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Acequias and the Effects of Climate Change

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Abstract: Traditional forms of acequia irrigation can be combined with ground based and remote sensing snow measurements and snowmelt runoff modeling to better estimate runoff volumes now and in the future under conditions of climate change. The experience gained over 400 years of irrigating small fields strongly binds communities and strengthens the resolve of acequia associations to contest challenges presented by climate change. Increased density of snow measurements in high elevations of the Rio Grande along with input of real-time data to snowmelt models has led to an improved potential for acequia decision making under the increased temperatures projected for the future by climate models. Acequia communities and similar Native American settlements have shown the willingness to share water during times of severe water shortages in the southwestern U.S. Acequia associations have shown the desire to adopt new forms of hydrologic data and modeling techniques and incorporate them into acequia association approaches.

Keywords: *Acequias, climate change, snowmelt runoff modeling*

Acequias or community ditches have been used in relatively high elevation, small settlements in New Mexico (and parts of Colorado and Texas) to irrigate small agricultural fields for almost 400 years. This Moorish-Iberian derived form of irrigation was introduced by the Spanish during their occupation of the southwest U.S. (Brown and Rivera 2000). Acequias are community-based water governance systems that can have one or multiple irrigation canals where through the use of low dam structures water is diverted from the main stream and delivered by gravity to agriculture fields downstream. Figure 1 shows an acequia in Las Cruces, New Mexico in 1891. Although no longer common in the southern part of the state, acequia irrigation still survives today in northern New Mexico and other locations despite expansion of large irrigation operations, urban growth, and condominium development. This kind of development has resulted in the purchase and consolidation of water rights that have been used for small-scale irrigation for about 400 years. For the most part, however, acequia irrigation from community ditches has persisted and the historic water rights have been retained. It is the sense of community in these small settlements that helps to maintain this traditional way of life. The strong social bonds are difficult to break, even by developers.

The community-based system of irrigation places a great value on water that is increased by the social and cultural values. In the past, acequias have survived periods of severe drought and external impacts similar to those posed by climate change. Studies have been conducted on how acequias adapt to outside threats through a strong community cohesion (Fernald et al. 2012). Hence, the landowners and long-time residents are often reluctant to sell the water rights to those outside the community. Irrigation methods used in small settlements in other water sparse-regions of the world have lasted for even longer time periods. Ancient water harvesting schemes used in the Negev Desert for irrigation some 3,000 to 4,000 years ago are still practiced in parts of the Negev today (Evenari et al. 1982).

Traditional irrigated agriculture practiced in the acequia communities of northern New Mexico today inspires great loyalty to the system and is ingrained into the way things have been done for hundreds of years (and even longer in other areas of the world). This way of life and culture is customary

Figure 1. View of Acequia Madre (main irrigation ditch) looking north toward old Lucero Mill in 1891 (Las Cruces, New Mexico) (from Branigan Memorial Library Photographs, New Mexico State University).

and imbedded into the traditions of culture of community residents. Acequia community rules, structure, and culture facilitate coordination, management, and sharing of responsibilities and shortages, such as those to be expected from climate change, strengthen community resolve (Mayagoitia et al. 2012). Because many of the towns where community ditches are used for the irrigation of small fields are in isolated areas in small narrow valleys, the traditional ways seem to be preferable to development of larger irrigated agricultural lands or to selling water rights for use in urban areas.

Background

In the western U.S., including New Mexico, the prior appropriation system of water allocation is used. Prior appropriation favors the acequia water users because they generally have senior water rights, have used this method of irrigation on small fields for many years, and irrigate in the same way year after year. The cultural and social aspects in these areas include the idea of communal maintenance of irrigation ditches under the direction of the acequia mayordomo. The irrigators are required to do the maintenance of the ditches either themselves or by supplying laborers. This further binds the members of the community to the land and water because it is a form of an investment. Acequia systems have a long tradition of equally sharing the water during times of abundance and during water shortages (Fernald et al. 2012). In times of water shortages, the community tends to band together and provides accessibility to water for all acequia water users (Rodriguez 2006), even when different villages or Native American pueblos use water from the same stream. During low-flow years, although Native American pueblos have the most senior water rights, they will and have made accommodations for acequia irrigators; for example, the pueblo will divert water four days of the week followed by the acequia for the remaining three days (Rodriguez 2006) despite the fact that the pueblo could divert the water for all seven days during the drought period.

Because most acequias have no storage, but rather diversion structures that rely on gravity flow, the fields to be irrigated must be close to the source of water, namely, the melting high elevation snow fields (Phillips et al. 2011). From a hydrologic point-of-view, the closer the acequia point-of-diversion from the main stream channel is to the melting snow field, the less the evaporative water loss while the water is being delivered from high elevations. Contra acequias (counter or lateral ditches) are used to transport irrigation water from the Acequia Madre (Mother Ditch or main acequia) to the fields to be irrigated. In many cases, at the lower end of the main acequia, water is delivered back to the stream or river. In some other cases, all available water is diverted into the irrigated fields and there is no return flow to the river from the main acequia. Furthermore, surplus water from the irrigated fields also finds its way back to the river, although this return flow takes longer than the water at the end of the main ditch to return to the river. A study conducted by Fernald et al. (2010) in an acequia-irrigated valley in northern New Mexico shows that, on average, nearly 60 percent of the total water diverted from a main acequia returns back to the river as surface return flow and 33 percent returns back as shallow groundwater return flow, whereas only 7 percent is lost by evapotranspiration due to the high elevation of the irrigated fields. In this irrigated valley, acequia seepage and deep percolation from irrigation contribute to the seasonal recharge of the aquifer (1169 mm / year) that acts as a temporary reservoir that slowly releases water back to the river (Ochoa et al. 2012). Because the melting of the seasonal snowpack, the diverting of snowmelt runoff, the irrigating of the farm fields, and the returning flows from the irrigated fields as well as from water that remains in the main acequia all takes place at high elevations, the acequia system provides an important factor in delaying runoff originating at high elevations. The delay of runoff provides an important extension of the runoff season so that more water users will have a chance to divert water in downstream portions of the basin later than if the acequias of northern New Mexico were not irrigating at high elevations.

The average elevation difference between the largest storage reservoir used for irrigation and selected SNOwTELemetry (SNOTEL) sites operated by the Natural Resources Conservation Service (NRCS) sites above the Elephant Butte reservoir is 1741 m compared to only 838 m for the average elevation difference between the acequia diversions and the SNOTEL sites. In order to minimize the elevation difference between the points-of-diversion and the melting snowpack like the acequias do, the points-of-diversions have to be high in the basin where evaporative losses are low and other water users have a chance to make use of return flow from the acequia irrigation. These characteristics make the acequia irrigation systems relatively efficient users of water. Figure 2 illustrates that SNOTEL sites are much more representative of available acequia water supply than they are of the low elevation, large irrigation operations.

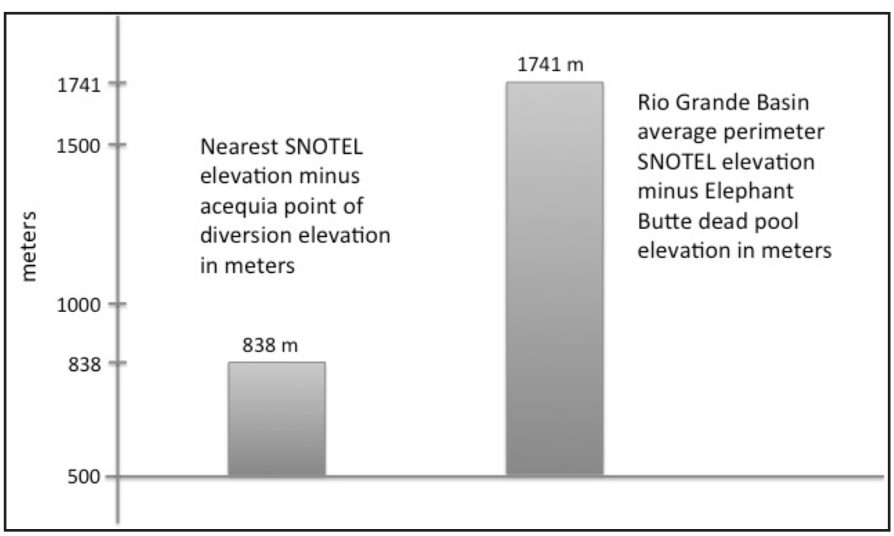

Figure 2. Elevation differences between acequias and SNOTEL sites compared to the Elephant Butte storage reservoir and Rio Grande basin perimeter SNOTEL sites.

Figure 3. Taos Powderhorn SNOTEL at 11057 ft (3307 m) installed in the Rio Hondo basin in August 2010.

Although SNOTEL sites are good indicators of water supply from the snowpack, New Mexico had far fewer sites than the other western states at the beginning of New Mexico's Experimental Program to Stimulate Competitive Research (NM EPSCoR) project in 2008. As a result, NM EPSCoR has significantly added to the number of SNOTEL sites throughout the state, particularly in the Rio Grande basin. Five new enhanced SNOTEL sites were installed and 12 existing basic SNOTEL sites were upgraded to enhanced sites. Figure 3 shows the new SNOTEL site, Taos Powderhorn, which is in the headwaters of the Rio Hondo basin. This SNOTEL should provide valuable data for improving streamflow forecasts from a very productive basin that has significant diversions for acequia irrigation.

Potential Effects of Climate Change on Acequia Systems and Recreation

Water users around the world are concerned with the effects climate change might have on available water supply. This is especially true in the southwest U.S. where water demand on average already exceeds the water supply, and where drought conditions are common. Climate change will likely cause increased temperatures, and daily evapotranspiration will also increase. Acequia systems have an advantage over large irrigated agriculture because of the difference in elevation of the two types of agriculture. The elevation difference means that cooler temperatures will be experienced while growing crops in the small irrigated fields in high elevation valleys as compared to irrigated agriculture at lower elevations along the Rio Grande or Pecos River. As the climate warms, the high elevation, small farms will lag consistently behind farms in large river valleys in experiencing severe high temperatures because of the large elevational difference and lapse rate considerations. Effects of climate change on precipitation in the Southwest is uncertain, but even if precipitation increases, it will likely come from more intense rain storms. An increase in intense storms does not translate to an increase in water supply for crops because acequia valleys do not have major water storage structures that can hold runoff increases for later applications to irrigated fields.

Because the acequias will largely make use of water supplies from melting snow at high elevations, acequia communities need to rely upon snowmelt runoff projections from models that allow input of changed climate variables such as maximum and minimum temperatures, precipitation, and resulting daily snowmelt volumes. Data also needs to be down-scaled from regional climate model runs to provide projections of future climates of acequia basins that can be accepted by a snowmelt runoff model. The output of temperatures and precipitation from climate model runs will interact in the snowmelt runoff model to produce estimates of future runoff for specific acequias. The timing of snowmelt runoff volumes will allow acequia associations to better plan their response to mitigate the changes in climate that will occur.

Although the Desert Research Institute, Reno, Nevada is not working directly with acequias, they feel that producing climate model scenarios for acequia users is a logical way to provide data to investigators who can produce climate change hydrographs with models like the Snowmelt Runoff Model (SRM). Figure 4 is a schematic diagram for SRM that shows the combined use of meteorological and remote sensing data and a climate change algorithm that will produce climate change-affected hydrographs. This has been tested

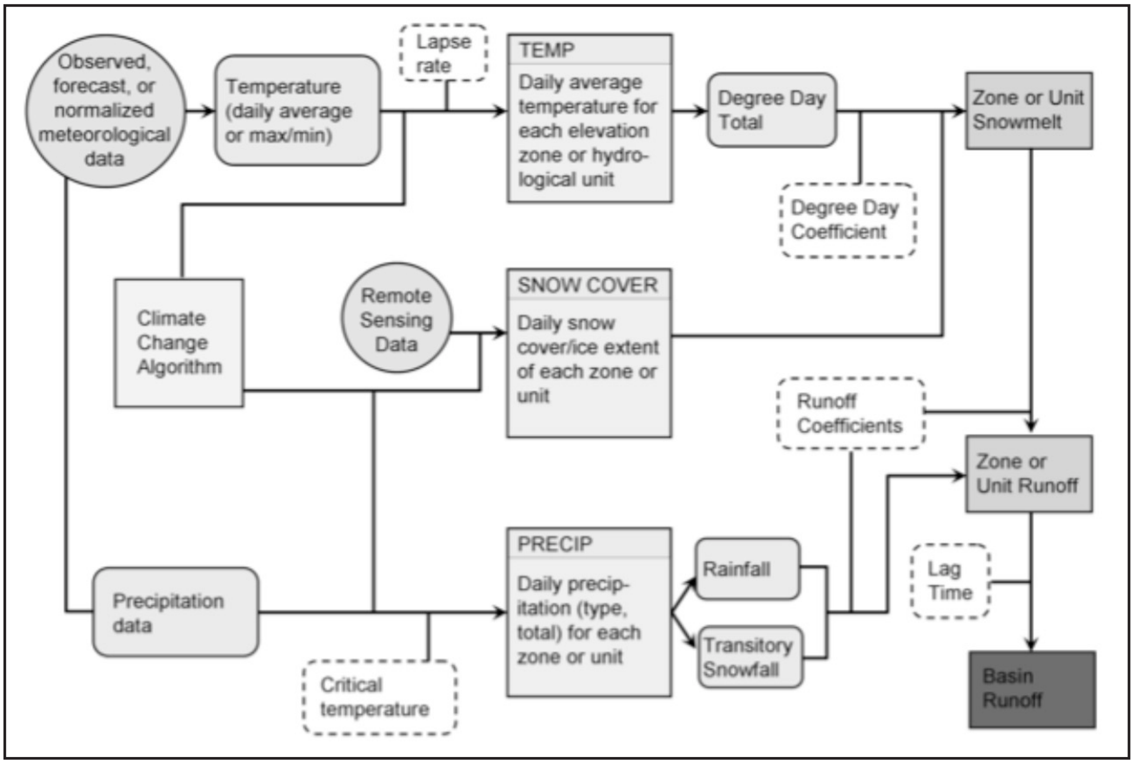

Figure 4. Schematic diagram of the organization of the Snowmelt Runoff Model (SRM).

on several tributaries to the Rio Grande where the first step is simulation of a hydrograph for a known, near-average year like 2001 as shown in Figure 5. The changes that have been produced are similar to climate change effects in other parts of the western U.S. and the world that depend on snowmelt for their water supply in a semi-arid climate.

Figure 6 shows the type of runoff change expected for a near normal runoff year like 2000 if the climate change expected for 2050 and 2100 occurred in the Del Norte basin in Colorado (3419 km^2). The response by 2050 in the Del Norte basin shows a shifting of streamflow from May and June to April. By 2100 this shift is more pronounced and the peak flow has increased by a significant amount from 2050. Figure 7 shows the comparison of measured versus SRM computed flow for an average runoff year (1999) on the Conejos River near Mogote, Colorado (730 km^2). Figure 8 shows the changes to be expected in the Conejos River flow as a result of climate change by the years 2049 (a) and 2099 (b) as produced by climate model inputs to SRM. The similarities to other parts of the world are earlier snowmelt and runoff in the basins (in early April and May) and a very much reduced flow later in the snowmelt season in June and July when the demand for water is the highest.

Climate change impacts on the acequias will include a need for an earlier cleaning of the acequia ditches, earlier planting of crops, and earlier irrigation of the fields, all by about 3-4 weeks. There may also be a change in the types of plants irrigated and grown if the normally grown plants are sensitive to the intensity and angle of solar radiation, cumulative sunlight, and day length, or to the soil moisture levels that may also change. Although water can be applied to the fields sooner and crops could be growing and harvested sooner, markets for the sale of the crops to consumers may not respond as quickly as the farmers may adapt to climate change. However, this may be positive or negative depending on how the consumers perceive the desirability of their favorite fruit or vegetable appearing in their farmers' market a month ahead of when they have normally purchased it in the past. The main source of income for acequia farmers is usually not derived from farm products, but rather from outside employment. The income from the irrigated farms, however, can be a valuable supplemental source of funds. The movement of

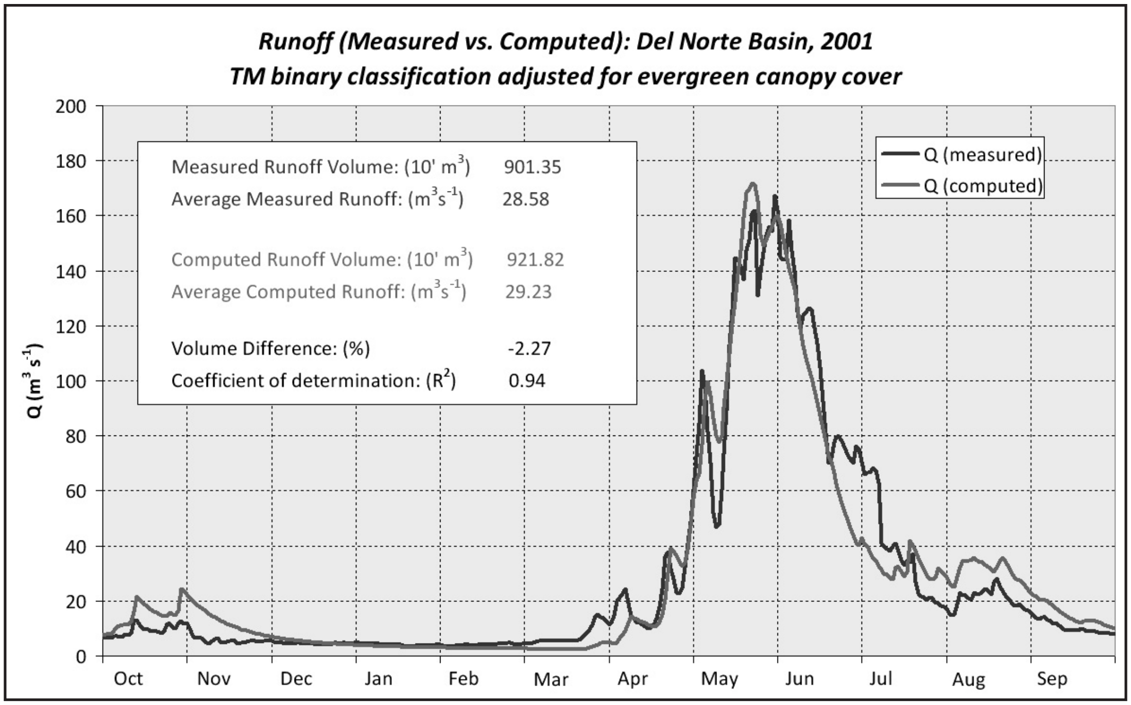

Figure 5. Runoff measured versus computed for the Rio Grande near Del Norte, Colorado (3219 km^2) as generated by SRM for 2001. The Landsat TM binary classification is adjusted for the evergreen canopy cover.

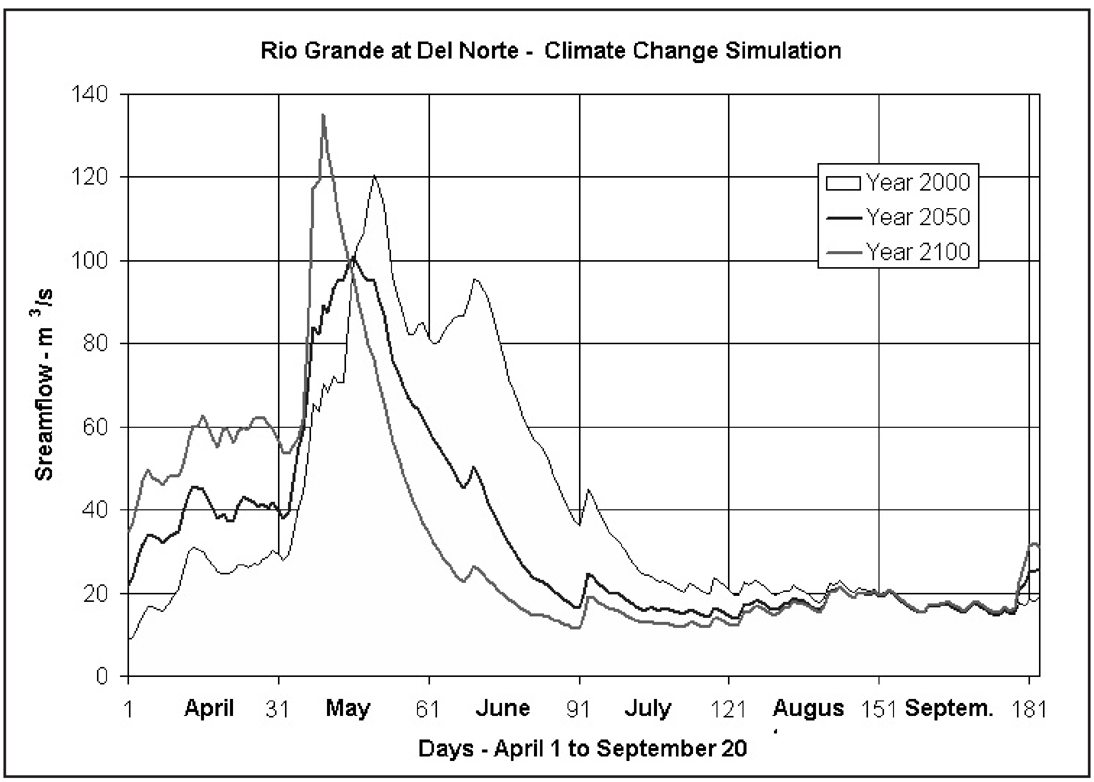

Figure 6. Climate change simulation for the Rio Grande near Del Norte, Colorado (3419 km^2) with periodic changes throughout the 21 century. This scenario for 2100 has a temperature increase of 4 °C, the diurnal temperature range has decreased by 1.4 °C, model parameters are shifted and a 10% increase in precipitation has also been applied. SRM has a formalized climate change algorithm to assist the user.

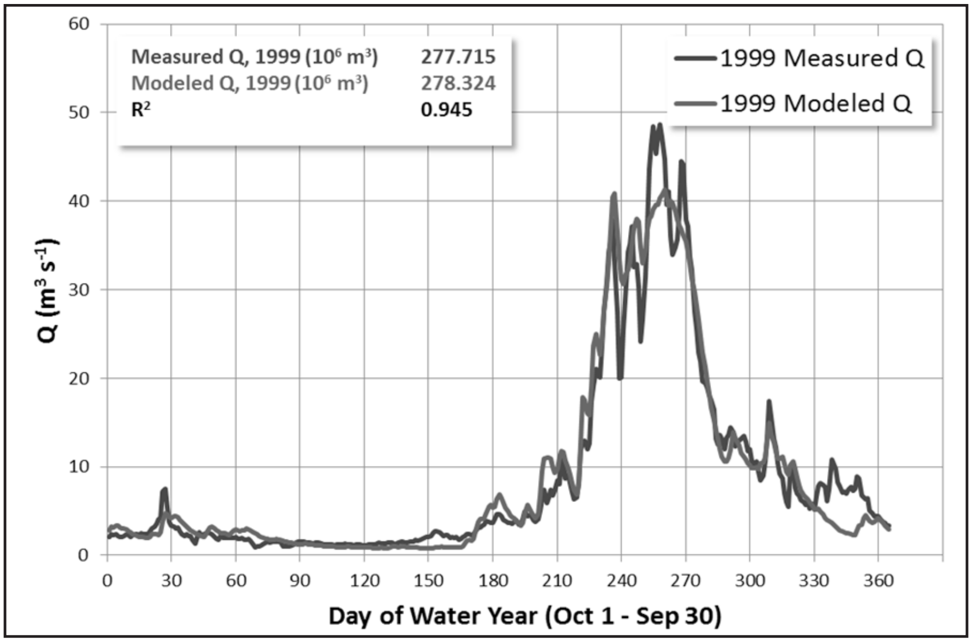

Figure 7. Snowmelt Runoff Model (SRM) computed vs measured runoff on the Conejos River near Mogote, Colorado (730 km^2) for 1999.

irrigation forward by 3-4 weeks will, of course, mean that water users further downstream will also have to move up their planting and harvesting schedule by a similar period of time if they are going to make use of water return flows produced by acequias.

As climate change progresses, circulation patterns, jet stream positions, frequency of tropical storms, and extra tropical storm tracks may also change. One common question is "if I plant my crops earlier, do I run the risk of increasing the chances that I will encounter more freeze events that would ruin my crop?" The answer is most likely not because climate and agriculture will all be shifting at about the same rate. If the farmers are conservative on when to plant seeds, there is probably about the same chance of a damaging event as today or any other historic year if the rate of temperature changes are monitored and factored into planting times.

As the shift of hydrographs shown in Figures 6 and 8 become more common, one conclusion to be drawn is that late summer runoff will decrease considerably, irrigation water will become scarce, and lake levels will drop accordingly. This will, of course, cause impacts on summer recreation like boating and fishing. Boating and fishing activities will need to be done earlier in the year during times that water levels provide suitable conditions. The need to move these activities to earlier times of the year, needs to be publicized by state and federal agencies so that recreationists can adjust planning of their activities accordingly. Winter recreation activities like skiing could suffer a major impact, much like summer recreation activities.

Potential Use of SRM and Remote Sensing Data by Acequia Groups

SRM is easily run on a personal computer because the current software was designed to run on this type of hardware (Martinec et al. 2008). This makes for rapid computer runs after all input data has been assembled. A complete daily annual hydrograph can be obtained in a matter of a few seconds. The input of daily temperature and precipitation can usually be easily obtained from existing weather stations in a tributary basin. The third required input data item is the snow-covered area of each specific elevation zone in a basin. These data can be obtained as automated products from earth observation agencies such as NASA, self-analysis of the original remotely sensed data, from specially arranged aircraft flights, or by contract with companies specializing in remote sensing.

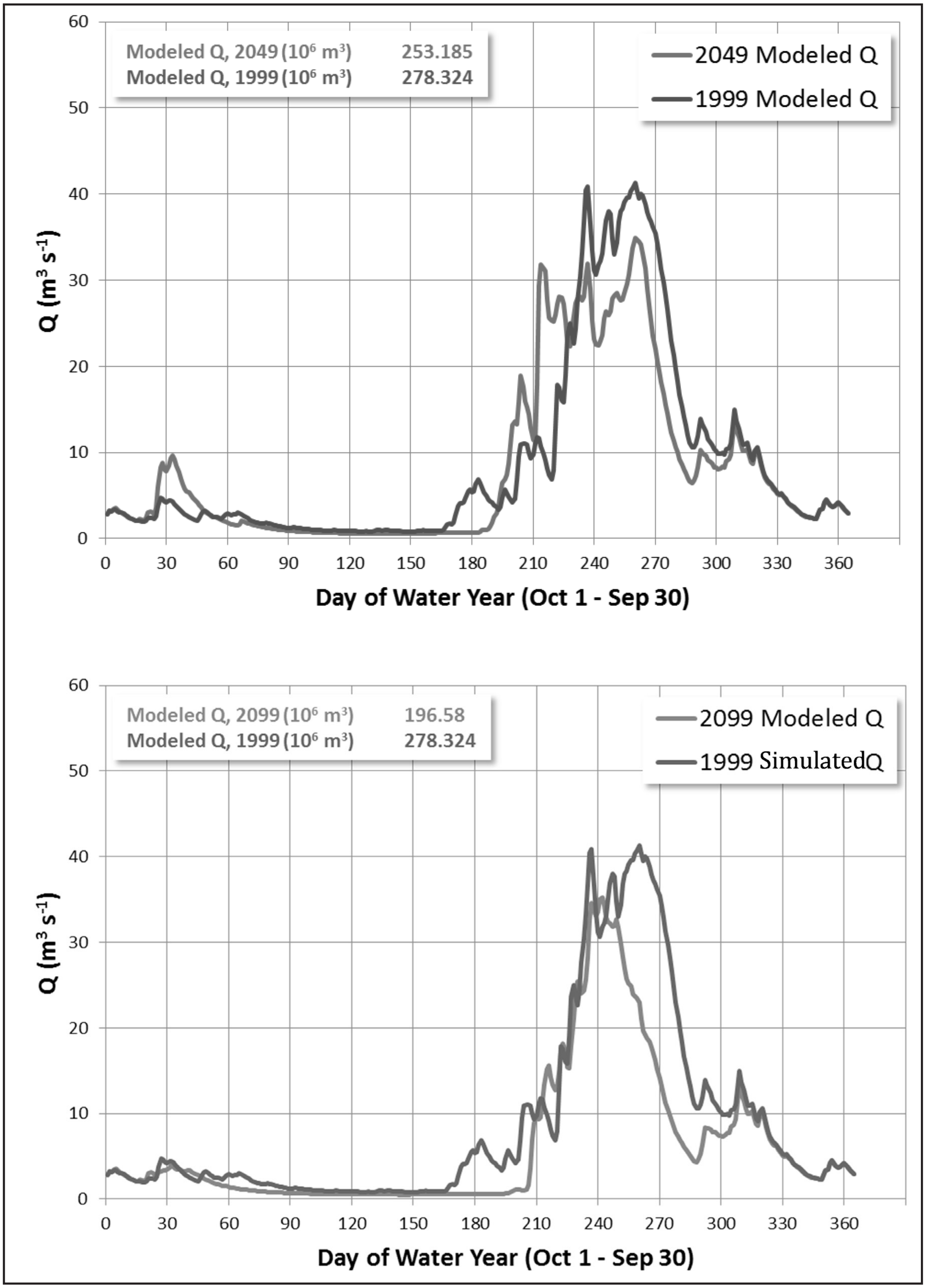

Figure 8. SRM runoff simulation for 1999 versus SRM modeled results using data from the Global Climate Model for a) 2049 and b) 2099 on the Conejos River near Mogote, Colorado.

Once the three main input variables are assembled, SRM can be run in the simulation, forecast, or the climate change mode. Numerous future climate change scenarios are being developed. Additionally, climate change models are also generating runs that can be down-scaled to an area of interest and can be used as a potential future year where the climate change has taken place. Either a scenario or a climate model-generated year can then be input into SRM. SRM will automatically produce the hydrograph of the future year based on the changes predicted by the scenario or the climate model. The climate-change hydrograph can be quantitatively compared to the "before" climate-change hydrograph by use of the model performance evaluation statistics used in SRM.

Surveys have shown that acequia organizations are eager to work with new technologies themselves to better understand how the changing climate will affect their specific acequias (Mayagoitia et al. 2012). Workshops can be conducted to train acequia SRM users or a small group of trainers who would in turn train acequia groups. Similar workshops could be run to train acequia personnel on how to conduct the snow mapping using satellite data. It is highly likely that the snow mapping function could be performed on the same personal computer that is used for running SRM. Again a small group of trainers might be most effective for providing the techniques to be used in interpreting satellite data to acequia groups.

Conclusions

The acequia community ditch systems may actually be somewhat less susceptible to the effects of climate change than large irrigation operations because acequia irrigators have leverage through holding senior water rights in several basins. The way acequia irrigators apply water to their fields may assist downstream water users, assuming that the upstream irrigators are flexible enough to move up their irrigation preparations and the irrigation itself to coincide with the warmer springtime temperatures and earlier snowmelt runoff production. The earlier application of the water to the farm fields will maintain the lag in return flow to the Rio Grande that exists today and will still be available for use by more junior water rights, thus reducing impacts on certain downstream water users as long as they can adapt to the three to four week earlier runoff that is likely to occur.

Retaining the traditional irrigation methods contributes to the continued existence of small communities in northern New Mexico and southern Colorado and allows them to benefit from the positive socio-economic effects that have built up for 400 years or more. Acequia community rules, structure, and culture facilitate the coordination, management and sharing of responsibilities and shortages which tends to better bind the community and strengthen its resolve when adverse conditions exist. Because the towns revolve around community ditches and have done so for a long time, it would be valuable for additional hydrologic capabilities to be added to the acequia organizations. The acequias could conceivably do their own forecasting using relatively simple hydrologic models, like SRM. Input of climate data and snow covered area data from satellite remote sensing can be done by individual acequias or by a consortium of acequias in a particular region of New Mexico.

The acequias of northern New Mexico already have an advantage over large irrigation districts (e.g., in southern New Mexico or west Texas) in that they are at much higher elevations and much closer to the source of melting snow. When this snowmelt water is diverted from the stream channel into the acequia system, it is very near the irrigated fields and consequently suffers from smaller evaporation losses. Because of the high elevations, runoff coefficients are high and the runoff process is relatively efficient.

The acequia tradition of sharing water in times of water shortages, such as drought, could bode well for adapting to climate change. Such techniques would not only be an excellent response to climate change in the acequias across the state but also in other irrigation systems of the Southwest U.S.

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References

Brown, J.R. and J.A. Rivera. 2000. *Acequias de Común: The Tension Between Collective Action and Private Property Rights.* Papers and Abstracts, Workshops in Political Theory and Policy Analysis, Indiana University [CD-ROM ISBN 1-889740-047] IASCP 2000.

Evenari, M., L. Shanon, and N. Tadmor. 1982. *The Negev: The Challenge of a Desert.* Harvard University Press, 2nd Edition, Cambridge, Massachusetts, 437.

Fernald, A.G., S.Y. Cevik, C.G. Ochoa, V.C. Tidwell, J.P. King, and S.J. Guldan. 2010. River hydrograph retransmission functions of irrigated valley surface water-groundwater interactions. *Journal of Irrigation and Drainage Engineering* 136(12): 823-835.

Fernald, A., V. Tidwell, J. Rivera, S. Rodriguez, S. Guldan, C. Steele, C. Ochoa, B. Hurd, M. Ortiz, K. Boykin, and A. Cibils. 2012. A multiperspective model for sustainability of water, environment, livelihood, and culture in traditional irrigation communities and their linked watersheds. *Sustainability* 4: 2998-3022.

Martinec, J., A. Rango, and R. Roberts. 2008. *Snowmelt runoff model (SRM) user's manual*. New Mexico State University, Agricultural Experiment Station, Special Report 100, Las Cruces, New Mexico, 175.

Mayagoitia, L., B. Hurd, J. Rivera, and S. Guldan. 2012. Rural community perspectives on preparedness and adaptation to climate-change and demographic pressure. *Journal of Contemporary Water Research and Education* 147: 49-62.

Ochoa, C.G., A.G. Fernald, S.J. Guldan, V.C. Tidwell, and M.K. Shukla. 2012. Shallow acquifer recharge from irrigation in a semi-arid agricultural valley in New Mexico. *Journal of Hydrologic Engineering* doi:10.1061(ASCE)HE.1943-5584.0000718.

Phillips, F.M., G.E. Hall, and M.E. Black. 2011. *Reining in the Rio Grande: People, land and water*. University of New Mexico Press, Albuquerque, New Mexico, 252.

Rodriguez, S. 2006. *Acequia: Water Sharing, Sanctity, and Place.* The School for Advanced Research Press, Santa Fe, New Mexico, 187.