WATER RESOURCES
IMPACT

CLIMATE CHANGE RISKS NEW MEXICO'S WATERWAYS: ITS BYWAYS AND ITS FLYWAYS

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Sin agua, la tierra no vale nada
New Mexico Proverb
("Without water, the land has no value")

CLIMATE, ECONOMY, AND CULTURE ALONG THE RIO GRANDE

The sentiment of this traditional proverb still echoes soundly throughout the desert communities of the Southwest, not withstanding a few tracts where minerals and oil are found. As much as it has for a thousand or more years, water continues to define and condition patterns of settlement and economic development throughout the Southwest, including where and how land is used, how communities prosper, and together interact and integrate within the larger environment. However, unlike years long past, many of the desert dwellers of today rely heavily on reservoirs and aquifers, which have seemingly raised the capacity of these arid environs to attract and support continuingly growing populations and their economies. But for how long and to what extent can these trends continue, especially in the face of climatic changes that will likely alter streamflow patterns and hydrographs that may follow? New Mexico has a unique blend of cultures and landscapes, of agrarian values and high-tech economies, of rare ecosystems, fertile valleys, and expansive desert rangelands. It is a place where people have long settled and where growing numbers still long to settle as migration trends illustrate and highlight growing communities praised for their quality of life, climate, and retirement opportunities. What implications lay in wait for various water users and economic interests who have come to rely not only on prevailing streamflows but on the continuing availability and performance of reservoirs and aquifers, particularly if drier and more frequent drought conditions emerge, as our studies tend to suggest? The Rio Grande valley, which bisects New Mexico as shown in Figure 1, has industry, tourism, residents old and new, and agriculture, all staking claim to water resources that also serve the 'prior and paramount' water rights of 23 Native American tribes and pueblos, and that irrigate the fields of 400 year-old Hispanic communities in canals known as *acequias*. The Rio Grande is also home to endangered silvery minnows where the last remnant of their historical habitat is found, and where flocks of migrating cranes and geese gather in vast numbers to rest and find refuge in riparian woodlands known as *bosques*. How prepared are these residents, local communities, ecosystems, and economies for the stresses of persistent water shortfall?

In this article we examine the role of water and the effects of climate change on its use and economic productivity in the upper reaches of the Rio Grande watershed of Colorado, New Mexico, and West Texas using scenarios of climate change, a hydrologic streamflow model, and an optimizing framework referred to as a hydro-economic model. The RioGEM hydro-economic model depicts the physical, economic, and institutional characteristics of the Upper Rio Grande watershed across both time and space, and then determines which monthly pattern of water transfer, use, and storage combine to optimize the watershed's long-run economic performance. By comparing economic outcomes and water use patterns across scenarios we describe a plausible range of consequences affecting the region's water users.

With climatic change and the expected decrease in available runoff shown across all the scenarios – even those that are relatively 'wet' – the competition for water will be exacerbated and pressure further increased to transfer water out of agriculture

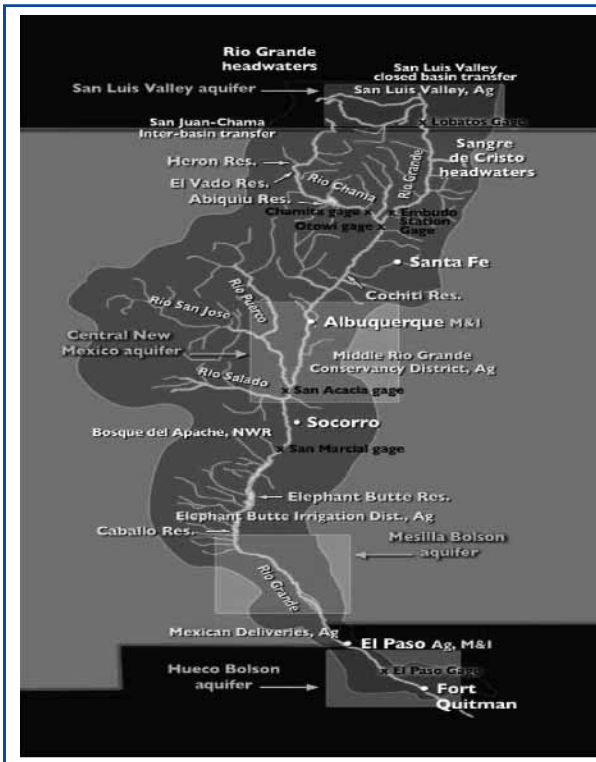

Figure 1. New Mexico and the Rio Grande.

CLIMATE AND POPULATION CHANGE SCENARIOS

Climate Change

From the suite of 18 global circulation models (GCMs) used in the Intergovermental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC, 2007), and driven by the moderate 'business as usual' emissions scenario (i.e., A1B scenario), we selected three scenarios considered most representative of the range of precipitation responses across the upper Rio Grande watershed.

1. *Wet* – – Hadley Centre for Climate Prediction and Research Met Office (hadcm3)
2. *Middle* – Atmospheric Research Australia (CSIRO)
3. *Dry* – U.S. Department of Commerce (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL0)

Two timeframes were simulated using these models over a 30-year simulation period; a relatively closer period, approximating expected climate conditions centered on 2030, and one further out that is centered on 2080. Temperature and precipitation scenarios are shown for the 2080 scenarios in Figures 2a and 2b, respectively.

Population Change

Demand for water is strongly affected by population size and perhaps, to a much lesser degree, by income and wealth. (Although household water demands can rise with income reflecting, for example, an increase in the size of homes, estimated income elasticities are generally quite low, and to a significant degree are likely to be offset by improvements in household water use efficiency that higher incomes enable.) To more accurately portray impacts, estimates of future water demand are needed for both the comparison baseline and for each climate change scenario.

In New Mexico and throughout the Southwest, population continues to grow at rates approaching 2% per year, often drawn ironically enough by good climate and by aesthetic and lifestyle amenities. Such growth often amplifies exposure and vulnerability of these communities to risks both from severe droughts and flash floods (Hurd *et al.*, 1999). Using data from the U.S. Census and New Mexico Bureau of Business and Economic Research, we estimated an annual population growth rate that was expected to fall over time from current rates of just under 2% to approximately 1% in 2030 and 0.5% by 2080.

HYDROLOGIC AND STREAMFLOW CHANGE

Streamflow and water supply changes were estimated by using a conceptual rainfall/runoff model called WATBAL (Yates, 1996), which simulates changes in soil moisture and runoff as a result of changes in temperature and precipitation. WATBAL was used to estimate monthly changes in Rio Grande streamflow hydrology under each of the climate change scenarios. WATBAL is conceptualized as a one-dimensional water balance model comprised of two elements. First is a water balance component that describes water movement into and out of a basin consisting of three subprocesses describing (1) surface runoff, (2) subsurface flow, and (3) maximum catchment water-holding capacity. The second models the system energy balance to model the snow storage and runoff and uses the Blaney-Criddle relationship to simulate evapotranspiration. Parameters in WATBAL include the size of catchment areas, and the water additions and removals, which are based on historical runoff relationships, calibrated changes, and input data such as monthly rainfall and temperature. Water is added by precipitation, can be accumulated to some extent, and is removed by evapotranspiration, surface runoff, or subsurface runoff. WATBAL was applied to each catchment area in the Rio Grande watershed to simulate runoff and streamflow such that it is spatially and temporally consistent with the hydro-economic model described in the next section. For completeness of the historical record and to simulate a realistic pattern of inter-annual variability, WATBAL was calibrated for each individual catchment within the Rio Grande watershed

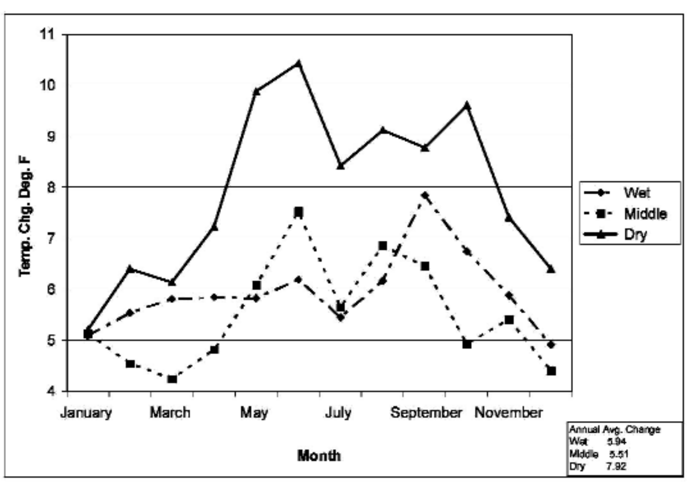

Figure 2a. Three Scenarios of Temperature Change Projected for the Rio Grande Basin in 2080.

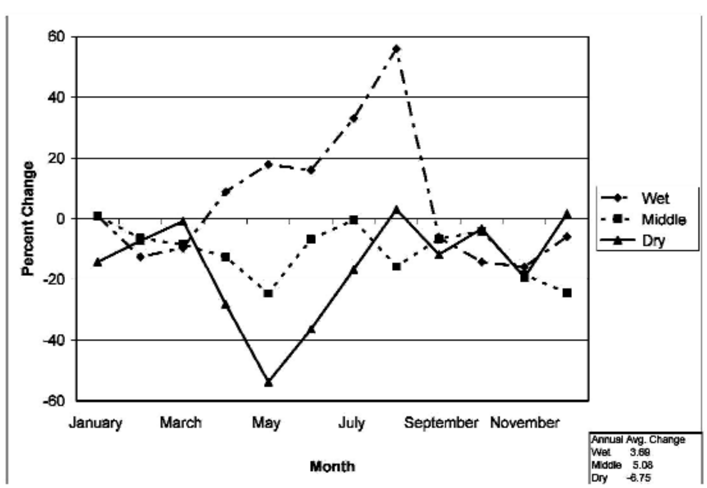

Figure 2b. Three Scenarios of Precipitation Change Projected for the Rio Grande Basin in 2080.

using data from the historical 30-year climatic period of 1971 to 2000 (obtained from the PRISM group www.ocs.orst.edu/prism). WATBAL was then used to estimate the corresponding monthly values of stream flow associated with each climate scenario for each watershed.

Estimated changes in the quantity and timing of regional streamflows for the 2080 climate change scenarios are shown in Figure 3.

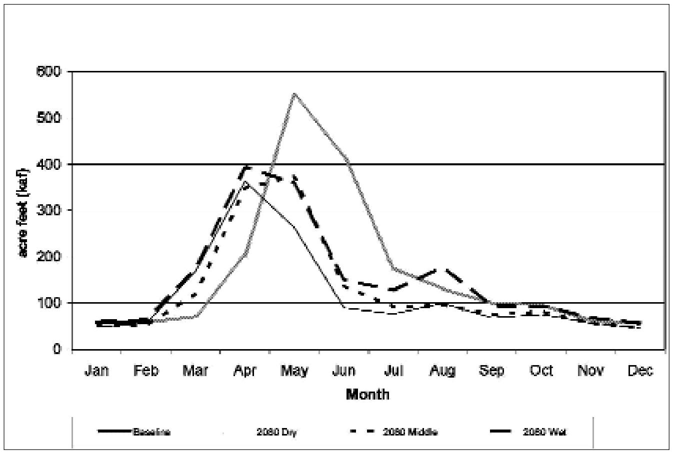

Figure 3. Estimated Average Monthly Streamflow for the Upper Rio Grande Surface Waters Under Baseline and Climatic Change Scenarios by 2080.

A HYDRO-ECONOMIC MODEL OF THE RIO GRANDE

One of the key aspects of the hydro-economic modeling framework is the explicit treatment of the underlying value of water, often represented as mathematical functions that relate the marginal economic value of water to the quantity of water use (i.e., 'water demand functions'). By specifying this relationship, the modeler is implicitly specifying the flexibility of the particular water user to changes in water prices. Economists often refer to this as the 'price elasticity of demand' – in other words how the quantity of water use changes in percentage terms to a percentage change in price. As climate change interacts with economic markets by affecting resource supplies and demands, ultimately resource prices are altered and signal to water users that a change in water use is indicated – providing that institutions and policies permit the direct and transparent relay of these implicit prices to water users. Adaptation to a water shortage, for example, occurs as some water users that are less tolerant of price increases begin to curtail their use.

Hydro-economic models have several advantages for long-term planning and assessment over alternative water budget and system simulation type models. First, by using an optimization framework such models replicate an active decision environment that explicitly recognizes the opportunity costs and economic tradeoffs inherent in any given water allocation and storage decision. Second, simulation and water budget models use a "what if" perspective to assess the consequences that would follow from a given allocation decision; however, only an optimization framework can systematically sift through all the permutations of possible allocation decisions and identify those that are potentially 'best' and worthy of closer scrutiny. This is a distinct advantage when examining and comparing the effects of large-scale, system-wide changes, especially if behavior within the system is dynamic and roughly follows the optimization objectives. Third, hydro-economic models provide explicit information regarding the value of water, how it is affected by water supply changes, how it varies both temporally and spatially, and how it is altered by physical limitations and institutional constraints. As a result, hydro-economic models excel in their capacity to identify strategies that can improve water use efficiency, infrastructure designs, investment decisions, and institutional arrangements.

RioGEM is a hydro-economic model of the Upper Rio Grande watershed from its headwaters in Southern Colorado to the river reach known as Fort Quitman about 80 km south and east of El Paso, Texas. Initially developed by Dr. James Booker (Siena College; described in Ward *et al.,* 2001), the model simulates the spatial and temporal characteristics of water supplies and demands within the Rio Grande watershed on a monthly basis from nine inflow tributaries, six storage reservoirs, four aquifers, and used by seven major urban and agricultural diverters while adhering to the system's physical and institutional settings (e.g., the Rio Grande Compact that divides the waters between Colorado, New Mexico, and Texas, and the 1906 Water Treaty with Mexico). Modeled streamflow and evaporation data from WATBAL were used to assess the impacts of climate change on, for example, water use and allocation, aquifer and reservoir storage, and changes in economic welfare under baseline and climate change scenarios.

KEY FINDINGS AND CONCLUSIONS

With limited opportunities for new water sources in the Rio Grande, continued population growth must necessarily compete with existing water users for available supplies. With climatic change and the expected decrease in available runoff shown across all the scenarios – even those that are relatively 'wet'– the competition for water will be exacerbated and there will be further increased pressure to transfer water out of agriculture. With the onset of more persistent and widespread shortfalls in streamflow, all water users will likely experience adverse economic consequences that accompany rising scarcity and water costs. Under the 'Dry' scenario in the 2080s, for example, average agricultural water use declines by 33% and results in an average economic reduction of $82.6 million per year (2000$). For the same scenario, water use in the domestic sector falls by nearly 2%, and incurs an estimated economic loss of $12 million per year. Add to this estimated annual losses of $6.1 million for reservoir recreation, and total direct economic losses reach nearly $101 million (2000$) – approximately 4% of the estimated total $2.5 billion in annual water generated direct economic benefits. Though direct economic losses to the agricultural sector are potentially substantial, there may be considerable economic consequences that follow from these potential changes in the character and composition of New Mexico's economy, and are the subject of indirect and secondary effects (Hurd and Coonrod, 2007).

In addition to direct economic impacts, there are indirect and secondary impacts that reflect, for example, 'losses' in income or employment in agricultural-related industries. For example, water that leaves agriculture and reduces irrigated acreage not only reduces farm incomes (i.e., the direct effect) but also reduces the demand for supporting economic services, including upstream activities such as farm machinery and repair; seed and chemical inputs, and labor; and downstream activities such as farm product processing and manufacturing. This can generate significant economic hardship and dislocation. Table 1 highlights the estimated economic effects, including estimates for direct, indirect, and total losses. Annual losses range from $15 million to $114 million in the 2030s to as much as $302 million in 2080.

Climate change poses distinct challenges for water managers and users in the Southwest as diminished water supplies compound stresses from increasing populations. In conclusion, we highlight the following consequences for climate change in the Upper Rio Grande watershed.

1. Warming is projected to result in less snowpack, earlier snowmelt, and more water lost to evaporation. Peak flow and total streamflow are projected to decline while peak runoff occurs a month earlier. Such changes in runoff would affect water storage systems and patterns of water availability, which in turn could seriously disrupt current human water use patterns, vegetation, and wildlife habitat.

2. Shrinking surface water supplies and rising populations will increase competition for water and raise the economic pressure to transfer water from agricultural to urban and industrial users.

3. Some water uses could be curtailed as surface water supplies are significantly diminished. The drier scenarios considered in this analysis lead to declines in surface water availability and use of about 12% by 2030, and 33% by 2080. Even the wettest scenarios project water use declines of 5% by 2030 and 8% by 2080 due to higher evaporation losses.

4. Substantial and transformational disruption to New Mexico's agricultural and rural economy is projected in a warmer and drier future. Under optimistic economic and institutional assumptions, direct and indirect economic losses are projected by 2030 to range from about $13 million under a relatively mild climate scenario to $115 million under the driest scenario, with losses that rise by 2080 to range from $21 million to over $300 million.

5. Agriculture's real value – and potentially the real loss to New Mexico's residents, tourists, and wildlife – goes far beyond this market value to the services that agriculture provides to the environment and quality of life. Losses and transfers amounting to over 30% of current water use levels will dramatically and negatively affect communities and environments across the region.

Table 1. Estimated Annual Economic Losses for Major Rio Grande Water Users Under Scenarios of Climate Change.

Climate Change Scenario	Change in Average Annual Runoff (percent)	Direct and Indirect Economic Losses (millions of 2000$)		
		Direct Losses (millions of 2000$)	Indirect Losses* (millions of 2000$)	Total Losses** (millions of 2000$)
Dry				
2030	-13.7	-38.1	-19.1 to -76.2	-57.2 to -114.3
2080	-28.7	-100.7	-50.4 to -201.4	-151.1 to -302.1
Middle				
2030	-3.5***	-8.4	-4.2 to -16.8	-12.6 to -25.2
2080	-22.8	-61.7	-30.9 to -123.4	-92.6 to -185.1
Wet				
2030	-6.3	-10.3	-5.2 to -20.6	-15.5 to -30.9
2080	-8.3	-14.2	-7.1 to -28.4	-21.3 to -42.6

*Indirect economic impacts are estimated at 0.5 to 2.0 of the direct impacts. This is arrived at by subtracting the direct impacts from estimates of total output impacts using a range of total output impact multipliers from 1.5 to 3.0 based on available studies and incorporating a margin of safety.

**In 2006, New Mexico's total gross domestic product was estimated at $76 billion, and therefore, even estimated total economic losses greater than $300 million are less than 1% of the regional economic output.

***The estimated losses to runoff for the 2030s under the 'middle' climate change scenario is less than the reduction indicated for the 'wet' scenario because of differences in the temperature change estimates in the underlying GCMs. In this case, although precipitation is greater for the 'wet' scenario, estimated temperature changes are also much greater and result in more evaporative losses relative to the 'middle' scenario.

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