Texas A & M University and U.S. Bureau of Reclamation

Hydrologic Modeling Inventory
Model description Form

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Name of Model: National Weather Service River Forecast System (NWSRFS)

Model Type: NWSRFS is not a single model but rather a comprehensive, end-to-end framework containing hydrologic/hydraulic algorithms to model a basin for river, flash flood, and water resources forecasting. It includes everything from data ingest procedures to the generation of river stage forecasts in deterministic and ensemble modes. The primary snow accumulation and melt model in NWSRFS is Snow-17, while the main precipitation/runoff model is the Sacramento Soil Moisture Accounting (SAC-SMA) model. These two models will be highlighted in this inventory while describing the major capabilities of NWSRFS.

The SAC-SMA model has been modified to generate physically-based soil moisture and soil temperature estimates for computing the effects of frozen ground. This modified model is called the SAC Heat Transfer or SAC-HT model. Techniques for assimilating streamflow data into the SAC-SMA model and snow water equivalent data into the Snow-17 model are available. Channel routing models in NWSRFS include hydrologic methods such as Lag/K, Muskingum, and the Layered Coefficient method. Hydraulic channel routing algorithms include a one-dimensional solution to the full St. Venant equations for unsteady flow. Various utility and display functions are also available in NWSRFS.

Model Objective: forecast flows, stages, and other variables such as soil moisture for river, flash flood, and water resources forecasting.

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Model Structure and Mathematical Basis: Models in NWSRFS can be linked in any order to describe the processes with a basin or group of basins. Data is transmitted from one model to another in the form of time series. These time series can contain point, spatially averaged, or gridded data. The SAC-SMA is a continuous model, computing internal state variables and runoff components in the wetting and drying cycles of the soil column. It is a conceptual representation of the active soil layer, using tension and free water storage zones to model the hydrologic response of a watershed, including low and high flows. The SAC-HT solves the physics/thermodynamic equations of heat transfer and moisture phase changes, and borrows its approach from the frozen ground algorithms developed for land surface models (Koren et al., 1999a). Snow-17 uses a temperature index method to compute melt in most cases. During rain-on-snow events, Snow-17 computes melt using an energy budget approach and assumptions about several of the meteorologic conditions.

Model Parameters: All the models and utilities in NWSRFS have parameters for which values must be specified.

Spatial Scale: The NWSRFS was designed as a lumped modeling system, with the capability to include elevation zones or sub-basins. Recently, distributed versions of the SAC-SMA and Snow-17 have been developed and show promise for capturing the spatial variability of forcings and basin characteristics (Reed et al., 2004). Koren et al. (2004) and Reed et al. (2007) cover gridded applications of the SAC-SMA for river and flash flood modeling, respectively. The SAC-SMA and Snow-17 models have been successfully applied at the 4km grid scale over CONUS and at the 2km grid scale for flash flood applications, the latter based on a threshold-frequency approach (Reed et al., 2007).

Temporal Scale: The models within NWSRFS can be run at 1, 2, 3, 6, 8, 12, 24 hour intervals

Input Data Requirements: NWSRFS requires mean areal precipitation, temperature, and evaporation; point flow, stage, snow, reservoir levels, freezing levels, gridded multisensor (gage, radar, satellite) estimates of precipitation; historical, real time, and forecast values for all forcings are needed.

Computer Requirements: Currently, Linux PCs are the official platforms for NWSRFS, although Windows versions are available.

Model Output: river stage and flow, rainfall excess, reservoir heights, reservoir outflows, water surface profiles, forecast uncertainty estimates, gridded soil moisture versus depth, gridded soil temperature versus depth, snow covered area, snow water equivalent.

Parameter Estimation/Model Calibration: Hydrograph analysis can be used to derive reasonable initial values of SAC-SMA parameters. CONUS-wide *a priori* estimates of 11 SAC-SMA parameters have been derived at the 1km grid scale over CONUS (Koren et al., 2003). These were developed from coarse scale State Soil Geographic Data (STATSGO) from the NRCS. Recently, the county-level high resolution soil survey data sets (SSURGO) have been used to derive *a priori* SAC-SMA parameters (Anderson et al., 2006).

Guidelines are available for deriving initial values of the Snow-17 parameters. *A priori* estimates of the max and min melt factors in Snow-17 have been developed at the 4km grid over CONUS using regression techniques. Updated versions of these parameters are being generated based on energy budget analyses. Initial evaluation of these updated parameters has shown promise. Estimates of the parameter for wind speed during rain-on-snow events (UADJ) and the snow correction factor (SCF) are also being developed at this time.

The NWSRFS contains an integral calibration system and procedures to minimize biases between the forecast and calibration systems (Smith et al., 2003). Extensive capabilities are available for expert/manual and automatic calibration of the NWSRFS models.

Model Testing and Verification: Models within NWSRFS have undergone nearly 30 years of development, testing, operational use, and verification inside and outside the NWS. For example, extensive external verification of the SAC-SMA in both lumped and distributed applications has occurred via major national and international projects such as the WMO series of experiments (WMO, 1975, 1992; Georgakakos and Smith, 1990), the Model Parameter Estimation Experiment (MOPEX; Duan et al., 2006), the North American Land Data Assimilation System (NLDAS, Mitchell et al., 2004), as well as phases 1 and 2 of the ongoing NWS-led Distributed Model Intercomparison Project (DMIP; Reed et al., 2004). External verification of the Snow-17 model in lumped and distributed applications has occurred in the WMO (WMO, 1986), phases 1 and 2 of the recent Snow Model Intercomparison Project (SnowMIP; Etchevers et al., 2004; Rutter et al., 2008), DMIP 2, and NLDAS.

Model Sensitivity: Like other conceptual models, the SAC-SMA can be sensitive to the space-time scale of the precipitation forcing (Finnerty et al., 1997; Koren et al., 1999b). Parameters calibrated at one space-time scale may not be appropriate for other space-time scales. The Snow-17 model has proven to be less sensitive to data errors than energy budget models (Franz et al., 2008; Lei et al., 2007; Sheffield et al., 2003; Pan et al., 2003).

Model Reliability: The NWSRFS and the component models have been used in their present architectural form for nearly 20 years with generally good results. NWSRFS performance increases with better estimates of the input data forcings, both observed and forecast.

Model Application: Currently operational at 13 NWS River Forecast Centers covering the entire US (McEnery et al., 2005; Stallings Wenzel., 1995; Larson et al., 1995) and numerous applications worldwide.

Case Studies: Numerous case studies and model intercomparisons have been published. A few of the major publications are listed below:

NWSRFS

Day, G. N, 1985. Extended streamflow forecasting using NWSRFS. ASCE Journal of Water Resources Planning and Management, 111(2), 157–170.

Fread, D.L. et al., 1995. Modernization in the National Weather Service River and Flood Program. Weather and Forecasting, Vol. 10, No. 3, 478-484.

Hudlow, M.D., 1988. Technological developments in real-time operationl hydrologic forecasting in the United States. Journal of Hydrology, Vol. 102, 69-92.

Larson, L.W., and co-authors, 1995. Operational Responsibilities of the National Weather Service River and Flood Program. Weather and Forecasting, Vol. 10, No. 3, 465-476.

McEnery, J. Ingram, Q. Duan, T. Adams and L. Anderson, 2005. NOAA's advanced hydrologic prediction service: building pathways for better science in water forecasting, Bull. Am. Meteor. Soc. 86 (3) (2005), 375–385.

Monroe, J.C., and Smith, G.F., 1974. National Weather Service River Forecasting System. ASCE Journal of the Hydraulics Division, Vol. HY5, 621-630.

Reed, S., and co-authors, 2007. A distributed hydrologic model and threshold frequency-based method for flash flood forecasting at ungauged locations. Journal of Hydrology, Volume 337, Issues 3-4, 30, 402-420

Shamir, E., Carpenter, T.M., Fickenscher, P., Georgakakos, K.P., 2006. Evaluation of the National Weather Service Operational Hydrologic Model and Forecasts for the American River Basin. J. Hydrologic Engineering, Vol. 11, Issue 5, pp. 392-407.

Smith, M.B., Laurine, D.P., Koren, V.I., Reed, S. M., and Zhang, Z., 2003. Hydrologic Model Calibration in the National Weather Service. In book: Calibration of watershed models. Water Science and Application 6, Duan et al., Editors, AGU Press, 133-152.

Stallings, E.A., and Wenzel, L.A., 1995. Organization of the River and Flood Program in the National Weather Service. Weather and Forecasting, Vol. 10, No. 3, 457-464.

SAC-SMA

Anderson, R.M., Koren, V.I., and Reed, S.M., 2006. Using SSURGO data to improve Sacramento Model *a priori* parameter estimates. Journal of Hydrology, Volume 320, Issues 1-2, 30, 103-116

Boyle, D.P, and co-authors, 2001. Toward improved streamflow forecasts: value of semi-distributed modeling. Water Resources Research, 37 (11), 2749-2759.

Burnash, R.J.C., 1995. The NWS river forecast system – catchment modeling. In: Singh, V.P., (Ed.) Computer Models of Watershed Hydrology. Water Resources Publications, Littleton, CO, 311-366.

Duan , Q., and co-authors, 2006. Model Parameter Estimation Experiment (MOPEX): An overview of science strategy and major results from the second and third workshops. Journal of Hydrology, Vol. 320, 3-27.

Finnerty, B.D., Smith, M.B., and co-authors, 1997. Sensitivity of the Sacramento soil moisture accounting model to space-time scale precipitation inputs from NEXRAD. Journal of Hydrology, 203, 21-38.

Georgakakos, K.P, and Smith, G.F., 1990. On improved hydrologic forecasting – Results from a WMO real-time forecasting experiment. Journal of Hydrology, Vol. 114, 17-45.

Koren, V., and co-authors, 1999a. A parameterization of snowpack and frozen ground intended for NCEP weather and climate models. Journal of Geophysical Research, Vol 104, No. D16, 19569-19585.

Koren, V., and co-authors, 1999b. Scale dependencies of hydrologic models to spatial variability of precipitation. Journal of hydrology, 217, 285-302.

Koren, V., and co-authors, 2003. Use of *a priori* parameter estimates in the derivation of spatially consistent parameter sets of rainfall-runoff models. In book: Calibration of watershed models. Water Science and Application 6, Duan et al., Editors, AGU Press, 239-254.

Koren, V., and co-authors, 2004. Hydrology laboratory research modeling system (HL-RMS) of the US National Weather Service. Journal of Hydrology, 291, 297-318.

Mitchell, K., and co-authors, 2004. The multi-institution North American Land Data Assimilation System (NLDAS): Utilizing multiple GCIP products and partners in a continental distributed hydrological modeling system. Journal of Geophysical Research, Vol. 109, D07S90, doi:10.1029/203JD003823.

Reed, S. and co-authors, 2004. Overall distributed model intercomparison project results. Journal of Hydrology, 298, 27-60.

Seo, D.J., Koren,V., and Cajina, N., 2003. Real-time variational assimilation of hydrologic and hydrometeorological data into operational hydrologic forecasting. Journal of Hydrometeorology, Vol. 4, No. 3, 627-641.

World Meteorological Organization (WMO), 1975. Intercomparison of conceptual models used in operational hydrological forecasting. Operational Hydrology Report No. 7. Geneva, Switzerland, 172 pp.

World Meteorological Organization (WMO), 1992. Simulated real time intercomparison of hydrological models. Operational Hydrology Report No. 38, Geneva, Switzerland, 241 pp.

Snow-17

Anderson, E.A., 1968. Development and Testing of Snow Pack Energy Balance Equations. Water Resources Research, Vol. 4, No. 1, 19-37.

Etchevers et al., 2004 P. Etchevers, E. Martin, R. Brown, C. Fierz, Y. Lejuene, E. Bazile, A. Boone, Y.J. Dai, R. Essery, A. Fernandez, Y. Gusev, R. Jordan, V. Koren, E. Kowalczyk, N.O. Nasonova, R.D. Pyles, A. Schlosser, A.B. Shmakin, T.G. Smirnova, U. Strasser, D. Verseghy, T. Yamazaki and Z.-L. Yang, Validation of the energy budget of an alpine snowpack simulated by several snow models (SnowMIP project), Ann. Glaciol. 38 (2004), pp. 150–158.

Franz, K.J., Hogue, T.S., and Sorooshian, S., 2008. Operational snow modeling: Addressing the challenges of an energy balance model for National Weather Service forecasts. Journal of Hydrology, In Press, Corrected Proof, Available online 18 July 2008.

Lei, F., Koren, V., Smith, M., and Moreda, F., 2007. A sensitivity study of an energy-budget snow accumulation and ablation model. Proceedings, 87th Meeting of the AMS, 21st Conference on Hydrology, paper J6.4, San Antonio, Texas, January 13-18, 2007.

Pan, M., and co-authors, 2003. Snow process modeling in the North American Land Data Assimilation System (NLDAS) 2. Evaluation of model simulated snow water equivalent. Journal of Geophysical Research, Vol., 108, No. D22, 8850, doi: 10.1029/2002JD003994

Rutter, N., Essery, R., and co-authors, 2008. Evaluation of forest snow processes models (SnowMIP 2). In preparation, to be submitted to Journal of Geophysical Research (Atmospheres).

Shamir and Georgakakos, 2006. Distributed snow accumulation and ablation modeling in the North American River basin. Adv. Water Resources, 29, 558–570

Sheffield, J., and co-authors, 2003. Snow process modeling in the North American Land Data Assimilation System (NLDAS) 1. Evaluation of model-simulated snow cover extent. Journal of Geophysical Research, Vol., 108, No. D22, 8849, doi: 10.1029/2002JD003274

WMO, 1986. Intercomparison of models of snowmelt runoff. Operational Hydrology Report No. 23, World Meteorological Organization, WMO-No. 646, Geneva, Switzerland.

Hydraulic Routing

Numerous publications are available describing the development of the NWSRFS 1-D models solving the St. Venant equations for unsteady flow. Two of the major publications are listed below.

Fread, D.L., 1992. Flow Routing, Chapter 10 of " Handbook of Hydrology), editor E.R. Maidment, McGraw-Hill Book Company, New York pp. 10.1-10.36.

Fread, D.L., 1985. Channel Routing. Chapter 14 of book ‘Hydrological Forecasting’, (Editors: M.G. Anderson and T.P. Burt) John Wiley & Sons. 1985, pp 437-503.

Additional publications for hydraulic routing can be found on the site:
http://www.weather.gov/oh/hrl/hsmb/hydraulics/publications_presentations/index.html

Documentation: NWSRFS User’s Manual is available online in two formats at:
http://www.nws.noaa.gov/oh/hrl/nwsrfs/users_manual/htm/formats.php

Comments: Please contact Michael Smith for additional questions.