P1.2 **DEVELOPMENT OF AN AUTOMATIC CALIBRATION SCHEME FOR MULTI-LEVEL WATERSHEDS IN THE COLORADO RIVER BASIN**

Eileen Aghnami and Terri S. Hogue
UCLA, Los Angeles, CA

1. INTRODUCTION

The National Weather Service (NWS) River Forecast Centers (RFCs) are undergoing efforts to modernize climate, weather, and hydrologic forecasts, updating models, data sources, and forecast procedures. Several of the RFCs are attempting to integrate automatic calibration schemes as tools to complement the manual calibrations commonly used. In the past, single-step, single-criterion calibration schemes were the primary automatic procedures available to hydrologists. These single-step schemes were not adequate enough to replace the use of traditional manual calibrations. In order to remedy this, researchers at the University of Arizona and now at the University of California, Los Angeles (UCLA) successfully combined the components of manual and automatic calibration techniques to produce a Multi-Step Automatic Calibration Scheme (MACS) (Hogue et al., 2000). This scheme varies from previous automatic routines in its global search algorithm and its ability to mimic NWS calibration procedures through a multi-step approach. MACS uses the OPT3 automatic optimization program within the current version of the NWS River Forecast System (NWSRFS).

MACS had been previously tested on basins in the North Central River Forecast Center (NCRFC) and South East River Forecast Center (SERFC). These "lumped systems" produced results closely resembling those of the RFC manual calibrations. The MACS procedure was then investigated for multi-tiered basins in the western United States. Initial testing revealed the need for additional work on the procedure in these regions. This study focuses on finding the best approach for use of MACS in the western U.S., using several forecast points in the San Juan River system in Colorado. Three different implementation strategies were evaluated, focusing on various methods for grouping of levels (or tiers). The study area, models, methods, and results are presented below.

2. STUDY AREA

The Colorado Basin River Forecasting Center (CBRFC) forecasting region, located in the southwestern United States, contains several major drainages. In consultation with the CBRFC, six basins in the San Juan River system located in Southwest Colorado, were chosen for this study. These six basins include three headwater basins: PSPC2 (San Juan River at Pagosa Springs), VCRC2 (Los Pinos River at Vallecito Reservoir), and PIDC2 (Piedra River at Arboles). The scope of the data and results presented here will pertain primarily to these three basins. Additionally, there are three down-stream basins: LOSC2 (Los Pinos River at La Boca), SJCC2 (San Juan River at Carracas), and NVRN5 (San Juan River at Navajo Reservoir). The six basins make up the sub-watersheds of the Upper San Juan River system, meeting and combining flow at the Navajo Reservoir. There are primarily two runoff seasons in this region: spring snowmelt and summer, convective-type storm runoff. Table 1 lists the study basins with the number of tiers or levels and the associated areas with each watershed level.

Table 1. Basin Characteristics

Basin	#Tiers	Tier	Area (km^2)	Total Area (km^2)
VCRC2	Two	Upper	295	655.0
		Lower	360	
PIDC2	Three	Upper	236	1674.1
		Mid	528	
		Lower	753	
PSPC2	Three	Upper	155	731.5
		Mid	394	
		Lower	228	
LOSC2	Three	Upper	150	862.1
		Mid	318	
		Lower	334	
SJCC2	Three	Upper	226	2204.5
		Mid	298	
		Lower	1680	
NVRN5	Two	Upper	803	1896
		Lower	1093	

3. MODELS

Two models were calibrated in this study: the Sacramento Soil Moisture Accounting Model (SAC-SMA) (Burnash, et al., 1973) and a Snow Accumulation and Ablation Model (SNOW-17) (Anderson, 1973). A total of 16 parameters for each level of the multi-tiered basins were optimized using the various MACS techniques: three were chosen from among the SNOW-17 parameters, and 13 were chosen from the SAC-SMA parameters. The SAC-SMA uses two layers to account for flow: an upper zone and a lower zone. Of the 13 parameters optimized in the SAC-SMA, seven pertain to the upper-zone, while six pertain to the lower zone. The upper-zone parameters optimized include PXADJ (precipitation adjustment factor), UZTWM (tension water maximum storage), UZFWM (free water maximum storage), UZK (free water lateral depletion rate), ADIMP (additional impervious area), ZPERC (maximum percolation rate), and REXP (exponent of the percolation equation). The lower-zone parameters include LZTWM (tension water maximum storage), LZFSM (supplementary water maximum storage), LZFPM (free water primary maximum storage), LZSK (supplementary free water depletion rate), LZPK (primary free water depletion rate), and PFREE (percolated free water storage). The SNOW-17 models the energy exchange at the snow surface, heat storage and heat deficit within the snowpack, liquid water retention and transmission through the snowpack, and heat exchange at the ground surface (Anderson, 1973). The three SNOW-17 parameters optimized include SI (mean areal water-equivalent at 100% snow cover), MFMAX (Maximum melt factor), and MFMIN (Minimum melt factor).

4. MACS METHODOLOGIES

MACS was developed to overcome single-step, single-criteria approaches, using a step-by-step process, with LOG or DRMS criteria used to emphasize different parts of the hydrograph throughout the calibration process. MACS was designed to mimic the manual calibration procedures of the NWS RFC hydrologists (Hogue et al., 2000).

> In *step one* of MACS, all of the parameters of the SAC-SMA and SNOW-17 which are selected (up to 16) are optimized using the LOG criterion. This first run places strong weighting on the low-flow portions of the hydrograph and gives good estimates of the lower zone parameters. However, by computing the criterion over the entire hydrograph and optimizing all of the parameters, this step also helps to loosely constrain the remaining (upper zone) model parameters into the region that provides coarse fitting of the peaks.
>
> The *second step* of MACS emphasizes the estimation of parameters that influence higher flow events (these typically include snow parameters). Lower zone parameters estimated in the first step are held constant, and a second optimization is run using the DRMS function using the upper zone parameters.
>
> Once parameters are obtained in step two, *step three* is run using the LOG function to fine-tune the parameters which affect the lower zone processes. Once the optimized values are obtained for the parameters (final run of step 3), the modeler may fine-tune the estimates manually using local expertise and knowledge of the system.

The current limitations on the OPT3 Program allows for calibration of up to 48 parameters at a time (this limitation is being addressed). During the initial stages of this study, however, there was a 32 parameter limit on the OPT3. As a result, only the third of the three different MACS approaches applied utilizes the simultaneous optimization of all 48 chosen parameters (16 for each level on the three-tiered basins). For all three methods, RFC values were used for those parameters not calibrated with MACS. The Shuffled Complex Evolution (SCE-UA), included within the NWSRFS, was utilized as the search algorithm within the MACS procedure. The breakdown of the MACS methodology for each of the three different approaches is briefly outlined below.

<u>MACS1: The Six Step Approach</u>

> The Six Step Approach groups the upper and middle tiers for calibration, optimizing those tiers during the first three steps. The process is then repeated, calibrating the lower tier for the final three steps. Parameters not initially optimized are set to mid-range values.

<u>MACS2: The Area Approach</u>

> The area approach runs each tier separately for calibrations during its nine step process. The tier with the largest area is calibrated in the first three steps, with the second largest being calibrated for the middle three steps. The smallest tier is optimized last, during steps seven through nine. Again, parameters not initially optimized are set to mid-range values.

<u>MACS 3: The Three-Step Approach</u>

> Due to the ability only during this final MACS approach to optimize 48 parameters at once, this final process groups all three tiers at once for optimization during its only three steps.

Every basin was calibrated for the ten year period spanning from October 1978 to September 1988. Parameters were then evaluated over the entire period of record available. Statistics were evaluated over this period, including percent bias (%Bias) and DRMS, monthly percent biases, and flow interval percent biases. Parameter ranges used as constraints in the optimization were obtained from the CBRFC.

5. RESULTS

After initial calibration of all basins, evaluation of the calibrated parameters was performed by running the models for the designated evaluation period. RFC and MACS statistics for the evaluation periods are displayed in Table 2.

In general, the three MACS procedures produce fairly similar DRMS and %Bias. For the VCRC2 basin, all three MACS procedures produce lower bias, but slightly higher DRMS, than the RFC calibration. On PIDC2 and PSPC2, statistics are fairly similar between all four procedures, with the RFC having slightly better %Bias for the PSPC2 basin.

Figures 1 through 6 also display the Monthly %Bias and the Flow Group % for each of the three basins. Each of the sub-basins shows varying success of the varying MACS procedures. In the VCRC2 basin, the MACS1 produces statistics similar to the RFC for both the monthly %Bias (Fig. 1) and flow group %Bias (Fig. 4). At the PIDC2 basin, MACS3 performs better in the fall and spring, but all three MACS procedures perform similar to the RFC for the various flow groups (Fig. 5). At PSPC2, MACS1 and MACS2 perform similarly and much better in general than MACS3 throughout the year. Flow group %Bias is similar for the three MACS at PSPC2. Interestingly, the RFC shows generally negative %Bias for most of the winter and spring, and positive biases in the fall for the three basins.

Table 2. Overall statistics for evaluation periods for the three headwater basins.

VCRC2	DRMS	%Bias
MACS 1	5.347	0.97
MACS 2	5.932	0.54
MACS 3	5.181	-0.81
RFC	-2.97	4.9
PIDC2	**DRMS**	**%Bias**
MACS 1	5.59	-2.96
MACS 2	2.06	7.284
MACS 3	5.07	3.34
RFC	5.45	1.7
PSPC2	**DRMS**	**%Bias**
MACS 1	5.01	3.94
MACS 2	6.04	-3.75
MACS 3	5.68	-2.41
RFC	5.17	-0.98

6. SUMMARY AND CONCLUSIONS

We have presented a brief overview of results for three of the headwater basins studied as part of the development of an automated calibration scheme for the complex, multi-level basins in the western U.S. Complete results for the San Juan forecast group (total of six sub-basins) are being tabulated and will be presented in detail. Based on these preliminary results, it appears that the three methods tested here perform similarly overall (%Bias and DRMS), but have slightly different performance seasonally and over the various flow levels. MACS1 (grouping 2 tiers or six-step approach) seems to perform most closely to the RFC and has lower monthly and flow group bias. In general, the MACS3 (three step approach) seems to have higher flow group and monthly %Bias than the other two methods. We hope the analysis of the remaining three basins provides further insight into these remarks. The goal of our work is to produce procedures which can provide similar, quality calibrations in a timely and efficient manner. The results presented here provide evidence that the MACS procedure, when adapted to the watershed system under study, can meet this need. With the advancement and improvement of automatic calibration techniques and the nearly exponential growth in available computing power, hydrologists can now take advantage of existing technology to aid in their calibration efforts.

Acknowledgements

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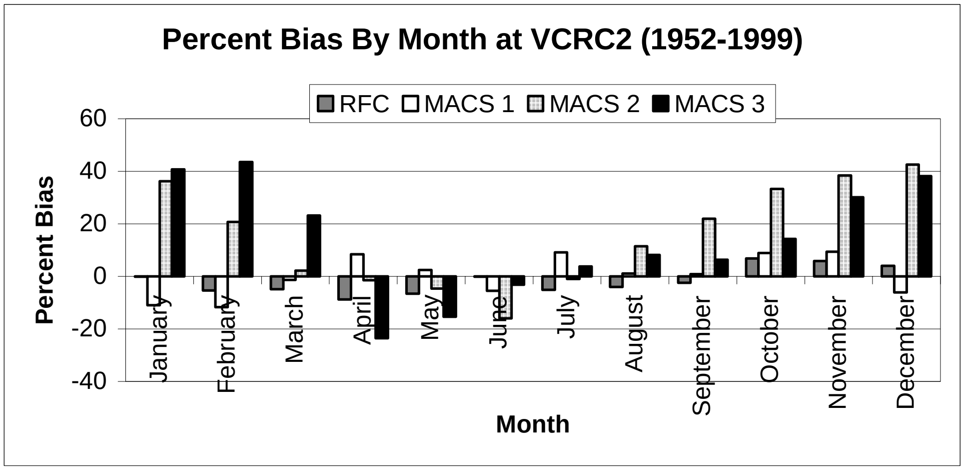

Figure 1. Monthly Percent Bias Values at VCRC2

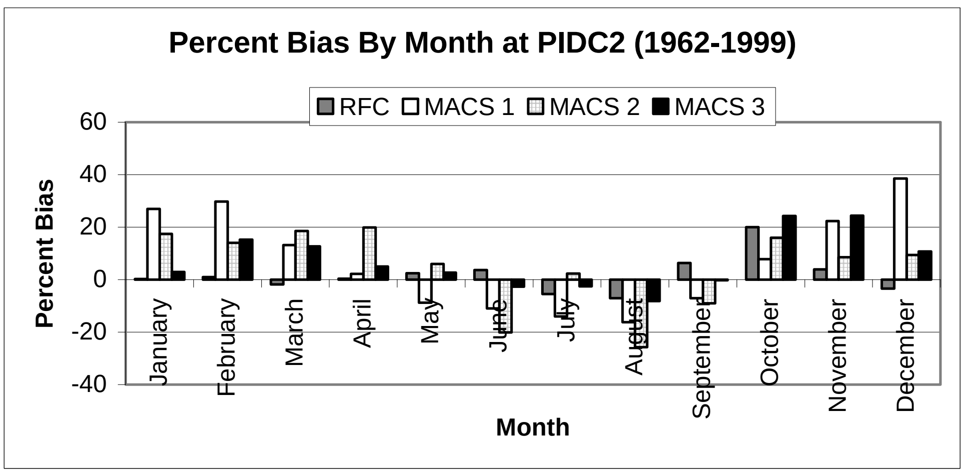

Figure 2. Monthly Percent Bias Values at PIDC2

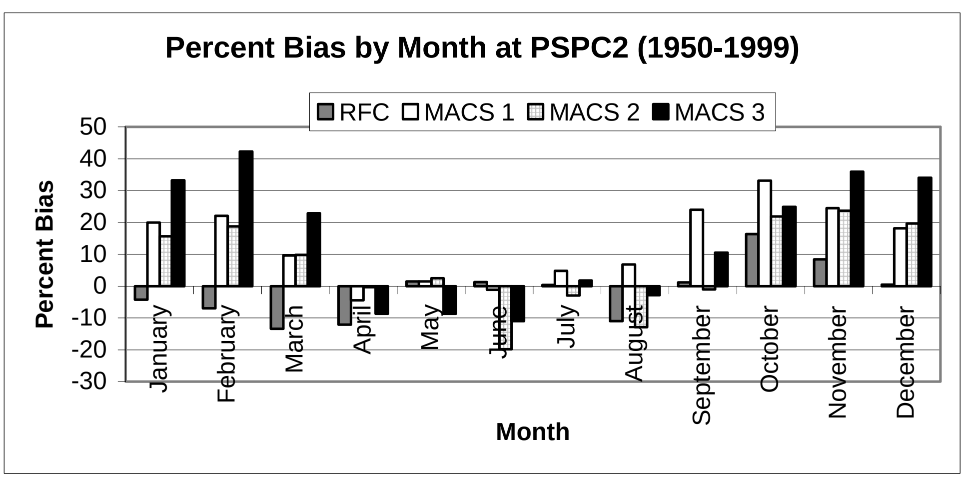

Figure 3. Monthly Percent Bias Values at PSPC2

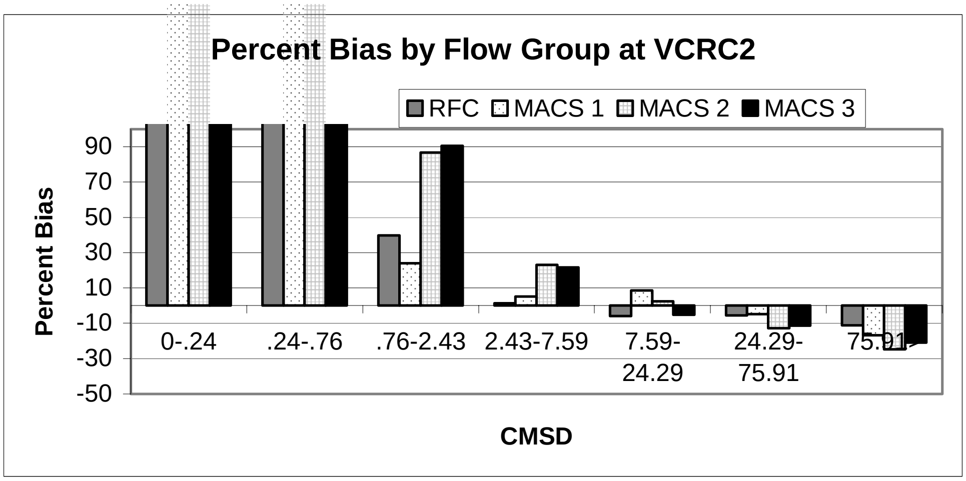

Figure 4. Percent Bias by Flow Group at VCRC2

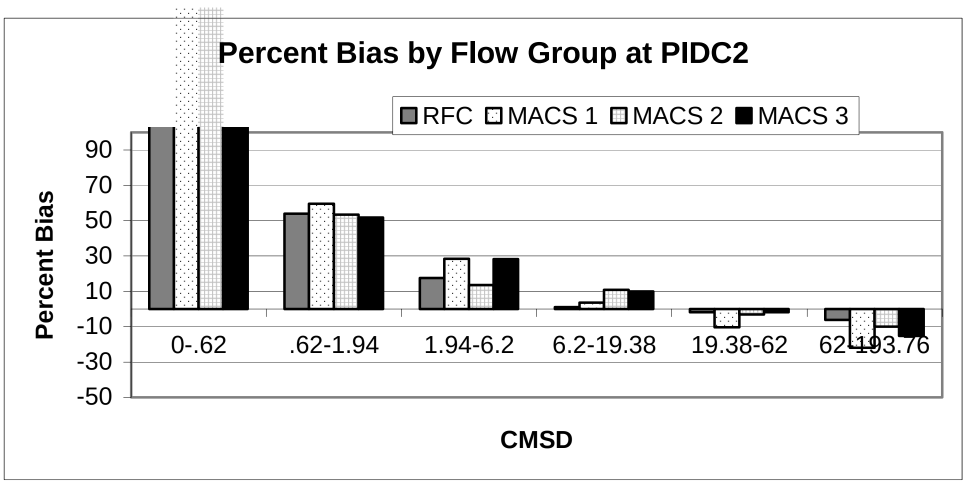

Figure 5. Percent Bias by Flow Group at PIDC2

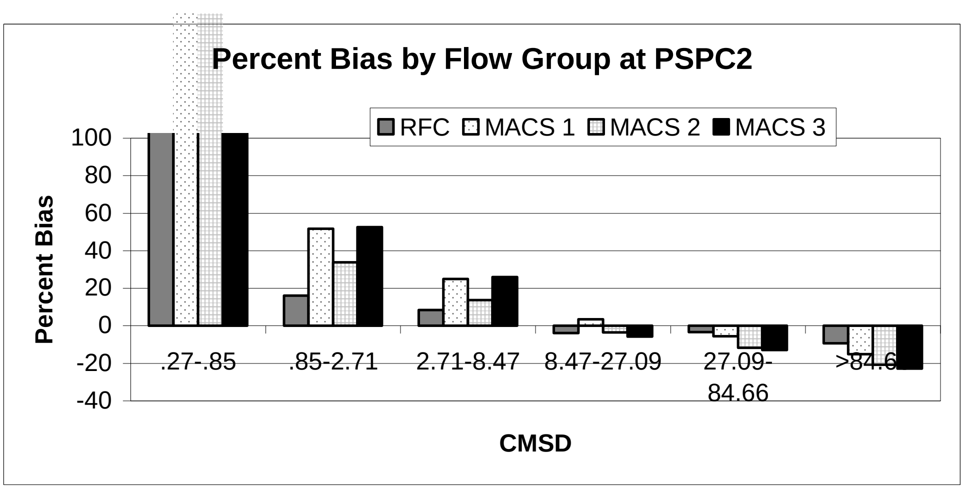

Figure 6. Percent Bias by Flow Group at PSPC2