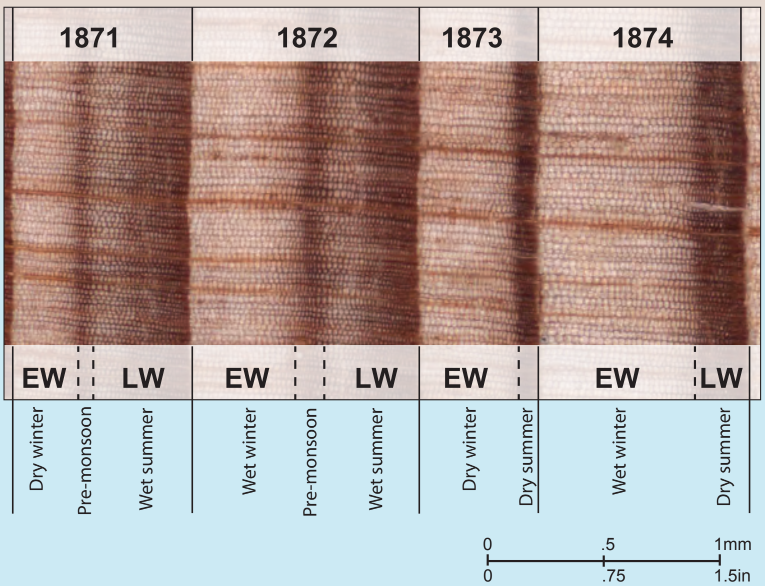
New Mexico Earth Matters

WINTER 2013

Tree-ring Insights on New Mexico's Monsoon and Rio Grande Stream Flow

Recent drought conditions have caught the attention of many people, and a question commonly asked is: How bad is this drought? Is this the driest series of monsoon years, and are these the lowest flows the Rio Grande has ever experienced? Are these drought conditions an indication of climate change, or just part of the natural variability of the climate system? How often are winters with low runoff followed by dry monsoons? Gage record of rainfall and stream flow for this region are little more than 100 years in the best cases. Do these records fully capture the range of conditions that could occur under natural climate variability?



Sequence of four Douglas-fir tree rings from southwestern New Mexico, for the four-year period from 1871 to 1874. Each annual growth ring is composed of light-colored earlywood (EW) and dark-colored latewood (LW). Both 1871 and 1872 contain density variations—"false rings"—which likely result from seasonal drought in the pre-monsoon period.

It is possible to extend instrumental records back in time using biologic or geologic evidence from sources such as tree rings, corals, ice cores, and sediments from the bottoms of lakes and oceans, all of which can reflect climate variations in their rings or layers. Data from these sources, called paleoclimatic or proxy data, provide information about past climate, before the time of modern climate measurements. Tree rings have been especially useful for documenting variations in rainfall, drought, and stream flow in New Mexico, because the growth rings in several tree species that grow in this area are limited by moisture. These species include Douglas-fir and ponderosa pine. A small ring in these trees indicates dry conditions and a wide ring indicates wet conditions. Because trees have annual rings, there is a ring-width value for each year, and because the widths correspond to growth-limiting moisture, the series of widths can be used as a proxy for climate extending back the length of the tree's life. Here in the Southwest, it is common to find trees 300–500 years old, and many as old as 600–700 years.

In order to create a tree-ring width record, about 25–35 trees at a single site are sampled with an increment borer, which is used to extract a pencil-width cylinder of wood from the tree. These tree cores are glued into core mounts, sanded to a fine surface, and each ring is assigned a calendar year date. Dating is accomplished using a method called cross- dating, which is anchored by the ring next to the bark—the year the tree was sampled—and matching the ring-width patterns between trees. The patterns are extremely consistent among moisture-sensitive trees across a climatic region, and this pattern-matching technique is used to ensure each and every ring is correctly dated. Dated rings are then measured, the measurements are adjusted to account for difference in ages of trees sampled, and then averaged together to create a tree-ring chronology for that site.

In New Mexico, detailed information about both the summer monsoon rainfall and the cool season precipitation that is largely responsible for Rio Grande peak runoff can be obtained from tree rings. It has long been recognized that annual growth rings have two parts: a light-colored part formed in the first part of the growing season, called the earlywood, and a dark part formed near the end of the growing season, called the latewood. Although it has been customary to measure the entire ring, if two measurements are made, of the earlywood and latewood widths separately, scientists have found that, throughout much of the southwestern U.S., earlywood widths correspond to cool season precipitation and the latewood widths correspond to monsoon season precipitation.

In 2008 the National Science Foundation funded a study to collect tree-ring data from across the Southwest for the purpose of reconstructing the North American monsoon. Previous

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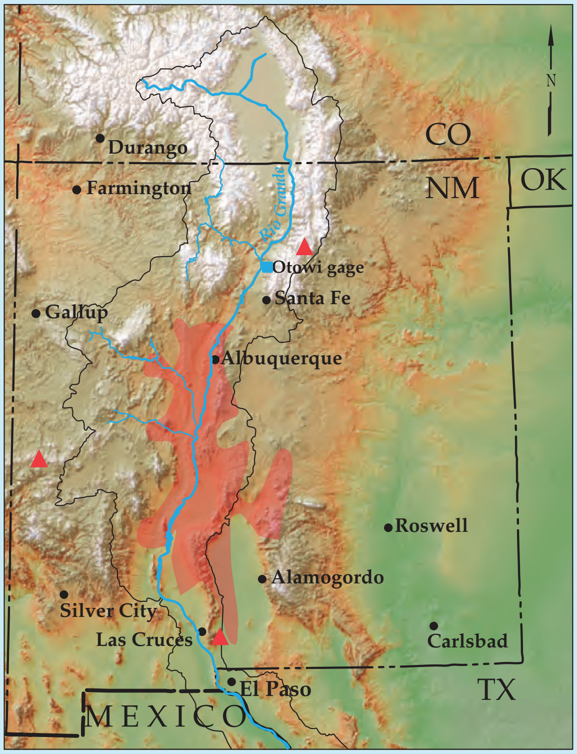


Rio Grande, Climate Division 5 (shaded red), Otowi gage (blue square), and tree-ring chronologies used in monsoon reconstruction (red triangles).

work had developed annual tree-ring chronologies from locations that reflect the cool-season climatic conditions of the Rio Grande headwaters region. Together, these sets of tree-ring data have been used to reconstruct past Rio Grande water year (October–September) stream flow, and central New Mexico monsoon (June, July, August) rainfall going back to 1600.

Developing Reconstructions of Past Climate and Hydrology

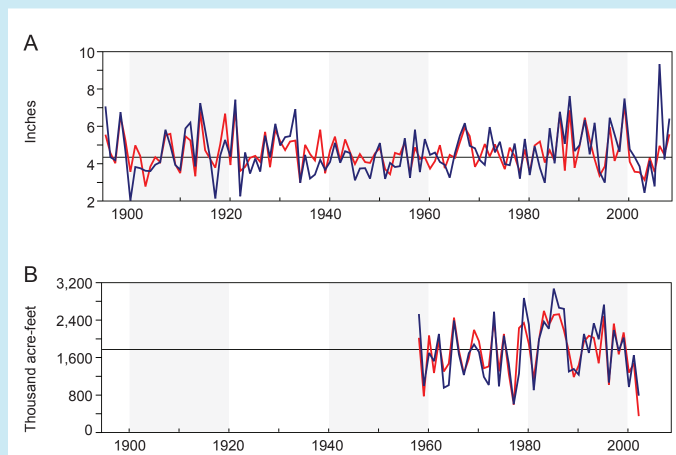
To develop a reconstruction of past climate or hydrology (sometimes called hydroclimate), tree-ring chronologies are calibrated with an instrumental record, typically using a statistical approach called multiple linear regression. A set of tree-ring chronologies or the main modes of variability in a set of chronologies (called principal components) are used as predictors of the values in the instrumental record. The result is a statistical model, in the form of an equation, with weighted tree-ring terms providing estimates of past hydroclimate. The model is evaluated in a number of ways to make sure certain features of the estimates meet assumptions of the statistical approach. Once a model has been deemed satisfactory, the full-length tree-ring chronologies are used in the model to generate a reconstruction that extends back in time.

In the case of the New Mexico reconstructions, two instrumental records were selected for reconstruction: the water year stream flow of the Rio Grande at the Otowi Bridge gage, and the total rainfall for June through August for New Mexico Climate Division 5 (shown on map on this page). Because the actual Otowi gage record is impacted by upstream diversions and depletions, the sum of ten upper basin tributary gages plus the gains on the Rio Grande between Lobatos (at the Colorado/New Mexico border) and Otowi were used for calibrating the reconstruction. The precipitation data for Division 5 were obtained from a gridded climate data set called PRISM. Latewood tree-ring chronologies were used to reconstruct the monsoon, whereas the total ring-width chronologies were used to reconstruct water year stream flow at Otowi.

Tree rings can never replicate 100 percent of the variability in the instrumental records. By comparing the observed instrumental records with the reconstructed records, it is possible to assess the skill of the reconstruction in estimating climate or hydrology. For the Rio Grande (B or lower plot), the tree-ring reconstruction accounts for 74 percent of the variability in the gage record. This is a very good result for tree-ring reconstruction models; it is not a perfect match, but that is to be expected. The reconstruction model for the monsoon (A or upper plot) is less skillful, accounting 53 percent of the variance in precipitation. Although the reconstructed values do not fully capture the wettest and driest values (A in plot), the ups and downs in the reconstruction tend to match the ups and downs in the observed precipitation record (PRISM data set). Thus, this record is most reliable for assessing sequences of wet and dry years, rather than the magnitudes of wettest and driest years. It still can be used to assess the magnitude of precipitation, but there is more uncertainty in these estimates, compared to the flow reconstruction, because of the lower amount of variance (53 percent) accounted for by this reconstruction. It should also be noted that the statistical treatment of the core measurements requires the removal of growth trends (typically trees have wider rings when the young and narrow rings when older and larger), which also removes any long-term climate information. Variability on scales of years to multiple decades remains, but variability and trends at longer time scales have been removed. Consequently, these reconstructions do not contain information on long-term trends.

Reconstruction of Rio Grande Stream Flow

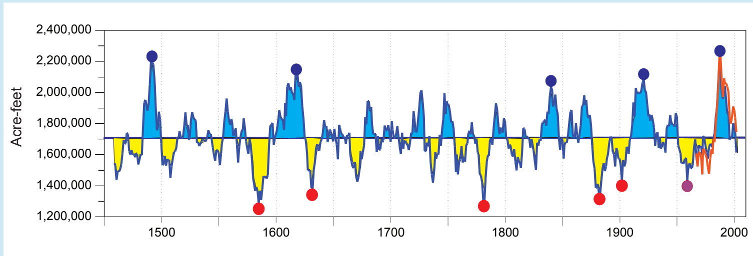
The reconstruction of Rio Grande stream flow extends from 1450 to 2002. This reconstruction can be used to answer questions such as: What have been the wettest and driest periods of flow, and how do those compare to the wettest and driest periods in the 20th and 21st centuries? What has been the frequency and duration of droughts (defined here as single or consecutive years of flow below the full reconstruction median value)?



A) New Mexico Climate Division 5 monsoon (June-August) precipitation and B) Rio Grande at Otowi water year stream flow. Reconstructions are shown in the red line, and observed records in the blue line.

A graphic of the full Rio Grande reconstruction is shown (top of next page), smoothed with a 10-year running average (each point represents the average of that year and the nine preceding years of flow). When all the 10-year periods are ranked, the five driest non-overlapping periods (in order of lowest flows) are

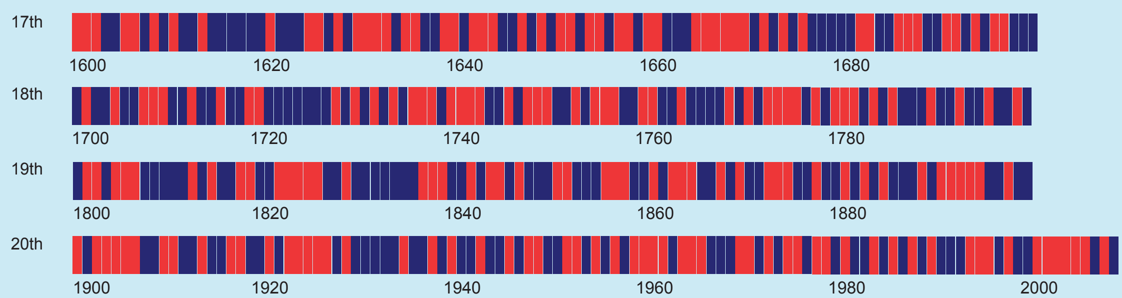
1576–1585, 1772–1781, 1623–1632, 1874–1883, and 1893–1902. The sixth lowest flow period is 1950–1959. In contrast, of the five wettest intervals in this record, two are in the 20th century, 1978–1987 and 1912–1921, ranking #1 and #4 respectively. The others are 1482–1491, 1610–1619, and 1831–1840.



Reconstructed Rio Grande at Otowi gage (data unimpacted by human activities) 1450–2002, smoothed with a 10-year moving average. Reconstruction in blue line, gage record in orange. Yellow fill indicates periods of below average flow and light blue fill indicates periods of above average flow. Dots mark highest (blue) and lowest (red) non-overlapping 10-year averages of Rio Grande flow. The purple dot marks the 6th lowest 10-year flow average.

In terms of drought frequency and duration, if the numbers of single and consecutive years below the long-term median are tabulated, the reconstruction indicates many single year and short-term low flow periods, and fewer longer periods of low flows, as would be expected. From 1900–2002, the longest period of below median flows is four years, but the full reconstruction indicates several five-year low flow periods, and one case each of six, eight, and eleven consecutive years of flow below the median. The eleven-year period occurred from 1772 to 1782.

The Rio Grande reconstruction clearly indicates that the relatively short period of the gage record does not contain the full range of droughts that are part of the long-term natural variability in stream flow. Since this reconstruction and the calibration record only extend to 2002, it is not possible to assess the most recent ten years of flow in the context of the full reconstruction. If we evaluate the gage record farther upstream in the watershed, Rio Grande near Del Norte, Colorado, we find the ten-year average flow interval in the 1950s is the lowest in the gage record when considering values from 1890–2011. The longest period of below median flow in this gage record does not exceed four years. Thus, the most recent ten years of flow do not show characteristics of drought that exceed the severity and duration of droughts in the 20th century, at least based on the Rio Grande gage near Del Norte.



Above median years are blue and below median years are red.

Reconstruction of Monsoon Precipitation

The reconstruction of Rio Grande monsoon precipitation extends from 1600 to 2008. This reconstruction can best address questions that concern sequences of wet and dry years, as mentioned above. What have been the longest runs of wet or dry (above or below the long-term median) years, and how do 20th and 21st century values compare to the full reconstruction?

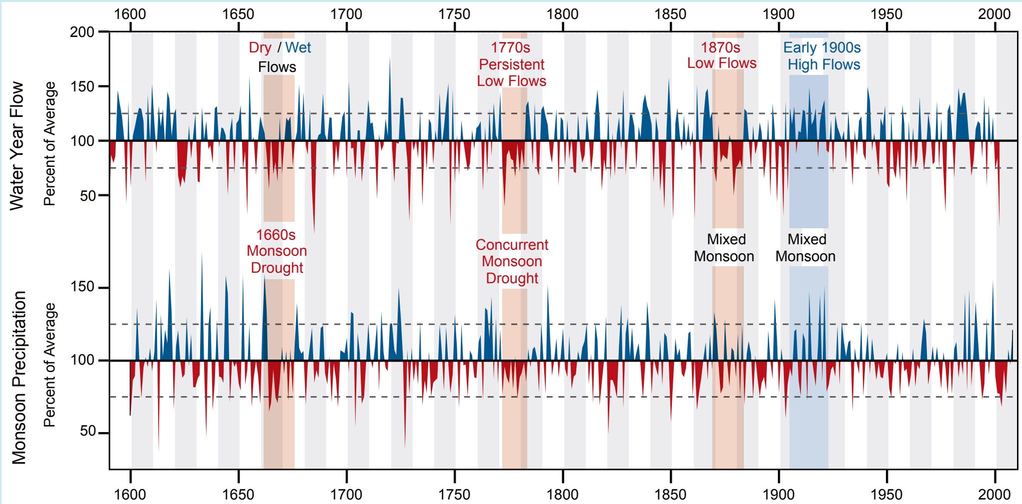
The monsoon reconstruction indicates periods of dry years (consecutive years below the median) lasting as long as six years, whereas periods of wet years extend to runs of seven consecutive years. As with the flow reconstruction, there are more short (one- to two-year) wet and dry periods than longer ones. However, there is a higher proportion of two-year wet periods relative to single wet years (41/54) compared to dry periods (24/63), suggesting wet summers tend to persist several years, relative to dry summers. When the interval 1900–2008 is considered, the longest dry period is six years, one of two six-year runs of below-median precipitation in the full reconstruction. The longest wet period in this interval is five years, whereas the full reconstruction contains one six-year and two seven-year runs of wet years. In several cases, long wet or dry intervals are broken by a single year (e.g., dry periods, 1735–1742, 1958–1965; wet periods 1614–1623, 1826–1835), as is evident in the figure of monsoon reconstruction below.

Again, the reconstruction does not quite extend to the present, but for comparison, the instrumental rainfall record shows six consecutive years of below-median precipitation from 2000–2005, and then below median precipitation in 2007, 2009, and 2011. Except for 2000, this pattern matches the reconstruction through 2008.

Comparison of Stream Flow and Monsoon Reconstructions

A dry winter leads to low runoff and depleted reservoirs (partly a result of management) on the Rio Grande. Monsoon precipitation is particularly important in these years, supplying needed water to crops and rangelands. Since 2000 stream flow at the Rio Grande near Del Norte gage has been below the median in eight of twelve years, as has monsoon precipitation in Division 5; in five of those years, low flows have been followed by dry monsoons. The monsoons can often provide a welcome reprieve to a dry winter, but how often are dry winters followed by dry summers? How often are they followed by wet summers?

The two reconstructions can be compared to address these questions. On a year-to-year basis, monsoon precipitation and Rio Grande stream flow at Otowi are uncorrelated, both in the instrumental and reconstructed record. Based on this, there is no expectation that winter conditions should be related to the monsoons. A comparison of the two records seems to bear this out, documenting a variety of conditions. Examples of different combinations



Reconstructed Rio Grande water year stream flow and Division 5 June–August precipitation, shown as percent of average (based on the full record), 1600–2002 (2008 for stream flow). Wet years are in blue, dry in red, with several examples highlighted.

of seasonal conditions are indicated, in the graphic above including a persistent period of drought and low flow in the 1770s, and the high flows/mostly wet conditions in the early 20th century.

One notable event is the major monsoon drought in the 1660s, with concurrent low flows for much of this monsoon drought. This period coincides with the social upheaval in northern New Mexico that led to the Pueblo Revolt. Many previous reconstructions have indicated this was a period of drought in the cool season; this

	Low Flow Dry Monsoon	High Flow Wet Monsoon	SHARED SUM	Low Flow Wet Monsoon	High Flow Dry Monsoon	OPPOSITE SUM
1600–1649	4	6	**10**	4	6	**10**
1650–1699	6	5	**11**	4	6	**10**
1700–1749	9	6	**15**	2	1	**3**
1750–1799	8	8	**16**	4	3	**7**
1800–1849	5	8	**13**	7	4	**11**
1850–1899	7	5	**12**	6	7	**13**
1900–1949	3	9	**12**	1	3	**4**
1950–1999	5	4	**9**	4	8	**12**
SUM	**47**	**51**	**98**	**32**	**38**	**70**

Number of years by half-century periods with different combinations of flow and monsoon conditions. Years with shared wet or dry conditions are summed, as are years with opposite conditions, and years in each combination. The totals for the periods with markedly more shared and less opposite conditions are highlighted.

monsoon reconstruction is one of the first to indicate conditions were extremely dry during the summer as well.

If the combinations of years with low flow and dry monsoons, high flow and wet monsoons, as well as low flows and wet monsoons, and high flows and dry monsoons are tabulated by half-century periods, it is possible to assess the frequency of years that share wet or dry conditions and years with opposite conditions. Here, a wet year is defined as a year in the wettest third of all values, and a dry year is in the driest third of values. In five of the eight half-century periods, the shared and opposite conditions are approximately even. In the other three, shared conditions predominate. In the period 1700–1749, shared dry conditions are most common, while in 1900–1949, wet conditions are most common, and from 1750–1799, shared wet and dry conditions happen in the same number of years. In contrast, the last half of the 20th century is characterized by more years with opposite conditions (especially high flows followed by dry monsoons) than any other period.

Records of the Past: Representative of the Future?

The reconstructions of past stream flow and monsoon precipitation extend the instrumental record into the past to provide insights on a broader range of hydroclimatic variability than provided by the instrumental records alone. These records demonstrate that the length-limited instrumental record do not contain the most severe or persistent low flow periods that have occurred over the past four centuries. The most persistent monsoon droughts are represented in the period of the gage record, but longer wet periods have occurred in prior centuries. When the stream flow and monsoon reconstructions are examined together over the full reconstruction period, shared seasonal wet or dry conditions are slightly more common than years of opposite conditions, but this varies over time.

Since humans are now having a discernible impact on climate, are these records of past climate still relevant? These records provide information about natural climate variability that has occurred in the past. Natural variability will continue into the future, with the added impacts of climate change. In New Mexico, this means temperatures will be warmer, and winters are likely to be drier (see Earth Matters, Summer 2007). We should expect the droughts like those documented in these records over the past four centuries to occur in the future, but under warmer and possibly drier conditions. The drought conditions we are seeing now are consistent with climate change projections for this region in winter, but so far, they are not beyond the range of conditions expected due to natural climate variability.

—Connie A. Woodhouse and Daniel Griffin

Connie Woodhouse is an associate professor at the University of Arizona in the School of Geography and Development. She studies past environments using tree rings and investigates ways this information can be used by resource managers.

Daniel Griffin is a graduate student at the University of Arizona. His research interests include paleoclimatology, drought, and water resource issues.

Bureau News

A New Bureau Building

Thanks to the hard work of many people on campus and off, New Mexico voters approved General Obligation Bond C in November, which (among other capital outlay projects) will provide $18 million toward a new building on campus for the New Mexico Bureau of Geology and Mineral Resources. This new building will house all of the bureau laboratories, offices, and public facilities including the Mineral Museum. It will also provide classroom and office space for students involved in collaborative research efforts. Finally, it will provide vastly improved public access to the resources the bureau has to offer, including the archives, publications office, and geologic information center. The new building will be located near the corner of Leroy Place and Bullock, adjacent to the Mineral Science and Engineering Complex (MSEC), which houses the Earth and Environmental Science Department. Site work will begin in March, and we anticipate that construction will begin this summer.

Awards and Honors

In 2012 our newest publication, *The Rio Grande: A River Guide to the Geology and Landscapes of Northern New Mexico*, took top honors in the New Mexico-Arizona Books Awards. This past year the publication also received a prestigious Silver Award in the Publishers Association of the West annual design awards.

Earth Science Achievement Awards

In January we announced the winners of the 2013 New Mexico Earth Science Achievement Awards. This year the awards will go to John Fleck of the *Albuquerque Journal* for outstanding contributions advancing the role of earth science in areas of public service and public policy in New Mexico, and to V.J.S. (Tien) Grauch of the U.S. Geological Survey for outstanding contributions advancing the role of earth science in areas of applied science and education in New Mexico. These awards, co-sponsored by the New Mexico Bureau of Geology and Mineral Resources, a division of New Mexico Tech in Socorro, and the Energy, Minerals and Natural Resources Department in Santa Fe, were initiated in 2003 to honor those often-unrecognized champions of earth science issues vital to the future of New Mexico. Selections were made following a statewide nomination process. The award presentation will occur at noon in the rotunda of the state capitol building on Monday, February 4, during the legislative session, in conjunction with Earth Science Day. Several agencies will be staffing tables and displays in the west wing of the Roundhouse from 9 a.m. to 3 p.m. on that day. The presentations will be made by John Bemis, cabinet secretary for the New Mexico Energy, Minerals and Natural Resources Department, and by L. Greer Price, director of the New Mexico Bureau of Geology and Mineral Resources. The public is invited to visit the Roundhouse throughout the day and to attend the ceremony.

San Juan Basin Project

At the end of 2012 the New Mexico Bureau of Geology and Mineral Resources embarked upon a project in the San Juan Basin of northwestern New Mexico. This project is directed toward a more detailed characterization of the Mancos Shale gas reserves and will include not only a re-evaluation of existing reserves but an evaluation of water resources available for future development of these reserves. This project is a joint effort of the Bureau of Geology, the Petroleum Recovery Research Center, and the Department of Petroleum Engineering at New Mexico Tech, and is funded by the U.S. Bureau of Land Management.

The End of an Era

In 2012, after 31 years of service, Jane Calvert Love retired as managing editor for the New Mexico Bureau of Geology and Mineral Resources. Most of you know Jane as the guiding force behind our quarterly, *New Mexico Geology*, which she managed for many years. But Jane managed to leave her mark on virtually all of the publications that we have issued during her tenure. A consummate professional, with a steady hand and a careful eye, there are few editors of Jane's caliber in the workforce these days. All of us will miss her gentle demeanor, her wisdom, and her patient willingness to contribute wherever she could. We wish her well in her retirement.

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Tree-ring Insights on New Mexico's Monsoon and Rio Grande Stream Flow (cont'd)

Additional Information

Web Sites

Investigating North American Monsoon Variability in the Southwestern USA using Instrumental and Tree-Ring Data http://monsoon.ltrr.arizona.edu/index.html

Tree-Ring Monsoon Workshop for Water Managers, May 14, 2012, Albuquerque http://monsoon.ltrr.arizona.edu/documents.html

Treeflow: streamflow reconstructions from tree rings http://treeflow.info/

WestMap, PRISM climate data http://www.cefa.dri.edu/Westmap/

Suggested Reading

North American drought: Reconstructions, causes, and consequences by E. R. Cook, R. Seager, M. A. Cane, and D. W. Stahle, 2007. Earth-Science Reviews 81, pp. 93–134.

Latewood chronology development for summer-moisture reconstruction in the U.S. Southwest, by D. Griffin, D. M. Meko, R. Touchan, S. W. Leavitt, C. A. Woodhouse, 2011. Tree-Ring Research 67, pp. 87–101.

Tree Rings reveal multi-season drought variability in the lower Rio Grande basin, USA, by C. A. Woodhouse, D. M. Meko, D. Griffin, and C. L. Castro, accepted. Water Resources Research.

Rio Grande and Rio Conchos water supply variability from instrumental and paleoclimatic records, by C. A. Woodhouse, D. W. Stahle, and J. Villanueva-Díaz, 2012. Climate Research 51, pp. 125–136. doi: 10.3354/cr01059.

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