Calibration and Analysis of the MESH Hydrological Model applied to Reynolds Creek

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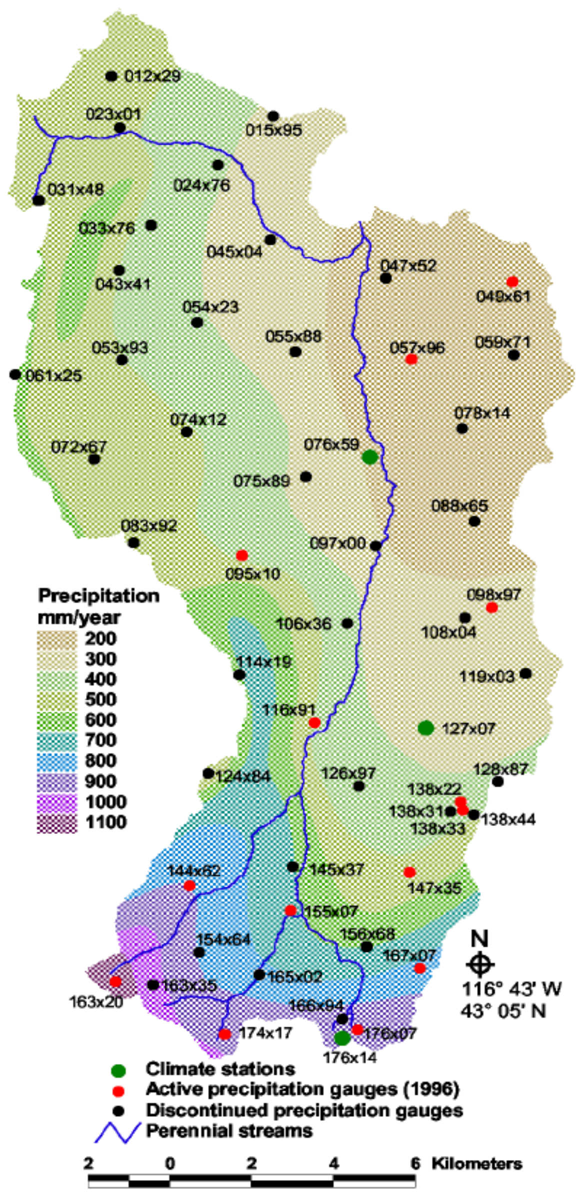
Overview of Research

1. Can MESH (v 1.2+) reasonably simulate measured hydrologic data observed in Reynolds Creek Basin, Idaho, USA?
2. What methods, decisions, assumptions etc, are necessary for high quality model results?

   – Focus on streamflow and SWE data
   – Reynolds Creek is research basin with high quality, quantity monitoring … really the best kind of case study a modeller could hope for

Introduction: Case Study

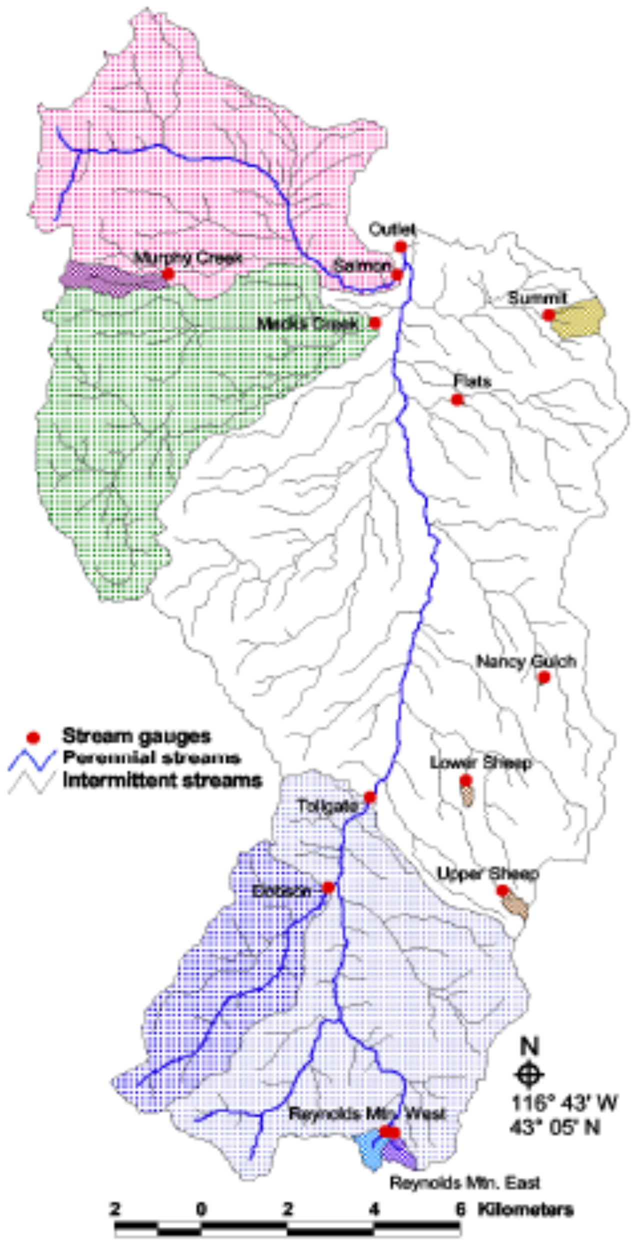


Reynolds Creek:

- Third order sub-watershed of the Snake River basin
- Drainage area 239 km^2
- Elevations range from 1101 to 2241 msl
- Mean air temperature ranges from 8.9˚C to 4.7˚C
- Precipitation in the lower elevations is about 230 mm/yr while the higher regions receive as much as 1100 mm/yr

Source: USDA Technical Bulletin

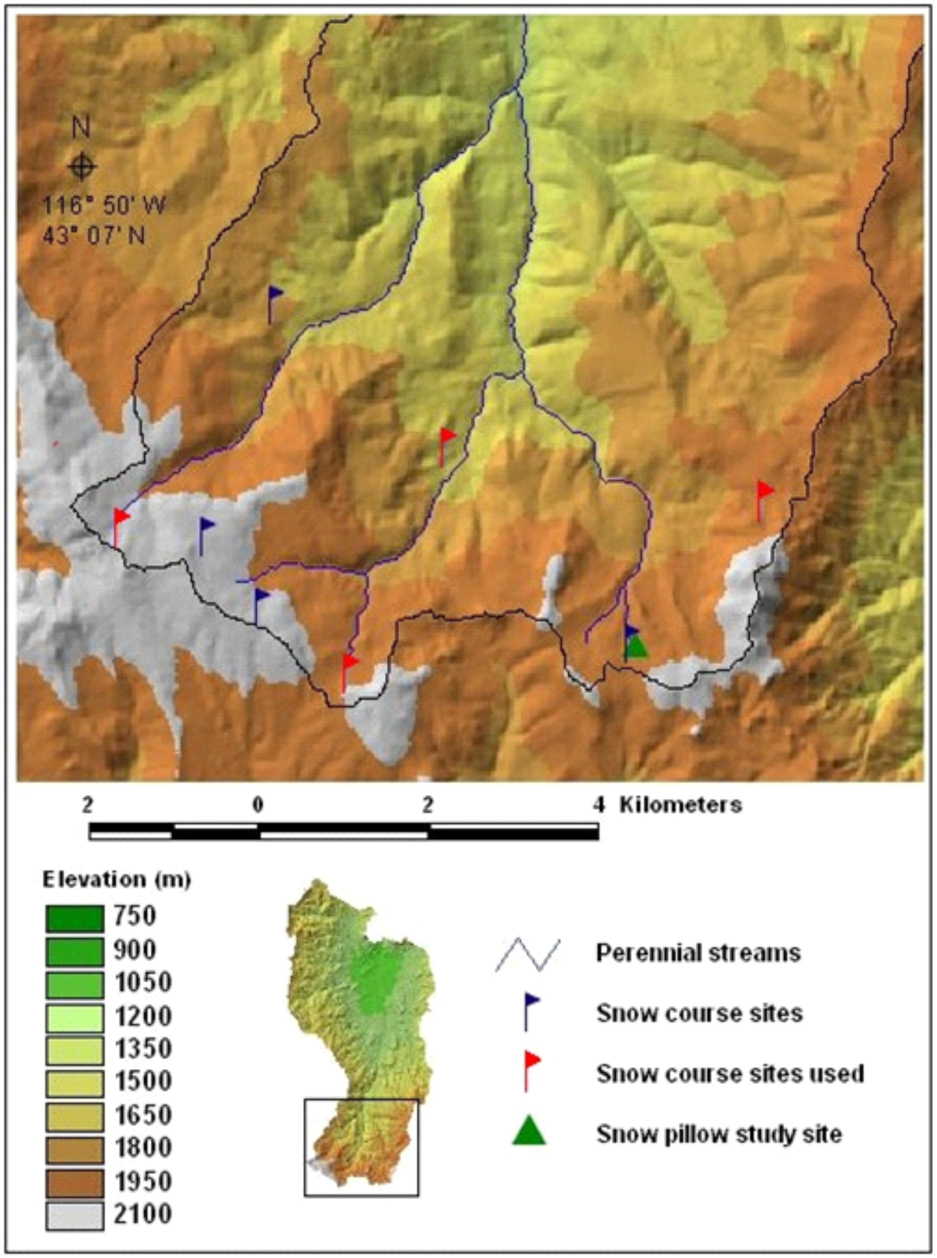
Introduction: Case Study



- Reynolds Creek contains 13 streamflow monitoring locations however due to crop irrigation in the lower elevations, the Tollgate weir was the focus of the calibration studies

- The Tollgate subwatershed encompasses the headwaters for Reynolds Creek and receives the most annual precipitation for the watershed

Introduction: Case Study



- Seven snow course sites were established in 1961, and one added in 1970
- A snow pillow was also installed on the site in 1983 to record daily snow water equivalent (SWE)
- The average peak annual SWE can vary from 200 mm/yr to 750 mm/yr between sites in the headwater areas (Marks et. al, 2000)

Introduction: Model Setup

Reynolds Creek Model Setup

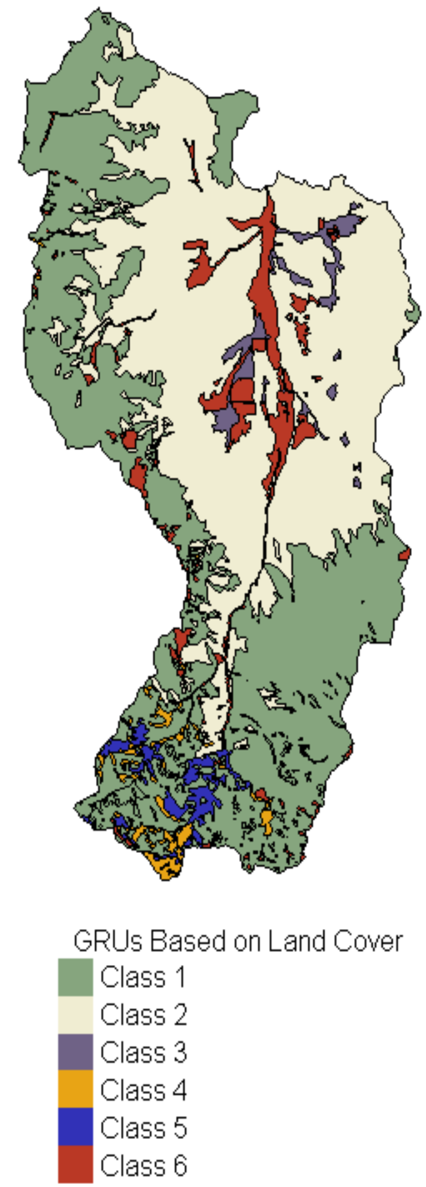
- The distributed model setup used 2 km grid cells (either 1 or 6 GRUs)
- Some meteorological data was distributed using inverse distance weighting
- Solar radiation, temperature, absolute humidity inputs for MESH distributed with more advanced methods …

Introduction: Model Setup

GRUs for Reynolds Creek

- defined based on vegetation cover for each grid cell*

GRU Number	CLASS code	Area (%) Reynolds,	Tollgate	CLASS Descriptions	Vegetation Description (USDA)
1	2	48%	64%	Broad Leaf	Low Sagebrush Mountain Sagebrush-Snowberry
2	2	40%	15%	Broad Leaf	Wyoming Sagebrush Wyoming Sagebrush-Bitterbrush
3	1	2%	0%	Needle Leaf	Greasewood
4	2	2%	9%	Broad Leaf	Quaking Aspen
5	1	2%	8%	Needle Leaf	Conifer
6	3	6%	4%	Crops	Cultivated Other Vegetation



Calibration Strategies

Calibration Strategies

Three calibration strategies were implemented for Reynolds Creek:

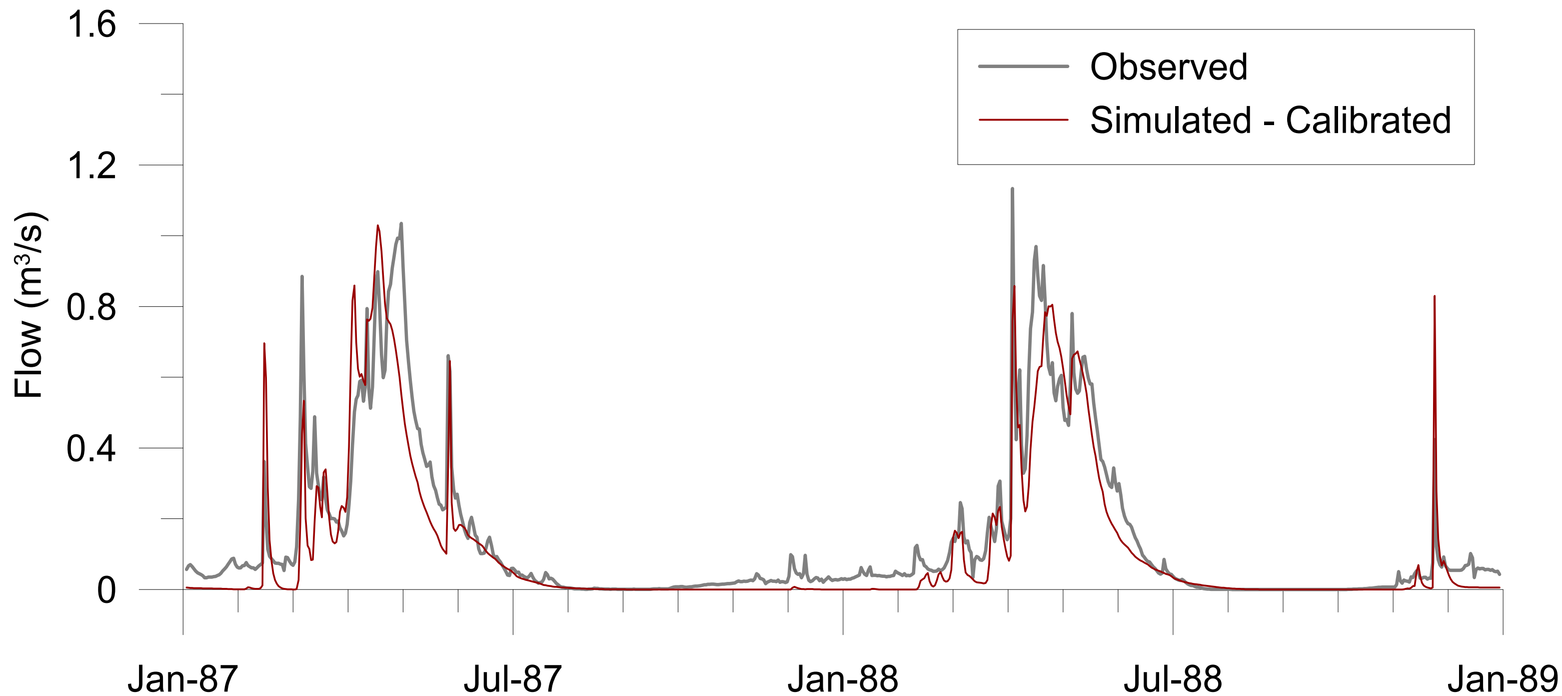
1) Single objective calibration of streamflow at two locations (effectively one location)
2) Single objective calibration of SWE at five snow monitoring locations
3) Multi-objective optimization of streamflow and SWE (combine 1 and 2)

Note: Each strategy involved automatic calibration (optimization) with DDS algorithm (Tolson & Shoemaker, 2007)

Calibration Results

1) Q Calibration Results

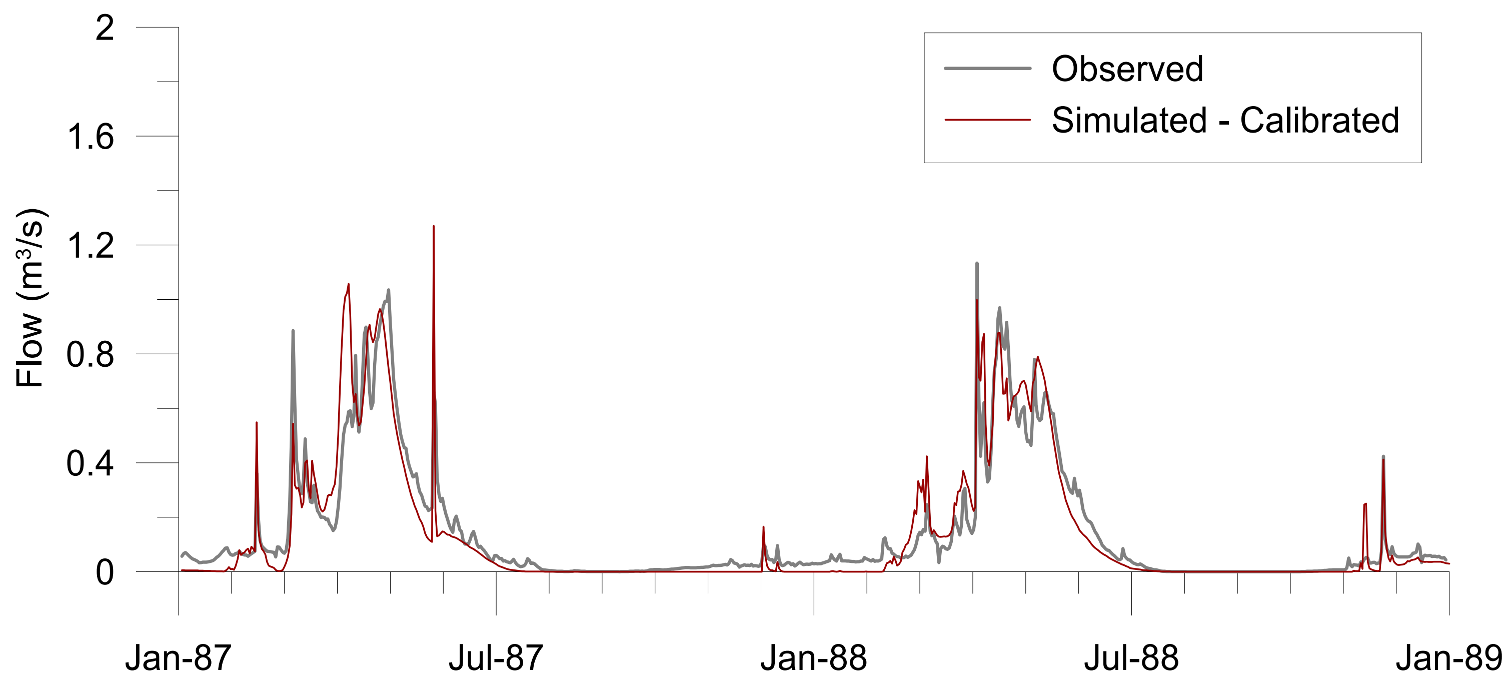
Single objective streamflow calibration



Tollgate subwatershed, 2km **1 GRU** model configuration
Daily Nash-Sutcliffe = 0.82

1) Q Calibration Results

Single objective streamflow calibration



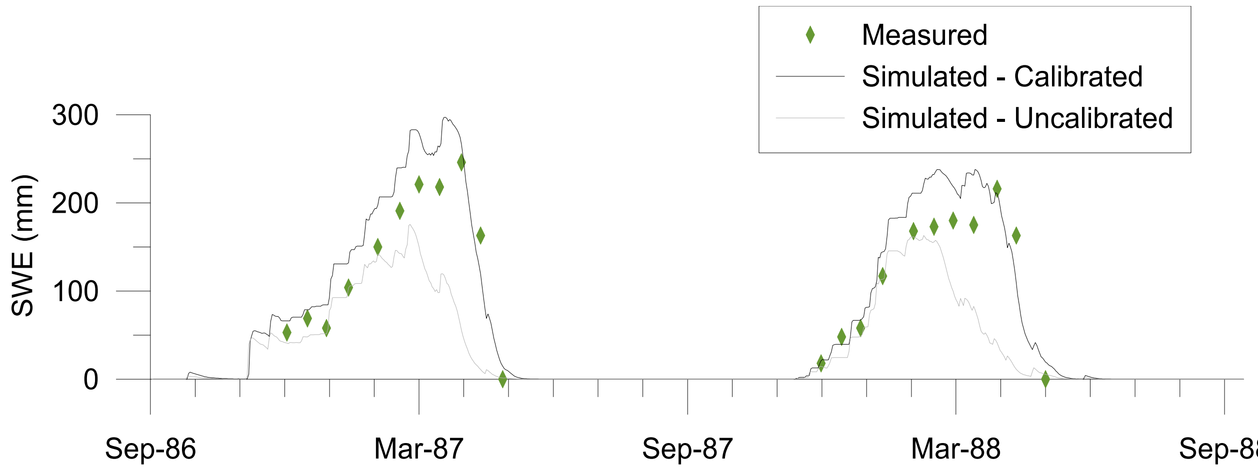
Tollgate subwatershed, 2km **6 GRU** model configuration
Daily Nash-Sutcliffe = 0.85

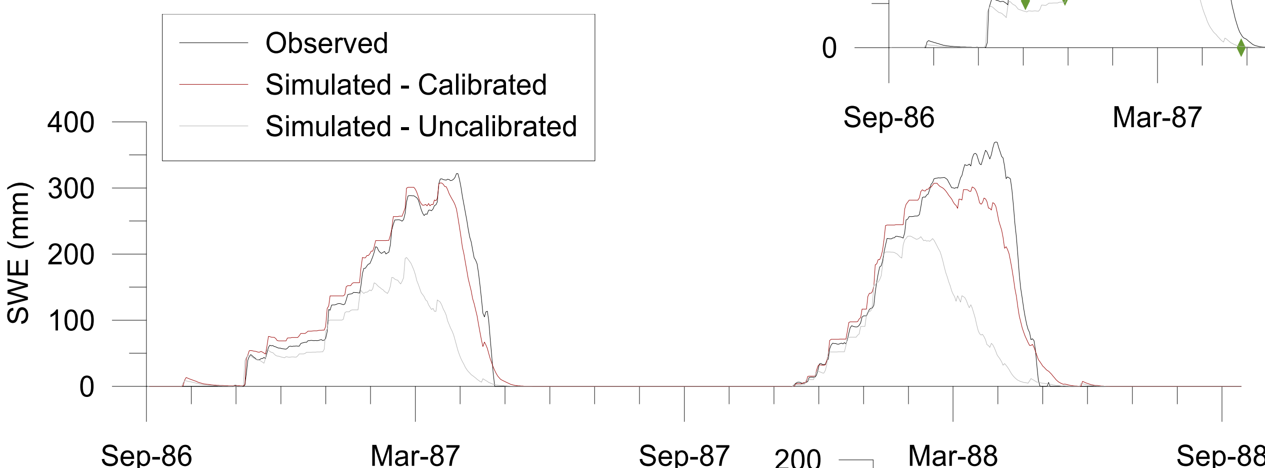
More spatial detail yields approx same quality result despite increase in calibration problem difficulty (31 to 62 parameters)

2) SWE Calibration Results

Single objective SWE calibration

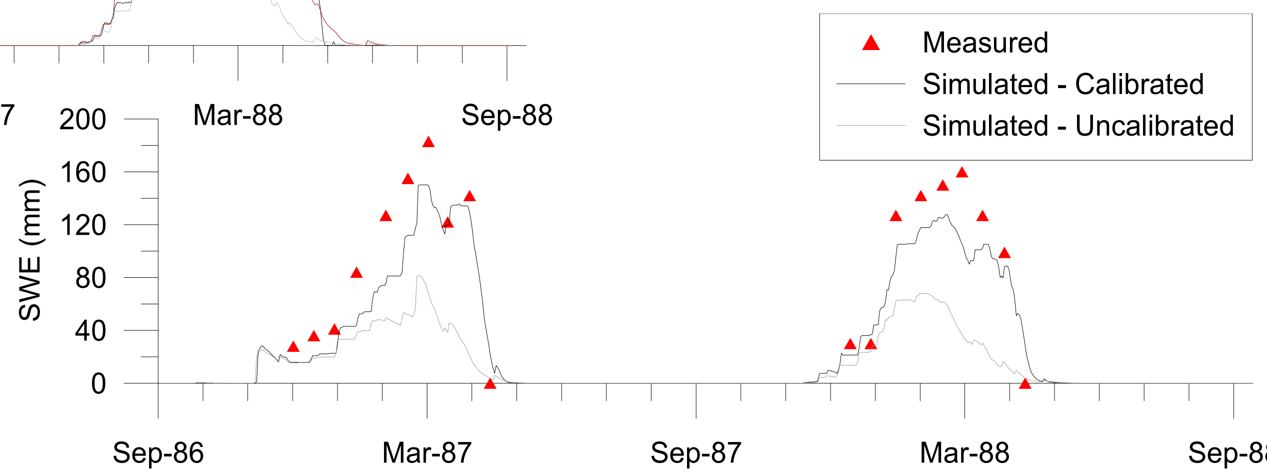
Snow site 167x07, 2km 6 GRU
Daily Nash-Sutcliffe = 0.72 →





Snow pillow site, 2km 6 GRU
← Daily Nash-Sutcliffe = 0.96

Snow site 155x54, 2km 6 GRU
Daily Nash-Sutcliffe = 0.69 →

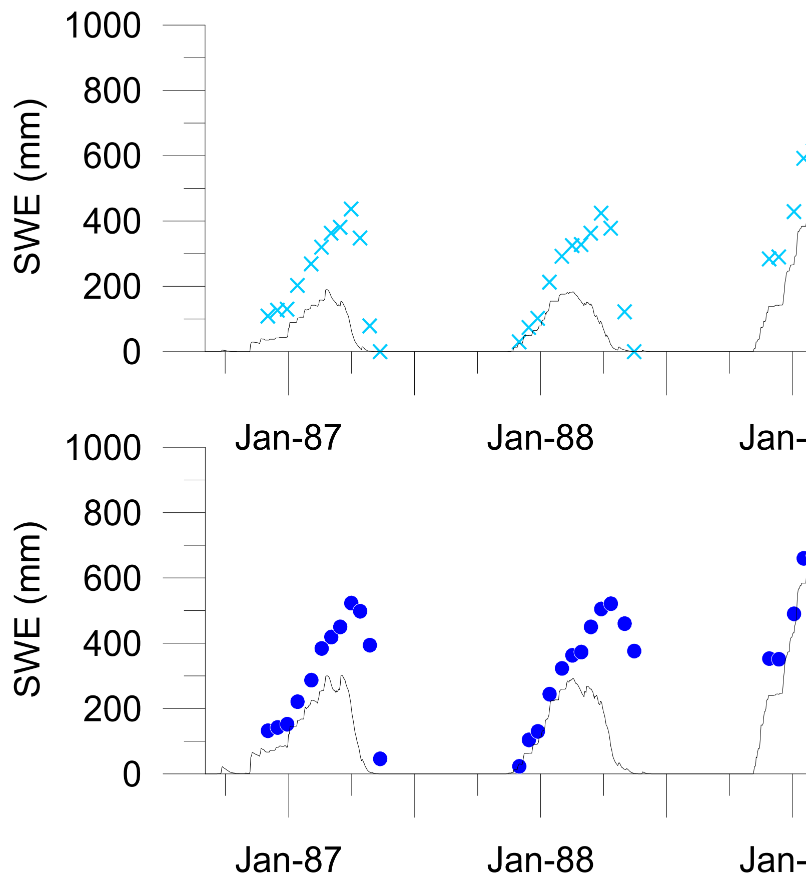


2) SWE Calibration Results

Single objective SWE calibration – poor results at shaded sites with high deposition

Snow site 174x26, 2km 6 GRU
Daily Nash-Sutcliffe = -0.4

Snow site 163x20, 2km 6 GRU
Daily Nash-Sutcliffe = 0.3

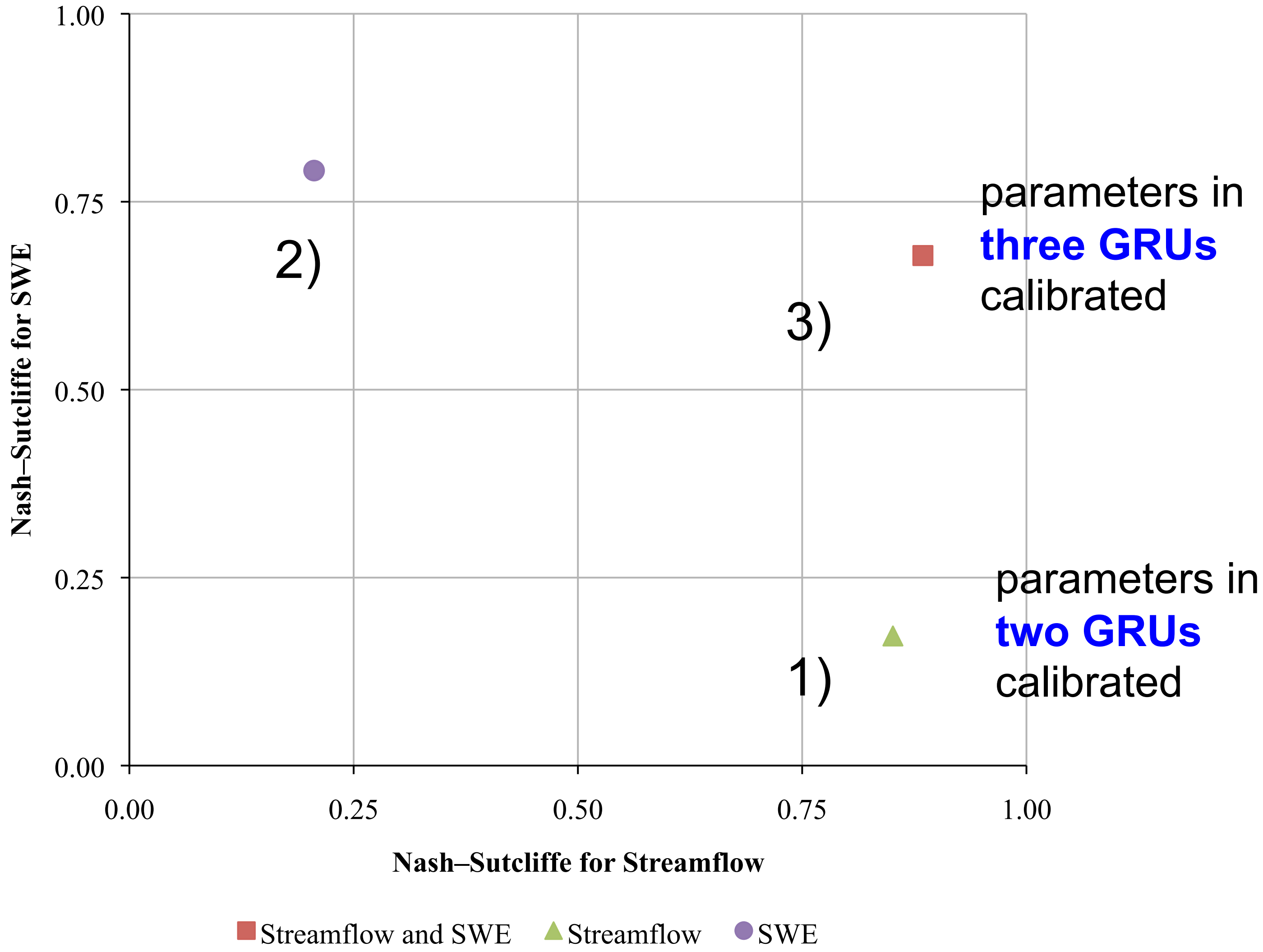


3) Q+SWE Calibration Results

Multi-objective Calibration

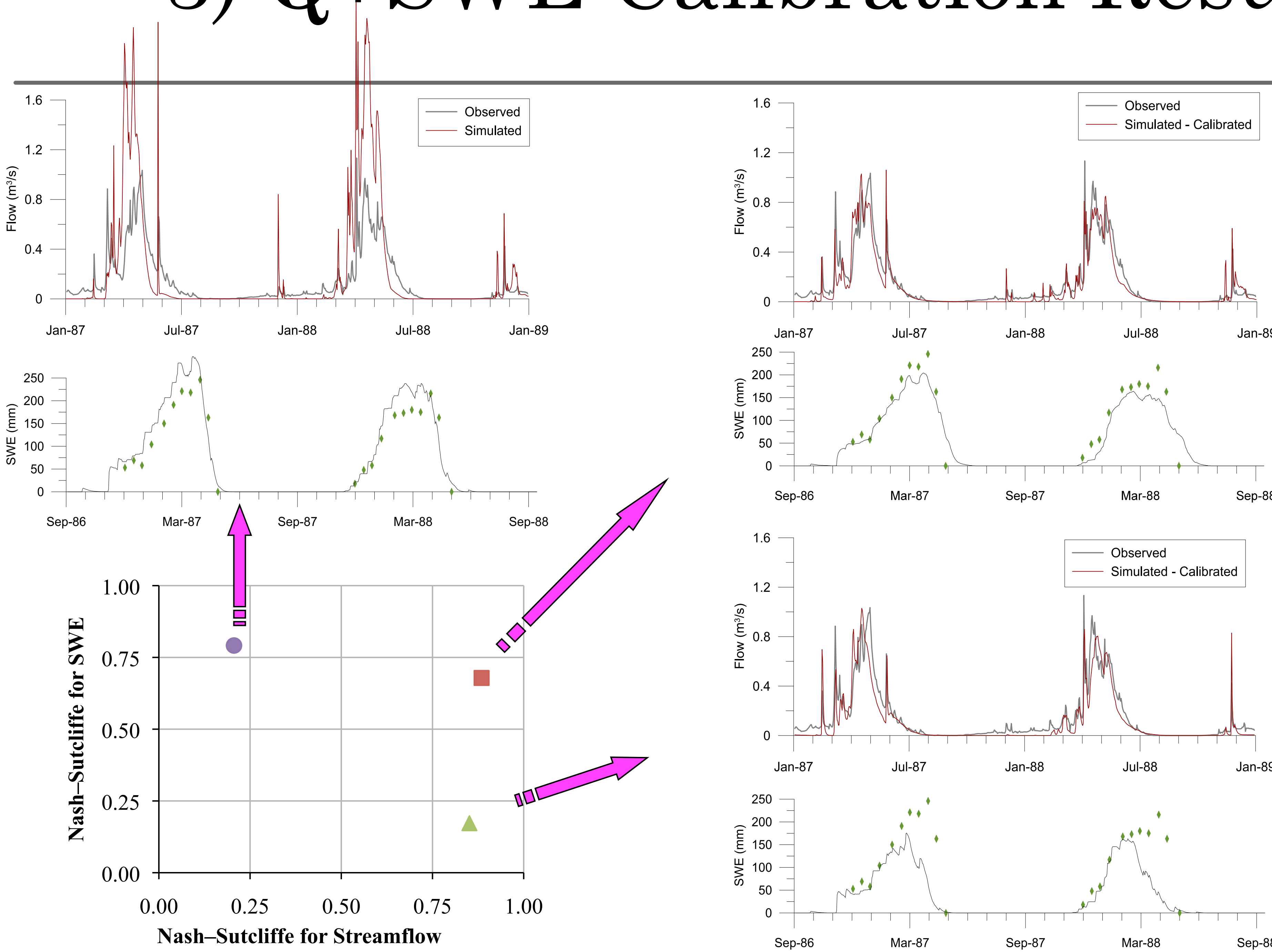
- Streamflow and SWE were optimized simultaneously
- Results are presented for **3 SWE sites** and the Tollgate streamflow site only
- equal weight given to fitting streamflow and SWE (average for 3 SWE sites)

3) Q+SWE Calibration Results



model capable of good quality simultaneous SWE and Q predictions

3) Q+SWE Calibration Results



Other Findings

- Performed multiple calibration experiments to ascertain the influence of various factors/decisions on calibration quality
- As a result, “tips” for calibrating MESH:
  - Notably better results if calibration is started from a good initial solution as opposed to a random initial solution
  - Proper delineation of the parameter ranges is required for successful calibration – excessively wide ranges generate very poor results
  - Soil parameters (sand, clay, organic %s) should be calibrated as fixing them to site-specific data values notably degraded calibration results.

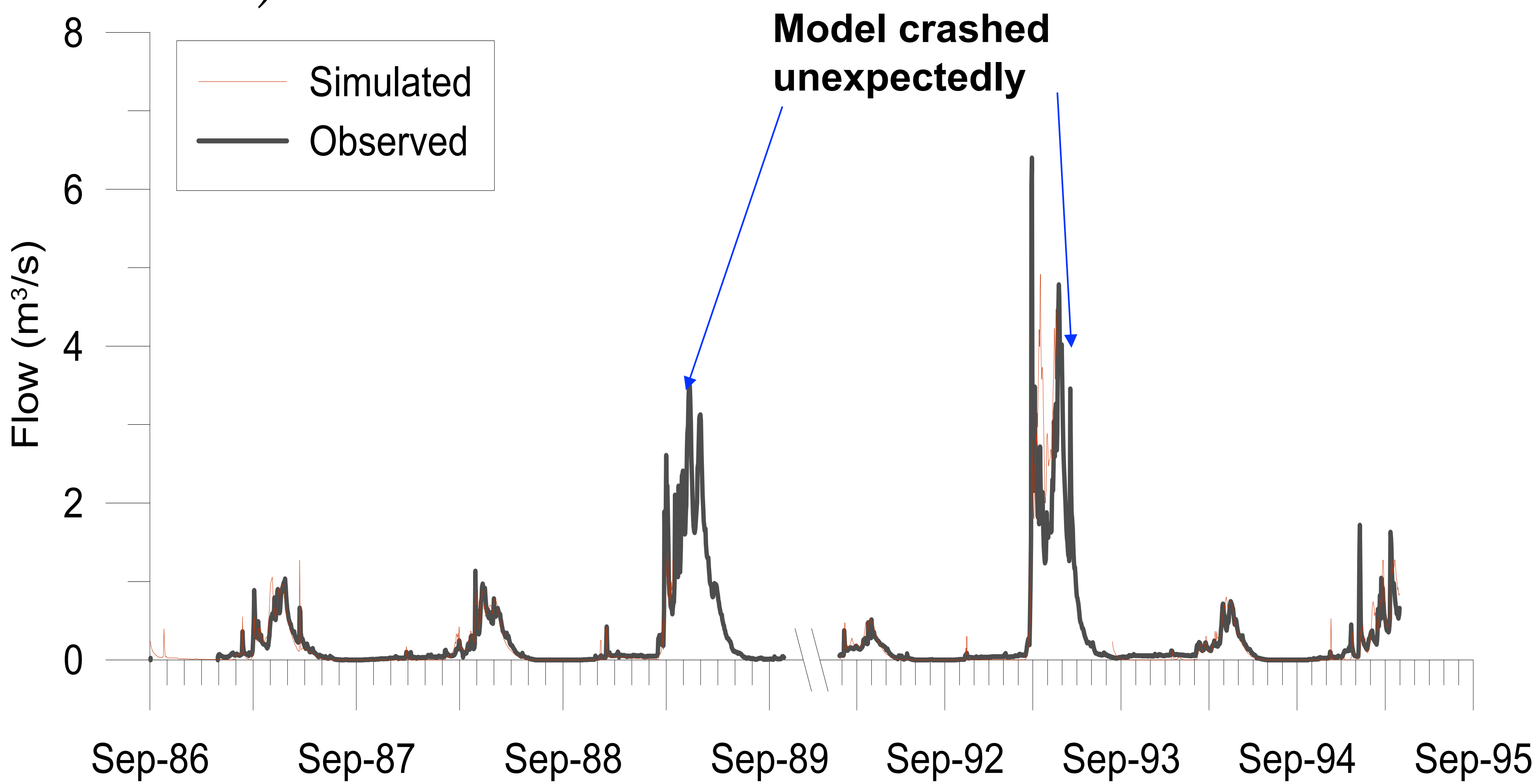
    (Instead, use measured parameters to more tightly constrain ranges)

Validation

… check whether calibration was meaningful or whether parameter sets were over-fitted to calibration data

Validation Results

Reynolds Creek at Tollgate sub-watershed (6 GRUs)



MESH v 1.2+ Model Instability

- Instability is preventing any reasonable length validation runs
- Different parameter sets resulted in different errors at different periods in time (during calibration and validation periods) generally during longer model runs
- Typical errors leading to model crashes included:
  - Energy balance error
  - Check water balance error
  - T-solve error, a result of elevated canopy temperatures
- The 2km 6 GRU model configuration experienced highest rate of model crashes during calibration (10%)
- Crashes do not seem to be associated with extreme parameter settings

Conclusions

- MESH, after automatic calibration, predicts Reynolds Creek SWE and Q very nicely
- but … the model seems to require changes to improve stability (MESH 1.3 could help?)

Future Work

- Overcome/address model instability problems to properly validate results
- Repeating MO streamflow+SWE calibration experiments with only 'sensitive' parameters

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- Test the Soulis et al. improvements to MESH soil water budget on Reynolds Creek
- Consider alternate GRU definitions in Reynolds Creek
- Calibrate to other measured data (soil temperature and soil water content) in Reynolds Creek
- Consider similar calibration experiments for other IP3 basins (Wolf Creek completed) … plus others

QUESTIONS ?

References:

Hanson, C. L., Marks, D., Van Vactor, S. S. (2000). "Climate Monitoring at the Reynolds Creek Experimental Watershed, Idaho, USA." ARS Technical Bulletin NWRC-2000-6.

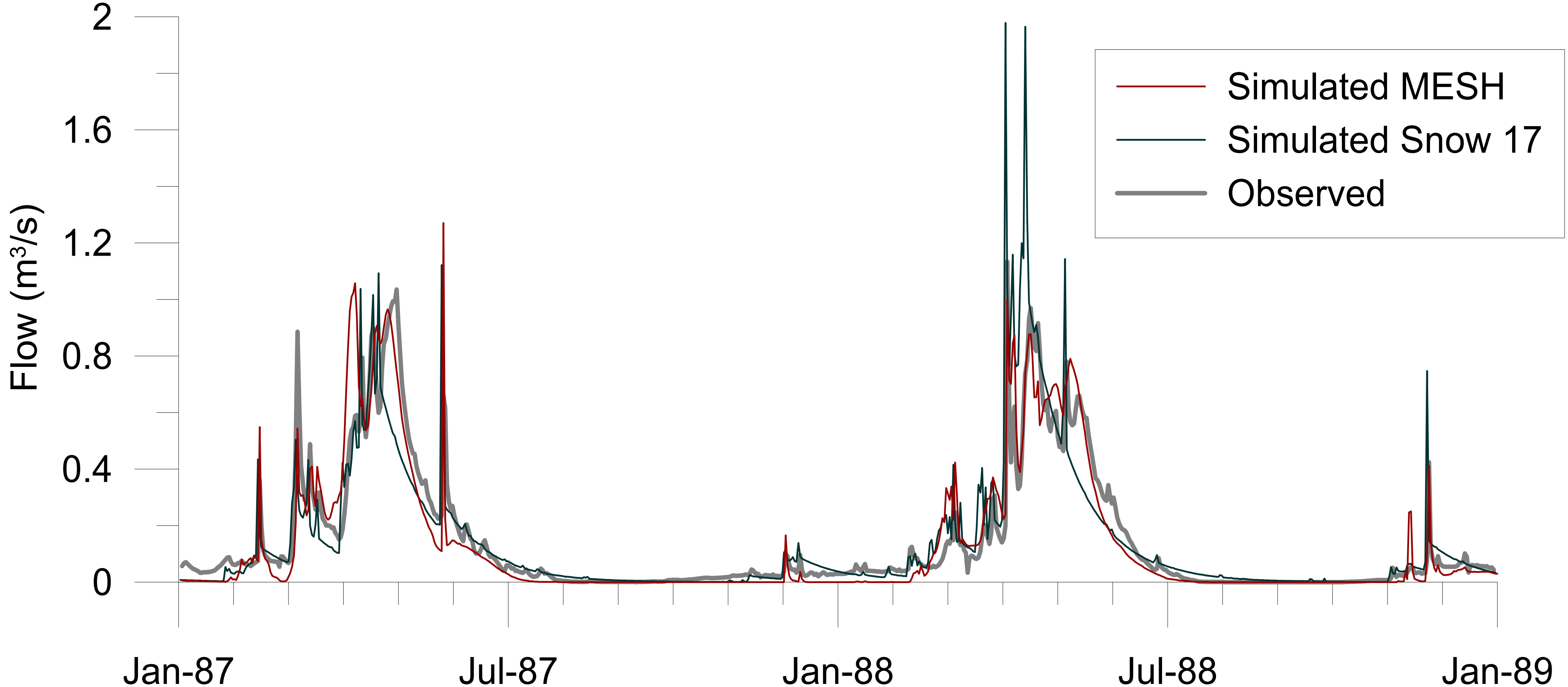
Marks, D., Cooley, K.R., Rovertson, D.C., Winstral, A. (2000). "Snow Monitoring at the Reynolds Creek Experimental Watershed, Idaho, USA." ARS Technical Bulletin NWRC-2000-5.

Pierson, F.B., Slaughter, C.W., Cram, Z.K. (2000). "Monitoring Discharge and Suspended Sediment, Reynolds Creek Experimental Watershed, Idaho, USA." ARS Technical Bulletin NWRC-2000-8.

Seyfried, M.S, Harris, C. R., Marks, D., Jacobs, B., (2000a). "A Geographic Database for Watershed Research, Reynolds Creek Experimental Watershed, Idaho, USA." ARS Technical Bulletin NWRC-2000-3.

EXTRAS

MESH predictions compared to Franz et al. (2008) at Tollgate



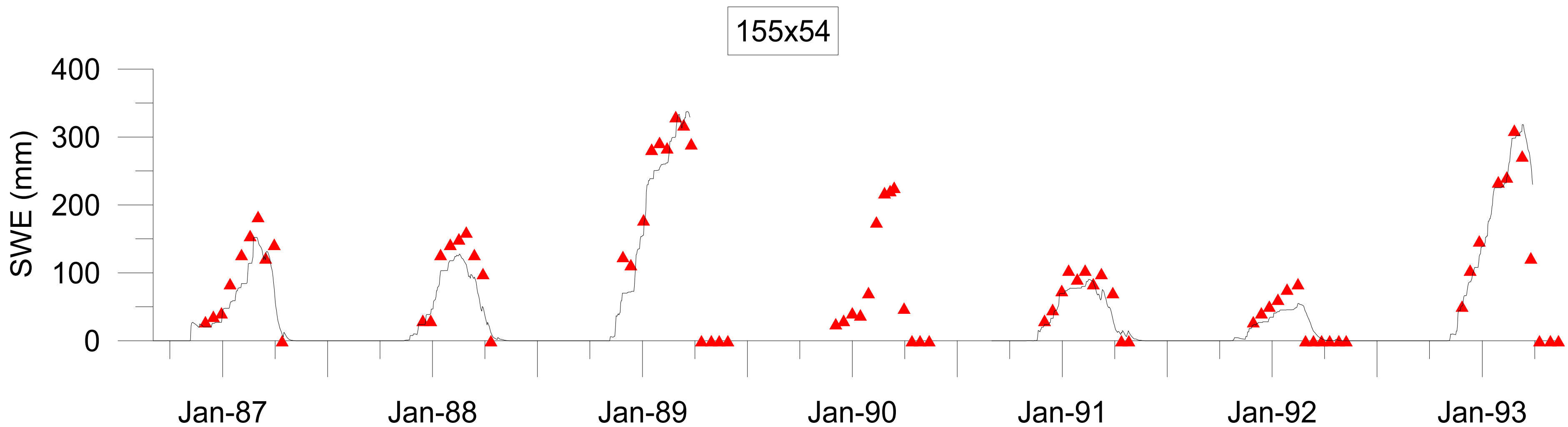
calibrated SNOW17 + SACSMA (calibrated to more than just our 2 yrs)

(NWS lumped operational forecasting model)

Model Results

Validation: SWE

	GRU	NS	APB	R^2
155x54	5	0.90	15%	0.98
163x20	1	0.08	30%	0.74
167x07	1	0.79	21%	0.95
174x26	4	-0.12	56%	0.84
Snow Pillow Site	4	0.85	28%	0.96



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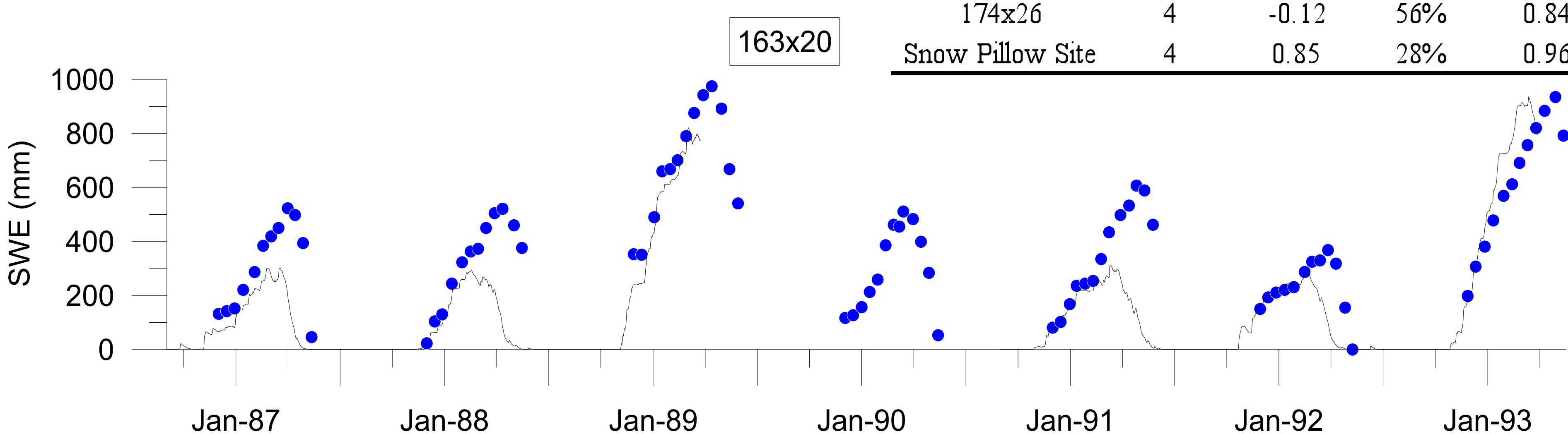

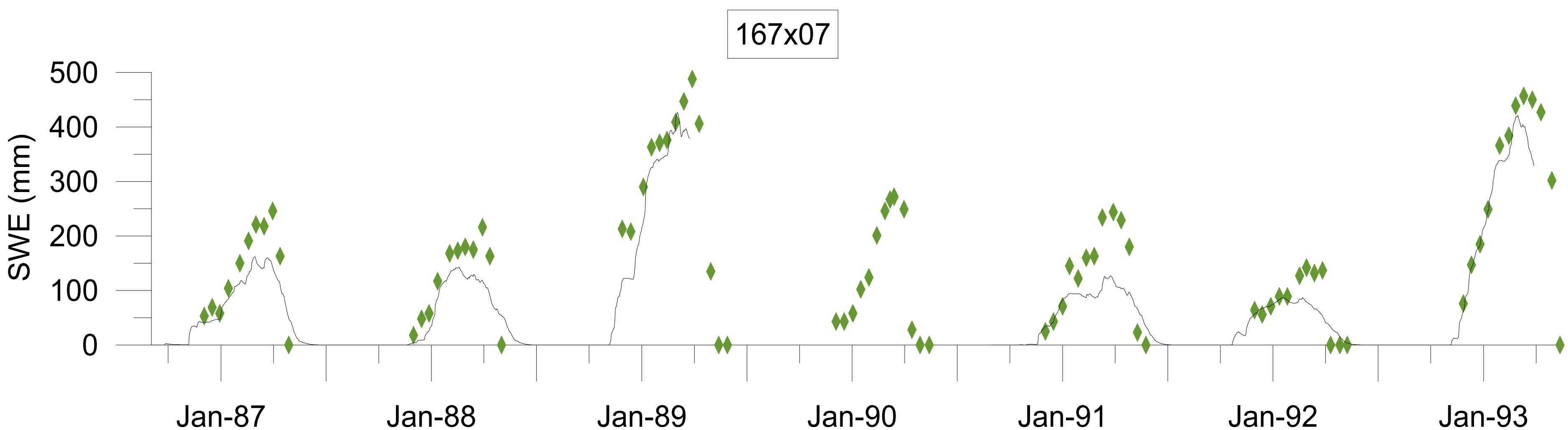

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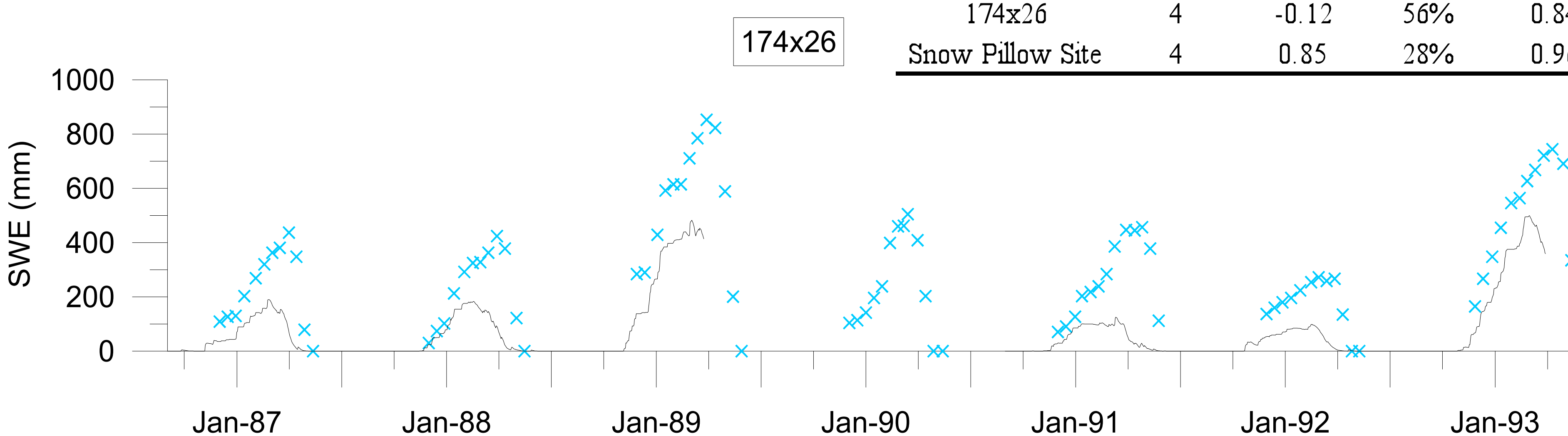
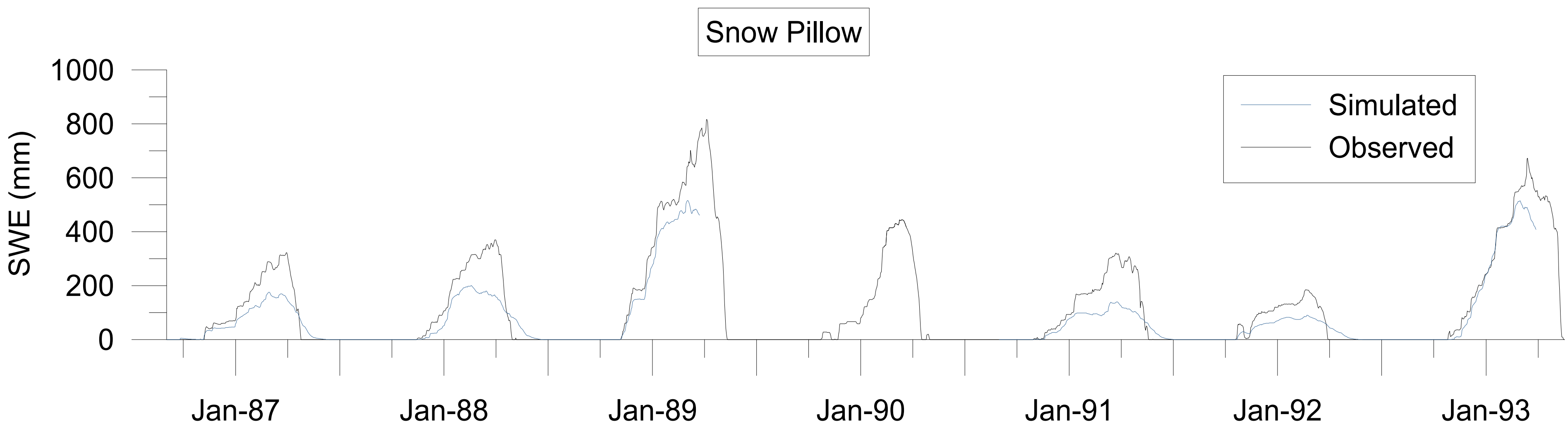
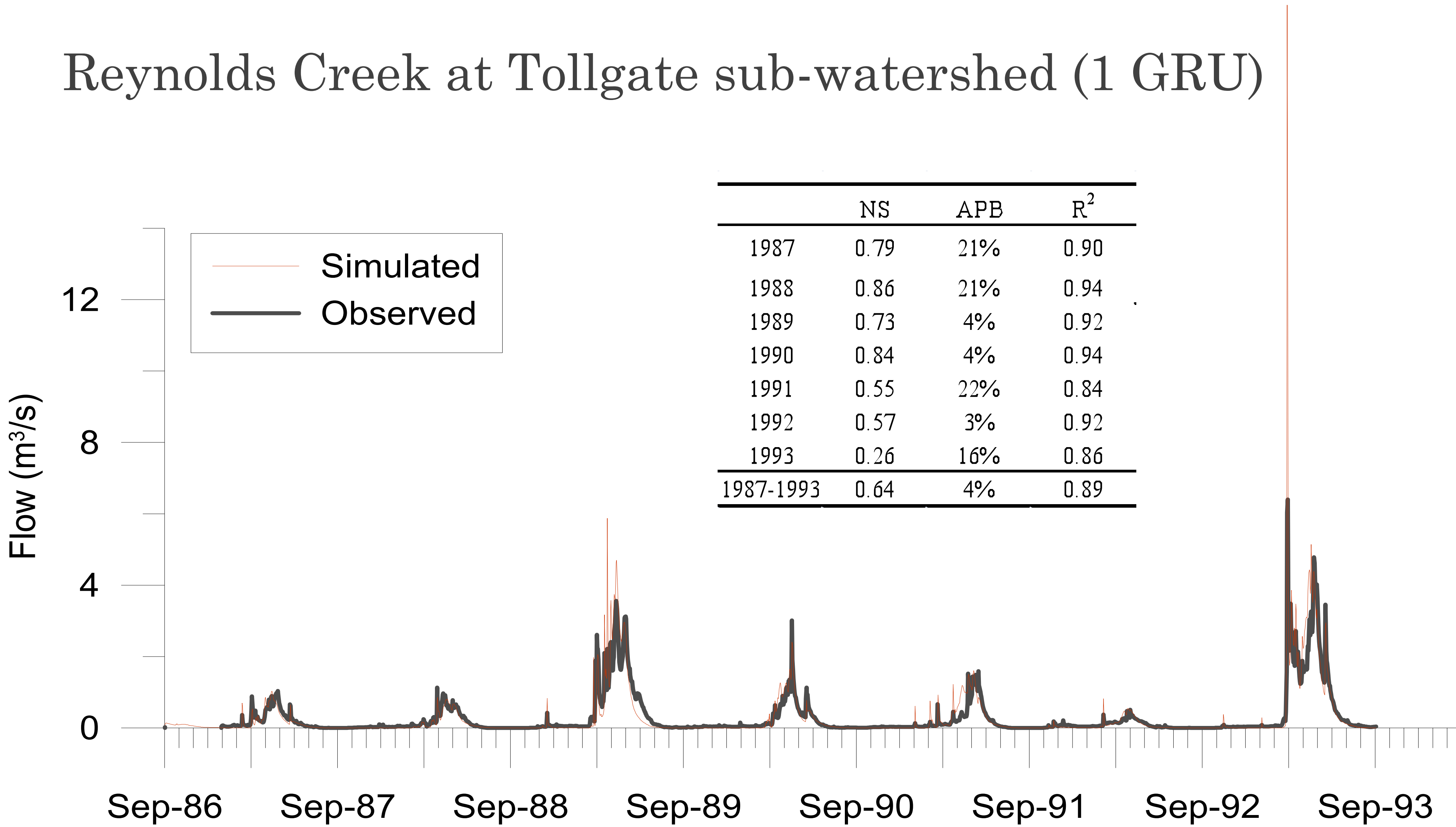




Model Results

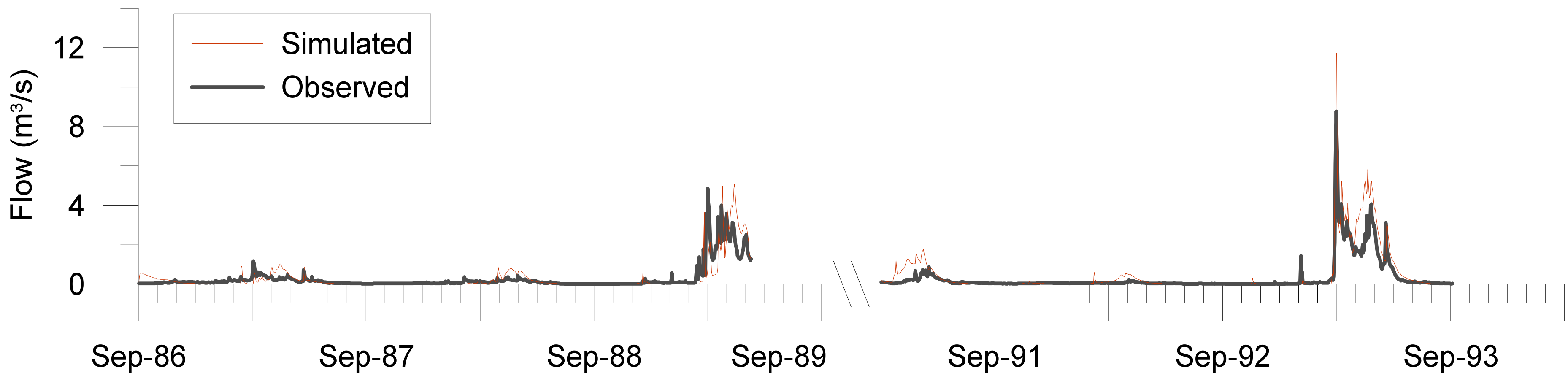
Reynolds Creek at Tollgate sub-watershed (1 GRU)

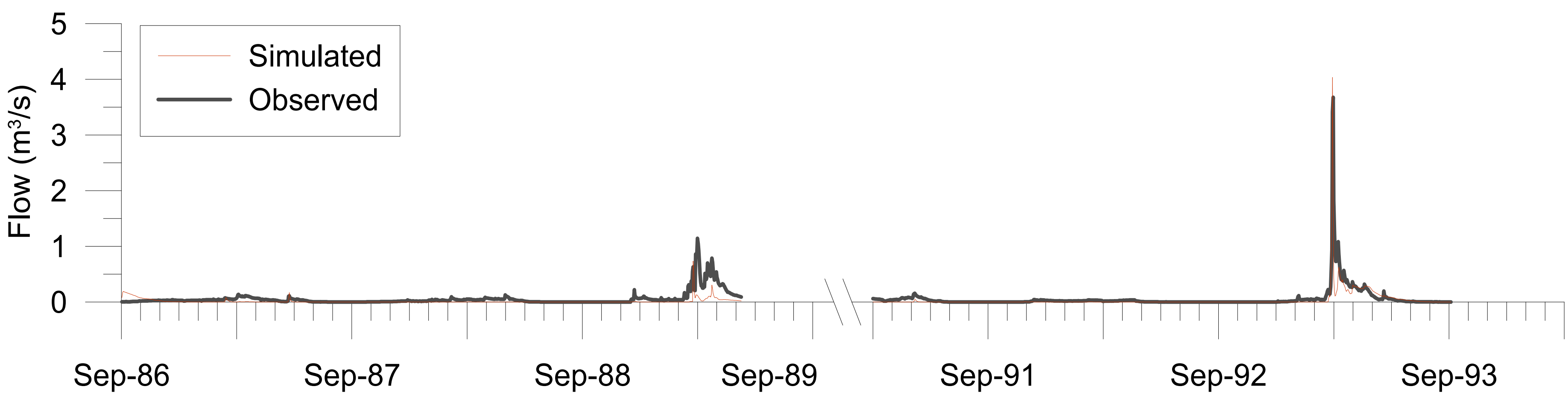
	NS	APB	R^2
1987	0.79	21%	0.90
1988	0.86	21%	0.94
1989	0.73	4%	0.92
1990	0.84	4%	0.94
1991	0.55	22%	0.84
1992	0.57	3%	0.92
1993	0.26	16%	0.86
1987-1993	0.64	4%	0.89



Model Results

Validation: Reynolds Creek at the Outlet and Salmon Creek (1 GRU)

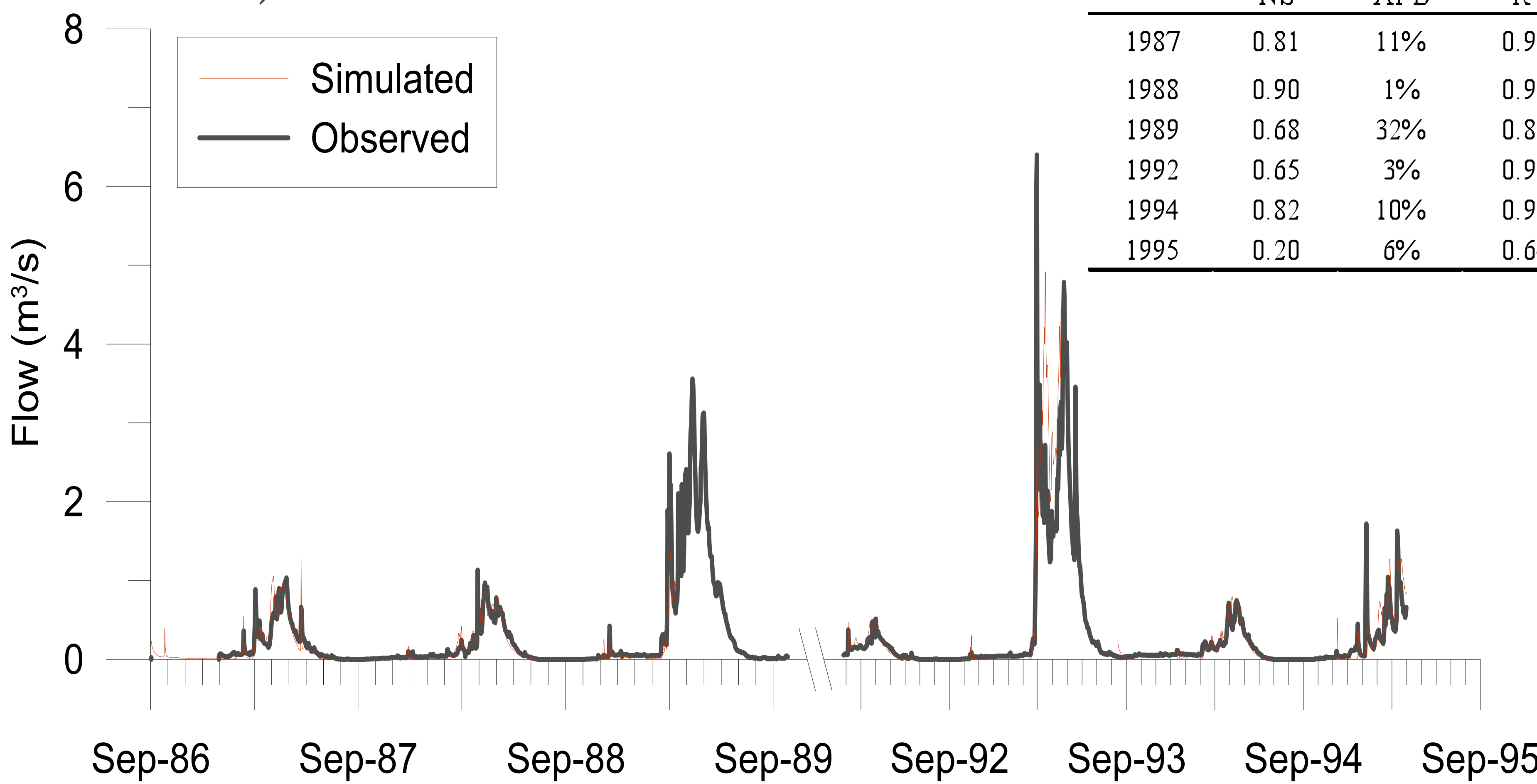




Model Results

Reynolds Creek at Tollgate sub-watershed (6 GRUs)

	NS	APB	R^2
1987	0.81	11%	0.92
1988	0.90	1%	0.95
1989	0.68	32%	0.86
1992	0.65	3%	0.92
1994	0.82	10%	0.93
1995	0.20	6%	0.64



Model Results

Reynolds Creek at Tollgate sub-watershed (6 GRU)

	NS	APB	R^2
1987	0.51	57%	0.86
1988	0.59	51%	0.88
1989	0.07	77%	0.82
1992	0.43	52%	0.73
1994	0.66	43%	0.87
1995	0.20	55%	0.63