# DEVELOPMENT OF A REMOTE SENSING-SNOWMELT RUNOFF FORECASTING SYSTEM IN THE RIO GRANDE BASIN

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## ABSTRACT

Large river basins in arid and semi-arid regions, such as the Rio Grande, need forecasting systems that make use of data obtained from new technologies. For the Rio Grande basin, we are developing a forecasting system comprised of two linked models designed to use remote sensing data, namely, SRM and SLURP. SLURP requires MODIS satellite data for land use and evapotranspiration determination, and SRM requires MODIS snow covered area data plus snow water equivalent data from the meteor-burst data relay of SNOTEL. Working on some tributary basins, we have produced streamflow forecasts for 2001-2003. We are in the process of expanding the forecasting to all the snowmelt sub-basins as well as basins where rainfall dominates. The final product should assist local, state, and federal agencies in making improved water management decisions in the complex and water limited Rio Grande basin.

## INTRODUCTION

Information on snow water resources is a major concern in river basins where snowmelt runoff can be a significant contributor to total discharge, even in basins of the southwest United States, such as the Rio Grande, where desert makes up much of the lower elevation areas through which the river channel runs. Because the water resource is extremely limited in these basins, i.e., the water demand exceeds the water supply, the uses to which water is put must be carefully balanced. Many factors must be considered when making water management decisions in the Rio Grande basin such as:

- flood regulation
- irrigation demands
- municipal and industrial supplies
- Indian water rights
- compact and treaty obligations
- water quality parameters
- riverine and riparian habitat protection
- endangered and threatened species protection
- recreational uses
- hydropower generation

It is imperative that a prediction procedure be developed and available to users and water managers in the Rio Grande basin that is able to produce accurate forecasts along the length of the Rio Grande from both snowmelt-dominated and rainfall-dominated sub basins. The basin is large scale in nature, and it seems well suited to incorporation of remote sensing data into the forecasting system.

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## BASIN CHARACTERISTICS

The Rio Grande basin is a large, international basin lying in the Southwest, straddling the border between the United States and Mexico, and covering portions of the states of Colorado, New Mexico, Texas, Chihuahua, Durango, Coahuila, Nuevo Leon, and Tamaulipas (See Figure 1). In Mexico, the Rio Grande is known as Rio Bravo del Norte. The basin spans numerous climatic zones, but arid and semi-arid conditions predominate in most of the basin, and especially so in the urban regions. For the approximately 5 million people who live in basin, the primary sources of water come from snowmelt and rainfall in upstream tributaries.

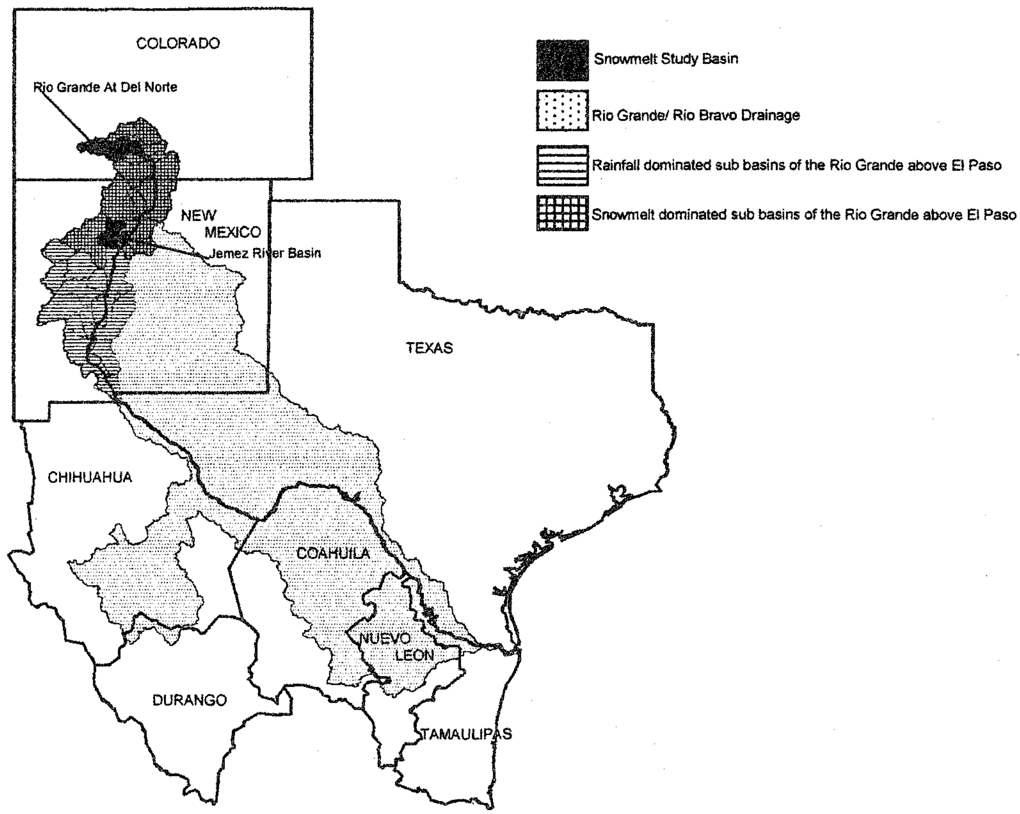



Figure 1. Location of the Rio Grande in the United States and Mexico showing sub-basin areas dominated by snowmelt or rainfall above El Paso, TX.

The length of the Rio Grande is about 3058 km (1900 mi), making it the third longest river in the conterminous United States. The drainage area is about 870,235 $km^2$ (336,000 $mi^2$) which includes the major tributaries of the Pecos River in the United States and the Rio Conchos in Mexico. The lower two thirds of the basin receives only 18-38 cm (7-15 inches) of precipitation annually on average. In the narrow mountainous rim region of the Rio Grande basin, average annual precipitation exceeds 65 cm (25 inches). In these areas, snow can make up to 75% of the annual precipitation, decreasing to the south. In the early stages of this project, we are concentrating on a smaller part of the basin, namely, the Rio Grande above El Paso, Texas which has an area of about 102,280 $km^2$ (39,490 $mi^2$). The northern half of this area, about 50, 675 $km^2$ (19,656 $mi^2$), has a very important snowmelt runoff component. In this area, we are first concentrating on the Rio Grande at Del Norte, Colorado (3417 $km^2$ or 1320 $mi^2$) and the Jemez River at Jemez Reservoir, New Mexico (2475 $km^2$ or 1060 $mi^2$).

## REMOTE SENSING AND HYROLOGIC MODELS

Only two hydrologic models have ever been designed with the input of remote sensing data as major elements. These two models are the Snowmelt Runoff Model (SRM) and the Semi-distributed Land Use Runoff Processes (SLURP) model. For this project, the operations of SRM and SLURP are being linked through a user friendly interface.

SRM was originally designed (Martinec et al. 1998) to operate in high elevation snowmelt runoff basins and has performed very well on over 100 basins worldwide. Since original development, SRM has also been shown to simulate flow accurately on large basins where rainfall dominates over snowmelt in addition to the high elevation basins (Seidel, et al., 2000). The original version of SRM is a degree day model with three primary input variables, namely daily temperature, precipitation, and snow covered area (as obtained from satellite data). A modified version of SRM allows the input of radiation data in addition to temperature for melting the snowpack (Brubaker and Rango, 1997).

SLURP (Kite, 1998) has additional capabilities beyond SRM, and, on specific sub-basins SLURP has been modified to accept runoff output from SRM as input. SLURP can be divided into hydrologic response units for operations. The land cover of each of these hydrologic response units is determined from remote sensing data for use by SLRUP in runoff generation. Another important use of remote sensing data in SLURP is for determining vegetation spectral indices for calculating leaf area indices and evapotranspiration. SLURP also takes into account man-made modifications to the hydrologic cycle such as dams and reservoirs, diversions, and irrigation schemes. The availability of both models working together will allow decision makers to test different scenarios concerning possible future conditions while adequately simulating existing conditions.

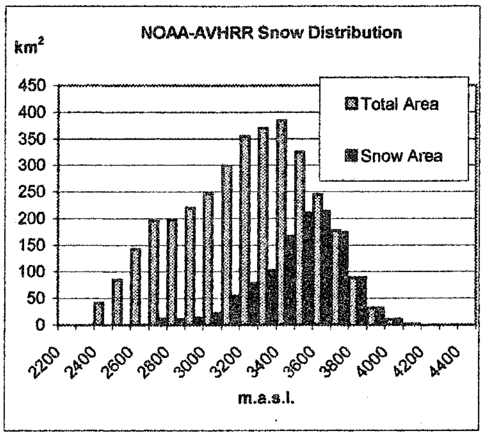
A study of the various sensors available for snow mapping (Rango et al, 2002) has led us to conclude that the MODerate resolution Imaging Spectroradiometer (MODIS) onboard both Terra and Aqua platforms of the Earth Observing System is the near ideal snow cover accumulation and depletion sensor. MODIS has moderately high resolution, especially when using the two most appropriate bands for snow mapping, namely, the 0.62-0.76$\mu$m and the 0.725-1.0$\mu$m channels which have a spatial resolution of about 250m. The other channels have resolutions of either 500m or 1km. Frequency of observation is daily, with a morning overpass for Terra and an afternoon overpass for Aqua. Processing is usually rapid with data generally being available the day after acquisition. MODIS data can be acquired free from NASA-DAAC or from direct broadcast facilities such as at Oregon State University. We have developed algorithms capable of correcting the MODIS data and rectifying it for snow mapping. For snow mapping, MODIS is currently the best sensor.

Figure 2 shows comparison of snow distribution in the Rio Grande at Del Norte, Colorado study basin in which 15m Landsat, 250m MODIS, and 1km NOAA-AVHRR data are evaluated. MODIS, for all practical purposes, preserves the fine snow cover detail (in 100m elevation bands) afforded by Landsat while viewing the target area daily as is characteristic of NOAA-AVHRR.

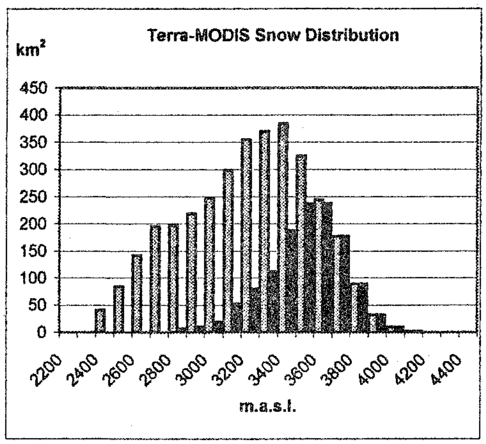
Using MODIS-derived snow cover values by elevation zones, snow cover depletion curves can be drawn without the need to have observations each day. The values for days in between the MODIS observations can be determined from the snow cover depletion curve. Those daily snow cover values are fed directly to SRM and combined with daily temperature and precipitation obtained from conventional climate stations to determine daily snowmelt values by elevation zone which are then converted to daily snowmelt runoff forecasts. Figure 3 shows the snow cover depletion curves for Rio Grande at Del Norte basin for the 2002 snowmelt season.

## FORECASTING PROCEDURE

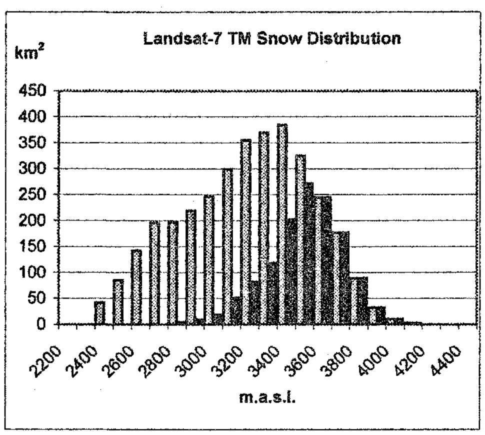
Two types of early season forecasts are being developed in the Rio Grande basin. One type uses SNOTEL data on the 1$^{st}$ of November, December, or January. Interestingly, in numerous cases, the seasonal volume forecasts on these dates are better than forecasts made in February, March and April. See DeWalle et al. (2003) for a more in-depth discussion of this forecast. An early season forecast of the April-September daily flows can also be made with SRM using a prior reference year in which excellent temperature, precipitation, and satellite data were




**Total Snow: 1,188.96 km$^2$**
**Percent: 34.82 %**



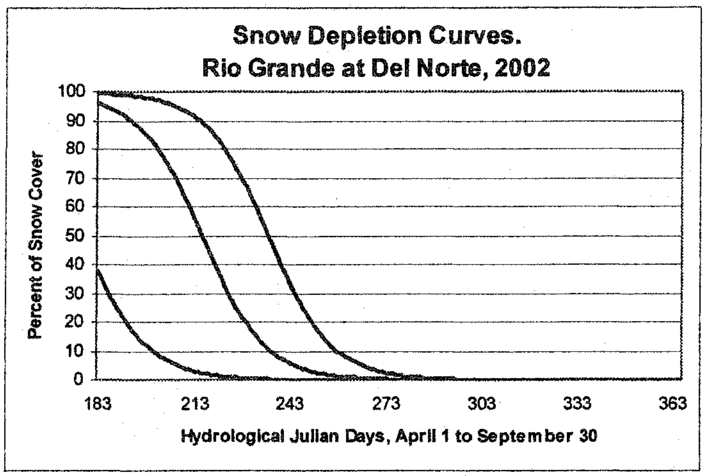

**Total Snow: 1,255.89 km$^2$**
**Percent: 36.78 %**




**Total Snow: 1,312.34 km$^2$**
**Percent: 38.43 %**

Figure 2. Comparison of snow cover mapping in 100m elevation bands on the Rio Grande at Del Norte, 3 March 2002 using Landsat TM, MODIS, and NOAA-AVHRR

available. This forecast is based mostly on average conditions, so progress is being made to link the seasonal volume forecast using SNOTEL to the SRM normalized forecast. Once accomplished, this will be a true early season forecast made before January 1 that will be of value to the agricultural sector in deciding crop plantings, grazing rotations, and irrigation planning.




| **Zone** | **Area ($km^2$)** | **Mean elev. (m a.s.l.)** |
|---|---|---|
| **A: 2,440-2,920 m** | **750.9** | **2,731.3** |
| **B: 2,940-3,340 m** | **1,248.8** | **3,162.3** |
| **C: 3,360-4,220 m** | **1,414.8** | **3,567.1** |

Figure 3. Conventional snow cover depletion curves for the Rio Grande at Del Norte for 2002 using MODIS 250m resolution data

On or about April 1, SRM can be used to make a daily streamflow forecast for the entire snowmelt runoff season. For the Rio Grande at Del Norte, Colorado, this was done in 2001, 2002, and now in 2003 as shown in Figure 4. The 2001 forecasts volume was within 15% of the actual volume and the timing of the hydrograph was good. The 2002 forecast volume was greater than observed as all forecasts were in this extreme low flow year. However, SRM provided a forecast that showed a significant low flow year was expected. For 2003, we will have to wait until Fall of 2003 to evaluate the forecast accuracy. The 2003 forecast was updated in May using SNOTEL observations in the basin. The seasonal volume forecast was lowered from 423,428 ac-ft ($522.3x10^6m^3$) to 278,609ac-ft ($343.6x10^6m^3$) based on very dry conditions prevailing after the initial forecast. Progress was also made on implementing SLURP on the basin. SLURP had divided the basin into the appropriate sub-basins, it has been modified to accept the direct input of SRM flows in all the snowmelt runoff basins, and progress has been made on the SLURP compilation and implementation of the man-made structures and diversions along the Rio Grande channel network.

## CONCLUSIONS

The Rio Grande basin is a large, complex international basin with many forecasting problems that need to be solved to improve water management. Both SRM and SLURP have been implemented on the Rio Grande, and these two models have been integrated with remote sensing data for development of a new and improve forecasting system. As most models do, SRM and SLURP require conventional climate inputs. These models differ from other hydrologic models in that they require remote sensing input data in order to operate. MODIS data are optimum for mapping of snow covered areas required by SRM because of its spatial and temporal resolution, plus MODIS can be used for land use and evapotranspiration inputs required by SLURP. Although still early in the Rio Grande project, we have been able to forecast early season volumes and peaks as well as daily flows for the April 1-September 30 runoff season for the last three years. The forecasted flow data have compared very well in most situations. We will do additional testing of the snowmelt forecasts and integration of the models to result in a comprehensive water resource management system employing meteor-burst (SNOTEL) and remote sensing (MODIS) technologies.

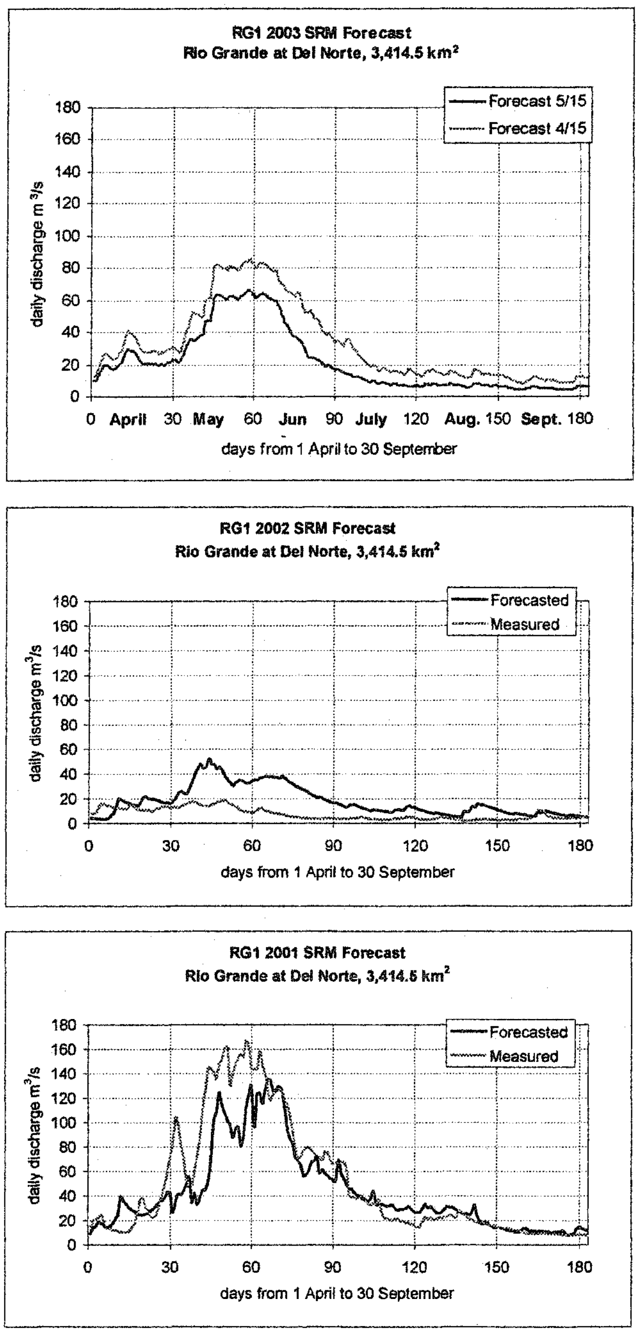



Figure 4. SRM forecasted versus measured streamflow for 2001 and 2002 and forecasted streamflow for 2003 for the Rio Grande at Del Norte.

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