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1. INTRODUCTION

Calculation of river flow is important for managing reservoirs and flood forecasting. In the western United States, a complex terrain which is characterized by steep slopes and narrow valleys often cause a substantial rise of river levels in a short period during heavy precipitation events. Since flood control is one of the major tasks of reservoir operation, inaccurate predictions of precipitation and river flow may cause flooding or waste of water resources.

Accurate calculations of river flow need accurate liquid water input to the river system at scales of individual watersheds. Precipitation and snowmelt are the most important natural source of water for a river. Reservoir operations significantly affect river flow in the western United States. Factors such as instantaneous soil water content, vegetation cover, terrain slope and ground water table structure are also crucial for river flow calculation.

There are two types of precipitation: rain and snowfall. River flow quickly responds to rainfall while snowfall does not directly affect river flow until it melts afterwards. Therefore, these two types of precipitation must be separately provided to the river flow model for correct calculation of river flows.

A large portion of snowfall is accumulated at high terrain during winter months in the western United States. Accumulation of snow causes the river flow to respond to instantaneous precipitation with a certain amount of time lag. During warm springs, large amounts of snowmelt can even cause local flooding. Hence, accurate estimation of snowmelt is another important step for calculating river flows.

As discussed in the above, river flows are affected by many different atmospheric and land surface processes. Hence, quantitative estimation of these processes and complex interactions among them is crucial for computing river flows. Therefore, a well-designed numerical modeling system which includes atmospheric-surface-hydrologic processes and is coupled to large-scale atmospheric data is an important tool for predicting and diagnosing local river flows and water resources.

2. MODEL AND EXPERIMENTAL DESIGN

The LLNL Coupled Atmosphere River Flow Simulation (CARS) System, which couples three models and geographical and terrain data bases computed by the Automated Land Analysis System (ALAS), was employed to compute atmospheric, surface, and river flows (Fig. 1). Detailed descriptions of the three models included in the CARS system, Mesoscale Atmospheric Simulation (MAS) model, Coupled Atmosphere Plant Snow (CAPS) model, TOPMODEL, and ALAS, as well as the CARS system are presented by Soong and Kim (1995), Mahrt and Pan (1984), Kim and Ek (1995), and Miller and Kim (1995).

![Diagram of CARS System]

Fig. 1 Structure of Coupled Atmosphere River Flow Simulation (CARS) System
The model domain covers the southwestern United States including states of California and Nevada (Fig. 2). This model domain is covered with a 20 km x 20 km grid mesh in the horizontal.

![Fig. 2 Terrain of the model domain. Dark areas indicate the Hopland and Head water of the north fork American River basins projected onto the domain.](image)

In order to obtain liquid water input to a river system, we need to compute area-averaged values of precipitation, snowmelt and other atmospheric variables. In order to compute the watershed-mean variables to run the TOPMODEL, areas of individual watersheds computed by the ALAS are projected onto the model domain as presented in Fig. 2 (Hopland watershed at the northern Coastal Range and the Head water of North Fork American River at the northern Sierra Nevada). Percent of grid boxes included within a watershed is then computed for all grid boxes within and at the boundary of a watershed. MAS-model simulated fields are then averaged over the grid boxes using the weighting factors obtained in the above process.

We utilized NMC ETA model initial data at 80 km resolution to drive the simulation from November 1994 to May 1995. The MAS model was initialized at 00UTC 3 November 1995. Time-dependent lateral boundary conditions obtained from twice-daily ETA initial fields were provided to MAS model for the next seven months to provide large-scale forcing. The CAPS model was initialized using the November climatology of soil water content obtained from Zobler (1986).

We selected two watersheds, the Hopland watershed at the northern Coastal Range and the Head water of North Fork American River, to examine responses of river flow to precipitation and snowmelt. Locations of the selected watersheds are illustrated in Fig. 2.

3. PRECIPITATION AND RIVER FLOW

We obtained good agreements between the simulated and observed precipitation and river flow, especially during the periods of extreme precipitation and flooding. Good correlations were obtained between the observed and simulated temporal and spatial variations of precipitation within California. Type of precipitation strongly depended on terrain elevations as most of precipitation below 1 km level was rain while most of it above 2 km was snow. For details of precipitation simulation, see Kim (1996).

Strong dependence of precipitation type on terrain elevations caused large differences in the way rivers at different elevations respond to precipitation. Fig. 3 presents the simulated daily precipitation, water released from an upstream reservoir, and river flow at the Hopland gauge station located at the northern part of the Russian River. Since most area of this watershed is located below 1 km level, rainfall has been the dominant type of precipitation. In Fig. 3, total liquid water input (water forcing) was obtained by integrating the simulated precipitation over the watershed area. The history of reservoir operation provided by the NOAA/NWS California-Nevada River Forecast Center at Sacramento, California, was used to obtain water forcing due to reservoir operation.

The simulated river flow (Fig. 3, bottom) agrees well with observations when we added the amount of water released by an upstream reservoir to the simulated area-averaged precipitation to provide the total liquid water input to the watershed. The simulated river flow was within 10% of
the observed value during January 1995 flooding event. The simulated precipitation within the Hopland watershed during the January flooding period was presented by Miller and Kim (1995).

Fig. 3 shows that rivers originating from low-elevation watersheds respond almost instantaneously to precipitation as most of precipitation within the basin is rainfall. During the periods without precipitation, water released by an upstream reservoir determined river flow volume. Note that river flow volume also strongly depends on the soil water content. Dry soil causes the river flow to show delayed response to precipitation. During the periods shown in Fig. 3, soil within the watershed was wet due to earlier precipitation.

Rivers originating from high-elevation watersheds respond to precipitation in a completely different way. Fig. 4 shows the simulated rainfall, snowfall, and snowmelt within the North Fork American River Headwater from 3 November 1994 to 31 May 1995. This watershed is located at and above 2 km elevation where snowfall dominates rainfall. Within this watershed, snowmelt is important for water forcing to the river. Peak snowmelt lags the peak precipitation by a few days during heavy precipitation period. However, significant portions of snowfall does not melt and was added to snowcover. Snowmelt becomes a dominant source of water from late April.

Fig. 4 The simulated daily-mean rainfall, snowfall, and snowmelt within the North Fork American River Headwater from 3 November 1994 to 31 May 1995.

Fig. 5 Daily mean snow cover within the same watershed and period as in Fig. 4.

The snow cover within this high-elevation watershed continued to increase until the
end of April, except during February that was unusually dry and warm (Fig. 5).

The river flow originating from this basin show characteristic response to the water forcing described in the above (Fig. 6). Peak river flow lags heavy precipitation by a few days. During dry months of February (days 91-118) and May (day 180-210), snowmelt is the dominant source of river flow.

Fig. 6 Simulated daily-mean river flow at the Headwater North Fork American River. The simulation period covers from 12 February to 31 May.

5. Conclusions

River flows originating from the Hopland watershed and the Headwater North Fork American River were simulated using the LLNL Coupled Atmosphere River Flow Simulation (CARS) System. The simulated river flows show strong dependence on terrain elevation due to the variations of precipitation type and snowmelt as a function of terrain elevation. The Hopland watershed, located below 1 km elevation, responded directly to precipitation and reservoir operation. The Headwater North Fork American River showed delayed response to precipitation due to large amounts of snowfall during winter time. Most of spring runoff from this basin came from snowmelt.

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References


