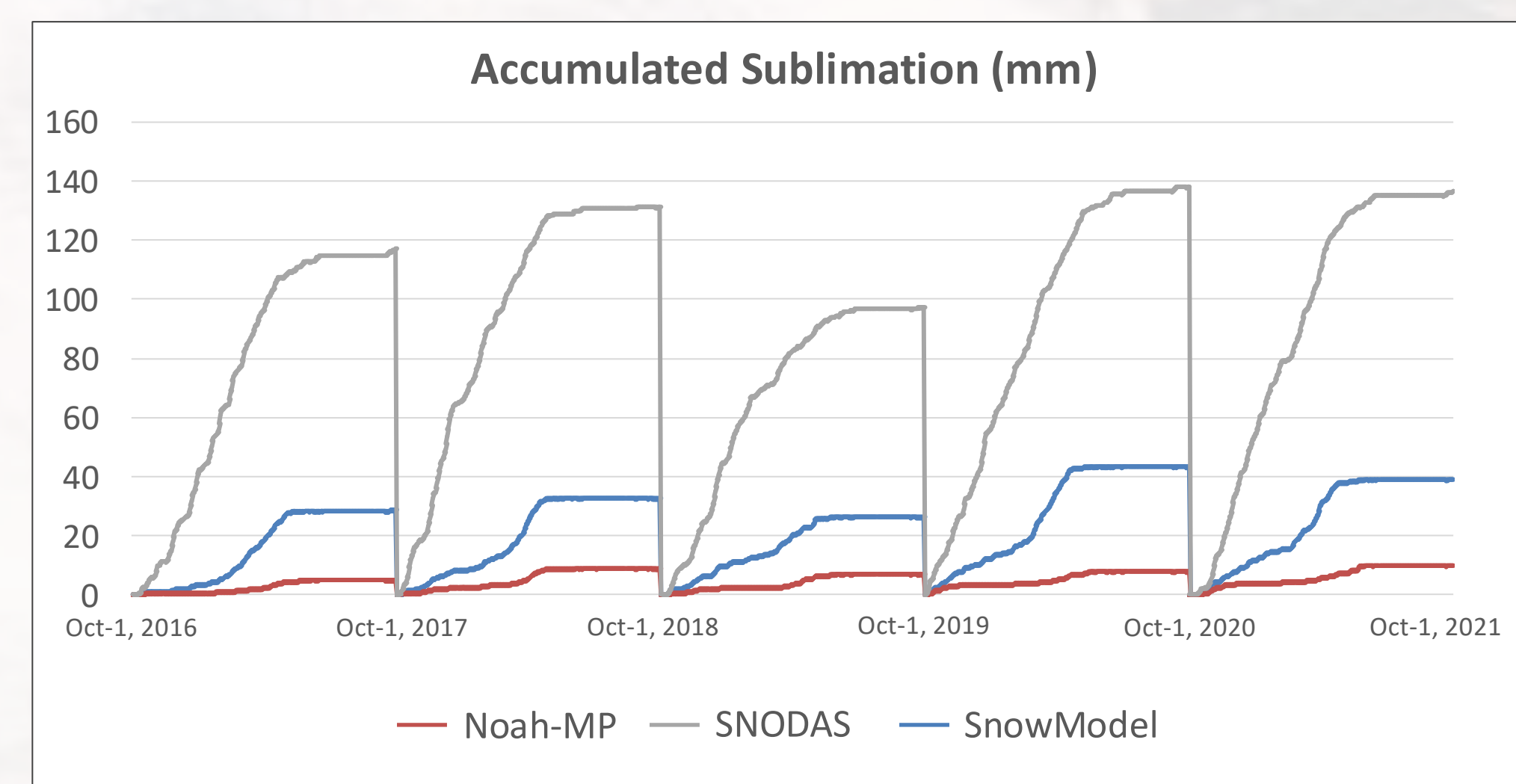
Sources: Noah-MP - Precipitation, ET, Δ Groundwater Storage, Δ Soil Moisture; SNODAS - Sublimation; USGS - Streamflow; LANID - Irrigation use

RESULT 2: Sublimation Differences

- Modeled sublimation values from Noah-MP, SNODAS, and SnowModel (personal simulation) vary significantly over the analysis period. We compared the annual accumulated snowfall values to the sublimation values for each dataset
- The amount of snow sublimated from the accumulated snowfall averaged at 3% for Noah-MP, 43% for SNODAS, and 17% for SnowModel per year during the analysis period. See supplementary information for SWE and sublimation comparisons across three elevations

WY	Noah-MP			SNODAS			SnowModel		
	Snowfall	Sublimation	% Sublimated	Snowfall	Sublimation	% Sublimated	Snowfall	Sublimation	% Sublimated
WY 2017	230	5	2%	320	112	35%	174	29	16%
WY 2018	359	9	3%	472	119	25%	262	33	12%
WY 2019	313	7	2%	275	84	31%	231	27	12%
WY 2020	291	8	3%	235	126	54%	186	44	24%
WY 2021	267	10	4%	193	134	69%	178	39	22%

(All values in mm)



Result 3: Snow-Generated Runoff

- We referred to the methodology of Li et al. (2017), using Noah-MP variables, to partition snowmelt-induced surface runoff (SR) and subsurface runoff (SubSR) from rain-generated runoff

Method:

- Formula to estimate snow contribution to total runoff: $\frac{Snow\ SR + Snow\ SubSR}{SR + SubSR}$

- Daily snow-induced surface runoff per pixel was quantified by subtracting snowmelt infiltration from snow melted on that day (supplementary material)

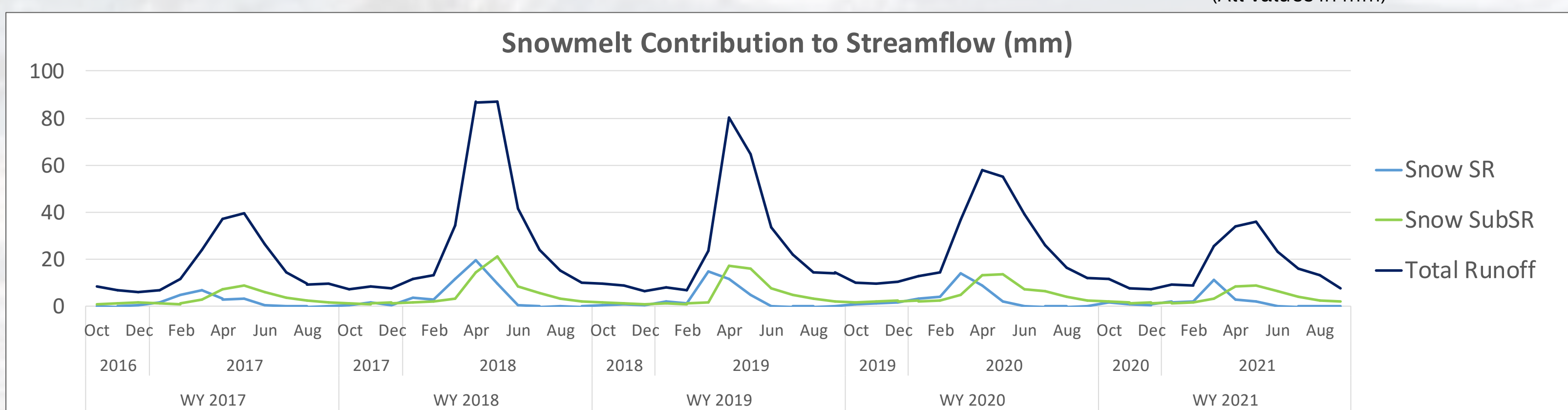
- Daily snow-induced subsurface runoff was calculated using a mass balance equation for groundwater and soil moisture to determine the contribution of infiltrated snow to water below the surface, and its eventual conversion to baseflow (supplementary material)

- On average, snowmelt contribution to surface runoff was estimated to be ~32 mm (45% of SR) per year, and ~53±7 mm (~27±8% of SubSR) to subsurface runoff

- ~85 mm of total runoff originates from snow annually in the watershed, accounting for 32% of total streamflow

WY	Snow SR	Snow SubSR	Total Snow Runoff	Total Runoff	% of Runoff
WY 2017	20	38	58	199	29%
WY 2018	49	65	114	346	33%
WY 2019	35	59	94	291	32%
WY 2020	35	62	96	300	32%
WY 2021	23	42	65	199	33%

(All values in mm)



Key Takeaways

- Result 1:** Sublimation, Δ groundwater, and Δ soil moisture change, along with irrigation water use, are important variables required to track the water balance and fate of snow. Noah-MP sublimation and streamflow values vary significantly compared to those of SNODAS sublimation and USGS streamflow
- Result 2:** Simulated sublimation values for Noah-MP, SNODAS, and SnowModel vary markedly in the region, accounting for 3%, 43%, and 17% of sublimated snow, respectively
- Result 3:** Snowmelt accounts for ~32% of total runoff within the Smith River Watershed for the analysis period of WY2017- WY2021

Future Scope

- We plan to compare the sublimation values of the Noah-MP, SNODAS, and SnowModel to sublimation values generated using AmeriFlux data to assess the accuracy of each model's sublimation estimates
- A separate analysis comparing SWE outputs from Noah-MP, SNODAS, SnowModel, University of Arizona (UA), Western United States Snow Reanalysis (WUS-SR), and Snow Telemetry (SNOTEL) datasets will be done to assess model performance within the watershed

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