ABSTRACT

It has become apparent that the effects of climate change will be especially important for Southwestern US water users. The NSF-funded EPSCoR project “Climate Change Impacts on New Mexico’s Mountain Sources of Water” focuses on improving hydrometeorological measurements, developing basin-wide and sub-basin snow cover mapping methods, generating snowmelt runoff simulations and long-term climate change assessments, and informing the public of the results through outreach and educational activities. Five new and 12 upgraded SNOTEL sites, four SCAN stations and about 30 new automated weather stations are being added to New Mexico measurement networks. 25 sub-basins of the Rio Grande have been identified as important snowmelt basins where development and testing of snow cover mapping methods will be conducted. High spatial resolution Landsat TM data (30 m) are being used to evaluate estimates of snow cover from Terra MODIS moderate spatial resolution data (250m and 500 m). We aim to identify the best snow-mapping algorithm for the Rio Grande basin using Snowmelt Runoff Model (SRM) simulations. For the snowmelt modeling, we are using an updated revision of SRM which can automatically assess the climate change effects on water supplies of future climate scenarios. (KEYWORDS: climate change, snowmelt runoff, hydrometeorological instrumentation, snow cover mapping, water supply)

INTRODUCTION

The two-year old New Mexico Experimental Program to Stimulate Competitive Research (EPSCoR) recognizes that all states do not compete for research dollars on an equal basis. The National Science Foundation is providing funding to make the 27 EPSCoR states more competitive in the research arena. In New Mexico, specific gaps in existing observational capabilities are being filled. An effort to provide improved observations through upgraded sensor networks and remote sensing in mountain source regions is underway. The major objective is to continuously measure the spatial distribution of key variables that affect the water quantity in New Mexico’s mountains such as snow cover and water equivalent, snowmelt, rainfall, evapotranspiration, soil moisture, and runoff. Additionally, a group of hydrological models that can be used for short-term forecasting and long-term assessments (e.g., for climate change) is being assembled. These will include semi-operational basin models, regional scale climate models, and decision support and economic impact assessment models. The duration of New Mexico EPSCoR is five years.

The study area is the upper Rio Grande basin above El Paso, TX. Figure 1 shows snow cover in the Rio Grande as observed by MODIS satellite data. New ground-based instrumentation is limited to the New Mexico portion of the Rio Grande basin whereas modeling and snow mapping can be conducted over the entire extent of the basin.

Ground-based instruments being installed are primarily SNOWTELEntry (SNOTEL) sites, Soil Climate Analysis Network (SCAN) stations, and conventional weather stations to improve the measurement density in New Mexico as compared to other Western sates. Five entirely new SNOTELs will be installed at manual snow survey sites and 12 existing basic SNOTEL sites will be provided with upgraded instrumentation. Four new SCAN sites were installed during the first year from south to north along the Rio Grande drainage at the Jornada Experimental Range, Sevilleta National Wildlife Refuge, Los Lunas Research Center, and the Alcalde Research Center. The SCAN stations will be of value for assessing the fate of snowmelt runoff when it flows from high elevation snowpacks into lower elevation valleys. A variety of weather stations will be added to existing networks in New Mexico. Ten interagency Remote Automatic Weather Stations (RAWS) in the New Mexico network will be winterized to permit year round data collection. Five new stations will also be added to the Navajo Nation Weather Station network, and 15 new stations will be included in the New Mexico State University Climate Center network.
Figure 1. Aqua MODIS view of snow cover in the mountain source areas (San Juan Mountains on the west and Sangre de Cristo Mountains on the east) of the Rio Grande Basin: April 14, 2008
SNOWMELT RUNOFF RESEARCH OBJECTIVES

The major work to be accomplished in this EPSCoR project involves a better understanding of snow accumulation, ablation, and runoff in the mountainous areas of the Rio Grande basin both currently and under future climate change conditions. This research has the following objectives.

1. Identify the most appropriate satellite snow mapping algorithm for use in the Rio Grande basin, which may also have applications to other similar semi-arid snow basins.
2. Test snow mapping methods using MODIS (500 m resolution) satellite data against results obtained using Landsat-TM (30 m resolution) on four selected sub basins. These are the Rio Grande near Del Norte, CO, Rio Chama, Costilla Creek and Rio Hondo.
3. Implement the selected snow cover mapping algorithm in all 25 important snowmelt sub-basins in the Rio Grande shown in Figure 2 and use it to provide the necessary input to run SRM.
4. Develop a forecasting methodology for short-term (2 weeks) to long term (3-12 month) applications.
5. Generate snowmelt runoff hydrographs to evaluate change under different climate change scenarios.

Figure 2: Twenty-five significant snowmelt runoff basins in the upper Rio Grande, used to evaluate the potential effects of climate change

Runs of SRM (schematic shown in Figure 3) are used to provide simulations, forecasts, or hydrographs under conditions of climate change using inputs of satellite snow cover and ground-based air temperature and precipitation data (Martinec et al., 2008). Additionally, the SRM hydrographs are compared to evaluate the different snow mapping algorithms to decide on relative algorithm performance.
Figure 3. Schematic diagram of the organization of the Snowmelt Runoff Model (SRM)

COMPARISON OF SNOW COVER MAPPING ALGORITHM PERFORMANCE

Snow covered area is obtained for each elevation zone of the study basin using MODIS, in this case for the Rio Grande near Del Norte, CO sub-basin for 2001 (Figure 4). The depletion curves in Figure 4 are used to extract daily snow covered area for direct input to SRM to produce simulations. Figure 5a is the simulated and measured hydrograph compared for the 2001 water year using the standard Binary NSDI product (Hall et al., 2002) of NASA. Figure 5b and 5c shows that the fractional NSDI (Salomonson and Appel, 2003) and a generic spectral mixing approach (SMA) (e.g. Andersen, 1982) produce simulated hydrographs that do not compare as well to the measured hydrograph as the standard Binary NSDI. However, all three simulated hydrographs underestimate the measured hydrograph in May-July indicating a consistent snow cover mapping problem.

Figure 4. Snow depletion curves: Rio Grande basin near Del Norte, CO

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Further examination of the properties of the different elevation zones of the Rio Grande near Del Norte, CO sub-basin revealed that in the lower two elevation zones (A: 2432-2926m and B:2926-3353m) significant evergreen forest cover was found to be partially obscuring the snow covered area, whereas in the uppermost elevation zone (C:3353-4215m) the characteristic patchiness of the snowpack was potentially causing an underestimate of snow covered area when using the 500m resolution MODIS data. The finer spatial resolution (30m) Landsat TM data was used to classify snow cover in all three elevation zones and classification results were corrected for forest cover to minimize the error in snow cover mapping. Figure 6 shows the difference that resulted in the depletion curves after Landsat TM-derived snow cover was obtained. These new snow cover data were used to replace the original MODIS Binary NDSI snow cover data used in Figure 5a.
Without changing the original temperature and precipitation data or changing any of the parameter values used in the original runs, SRM was re-run with the Landsat TM data. The resulting SRM hydrograph is shown in Figure 7. The difference in volume and R² values are improved and the underestimated runoff from May to July is much closer to the observed runoff.

Figure 6. Depletion curves for TM-derived snow cover estimates adjusted for evergreen canopy cover.

Figure 7. Runoff results after adjusting snow covered area for underestimates caused by evergreen canopy cover and high elevation late season patchiness.
FUTURE RESEARCH

Correction for evergreen canopy cover in forested snow zones is necessary. We propose to use simple reclassification rules within a GIS to improve estimates of snow covered area. These rules will be developed from field observations of duration of sub-canopy snow cover and its relationship to deciduous and evergreen canopy cover, aspect, slope, and elevation. The high elevation snow cover that is underestimated because of patchiness may be best addressed by using higher resolution data such as from MODIS (250m), Landsat TM (30m), SPOT (20m), or ASTER (15m) when these data are available. Once the final method is developed, it will be transferred to all 25 sub-basins where snowmelt runoff is significant.

Currently, we are working with climatologists to develop likely future climate scenarios for the Rio Grande basin based on relevant runs of Global Circulation Models (GCM) over the Rio Grande drainage area. Our output will be daily temperature and precipitation for each of the 25 sub-basins. SRM will be used to produce the accompanying future snow cover scenarios. We will then be able to produce climate change affected hydrographs like that shown in Figure 8 for all the sub-basins. Figure 8 shows a hypothetical scenario based on the literature for years 2000, 2050 and 2100 (Rango et al, 2003). SRM has a climate change algorithm to assist the user. In Figure 8, it is notable that the runoff peak moves to earlier in the year and may actually increase toward the end of the 100-year period. Our New Mexico EPSCoR project results will allow greater specification of flow changes that should be a great value for water managers attempting to make decisions to cope with a future climate.

Figure 8. Climate change simulation for the Rio Grande near Del Norte with periodic changes throughout the 21st century. By 2100, temperature has increased by 4°C, the diurnal temperature range has decreased by 1.4°C, model parameters are shifted, and a 10% increase in precipitation is expected.

PRELIMINARY CONCLUSIONS

Based upon our early SRM runs and climate scenarios, we can make several conclusions:

- In extreme years: a) droughts will be intensified and b) floods will become more common
- The gap between water supply and water demand will grow even faster than it is now. Even without a volume reduction, the temporal redistribution of runoff will cause this.
- GCM generated changes are required as inputs to hydrologic models, but it is difficult to come to a consensus on the climate changes to be expected for a particular basin. We are working with a climatologist to produce climate scenarios for the next 100 years for our 25 sub-basins.
• States like New Mexico will be the first to experience reduced runoff from mountain snowpacks due to its southerly location and will be the first to need improved modeling to establish alternative approaches for use by water managers.
• Reservoir operating rules will have to change. Old and weakened water systems will fail. New or reinforced reservoirs and distribution systems will be needed.

REFERENCES


Martinec, J., A. Rango, and R. Roberts. 2008. Snowmelt Runoff Model, Users Manual, New Mexico State University, Agricultural Experiment Station, Special Report 100, Las Cruces, New Mexico.
