RESULTS FROM THE SECOND INTERNATIONAL WORKSHOP ON MODEL PARAMETER ESTIMATION EXPERIMENT (MOPEX)

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Abstract

Model Parameter Estimation Experiment (MOPEX) was funded by NOAA Office of Global Programs to investigate techniques for the *a priori* parameter estimation of hydrologic models and land surface parameterization schemes used in atmospheric models. A major step is to assemble the necessary hydrometeorological data and the associated land surface characteristics data. A comprehensive database has been developed by the MOPEX project that contains historical hydrometeorological time series data and land surface characteristics data for many basins in the United States and in other countries. A number of international MOPEX workshops have been convened or planned for MOPEX. The Second International MOPEX Workshop was held in Tucson, Arizona, April 8-10, 2002. This workshop was designed to bring together interested US and international hydrologists and land surface modelers to exchange experience in developing techniques for *a priori* estimation and calibration of hydrologic model parameters. Participants of the MOPEX project were given data for 12 basins selected in the Southeastern United States and were asked to carry out a set of numerical experiments using a priori parameters as well as calibrated parameters developed for their respective hydrologic models. More than 30 scientists from 8 countries directly participated in the workshop and a few more have submitted results of their hydrologic model simulations to the workshop. The preliminary results from the workshop are summarized in this paper. Due to preliminary nature of the results, only a brief analysis was conducted to understand the differences in the results from various models. More complete results must be obtained and further analysis should be done in the future to help MOPEX participants to enhance their parameter estimation procedures. The paper will conclude with a discussion of further work and future strategy.

1. INTRODUCTION

A critical step in applying a hydrologic model to a watershed or a land surface parameterization scheme (LSPS) of an atmospheric model to a specific grid element is to estimate the coefficients or constants in the model or LSPS known as parameters. These parameters are inherent in every model. They vary spatially so they are unique to each watershed or a grid point. Some model parameters may also vary seasonally as well as spatially. How to estimate model parameters has been receiving increasing attention from the hydrology and land surface modeling community.

Presently *a priori* relationships linking model parameters and land surface characteristics such as soil and vegetation classes are available for many hydrologic models and LSPSs. But these relationships have not been fully validated through rigorous testing using retrospective hydrometeorological data and corresponding land surface characteristics data. This is partly because the necessary database needed for such testing has not been available. Moreover, there is a gap in our understanding of the links between model parameters and the land surface characteristics. Generally available information about soils (e.g., texture) and vegetation (e.g., type or vegetation index) only indirectly relates to model parameters such as hydraulic properties of soils and rooting depths of vegetation. Also it is not clear how heterogeneity associated with spatial land surface characteristics data affects those characteristics at the scale of a basin or a grid cell. Consequently, there is a considerable degree of uncertainty associated with the parameters given by existing *a priori* procedures.

Recent studies have illustrated clearly that existing *a priori* parameter estimation procedures do not produce proper parameter values and that improper model parameters result in poor model performance (see Liston et al, 1994; Duan et al., 1995). Figure 1 shows modeled partition of annual runoff and evapotranspiration for many different land surface models (LSMs) participated in the Project for Intercomparison of Land-surface Parameterization Schemes Phase 2c (PILPS-2c) (Wood et al., 1998). These LSMs were driven by the same meteorological forcing data. More interestingly, they were required to prescribe the same values for commonly named parameters such as soil hydraulic properties and vegetation phenology parameters. The large scattering of model performance can be partly be explained by the uncertainty in the values of the best parameters to use in each model. Liston et al. (1994) conducted a study of runoff produced by the VIC LSM in the Mississippi River basin. They compared runoff simulation using default (*a priori*) parameters as prescribed by VIC and using parameters that were partially tuned. Their conclusion is that partially tuned parameters produced much more realistic runoff simulation when compared to observed runoff (see Figure 2).

Clearly there is a need to improve the existing a priori parameter estimation procedure. A project known as Model Parameter Estimation Experiment (MOPEX) has been funded by NOAA Office of Global Programs to investigate techniques for the *a*

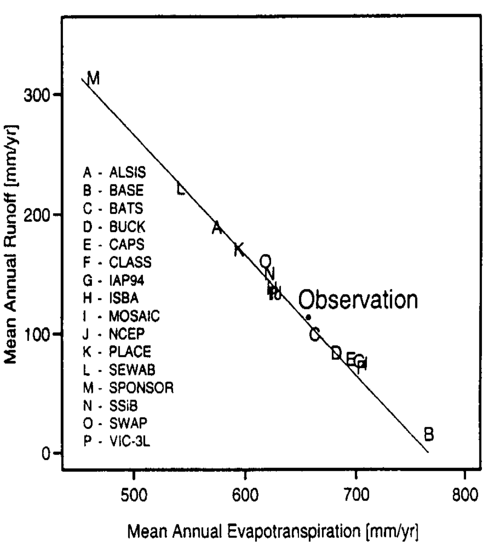

Figure 1Summary of PILPS-2c Results: Mean Annual Runoff/Evapotranspiration Partition

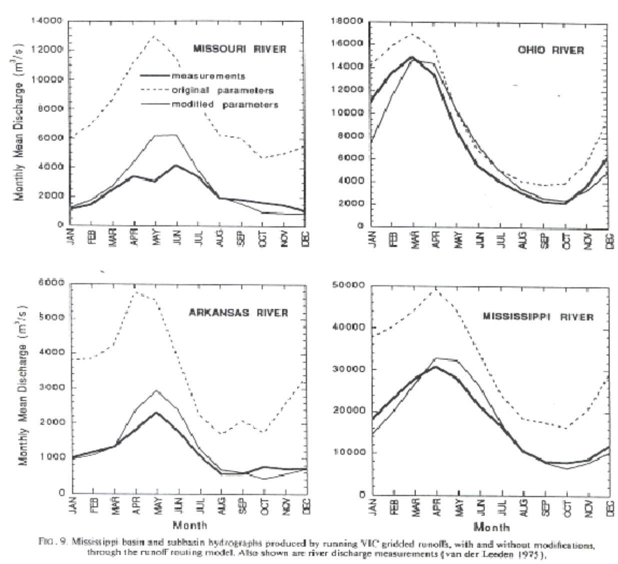

Figure 2Comparison of streamflow simulation using a priori and tuned parameters

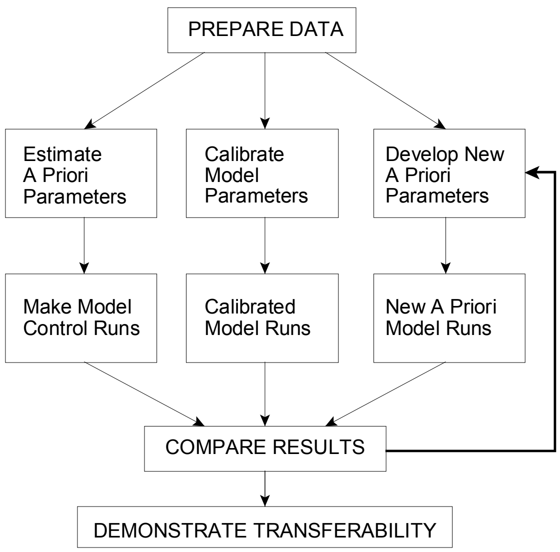

Figure 3 MOPEX Implementation Strategy

priori estimation of the parameters used in land surface parameterization schemes of atmospheric models and in hydrological models. A first major step by MOPEX project is the development of a comprehensive database that contains many years of historical hydrometeorological time series and land surface characteristics data for many basins in the United States and from other countries. MOPEX project has been truly an international collaborative effort with involvement of international scientists and data assembled from different countries. Two international workshops on MOPEX have been convened to date. First one was held in July 1999, as a part of International Union of Geodesy and Geophysics (IUGG) 21st General Assembly in Birmingham, England. The second workshop, co-sponsored by National Weather Service Hydrology Laboratory and by National Science Foundation Center for Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) at the University of Arizona, was held in Tucson, Arizona, in April 2002. A third MOPEX workshop is scheduled for July 2003, in Sapporo, Japan, as a part of the 22nd IUGG General Assembly.

The Tucson Workshop was designed to bring together interested US and international hydrologists and land surface modellers to share experience in estimation of hydrologic model parameters. A set of numerical experiments was constructed. The MOPEX participants were given data for 12 basins selected in the Southeastern quadrant of the United States. Numerical test results from different modeling groups were assembled prior to the workshop. This paper summarizes the preliminary results from the workshop. The paper is organized as follows. First the MOPEX implementation strategy is presented. Then a discussion is given to the Tucson MOPEX workshop objectives and numerical experiment design. The data sets assembled for the workshop are described afterwards. Due to the preliminary nature of the results, only a brief analysis of the results is conducted to understand the differences in the results from different models. Finally, further work and future strategy are discussed.

2. MODEL PARAMETER ESTIMATION EXPERIMENT STRATEGY

The first step of the MOPEX strategy is to develop the necessary data sets. The strategy is then to use these data to study individual models using three parallel paths illustrated in Figure 3. The first path is to make control runs with model parameters estimated using existing *a priori* parameter estimation procedures. The second path is to make model runs using calibrated or tuned values of selected model parameters. Then, relationships are developed between the calibrated parameters and basin climate, soils, vegetation and topographic characteristics. These relationships are used to define the new *a priori* parameters. The third path is to make new model runs using the new *a priori* parameter estimates. Achievement of the parameter estimation goal is then established in two steps. The first is to measure how much of the potential improvement in model performance when operated in calibration path is obtained when the model is operated using new *a priori* parameters. This step uses the same data sets as were used to develop the new *a priori* parameter estimates. The second step is to demonstrate that new *a priori* techniques produce better model results than existing *a priori* techniques for basins not used to develop the new *a priori* techniques. The outcome of this step has very strong implications for the Predictions for Ungaged Basins (PUBs), a major initiative undertaken in the International Association of Hydrological Sciences (IAHS).

The MOPEX Project has assembled hydrometeorological data as well as land surface characteristics data that are needed to implement its parameter estimation strategy. Data from many basins in the United States and other parts of the world are being assembled. These basins cover a wide variety of climates. They are selected such that rain-gauge density of the basins must be above the minimum established by an empirical equation (Schaake et al., 2000). Also a minimum of 10 years of data is required for all basins. A later section describes the data set used for the Tucson workshop.

A major effort in implementing the MOPEX strategy is to develop a systematic procedure for automatic calibration of selected model parameters and to apply this procedure to a large number of basins in different climatological and hydrologic settings. Then, empirical relationships will be sought between the parameters and various characteristics of soils, vegetation and climate. Much progress has been made in the area of model calibration. Duan et al. (1994) developed a robust method for optimum estimation of model parameters. Yapo et al. (1997) and Gupta et al. (1999) have extended Duan's approach in the context of multi-objective theory. For more on the state-of-the-art on model calibration, readers are referred to Duan et al. (2002).

Numerous studies have been directed at developing improved *a priori* parameter estimation procedures for selected hydrologic models and LSPSs (Abdulla et al, 1996; Koren et al., 2000; Duan et al., 2001). Abdulla et al. (1996) developed regional equations for the parameters of the VIC-2L LSM for the Arkansas-Red River Basins. This was done by calibrating the VIC model to historical hydrometeorological data. The calibrated parameters were then correlated to land surface characteristics data such as soil attributes, climatological and topographic characteristics. Duan et al. (1996) used a similar procedure to regionalize the five parameters of the monthly Simple Water Balance (SWB) Model by correlating calibrated model parameters at 50 catchments in the southeast quadrant of the United States to local land surface characteristics. More recently Koren et al. (2000) developed an *a priori* parameter estimation procedure for the Sacramento Soil Moisture Accounting model (SAC-SMA) by relating the SAC model parameters to the 1 km resolution State Soil Geographic Database (STATSGO) and the Soil Conservation Service Curve Numbers. This procedure has shown to be reasonably successful based on studies on a few selected basins (Duan et al., 2001). Koren et al. (2002) have also demonstrated that the *a priori* parameters can be used to constrain automatic calibration to ensure that calibrated parameters are physically realistic and the calibration results are satisfactory.

3. THE TUCSON MOPEX WORKSHOP

3.1 Workshop Objectives:

Many research groups have more or less followed the strategy depicted in Figure 3. The Tucson workshop focused on the first and second steps of the strategy: data preparation and development of parameter estimation procedure. For the later step, the emphasis was on validation of existing a priori procedure and on model calibration. Because all hydrologic models are formulated differently, parameter estimation procedures tend to be model-specific. A challenge facing hydrologic models is how the knowledge gained from one model can be transferred to another model. This is also the principal reason to convene the Tucson MOPEX workshop. The specific objectives of the Tucson workshop were to seek answers the following questions:

(1) How do we define the relationships between model parameters and basin characteristics?

(2) How can model calibration be used to refine the *a priori* parameters?

(3) How do we evaluate the uncertainty due to model structure, calibration data and model parameters?

3.2 Design of MOPEX Numerical Experiment:

To answer these questions, a set of numerical experiments were set up. Data for 12 basins located in the Southeastern Quadrant of the United States were prepared. The data sets include hydrometeorological data as well as basin land surface characteristics data. More discussion on these data sets is given in the next section. The data were distributed to MOPEX participants via ftp and CD-ROMs. The MOPEX participants were asked to run two sets of runs. The first set of runs are to run their respective models on all 12 basins using existing *a priori* parameters developed for their models. The second set of runs involves model calibration for pre-selected common data periods. After model calibration, the participants are asked to run their models using calibrated parameters for the calibration and verification data periods. All results were collected by the MOPEX project for analysis.

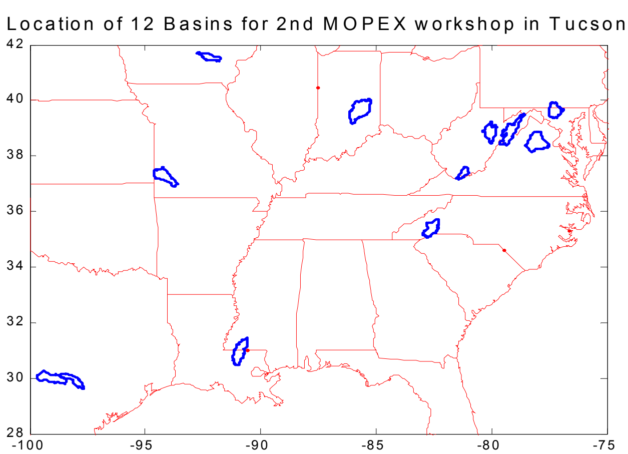

Figure 4. Location of MOPEX Test Basins

3.3 Description of the Data Set for Tucson Workshop:

As stated previously, the first step in MOPEX strategy is to assemble a large number of high quality historical hydrometeorological and river basin characteristics data sets for a wide range of Intermediate Scale Area (ISA) river basins (500 - 10 000 km^2) throughout the world. For the second international MOPEX

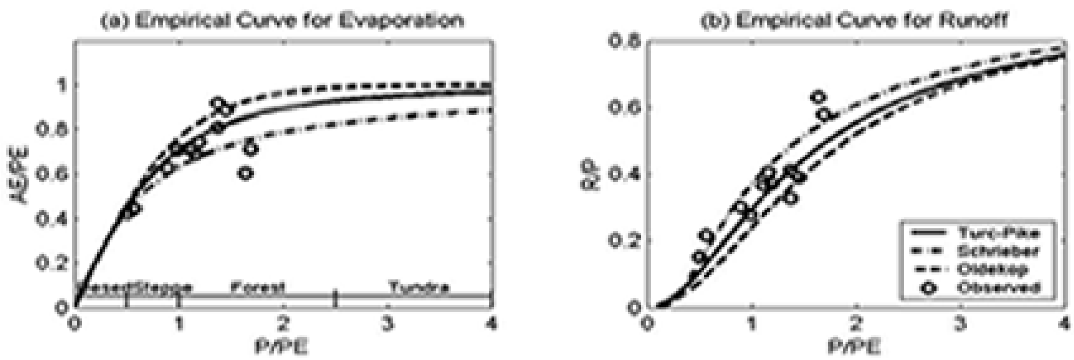

Figure 5 Ratios of annual hydrologic statistics

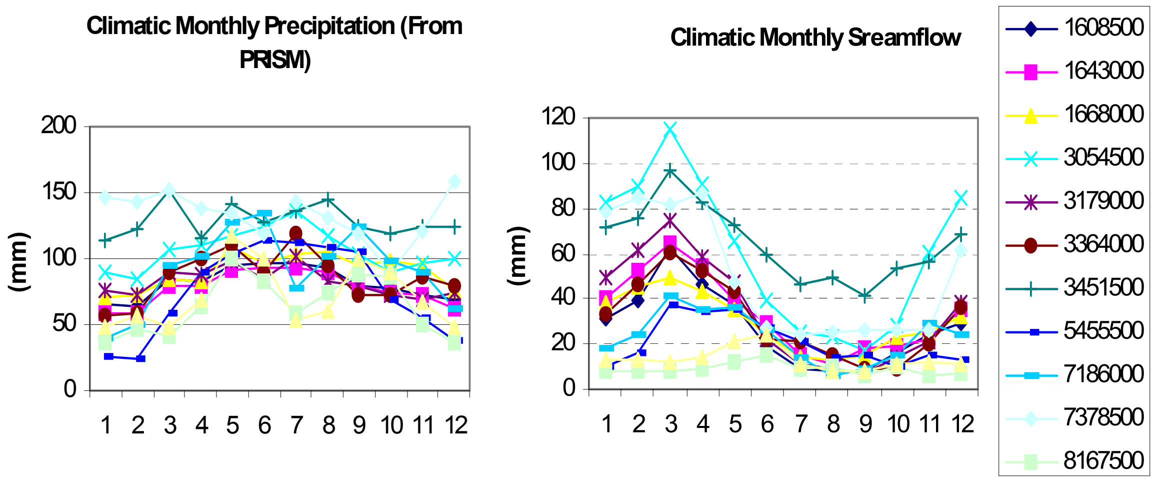

Figure 6 Climatic monthly precipitation and streamflow

workshop held in Tucson, Arizona, hydrometeorological data as well as basin land surface characteristics data for 12 basins in the Southeastern quadrant of the United States were assembled.

Figure 4 shows the location of the 12 basins. These basins represent a wide range of different climate, as indicated by the ratios of annual precipitation (P) and potential evapotranspiration (PE) in Figure 5. A high value for P/PE indicates wet climate and a low value dry climate. The climatic seasonal precipitation and streamflow distributions are shown in Figure 6. The hydrometeorological data sets prepared for the workshop included hourly mean areal precipitation, daily streamflow, climatic daily potential evapotranspiration. Also included are hourly meteorolological forcing developed by the University of Washington (Maurer et al., 2001). The historical data periods cover from 1960 to 1998.

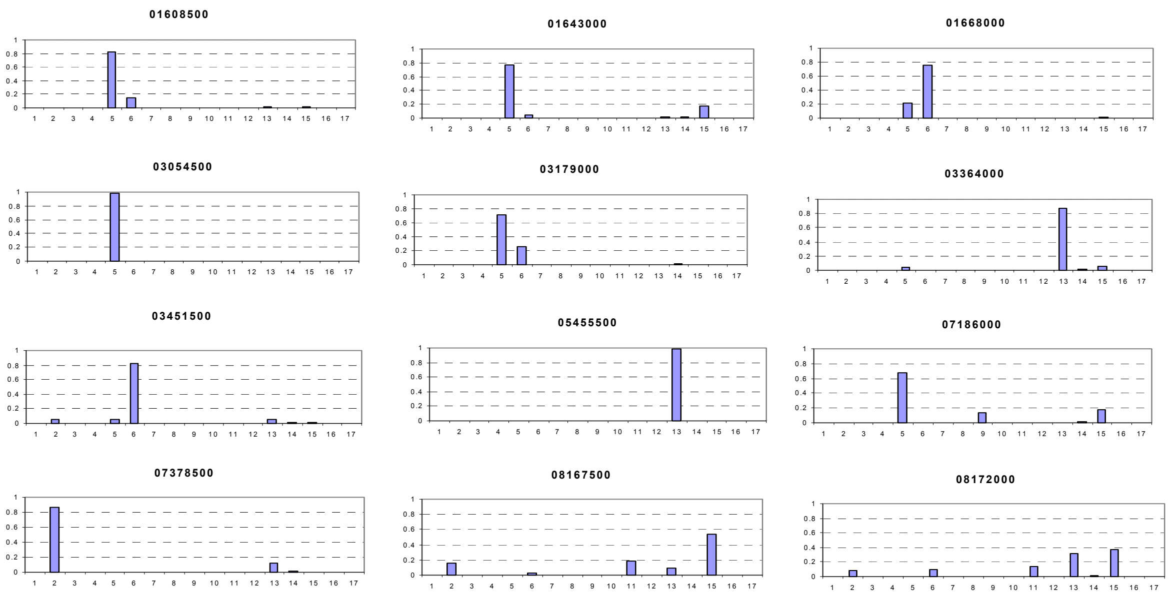

Figure 7 Distribution of vegetation type

The land surface characteristics data sets include 1 km soil type data from the STATSGO data set (Miller and White, 1999), the 1 km vegetation type, 5-min greenness fraction data and others. Figures 7 and 8 show the vegetation type and soil type distributions of the 12 basins. A number of different vegetation and soil type are represented. For more information about the data included for MOPEX, refer to Duan et al. (2001).

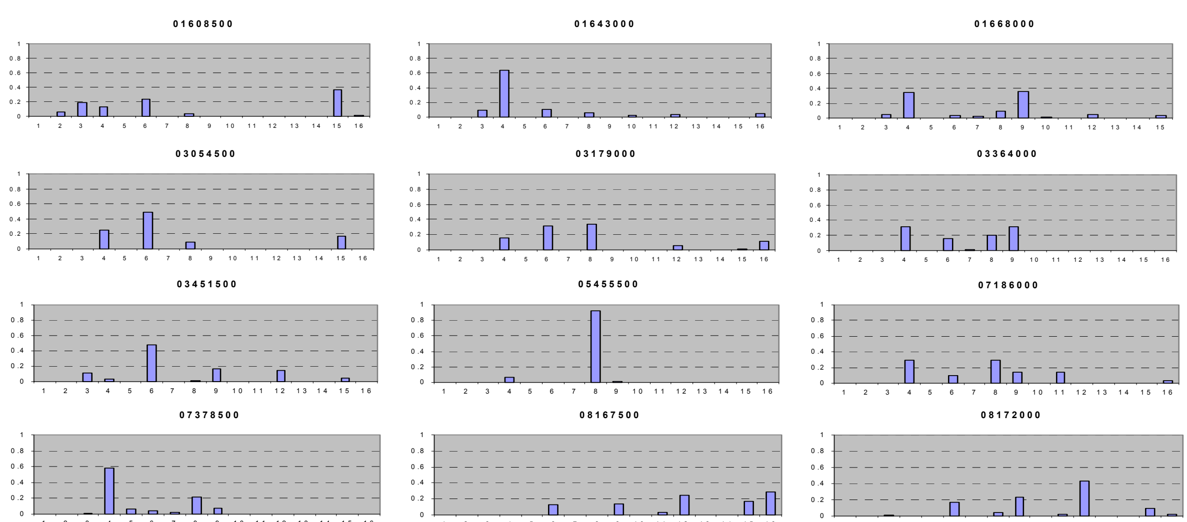

Figure 8 Distribution of soil type

4. PRELIMINARY RESULTS FROM MOPEX NUMERICAL EXPERIMENTS

More than 30 scientists from 8 countries participated in the Tucson workshop. A few additional groups submitted MOPEX numerical experiment results to MOPEX project prior to the workshop. Table 1 lists the participating models.

Table 1. Participating models and modeling agencies

Model Names	Model Agencies
Simple Water Balance (SWB)	NWS
Sacramento (SAC)	NWS, U. of Alberta
ISBA	Meteor-France
SWAP	Russian
VIC	Princeton U.
PRMS	USGS
NOAH	NWS HL/NCEP
BTOPMC	Japan
HBV	The Netherlands

This paper gives only a preliminary analysis of the results. This is because the submitted results are not complete at this point. For this reason the results presented below do not list the models explicitly. A more complete analysis will be done in the future when more complete results are collected.

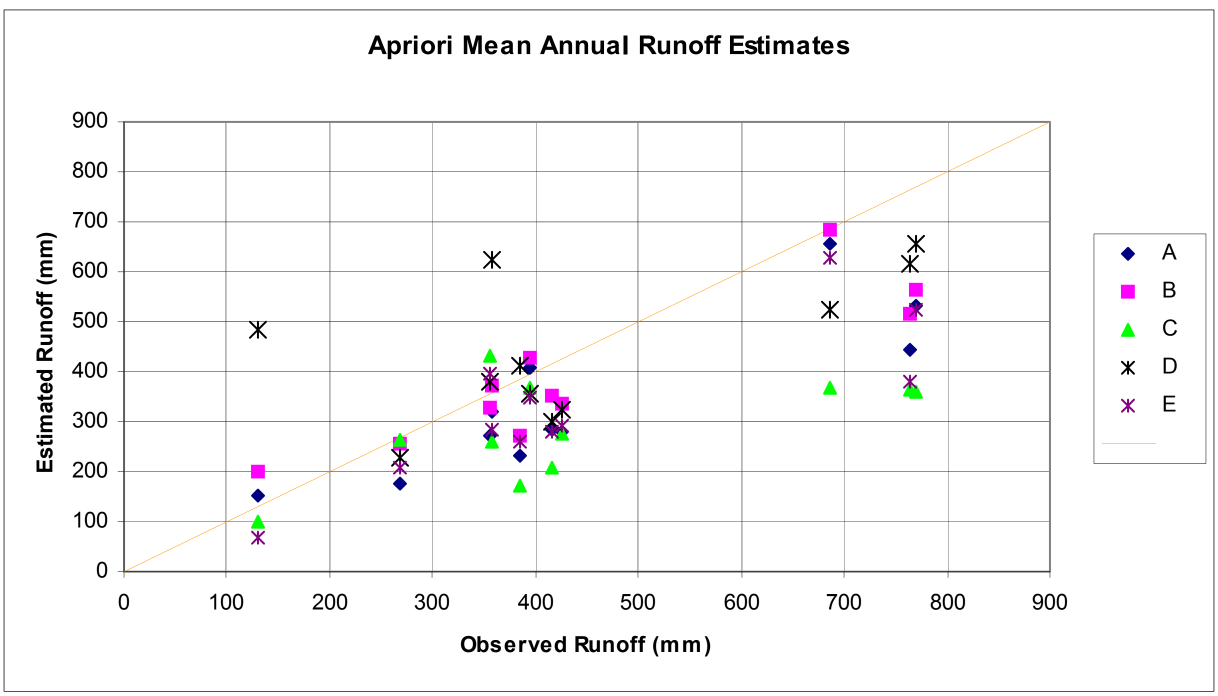

Figure 9 Comparison of simulated and observed streamflow when a priori parameters are used.

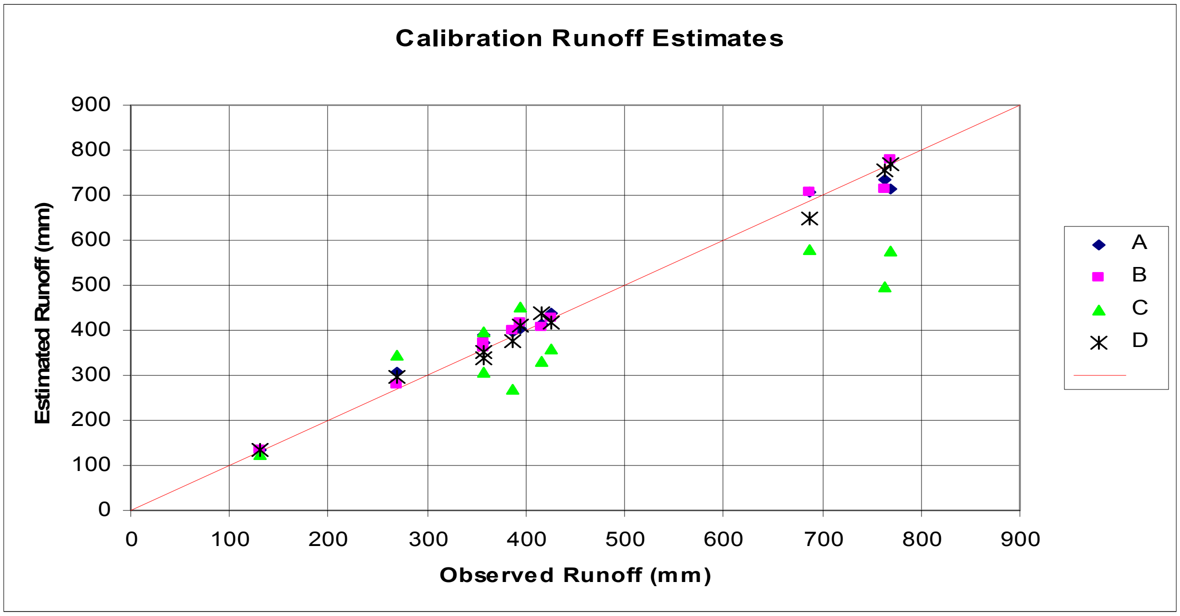

Figure 10. Comparison of simulated and observed streamflow when calibrated parameters are used.

Figures 9-11 compare the simulated annual streamflow totals to observed annual streamflow totals. Figure 9 summarize the results for the numerical experiments where *a priori* parameters are used. Figure 10 shows the results for calibrated parameters for the calibration period only, while Figure 11 shows the results for calibrated parameters for the verification period. These results indicate that different hydrologic models generate different results. For all models, *a priori* parameters cannot provide consistently good

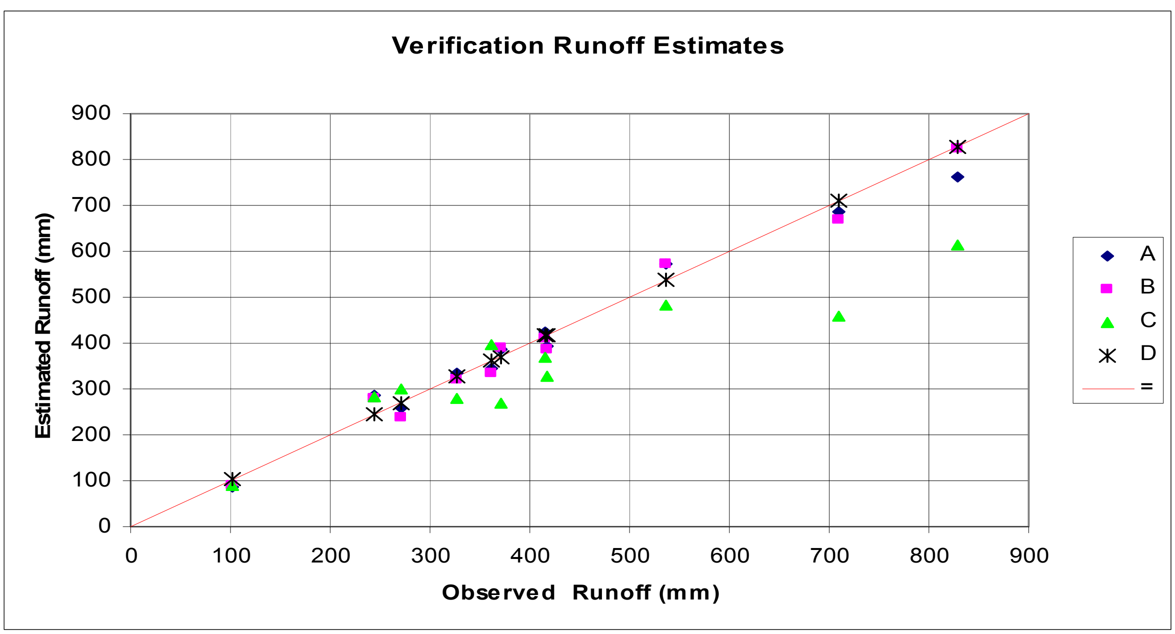

Figure 11 Comparison of simulate and observed annual streamflow for verification period.

simulation of annual streamflow totals for all basins. On the other hand, calibration can drastically improve the *a priori* results. With the calibrated parameters, verification results are also very good in capturing annual streamflow totals.

5. FURTHER RESEARCH AND FUTURE DIRECTIONS

We have presented a brief analysis of the preliminary results from different modeling groups. It is worthy to point that, due to the preliminary nature of these results, more complete results must be obtained and further analysis must be carried out for us to understand the differences in model performance. Still, these results confirm our earlier statements that the existing *a priori* parameter estimation procedures are problematic and must be improved. Calibration can help to achieve this objective. Much research needs to be done to understand how model parameters are related to basin land surface characteristics. Further, how to use the calibrated results for improve *a priori* parameters is still not clear and this issue needs to be looked at. Different modeling groups can learn from each other because many model parameters have similar physical interpretations and should have similarity in space-time patterns.

One issue that has not been examined in the workshop is the parameter transferability issue. This issue is very important for Predictions for Ungaged Basins (PUBs) and for application in land surface parameterization schemes. To study transferability issue, data from a wide range of climatic conditions should be used. The MOPEX project has assembled data from many different countries. These data should be used to test enhanced *a priori* parameters.

One of the driving forces behind the progress in parameter estimation research is the increasing array of data sources, including satellite and other advanced observational technologies. With the new sources of data, it is important to investigate the ways to maximize the use of high resolution spatio-temperal information. Meanwhile the issue of uncertainty attributed to data errors should be addressed.

Any improvement in parameter estimation procedures must be tied to how we represent the physical processes. As our knowledge of the physical processes advance, more complicated distributed hydrologic models emerge. This will bring more challenge to us in terms of parameter estimation and model calibration.

The third international workshop on MOPEX has been scheduled for July 2003, in Sapporo, Japan, as a part of the 22nd General Assembly of IUGG. Much of the work cited above will be already carried out and reported by MOPEX project participants. With a true collaborative spirit by international scientists, enhanced *a priori* parameter estimation should be available to us. This in turn should result in improved skills in hydrologic predictions.

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