CHAPTER THREE

CURRENT ISSUES

DECISION-MAKERS
FIELD CONFERENCE 2003
The Lower Pecos Region

Assessment Of New Mexico's Stream Gaging Program

Tom Morrison and Jack Frost, *Office of the State Engineer*

Many of the activities of the New Mexico Office of the State Engineer and Interstate Stream Commission (OSE/ISC) require high quality data regarding surface water flows, diversions, return flows, and stream effects of ground water pumping. The U.S. Geological Survey (USGS) and the OSE/ISC jointly fund stream gaging at approximately 100 sites in New Mexico. In 2002 the agencies assessed the gages and the statewide network for the ability to meet OSE/ISC goals for the Active River Management (ARM) program. ARM requires accurate stream flow estimates at key sites and river reaches, followed by the capability to process these data quickly and make them available for water managers. Improvement in the measurement of low and high flows is a priority, as these levels are critical to ARM's goals.

The USGS operates our program as part of its national gaging network. Overall, the program has not kept pace with current surface water information needs. These needs include monitoring very low flows in response to drought, the Endangered Species Act, increased competition for water, and the state's interstate compact delivery obligations. The Pecos River, the Rio Grande, and the San Juan River each have been confronted with shortages and new endangered species issues during the recent drought.

Not included in this review are many gages, dam releases, and diversions managed by the Bureau of Reclamation, the Corp of Engineers, and many irrigation and conservation districts. In fact, federal and local entities such as irrigation districts control most of the water works throughout the state. In the past the OSE/ISC has relied on the USGS and these entities for data and procedures in our accounting of surface water movement in New Mexico.

NATURE'S CHALLENGE

Estimating stream flow is difficult at the precision sometimes needed. To estimate flow, stream gages relate stream height to measured discharge. Occasionally, manual flow measurements calibrate (rate) the gage. Most gages are situated on favorable, yet natural stream reaches. Fewer gages have constructed control structures to enhance precision.

The Dunken gage on the Rio Peñasco.

Gaging problems are obvious: The variability in stream flow affects accuracy; data are most abundant for average flow conditions, and poorest during infrequent high and low flows. Many sites have broad sand channels that constantly shift. Tamarisk and other water loving plants choke channels and gages. Low flows meander away from the gage. Although sites are carefully selected, at some locations even the best estimates contain uncertainties unacceptable for monitoring—very low maintenance flows for endangered species, for example. Yet gages are being used for this purpose.

The statewide network straddles water projects including dams, diversions, return flows, and ungaged tributaries. New, constructed stream alterations may facilitate better gaging, but they may not be feasible at many sites. For the foreseeable future labor-intensive, frequent manual measurements are the best solution at some gages.

FINDINGS OF THE ASSESSMENT

By several criteria, the USGS national gaging program has declined, and ours has followed this trend. Declines are attributed primarily to diminished funding. The number of active gages in New Mexico has decreased to about the same number that were active preceding the 1950s drought. Some neighbors, like

Colorado, now do more measurements themselves (as part of their ARM program).

Of the 84 gages inspected in 2002, 19 need to be replaced and 25 require improvements in order to maintain (but not necessarily enhance) data quality. ARM will also require additional, high quality measurement locations, including diversions and returns. However, in planning new gages, it is important to recognize that rivers adapt to constructed structures in such a way that their effectiveness is uncertain until they are installed and calibrated at varying flows.

On a positive note, technology has led to real-time gaging and reporting. Most gage data are now telemetered to the USGS, processed, and posted on the Internet. However, processing time lags (called "finalizing the data") have caused problems in instances where information is needed for endangered species and compact compliance. Although provisional, real time data are relied on by many water managers.

BASIN CONDITIONS

For compact accounting and other purposes, the agencies identified 14 gages as most important in the cooperative program. The distribution of key gages by basin is as follows:

Pecos River	5
Middle Rio Grande	4
San Juan River	3
Upper Rio Grande	2

In the Pecos River basin, sandy channels and very low flows result in poor discharge estimation. Although important for compact administration, several sites are very problematic. Although average flows are much higher in the Rio Grande basin, several sites are problematic because of shifting and infilling channels. For example, San Marcial is critical for the silvery minnow, yet the channel has built up 15 feet, and low flows elude measurement.

PECOS AT ACME GAGE

Measurements of the Pecos River at Acme gage are essential for compact accounting and are also relied upon for maintaining minimum flows for the Pecos bluntnose shiner. Two gages monitor this site, one on each side of the channel, which is subject to very low flows. The gages switch back and forth depending on which side of the channel is occupied by the flow. The wide channel means small stream-height changes are associated with large changes in flow. Block releases at Sumner Dam also affect the channel and gages when higher flows leave the channel and move into the salt cedars lining the bank. Consequently, the gage rating is unstable, and the daily discharge estimates are poor (estimates may err more than 15 percent), whereas the annual records are rated "good" (within 10 percent). Because of the site conditions, no gage enhancement by itself will improve the flow estimates. The USGS has suggested a Web camera to observe flow conditions in real time, a control structure to guide low water toward a gage, and removal of salt cedars for about a mile above and below the gage.

According to the USGS, an "excellent" record (meaning 95 percent of the daily discharge data are within 5 percent of actual flow) is not achievable at this gage. The USGS states, "Good to fair is the best accuracy level that can be achieved over a long period." This translates into estimation accuracy where 95 percent of the daily records are within 15 percent of the actual flow.

NEW GAGES

Further study is needed to identify additional gaging sites. Future gaging requirements will be influenced by new stresses like municipal direct surface water diversion projects. Measurement needs associated with irrigation districts and acequias also require consideration. For example, the Middle Rio Grande Conservation District, one of the state's largest water users, only recently began measuring its diversions and returns. We need an integrated gaging plan that includes stakeholder participation.

FUNDING CONSIDERATIONS

In addition to challenging field conditions, funding availability has influenced the surface water program. Due to the constant threat of federal funding reductions, the agencies' ability to maintain the program is at risk. For the 2002 fiscal year both the State and USGS each provided $442,000 to fund the program. In a change to long-standing practice, in the 2003 fiscal year the USGS was no longer able to maintain an even match.

The New Mexico base cost is $11,900 per gage, similar to surrounding states. Of 84 gages, the USGS identified 17 substantial control-structure improvements totaling $300,000. Additional capital improvements were identified, but the effectiveness of different options requires further evaluation. A final determination of total funding needs to implement ARM goals must await detailed scoping.

IN CONCLUSION

Accurate flow estimates are fundamental for proper management of surface water resources. OSE/ISC, like agencies in most western states, still relies on the USGS for stream gaging. The stream-gaging expertise of the USGS is well established, and they are widely recognized for their independence and reliability, which confers a level of legitimacy in litigation and interstate compact interactions. Overall the cooperative program has served New Mexico reasonably well. Unfortunately, the existing gaging program has not kept pace with today's information demands. To adopt a more proactive stance in river management, New Mexico should begin conducting its own measurements to augment the USGS gaging program. Although the USGS has maintained a viable program, there are obstacles to addressing today's challenges. Water accounting has a long way to go in New Mexico, and it is important to recognize that there are limitations to accurate measurement caused by nature.

Although this gage assessment outlines many local improvements, it does not fully address the actions needed to improve the statewide network. Where gaging is inadequate, further study must determine whether more frequent measurement, improved controls or gages, or replacement or relocation, is the best approach. The future responsibilities and gaging plans of federal agencies and entities like tribes, municipalities, irrigation districts, and acequias have yet to be considered. An integrated gaging network must include stakeholder participation and funding, and it will require coordination between the various parties.

Ground Water Is Renewable Only If Managed That Way

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About half of the water used in New Mexico comes from aquifers—those underground geological strata that will yield water readily to wells. Annual ground water depletions have increased from less than a half million acre-feet in 1940 to one million acre-feet in 1965 and about 1.4 million acre-feet in 1990. More significantly, 90 percent of New Mexico's population uses ground water for its drinking water. This is the highest percentage anywhere in the western United States and the fourth highest in the United States. Although there is a huge amount of ground water in the state (thought to be around 20 billion acre-feet), only one-fourth of that is relatively fresh water.

Of course 5 billion acre-feet of fresh water is still a huge amount. So why are we worried? Because that water is spread so unevenly over the state. Some ground water, as in parts of the Rio Grande valley, the Roswell artesian basin, and parts of New Mexico's High Plains, is in great aquifers. But that is precisely the ground water already being heavily exploited or over-exploited, which is central to our concerns here. The rest, although cumulatively still a huge amount, is spread widely in small volumes in limited aquifers, remote locales, fluctuating (therefore unreliable) volumes, at great (therefore uneconomic) depths, of marginal quality, or is present in other situations that make it unavailable for other than local or small-scale use.

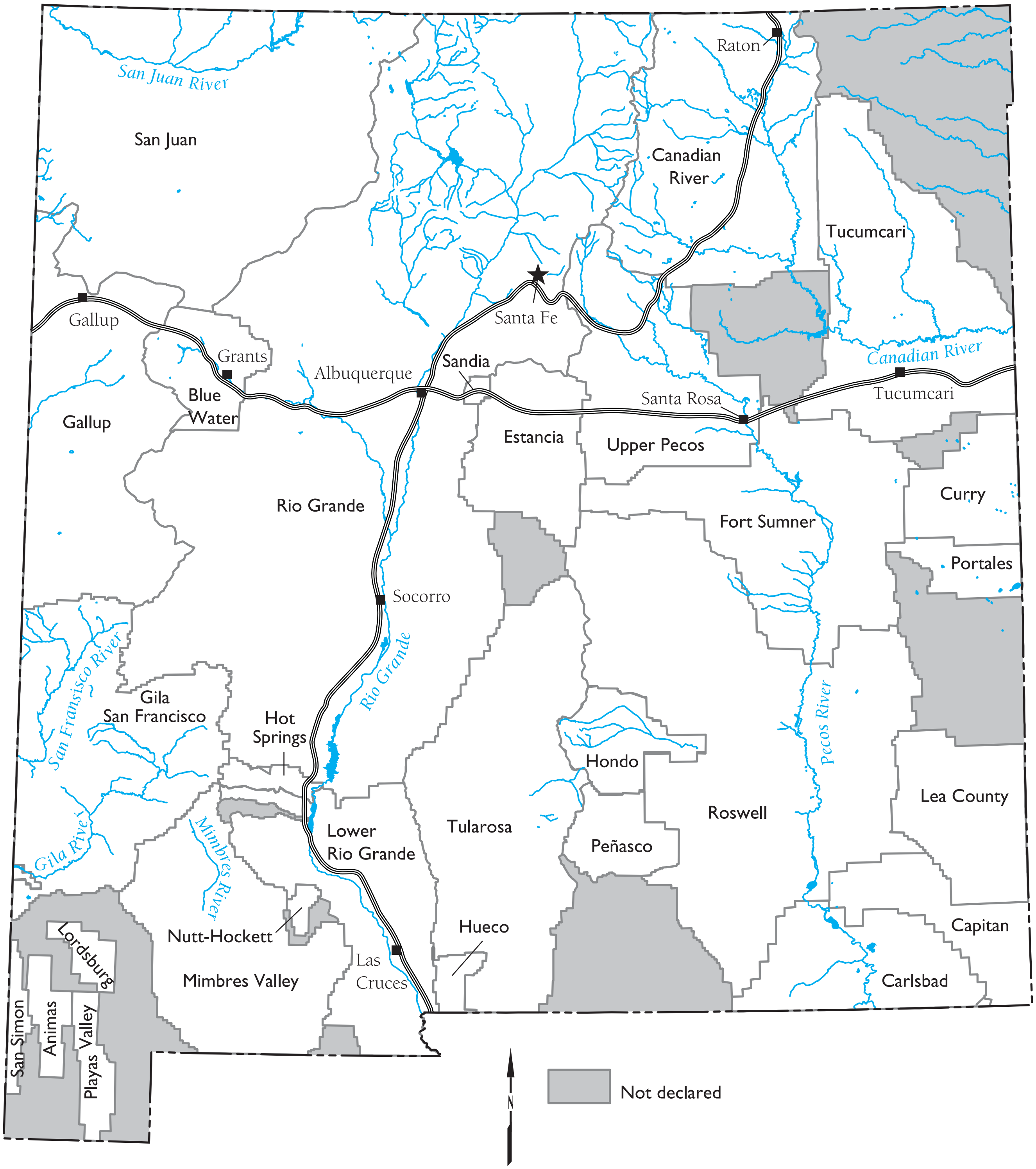
Unfortunately, because in the past we have elected to "administer water rights" rather than manage our water resources, we find ourselves relying more and more on ground water resources that are being used up. In areas where there is no recharge from surface water, the state engineer usually assigns ground water basins a forty-year life and assumes that new appropriations will not impair existing users, so long as the water in the aquifer will last each permittee (including the last to get a permit) at least 40 years. In stream-connected aquifers, the state engineer allows mining of ground water at rates that exceed the rate of aquifer recharge. When these policies were developed, the hope was that additional water could be obtained when needed from new water projects. The consensus now is that no new, large-scale water projects will be built and that water importation from outside the state is not likely in the foreseeable future. After all, other states are finding their populations increasing and their water reserves diminishing, just like New Mexico.

In some areas of the state, aquifers are declining at an alarming rate. This is true for parts of the Ogallala aquifer, a giant aquifer that stretches through eight states, including much of the eastern part of New Mexico. As the state engineer's office stated in a 1999 report, "…concentrated pumping in Curry and Roosevelt Counties in New Mexico as well as Bailey County in Texas will de-water large portions of the most productive areas of the basin as early as the year 2010." The Albuquerque aquifer is also suffering major declines. Locally, around some city wells, the water table has been lowered more than 150 feet. The rate of ground water mining in the middle Rio Grande is estimated at approximately 60,000 acre-feet per year.

We cannot continue to mine our ground water at current rates. Not only will we run out of water—in some places quite soon—but using more water will reduce river flows, dry up many springs, and potentially lead to land-surface subsidence, as occurred recently near the Buckman well field west of Santa Fe. Finally, holders of senior surface water rights suffer impairment from excessive ground water pumping.

THE WAY THE GROUND WATER RIGHTS SYSTEM WORKS

Until the state engineer "declares" a ground water basin, people may drill new wells without needing any approval whatsoever from the state engineer. New wells in undeclared ground water basins, or outside the declared boundaries of other basins, have been at the heart of serious water resource problems in our most important water basins. In the Pecos River valley, this process—unbridled ground water exploitation to the detriment of river flow—was well advanced



Declared ground water basins. Figure is from the Office of the State Engineer.

Declared Ground Water Basins	
Year	**Square miles**
1970	40,067
1980	71,706
1990	86,073
1997	102,598
1998	107,925
2000	110,345

Declared ground water basins in New Mexico.

decades before the functional interdependence between ground water and river flow was appreciated.

Once a ground water basin has been declared by the state engineer, new wells require a permit. Even so, water rights for wells in place when the basin was declared unfortunately are not compiled or separately evaluated when the basin is declared; that occurs only if the basin is adjudicated. By statute, the state engineer can approve applications for new water uses only if there is unappropriated water, and if the new use of water will not impair existing water rights. As noted above, however, in basins isolated from stream systems, well interference is allowed so long as the basin will provide water for the 40-year period designated by the state engineer as the "life of the basin."

In stream-connected aquifers, the state engineer now makes an effort to protect senior surface water rights and to keep the river "whole" for purposes of delivering water to downstream users and as required by interstate stream compacts and treaties with Mexico. The state engineer considers the timing and extent of anticipated pumping impacts on existing surface water rights in the streams. In theory, he allows new appropriations of ground water that will impact surface water only if there is no impairment to senior water rights owners and if the applicant buys and retires existing surface water rights to protect the river from further flow reductions.

Even so, the safeguards against ever-increasing interference with surface water rights through ground water exploitation are sometimes inadequate. State engineer models often have overestimated return flows, thus underestimating surface water depletions from pumping. And surface water rights provided by applicants to offset depletion often have been rights never exercised regularly or fully, which is exactly why they were for sale, whereas the new ground water permits tend to be fully exercised. In addition, pre-basin water rights—those that come from pumping before a ground water basin is declared—carry with them the right to deplete surface water up to the full amount of the right. Not only are these rights not listed separately in compilations of surface water rights, but they have the disconcerting impact of causing surface water depletions that are delayed, and that increase year after year over a long period of time. All in all, cumulative impacts of pumping on surface water flows are inexorably increasing in many places in the state.

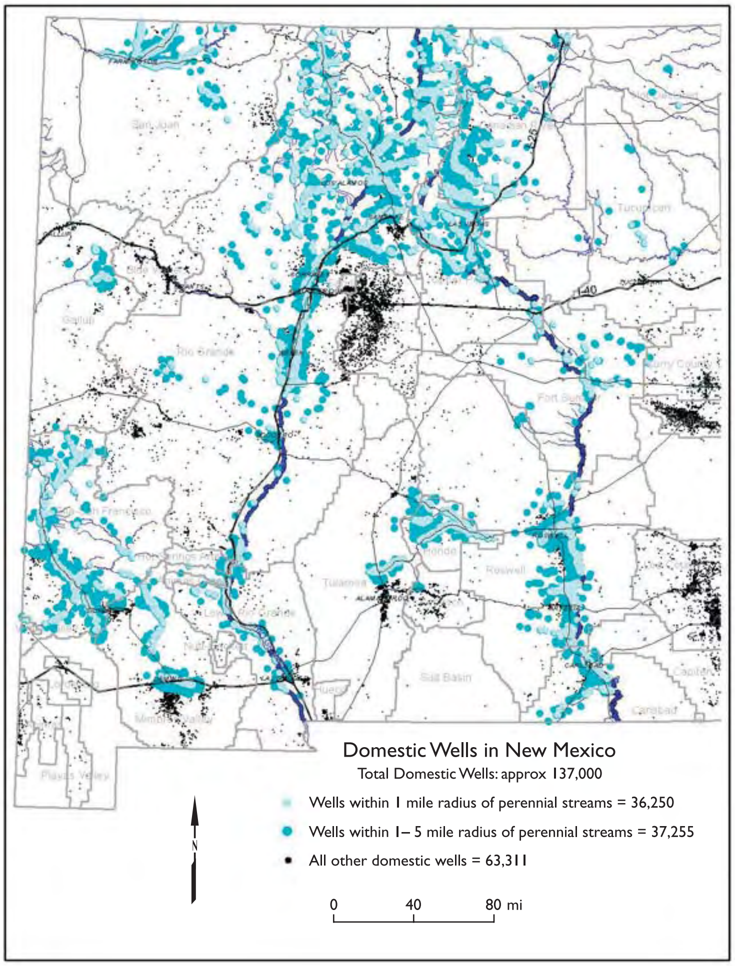
Interestingly, in a few places, the opposite is occurring. Some cities are pumping ground water, running sewage through water treatment plants, and discharging the treated effluent into a river at a greater rate than the accumulating negative effects on surface flow from the ground water pumping. Albuquerque's water treatment plant, for example, has a sign at the canal where its treated discharge flows into the Rio Grande announcing that this is the river's fifth largest tributary. Meanwhile, the city's ground water mining in the past 40 years has lowered the water table more than 100 feet under much of the city.

LACK OF METERING

The state requires well-discharge metering only in parts of some of its ground water regions, and there, only of large-yield wells. Domestic wells in most basins are not required to be metered unless they serve more than one household. We can estimate only roughly how much ground water domestic wells are withdrawing. And we don't know how much of the withdrawals are depleted, how much is returned to ground water as recharge, or what the effects are on surface water. Without this information, we cannot hope to develop an accurate and detailed water budget for the state's ground water use.

THE DOMESTIC WELL EXEMPTION

There is a significant exception to the prohibition against any new water uses that will interfere with existing users. It is the so-called "domestic well statute." This law provides that anyone may obtain a state permit for a domestic supply well—no matter what the consequences for anyone else's water rights. (A few municipalities have placed limitations on this.) Regulations have (until recently) allowed a standard three acre-feet per year (2,680 gallons per day) to be pumped, even though the state engineer estimates gross withdrawals per residence to average 0.35 acre-feet per year (313 gallons per day). The state engineer's office now estimates that about nine percent of New Mexico's residents rely on domestic wells.



Domestic wells from W.A.T.E.R.S. database, Office of the State Engineer, August 2000.

When the domestic well statute was enacted in 1953, people believed that domestic wells would not have much impact on aquifers. The state engineer's office has issued approximately 140,000 domestic well permits since then, however, and it continues to issue thousands of new permits each year. In 1999 nearly 6,000 domestic well permit applications were received and approved.

A recent report from the Office of the State Engineer on the domestic wells estimates that the potential annual domestic use ground water withdrawals range between 48,000 and 137,000 acre-feet per year (assuming the average amount withdrawn ranges between 0.35 and 1.0), roughly 45 percent of which is estimated to be net depletions. Yet with 140,000 domestic wells permitted at three acre-feet each, the actual withdrawals and depletions legally could be as high as ten times these amounts. We simply don't know.

The state engineer has concluded that the current domestic well statute gives him no discretion to deny an application and no grounds for investigating whether a domestic well would potentially impair senior water rights. Thus, although many of the tens of thousands of domestic wells in the state (when considered cumulatively) are interfering with senior water rights, new wells continue to be approved automatically. Whether or not the state engineer can constitutionally grant domestic well permits for wells that will impair existing water rights, it is plainly bad policy to ignore the impacts of those wells in areas where ground water aquifers are already overtaxed and where ground water demands are depleting water from fully appropriated stream systems.

For nearly 10 years the state legislature has tussled with the idea of changing domestic well policy. Policies from the Office of the State Engineer for most of this period have been nebulous and therefore have offered scant guidance to legislators. Recently, though, the state engineer's policies have become more focused. In recent annual legislative sessions, bills have been introduced that would mandate change, but they have died in committee.

Even though the state engineer believes that domestic wells cumulatively are impairing surface water rights in some areas, as well as the state's ability to meet its compact obligations, he has yet to amend the general regulations specifying a production limit. However, he has agreed that domestic well production may have more stringent restrictions imposed by local governments. Santa Fe County, for example, limits domestic wells in certain areas to 0.25 acre-feet per residence (223 gallons per day).

In a few adjudications, including in the *Aamodt* water rights adjudication in the Pojoaque valley, the court limited domestic wells to providing indoor water only (although a subsequent agreement in *Aamodt* has been reached that allows use of as much as 0.7 acre-foot per residence per year, or 625 gallons per day). Pursuant to a court order in *Arizona v. California*, on the Gila River the state engineer grants new domestic wells permits only for indoor use. Finally, in new guidelines for the Estancia Valley, the state engineer allows new domestic wells 0.5 acre-feet per year (447 gallons per day). If the well supplements an existing, permitted well, or if it also provides livestock water, it gets three acre-feet, but it must be metered.

SOME SOLUTIONS

Given the increasing population and corresponding increasing water demands in New Mexico, we do not think that the state realistically can reduce its ground water use to a truly sustainable level any time soon. We simply have grown too dependent on mining ground water (that is, exceeding the replenishment rates of an aquifer). To date, we've shown no willingness to limit water use to the amount annually available or to take the steps necessary to link growth to water availability.

Putting aside questions of whether sustainable ground water use is possible, or even desirable, we believe there are many steps that can and should be taken to improve the state's management of its ground water and begin to approach a more sustainable level of use. At minimum, these steps will help to reduce water waste, reduce impairment of senior water rights, and ensure that we use our ground water in the manner that most benefits the people of the state.

METERING AND REPORTING

Metering and measuring water is a cornerstone upon which effective and equitable water management depends. Whether the tiered ground water regulatory system described below is adopted or not, we must require metering on most, if not all, wells and return flows, and require reporting the results to the state engineer. Metering not only provides crucial data on water use, it is clear that it also can reduce water use. Presumably this is because the metering data give immediate and accurate feedback to water users. Without metering, it is difficult to develop and apply a water budget.

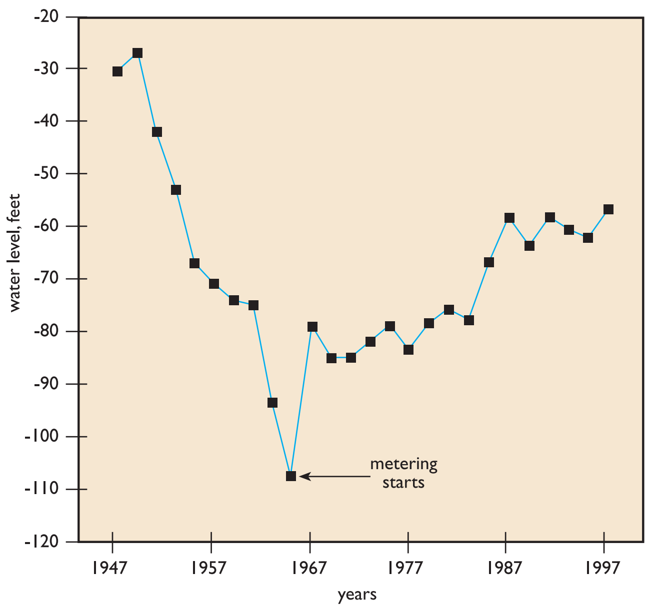
The degree to which metering and reporting to the state engineer are required could vary according to the degree of ground water problems in different areas, if a tiered system were to be adopted. Issues that need to be considered include whether the requirements would affect existing wells or only new wells, whether meters should be required on wells with very limited output, and how reporting to the state engineer would be implemented.

TIERED WATER MANAGEMENT AREAS

Some areas of the state are experiencing severe ground water declines and shortages. In other areas, demand is not yet outstripping supply, and there is no immediate need to alter the current regulatory system. This variation in impacts on available ground water calls for a layered or tiered regulatory system, with greater controls where the impacts are more severe and where communities' water supplies are most threatened.

We support a three-tiered ground water management system for the state. The most aggressive management would be in "critical management areas" (CMAs), those areas with excessive ground water level declines or where existing water rights are being impaired. The second tier would be an intermediate set of regulations for "Stressed Water Management Areas," where population density is sufficient to have a significant impact on water supply and the area is at risk of becoming a CMA but the problems are still less severe than those in a CMA. Measures could be taken in stressed water management areas that would be designed to prevent the need to elevate them to CMAs, or at least to delay elevation for some time. The third tier would be for areas that are sparsely populated, and where wells are dispersed and have a minimal impact on water supply and on other users (i.e., "minimal impact areas"); changes in these areas would be minimal or non-existent.

Recently, the state engineer has developed basin-specific ground water management guidelines for three areas with serious aquifer overuse problems: New Mexico's lower Rio Grande (below Elephant



Pecos aquifer well levels in the Roswell artesian basin. Vertical scale represents average water levels below land surface in 10 wells, measured 3 times per month. Figure from New Mexico State University, Agricultural Service Center.

Butte Reservoir), the middle Rio Grande valley, and the Estancia Basin. CMAs are established where ground water levels are declining rapidly and where the saturated thickness of an aquifer is expected to go below specified minimum levels within the 40-year planning period. The guidelines, among other things, attempt to protect CMAs by imposing extra limitations on pumping in and adjacent to those areas. The guidelines' restrictions on CMAs include some limits on domestic wells (required metering, prohibition on outdoor watering) and a prohibition on new appropriations. We applaud these new guidelines, but suggest there is a need for a more systematic process to establish and manage stressed and critical management areas throughout the state.

DOMESTIC WELLS

Domestic wells should be regulated. New local guidelines by the previous state engineer, Tom Turney, were encouraging. We trust that the new state engineer, John D'Antonio, will continue and expand these policy revisions. It is foolish for the state engineer to continue the inflexible pattern of past decades when wise water management statewide is so clearly needed.

In critical management areas, where an aquifer is in dire straits, new domestic wells should either be prohibited (unless existing water rights are acquired to offset the impacts), limited to 0.25 acre-feet per year, or limited to indoor use. Where a public water supply is available, domestic wells could easily be prohibited. (They are prohibited by municipalities in some limited areas.) Except in minimal impact areas, the developer or homeowners for all new developments should have to acquire sufficient water rights to supply the development rather than relying on domestic wells.

Metering of all new domestic wells should be required, and retrofitting meters on existing wells should be considered. Existing wells could be restricted to their historical use amounts—consistent with existing law that requires that a water right exists only for that water that has been beneficially used. In almost all cases this will be significantly less than three acre-feet per year. Residents would still be free to acquire additional water rights and transfer them to their residence if they wanted to have supplemental water. Acceptance of mandatory metering of domestic wells for existing wells could be greatly enhanced if the state provided at least partial funding. Meters can cost from about $85 to $250.

For effective regulation of domestic wells, the domestic well statute under NMSA 1978 chap 72, arts. 12-1 will have to be amended. A first step was taken in 2001 when the legislature enabled municipalities with water systems to prohibit new domestic wells near existing water lines. We trust that the legislature will ultimately accept this responsibility. The state engineer should have additional discretion to condition or deny new domestic well permits in areas where new wells would impair the right of existing users or hinder the state's ability to make interstate compact deliveries.

RECOMMENDATIONS:

- Create a tiered ground water management system with appropriate safeguards to protect areas where ground water supplies are threatened.
- Increase measuring, metering, and reporting of water diversions and consumption.
- Amend domestic well regulations and statutes to reduce the amount of pumping allowed and to remove the statutory requirement that every domestic well application must be approved; thereby limiting domestic-well impairment of prior rights and negative impacts on interstate compact deliveries.

This paper is a slightly modified version of a paper that first appeared as chapter 5 in *Taking Charge of Our Water Destiny* by Belin, Bokum & Titus (2002).

SUGGESTED READING

William M. Alley, Thomas E. Reilly, O. Lehn Franke, 1999, "Sustainability of Ground-Water Resources," USGS Circular 1186.

Belin, Alletta, Bokum, Consuelo, and Titus, Frank, 2002, Taking charge of our water destiny: A water management policy guide for New Mexico in the 21st century: 1000 Friends of New Mexico, 82 pp.

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Environmental Regulation of New Mexico's Dairy Industry

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Dairy farming in New Mexico has a long history dating back to Spanish colonization. According to the New Mexico Department of Agriculture, herd sizes statewide were as large as 40,000 in 1912, growing to 83,000 by the 1940s. During the middle part of the century herd sizes fluctuated as the dairy industry made the nationwide transition from small independent dairy farms to larger operations, marketing through nationwide cooperatives. The late 1990s were a period of rapid growth for New Mexico's dairy industry. The New Mexico State University Cooperative Extension Service reports that the industry grew from 105 producers and 80,000 cows statewide in 1990 to 175 producers and 310,000 cows in 2003. The industry had a 375 percent increase in overall milk production statewide during the same period. New Mexico now ranks seventh in the nation in milk production, eighth in the nation for cheese production, and has the largest number of cows per herd in the nation. New Mexico State University estimated the economic impact of New Mexico's dairy industry as approximately 1.5 billion dollars in the year 2000.

The large influx of dairies relocating to New Mexico from California, Texas, and Arizona in the early 1990s is attributed to a combination of several factors, including an ideal climate for herd health, availability of ready-made feed supplies, improved methods of transporting milk, and affordable farm land. The largest milk-producing counties in New Mexico are Chaves, Doña Ana, Roosevelt, Curry, Lea, and Eddy.

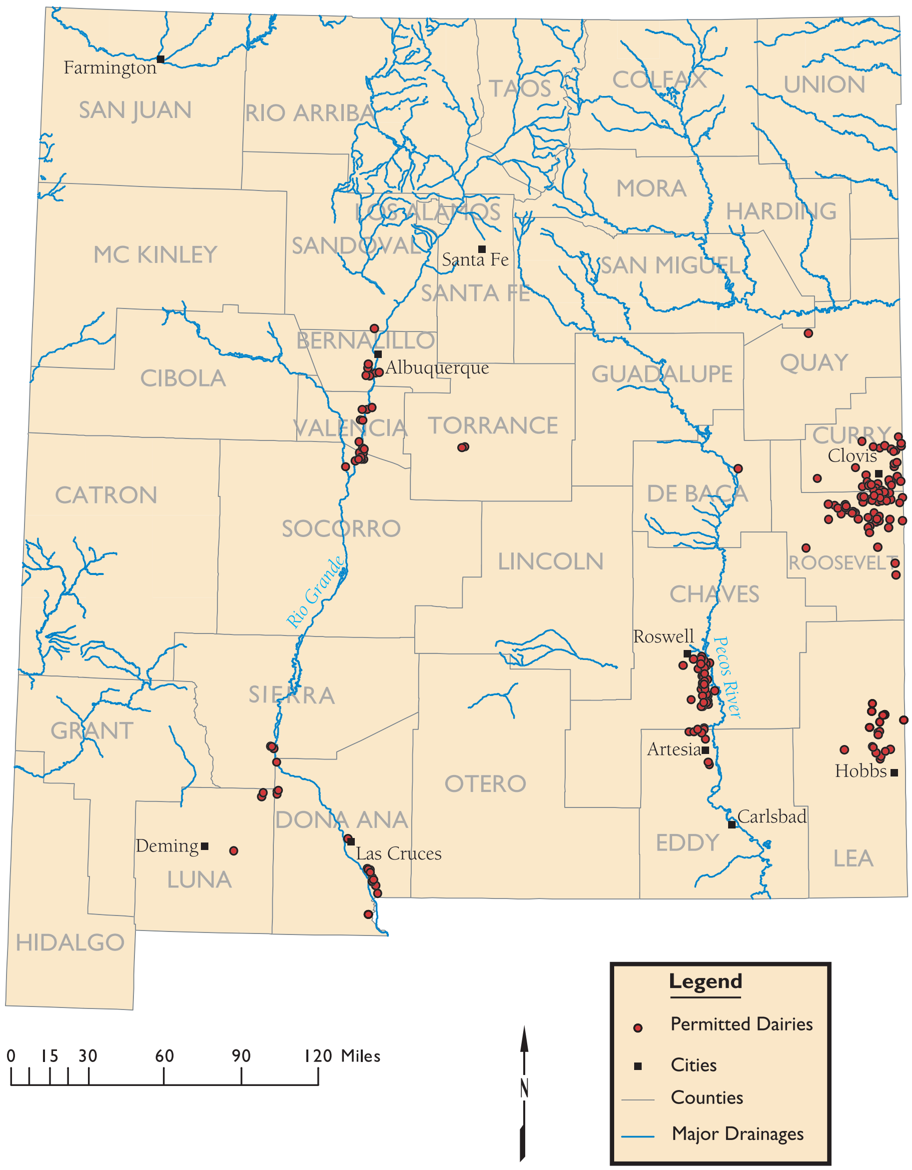
A routine part of business start-up operations for a dairy facility is obtaining required permits. Dairies are regulated by multiple state and federal agencies including the U.S. Food and Drug Administration, U.S. Department of Agriculture (USDA), U.S. Environmental Protection Agency (EPA), New Mexico Department of Agriculture (NMDA), New Mexico Office of the State Engineer (OSE) and the New Mexico Environment Department (NMED).

This paper will serve as an introduction to environmental regulation of the dairy industry in New Mexico, with a focus on water-quality regulation under the jurisdiction of the New Mexico Environment Department.

LAWS AND REGULATIONS GOVERNING WATER QUALITY AT DAIRY FACILITIES

Both state and federal agencies play a significant role in water-quality protection in New Mexico. New Mexico's ground water protection program was well established before most federal legislation and regulations addressing ground water quality were adopted. In 1967 the state's first water-quality protection law, the Water Quality Act, was adopted by the New Mexico legislature. This law was amended in 1973 to allow the State of New Mexico to adopt regulations requiring permits for water-quality protection.

By 1977 the State of New Mexico had adopted a comprehensive ground water-quality program applicable to most types of discharges through regulations promulgated by the New Mexico Water Quality Control Commission (WQCC). The WQCC regulations are the basic framework for New Mexico's water-quality management and protection programs. Key features of the WQCC regulations include numerical ground water quality standards, ground water discharge permit and pollution prevention requirements, and abatement requirements. The regulations and standards are designed to protect all ground water in New Mexico with a total dissolved solids concentration of 10,000 milligrams per liter (mg/l) or less.



Permitted dairies in New Mexico.

The foundation of the state's ground water pollution prevention program is the ground water discharge permit regulations. These regulations require that a person discharging onto or below the surface of the ground demonstrate that the discharge will not cause ground water standards to be exceeded at any place of withdrawal for present or foreseeable future use, and will not cause any stream standard to be violated. NMED's Ground Water Quality Bureau (GWQB) is responsible for administration of the WQCC ground water regulations as they apply to mining, industrial, domestic, and agricultural discharges. Ground water discharge permits include industry-specific and site-specific requirements.

The State also coordinates with the EPA in implementing the federal Clean Water Act, Safe Drinking Water Act, and other federal laws that contain water-quality protection provisions. The EPA administers permits that are applicable to Concentrated Animal Feeding Operations (CAFOs) pursuant to the federal Clean Water Act. These permits are federal permits intended primarily to protect surface water quality. The NMED Surface Water Quality Bureau (SWQB) coordinates with EPA in administering the CAFO program by certifying permits, conducting inspections, and providing program information to the public and permittees.

SOURCES OF GROUND WATER CONTAMINATION AT DAIRIES

New Mexico's dairies are concentrated in four areas. Three of these areas are located over alluvial aquifers along the middle Rio Grande, lower Rio Grande, and the Pecos River near Roswell. The fourth area is clustered in the east-central and southeastern side of the state on the Llano Estacado, which overlies the Ogallala aquifer. Shallow ground water and highly permeable coarse-grained sediments in alluvial environments along the Pecos River and Rio Grande are highly vulnerable to migration of contaminants to ground water. The permeable sediments overlying the Ogallala aquifer and its equivalent are also vulnerable to contaminant migration, although ground water occurs at greater depths in this area.

The primary ground water contaminant at dairies is nitrate, which is present in the form of organic nitrogen in dairy wastewater. Wastewater that moves downward through the vadose (unsaturated) zone usually encounters conditions that allow the conversion of organic nitrogen to nitrate, a common contaminant in ground water. Total nitrogen concentrations in dairy wastewater typically range from 200 to 500 mg/l as compared with domestic wastewater, which averages 60 mg/l. Nitrate is the contaminant of primary concern at dairies because the ground water standard of 10 mg/l for nitrate is based on human health impacts. Chloride and total dissolved solids present in the wastewater may also threaten ground water quality. NMED has identified ground water contamination at approximately 30 percent of permitted dairies, contamination that is primarily associated with past waste disposal practices. At several of these sites, nitrate concentrations in ground water have exceeded 150 mg/l.

Wastewater at dairies is typically disposed of by evaporation in lagoons and/or by land application to crops. Potential wastewater discharge sites at a dairy may include: the collection sump, wastewater delivery pipelines, irrigation ditches, storage lagoons, stormwater lagoons, manure solids storage, and land application areas. Unlined or improperly lined storage lagoons present the greatest risk of subsurface wastewater migration due to the constant hydraulic head that is produced from standing water in the lagoon.

Areas in which wastewater is applied to a crop can also be a significant source of ground water contamination when wastewater containing high concentrations of nitrogen is applied unevenly or at a rate that exceeds the nitrogen utilization capacity of the crops being grown. Facilities may apply chemical fertilizer and manure solids in addition to wastewater and therefore exceed the nitrogen uptake capacity of the crop. The vulnerability of certain soils to rapid infiltration is an important consideration in the design of land application programs.

As the dairy industry has grown in New Mexico, so has the understanding of management practices best suited for ground water protection at dairy operations. Initially, permits for dairies focused primarily on wastewater lagoons, the need for liners, and ground water monitoring. As the understanding of contaminant sources has progressed and data from ground water monitoring has become available, a more integrated approach to ground water protection based on site-specific dairy operations has been developed. For example, permits now require crop and nutrient management plans and include soil sampling to provide

Protection of New Mexico's Ground Water Resources

Programs to prevent ground water pollution have proven to be much more effective than cleanup programs in sustaining usable ground water supplies. Prevention of ground water pollution is much more cost effective than trying to clean up an aquifer after it has become contaminated. Cleanup is always expensive, often costing hundreds of thousands or even millions of dollars, and taking many years. In fact, cleanup is sometimes impossible at any price. Therefore, it is much less expensive in the long run to be sure that adequate resources are devoted to prevention of ground water pollution.

The ground water pollution prevention provisions of the WQCC regulations are designed to ensure the long-term protection of New Mexico's ground water resources. These ground water resources are essential to sustaining the state's populace, business, and agriculture. Approximately 90 percent of the total population of the state depends on ground water for drinking water. Nearly 80 percent of the population is served by public systems with water derived from ground water sources. Approximately 10 percent of the state population depends on private wells for drinking water. Nearly half of the total water annually withdrawn for all uses in New Mexico, including agriculture and industry, is ground water, the only practical source of water in many areas of the state.

In recent drought years, the state has depended even more heavily on ground water to sustain the state's residential population and business community. New Mexico encompasses some of the fastest growing areas in the United States. According to the U.S. Census Bureau, the population of New Mexico increased by more than 20 percent from 1990 to 2000. In November 1998, U.S. News and Water Online reported that population growth in parts of New Mexico is expected to outpace the water supply by 2025, despite conservation and reclamation projects. If these growth trends hold true for the future, New Mexico's need for clean water supplies will increase each decade. The scarcity of fresh water is and will continue to be one of the biggest issues facing New Mexico.

for early detection of potential ground water contamination. All dairies with lagoon systems now are required to have properly constructed liners with engineering oversight. Site-specific conditions dictate whether the liner is clay or synthetic. Written policies and guidelines have improved consistency in the requirements imposed on different facilities, and in communicating to the regulated community minimum standards for permit approval. The program has also been working with older permitted facilities to bring them into compliance with current standards, policies, and guidelines. As a result of these types of improvements, ground water permits are more protective of ground water quality today than in the past.

COOPERATIVE APPROACH TO WATER-QUALITY PROTECTION

During the past several years the Ground Water Quality Bureau has established a proactive and cooperative working relationship with dairy producers as well as other agencies that regulate and assist dairies. The New Mexico Environment Department understands that input from dairy producers provides important insight into dairy operations that is essential for developing practical management practices that are protective of ground water quality.

In light of the potential contamination sources associated with dairy operations, NMED and the dairy producers worked together in 1996 to develop a policy that set forth best management practices for storage and disposal of dairy wastes. The policy was designed to provide flexibility as well as consistency in the application of the regulations to the dairy facilities. The GWQB has also developed guidelines for liner material and construction of clay and synthetic lined lagoons as well as other guidelines that are applicable to dairy facilities. In 1997 the GWQB established a technical working group to provide a forum for open exchange of technical information related to ground water quality protection issues involving dairy operations. The dairy technical working group includes representatives from agriculture and dairy organizations, academia, state, federal and local agencies, and individual dairy farmers.

The federal CAFO regulations and permit requirements have significant overlap with ground water discharge permit requirements. Dairy operators are concerned about duplication of state and federal requirements. NMED has undertaken a collaborative effort to develop a unified regulatory approach for dairies that would satisfy requirements of both the federal Clean Water Act and the state Water Quality Act, within the limitations of each statute and respective regulations. Toward this goal the GWQB and SWQB are working with EPA and the Natural Resources Conservation Service to increase permit consistency and to reduce regulatory duplication and confusion.

Collaboration on water-quality protection between agencies and the regulated community has resulted in a better understanding of issues and a more comprehensive approach to regulation of dairies, which improves NMED's ability to protect water quality.

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Post-Wildfire Hydrology: Effects of Wildfire in New Mexico Ecosystems and Hydrological Response of Burned Watersheds

Deborah A. Martin, *U.S. Geological Survey*

New Mexico is dominated by fire-adapted ecosystems that have experienced frequent wildfires. On the basis of charcoal in bog sediments from the Jemez Mountains, scientists have determined that wildfires periodically burned these ecosystems throughout the last 9,000 years. However, since 1880 charcoal is noticeably absent from bog sediment cores, and the number of fire scars preserved on trees is significantly less. Both types of evidence indicate that the frequency of wildfires had diminished during the past century, probably as a result of overgrazing and active fire suppression.

In recent decades, however, there has been a dramatic increase in the frequency and size of wildfires in New Mexico. In the ten years between 1992 and 2002, an average of 1,986 fires per year burned an average of over 250,000 acres per year. More significant is the change in fire type, from low-intensity ground fires to stand-replacing fires in ponderosa pine ecosystems, which may then experience substantial flooding and erosion. This paper evaluates the hydrological and erosional consequences of wildfire by asking the question, "How are burned watersheds fundamentally different than unburned watersheds?" The main focus is the consequences of fire in steep, mountainous terrain dominated by ponderosa pine (*Pinus ponderosa*), because that is where most of the post-fire hydrological research has been conducted.

The hydrology of an unburned watershed can be depicted in terms of storage reservoirs and the transfer of water between those reservoirs. The main storage reservoirs are the vegetation canopy, the dead organic layer on the soil termed the "litter and duff," and the soil itself. The canopy includes the structure of needles, twigs, branches, and trunks that captures rainfall or snow. This precipitation is either evaporated to the atmosphere or delivered to the soil surface once the storage capacity of the canopy is exceeded. Excess water from the canopy storage, along with water falling directly on the soil surface, fills up the storage capacity of the litter and duff. Excess water is then delivered to the underlying soil surface, and it infiltrates the pore spaces of the soil. Two processes, saturation excess and infiltration excess, generate surface flow from hillslopes. If the storage capacity of the soil is exceeded (saturation excess), surface flow can occur. Saturation excess is rare in mountainous terrain, where it is more likely that surface flow will be generated by infiltration excess. That is, when the storage capacity of the litter and duff is exceeded and the excess water cannot infiltrate (infiltration excess), the water will run off over the surface of the soil. Infiltration excess also occurs when the rainfall rate exceeds the infiltration rate. Surface flow is the primary mechanism by which water is delivered to channels.

What has changed in a burned watershed? The most obvious change in a severely burned watershed is the loss of canopy by the combustion of needles and even tree branches. After a burn, the forest often looks like a moonscape with standing, blackened trees. Most of the structure of the trees will remain, though some trees will have fallen during the fire. Although diminished, the burned canopy still stores water. Measurements of the canopy storage capacity of three different sizes of ponderosa pine trees (small, medium and large) were made in both burned and unburned areas of Colorado, which are similar to burned and unburned areas in New Mexico. For a variety of storms having a range of intensities, durations, and total rainfall amounts, on average, unburned trees stored 61 percent of the incident rainfall, whereas burned trees stored 20 percent. Additional data need to be collected to strengthen these results, but this preliminary work may argue against cutting burned trees that continue to serve as storage reservoirs in a burned watershed, at least for a couple of years after a fire.

During a wildfire, the dead organic layer on the soil surface is completely or partially burned, leaving behind an ash layer and partially burned litter and duff. Both ash and the partially burned litter and duff retain some storage capacity and protect the soil surface from rain splash impact. But both are easily eroded from the soil surface by water and wind. Once the ash layer and litter and duff are removed from the soil surface, raindrops dislodge particles and pulverize soil aggregates to smaller sizes. These particles can clog the soil pores and reduce infiltration rates by sealing the soil surface. Decreases in infiltration rates after a wildfire are also attributed to a fire-induced reduction in soil wettability (hydrophobicity). Gasses that are produced by the burning of organic matter condense onto soil particles, making them water repellent or hydrophobic. In addition, the intense drying of the soil by wildfire can make it very difficult to wet the soil surface. The consequence of reduced infiltration rates and the difficulty in wetting the soil surface is that more water runs off a burned watershed than from an unburned watershed.

If rain falls on recently burned hillslopes at intensities greater than 0.4 inch per hour, surface flow increases rapidly and leads to flooding in stream channels. Often the flooding widens the channels, and the eroded sediment is transported downstream in the watershed, perhaps ending up in water-supply reservoirs. Very few burned areas have pre-fire hydrological data, including peak stream flow, which can be compared to post-fire data. Peak stream flow is the maximum amount of stream flow recorded, or known to have occurred, at a location. One area in New Mexico that has both pre-fire and post-fire data is Capulin Canyon. After the 1996 Dome fire in Bandelier National Monument and the surrounding Dome Wilderness, peak stream flows were 160 times the previously recorded peak stream flows. Even 22 years after the 1977 La Mesa fire, which also burned parts of Bandelier National Monument and adjacent Santa Fe National Forest, peak stream flows continue to exceed pre-fire magnitudes.

Evidence of the height of peak flows in Rendija Canyon after the 2000 Cerro Grande Fire. View is looking downstream. The bark on the upstream side of the burned trees has been abraded away by floodwaters carrying ash and sediment. Sand grains are imbedded in the tree trunks attesting to the force of the flowing water. Notice the sediment deposited in the channel and the 3-foot backpack leaning against a tree. Photograph by John Moody, U.S. Geological Survey, October 2001.

Downstream view of a flooding in Rendija Canyon burned by the 2000 Cerro Grande fire near Los Alamos. Water laden with ash and sediment is flowing in a channel that was completely dry before the fire. Because residents of Los Alamos use these channels as hiking trails, notification of the public of post-fire flooding hazards is extremely important. Photo by Thomas Trujillo, July 2001.

The severity of a wildfire has a substantial effect on a watershed's post-fire hydrological behavior. Severe wildfire will completely burn the litter and duff layer and the tree trunks on the ground, both of which impede surface flow off hillslopes. This occurred in parts of the Cerro Grande fire near Los Alamos. Also, in a high-severity wildfire all the needles on the trees are burned. By contrast, in a moderate-severity wildfire brown needles are left on burned trees. Those needles subsequently fall to the ground surface, protecting the soil against rain splash impact and acting as another storage reservoir. Moderate- or low-severity wildfires will leave partially burned litter and duff on the soil surface that are carried by surface flow to form small dams that impede flow. Interestingly, even the species of tree may make a difference in surface flow from hillslopes. Researchers have documented that ponderosa pine needles are more effective than Douglas-fir (*Pseudotsuga menziesii*) needles in forming the small dams. In short, there are several factors that will alter the surface flow from burned hillslopes, subsequently affecting the amount of water delivered to channels. Scientists are trying to quantify the relative importance of changes in storage reservoirs, surface flow, and infiltration rates in determining the hydrological behavior of burned watersheds.

Post-wildfire flooding and the subsequent erosion and deposition of sediment are major consequences of wildfire. These consequences may affect water users and aquatic organisms many miles downstream from the location of a wildfire. Most water-quality effects of wildfire are substantial, but ephemeral. In contrast, sediment and stream channel alteration are a persistent legacy of wildfire. With a shift toward an increasing number of stand-replacing wildfires in New Mexico ecosystems and other ecosystems in the western United States, a better understanding of the hydrological response of burned watersheds is needed. This is especially important in a scenario of climate change where extreme meteorological events may occur with greater frequency.

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Effects of Forest Harvest on Water Yields

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The effects of forest management on the quantity, quality, and timing of runoff have long been of interest to land managers and water users. The ancient Greeks noted that clearing the forests could cause springs to dry up, although a large number of recent studies generally show that forest harvest increases annual water yields. The large variation in the hydrologic effects of forest management means that one or more studies can be found to support nearly any point of view. The resolution of these apparently disparate results requires a basic understanding of the underlying processes, including infiltration, interception, soil moisture storage, and evapotranspiration. Forest management, or the lack of management, can affect each of these processes in different ways, depending on the site conditions, how an action is carried out, and the hydrologic event of concern (e.g., annual water yields, summer low flows, spring snowmelt, or extreme rain events). Managers and decision makers commonly want a simple answer, but generalizations and predictions can be incorrect unless there is a clear link to the underlying causes.

The purpose of this paper is to summarize how changes in forest cover affect the amount and timing of runoff in forested areas in New Mexico, including the lower-elevation ponderosa pine zone, the middle-elevation mixed conifer zone, and the upper-elevation forests that grade from fir to spruce. The latter are the most important in terms of water yield because these high-elevation forests receive more annual precipitation, have lower evapotranspiration losses, and thereby produce most of the runoff. As discussed below, there is relatively little potential to affect annual water yields through forest management in the lower- and middle-elevation forests in New Mexico.

EFFECTS OF FOREST HARVEST ON ANNUAL WATER YIELDS

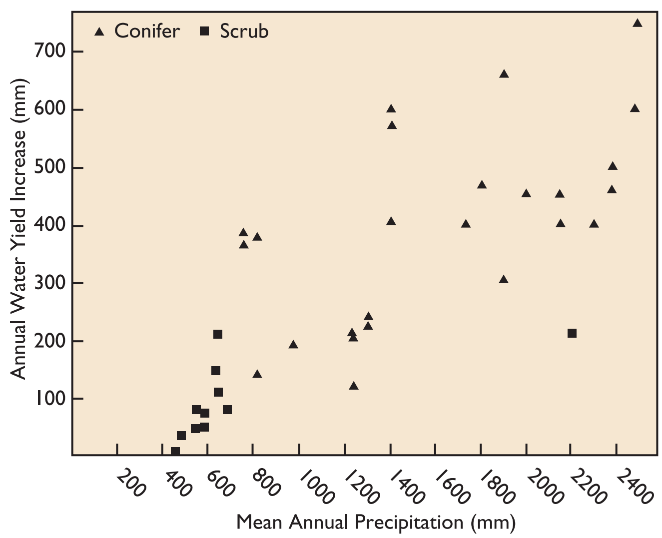
A useful starting point for understanding the effects of forest management on runoff is the simple water balance equation:

Runoff = Precipitation - Evaporation - Transpiration + Change in Storage

Evaporation also includes the loss of water by interception, which is the evaporation of water captured on plant surfaces during or immediately after a rain or snow event. Transpiration is the water lost through plants as a result of photosynthesis and respiration. In practice the evaporation and transpiration terms often are combined into a single evapotranspiration (ET) term, as it is difficult to distinguish the water lost to the atmosphere by evaporation from the water lost to the atmosphere through plants by transpiration.

In most cases the Change in Storage term in this equation can be ignored at the yearly time scale. In areas such as New Mexico, summer ET demand is much greater than the amount of summer precipitation. Hence the amount of water stored in the soil of an undisturbed forest at the end of the dry season is very low, resulting in minimal differences in soil moisture storage between years. Changes in the amount of stored water can be significant over shorter time scales (e.g., seasonally, monthly), but the annual change in storage for undisturbed forests will be very small relative to the errors in the other terms in the equation. Hence, the annual water balance equation can be reduced to the following, simpler relationship:

Runoff = Precipitation – Evapotranspiration



First-year increases in annual water yield after clearcutting as a function of mean annual precipitation. Each point represents a separate paired-watershed experiment. 100 mm is about 4.0 inches.

If the amount of annual precipitation is assumed to be constant, this equation indicates that the amount of runoff is controlled by the amount of evapotranspiration. It follows that a reduction in vegetation cover can reduce the amount of ET. However, in relatively dry areas or in dry years reducing the amount of vegetation may have little or no effect on runoff because increased evaporation from the soil compensates for the reduction in interception and transpiration.

A 1982 review of paired watershed experiments showed that removing much of the vegetative cover has no effect on annual water yields until annual precipitation is at least 18–20 inches. As annual precipitation increases beyond 18–20 inches, vegetation density increases and the water lost by ET shifts from soil evaporation to interception and transpiration. For the higher elevation forests in Colorado, all of the precipitation is used for evaporation and transpiration, regardless of the amount of vegetative cover, until annual precipitation exceeds 18 inches. In undisturbed forests approximately 72 percent of any additional precipitation beyond 18 inches becomes runoff, and the other 28 percent is lost to interception.

Because ET increases with increasing annual precipitation, removing the vegetative cover will result in progressively larger increases in annual runoff as precipitation increases. Studies in Colorado and elsewhere have shown that increases in water yield after forest harvest increase until annual precipitation reaches approximately 60 inches. For example, clearcutting a watershed in south-central Colorado with 21 inches of annual precipitation increased annual water yields by an average of 1.0 inch. At a site in central Colorado with approximately 26 inches of annual precipitation, cutting 50 percent of the vegetation (40 percent of the watershed) increased the average annual water yield by 3.1 inches. Forest harvests in ponderosa pine forests in Arizona typically have produced first-year water-yield increases of approximately 0.5–2.0 inches in areas that receive from 23 to 29 inches of annual precipitation.

This means that higher-elevation forests have the greatest potential for increasing water yields. However, the structure and density of these forests generally have been less affected by human activities and fire suppression. The lower- and middle-elevation forests have been more severely altered by human actions and generally pose a greater wildfire risk. Treatments to reduce the risk of wildfires in the lower- and middle-elevation forests have very limited potential to increase water yields.

TIMING AND VARIABILITY OF WATER-YIELD INCREASES

A reduction in forest cover increases water yields by reducing interception and transpiration losses. However, these water-yield increases vary considerably in timing, magnitude, and duration depending on the specific climatic, topographic, and geographic conditions in the watershed, and the pattern of forest harvest. In most forested areas in New Mexico the reduction in summer ET after forest harvest will be the main cause of any increase in runoff. General principles dictate that in drier years and in drier sites, as are common in New Mexico, the residual vegetation and soil evaporation use most of the available water, so summer ET savings due to forest harvest are minimized. In wetter years, and in areas where snow interception is less important, the reduction in summer ET contributes proportionally more of the increase in water yield. Similarly, summer ET will contribute more of the increase in water yield in areas with more summer precipitation, such as some of the ponderosa pine forests in Arizona and New Mexico. In areas with shallow soils there is much less potential to increase water yields because these soils will dry out regardless of vegetative cover.

In areas where most of the annual runoff comes from snowmelt, winter interception can be a much larger component of the annual water balance. In areas with a cold, dry snowpack, such as in much of the Rocky Mountains, forest harvest significantly increases the snowpack by reducing the amount of winter interception. Studies in high-elevation forests in Colorado have shown that the complete removal of the tree canopy can increase the total water content of the snowpack by approximately 20–45 percent, depending on aspect (the direction toward which a slope faces with respect to the rays of the sun). The reduction in winter interception is directly proportional to the amount of the canopy that is removed. In these snow-dominated areas, nearly all of the water-yield increase occurs in early spring when less water is taken up by soil moisture recharge and more of the early snowmelt is converted into runoff. Some of the water-yield increase in these snowmelt-dominated areas is also due to the reduction in summer ET, and this component is progressively more important in wetter areas and in wetter years.

The pattern of harvest can affect the magnitude of the resulting water-yield increase, particularly in areas with a transient winter snowpack and where reduced summer ET is the primary source of increased water yields. In the latter areas, any “excess” water may be scavenged by the adjacent trees before it is able to reach the stream channel. Hence the pattern and location of forest harvest relative to the stream channel can substantially affect the magnitude of a water-yield increase in lower elevation areas, and in the snow zone in drier years. In the higher-elevation and wetter subalpine zone, studies have shown that most of the winter interception savings following forest harvest will be transformed into runoff, regardless of the pattern of harvest or proximity to a stream channel.

Aspect can also affect the magnitude and timing of potential water-yield increases in higher-elevation forests by affecting both the amount of interception and the rate of snowmelt. In the subalpine zone, north-facing slopes typically have denser vegetation than south-facing slopes. The denser vegetation on north-facing slopes has higher interception rates, and this results in a greater potential for increasing water yields than on south-facing slopes. South-facing slopes also have a smaller potential for water-yield increases because they have more incoming radiation and higher temperatures, and this increases the potential losses due to soil evaporation.

There is considerable variability in the observed increases in water yields after forest harvest, and these can be explained by the interplay between evaporation, interception, and transpiration. In dry years a greater proportion of the precipitation is needed to recharge soil moisture and satisfy ET demands. In wet years less of the snowmelt or winter precipitation will be needed for soil moisture recharge, and there can be more soil moisture carryover. The net result is that the increase in runoff from forest harvest is substantially greater in wet years than in dry years. In the Fool Creek experiment in Central Colorado, the annual water yield increase ranged from 1.6 inches in the very dry year of 1963 to 6.4 inches in the exceptionally wet year of 1957. Similarly, the water-yield increase in a study in south central Colorado was twice as large in a wet year than in an average year, and no increase was recorded in years with below-normal precipitation. Studies in the ponderosa pine zone in Arizona also have shown that forest harvest may have little or no effect on annual water yields in dry years, but forest harvest can generate relatively large water-yield increases in wet years.

REDUCTION IN WATER-YIELD INCREASES OVER TIME

The discussion to this point has focused on water-yield increases that might be expected after removing some or all the forest canopy. In the absence of any other management activities, these increases in runoff will decline over time with forest re-growth. The snowmelt-dominated forests have the greatest potential for increasing water yields, as these areas produce most of the runoff and forest re-growth is slow due to the relatively cold, dry climate. This results in relatively slow rates of hydrologic recovery to pre-treatment runoff amounts. The longest-running study in the Rocky Mountains is the Fool Creek experiment on the Fraser Experimental Forest in central Colorado. Results from this study show an approximately linear decline in water yields after forest harvest from 1958 through 2000. The trend line from these data suggests that annual water yields will return to their pre-treatment values in approximately 65–70 years.

A faster rate of hydrologic recovery can be expected for faster-growing forest types, for species that re-sprout, and in drier areas. In Oregon and the southeastern U.S., annual water yields usually decline to pre-cut conditions within 10–25 years. Hydrologic recovery has been estimated to be 15–45 years for aspen. Recovery in drier sites, such as ponderosa pine forests, should be faster because relatively less re-growth is needed to return summer water losses to pre-harvest levels. Several studies in Arizona have shown that forest harvest can increase annual water yields from ponderosa pine forests, but vegetative re-growth eliminates these increases within 10 years. The increases were shorter-lived on drier sites and in watersheds where less harvest had taken place, and more persistent on wetter sites and where a higher percentage of the forest canopy had been removed.

EFFECTS OF FOREST HARVEST ON PEAK FLOWS

The effect of forest management on the size of peak flows is an important concern for resource managers and the public. An increase in the size or duration of high flows can increase sediment transport capacity, alter channel geometry by scour or bank erosion, and raise water levels in the affected streams. In general, forest harvest in snowmelt-dominated areas in the Rocky Mountains will increase the size and frequency of the larger flows. In the Fool Creek catchment, the annual daily maximum peak flow increased by 23 percent as a result of removing 50 percent of the forest cover. The average number of days with flow at or above bankfull increased from 3.5 to 7 days per year. Data from other studies in the central and northern Rocky Mountains have consistently shown that the annual maximum daily flow (i.e., the day in each year with the highest total runoff) increases by 40–50 percent as a result of completely removing the forest canopy. If only part of the forest canopy is removed, the increase in the size of the annual maximum daily flow is directly proportional to the amount of cover removed.

There is little evidence for an increase in the very largest instantaneous peak flows that have a recurrence interval greater than 2 years. In general, changing the amount of forest cover has a progressively smaller effect on the size of a peak flow as the magnitude of the peak flow increases. The underlying logic is that during the largest rain or snowmelt events the soils and vegetative canopy will have little additional storage capacity. Under these conditions much of the rainfall or snowmelt will be converted to runoff regardless of the amount or type of vegetative cover. There is little evidence to suggest that forest harvest can consistently and significantly change the timing of peak flows in snowmelt-dominated areas in the Rocky Mountains.

EFFECTS OF FOREST HARVEST ON LOW FLOWS

In snowmelt-dominated watersheds, summer rainstorms have little effect on summer stream flows, as the amount of rain is usually small relative to the available soil moisture storage. Summer low flows depend more on stored moisture than summer precipitation, and two recent studies have shown no statistically significant increase in low flows as a result of harvesting from 25 to 40 percent of the watershed. However, summer minimum daily flows did increase by approximately 10 percent for the harvested watershed in the Wagon Wheel Gap experiment in south central Colorado. This increase was attributed to the reduction in summer ET and resulting higher soil moisture on the treated watershed. However, this increase in summer low flows persisted only for the first five years after harvest.

Hydrologic theory and studies from other areas indicate that any increase in low flows is relatively short-lived compared to increases in peak flows and annual water yields. This can be attributed to the more rapid recovery of summer evapotranspiration rates after forest harvest than winter interception rates. Because water-yield increases are smaller in dry years and summer ET recovers more rapidly in drier areas, forest management generally will have little effect on summer low flows in the central and southern Rocky Mountains. Because most of the increase in water yields will come in the fall and winter in rain-dominated areas and in spring in snowmelt-dominated areas, water storage facilities are needed if an increase in runoff due to forest management is to be captured and used during the summer growing season.

SUMMARY

Reducing forest density has the potential to increase water yields, but the average long-term increase in water yield depends on the annual precipitation, the species being treated, the proportion of the canopy that is removed, the re-growth rate, and the length of time between treatments. Some of the key limitations on the potential to increase annual water yields include:

- Little or no water-yield increases can be expected in areas where annual precipitation is less than 18 inches.
- The greatest potential for increasing water yields is in the higher-elevation fir and spruce forests, with more limited potential in aspen and mixed conifer forests, and the smallest potential is in the ponderosa pine forests.
- At least 15 to 20 percent of the forest within a watershed must be removed in order to detect a statistically significant change in runoff.
- Most of the increase in runoff will come during the winter or spring, and there is little potential for forest harvest to increase baseflows.
- Forest re-growth means that hydrologic recovery occurs over a period ranging from approximately 10 to 70 years, so the long-term sustainable increase in water yield from forest harvest is much less than the potential water-yield increase in the first few years after forest harvest.
- The timing of the increase in runoff after forest harvest may limit the usefulness of an increase in water yield. The timing of an increase in runoff may not match up with the timing of peak demand.
- Water-yield increases from forest harvest also are smallest in dry years, when they are most needed, and larger in wet years, when they may be less useful. The seasonal and interannual timing of potential water-yield increases means that reservoirs may be needed to capture any increase in water yields resulting from forest harvest.

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Waters of the Sacramento Mountains Forest

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The Sacramento Mountains are located in south central New Mexico. They rise gently in elevation from the east and south to the escarpment along the western side and end at Sierra Blanca to the north. Their influence extends as far as they can be seen across the surrounding lowlands. Streams and aquifers charged by the mountain watersheds include the Tularosa Basin to the west, the Salt Basin to the south, and the Pecos River valley to the east. Today, the economy of the area is recreation and agriculture, with some logging.

The Sacramento Mountains have undergone many changes since European settlers arrived in the last half of the nineteenth century. At that time, large majestic trees dotted the landscape. Mountainsides were covered with lush grass, and springs or wet areas were prevalent. Ponderosa pine was the dominant tree at middle elevations, with fir and spruce dominating many of the higher slopes. Stands of aspen trees were common, mostly on old burns. Lower slopes were populated with ponderosa pine, piñon pine, one-seeded juniper, and alligator juniper. At all elevations, trees were much larger than they are today. Early records depict a landscape with large grassy parks interspersed with stands of timber in what is known as an open savannah. Low-intensity ground fires maintained this landscape of large trees with a lush carpet of grass underneath.

In 1883 a firewood inventory was commissioned for the territory of New Mexico. The inventory for the Sacramento Mountains indicated that 2–5 cords per acre of firewood were available throughout the higher elevations. This correlates to approximately 4–10 fairly large juniper or piñon pine trees per acre. The piñon-juniper foothills had 1–2 cords of firewood per acre, or 2–4 trees per acre.

Other territorial and early twentieth century surveys describe a similar savannah setting. General Land Office Survey notes from 1885 describing the Sacramento River area state that the “entire township is covered with a luxuriant growth of grass. Almost the entire township is covered with heavy timber of pine and fir of very good quality.” In 1908 surveys along the southern boundary of the Lincoln National Forest noted scattered pine, piñon, juniper, and cedar.

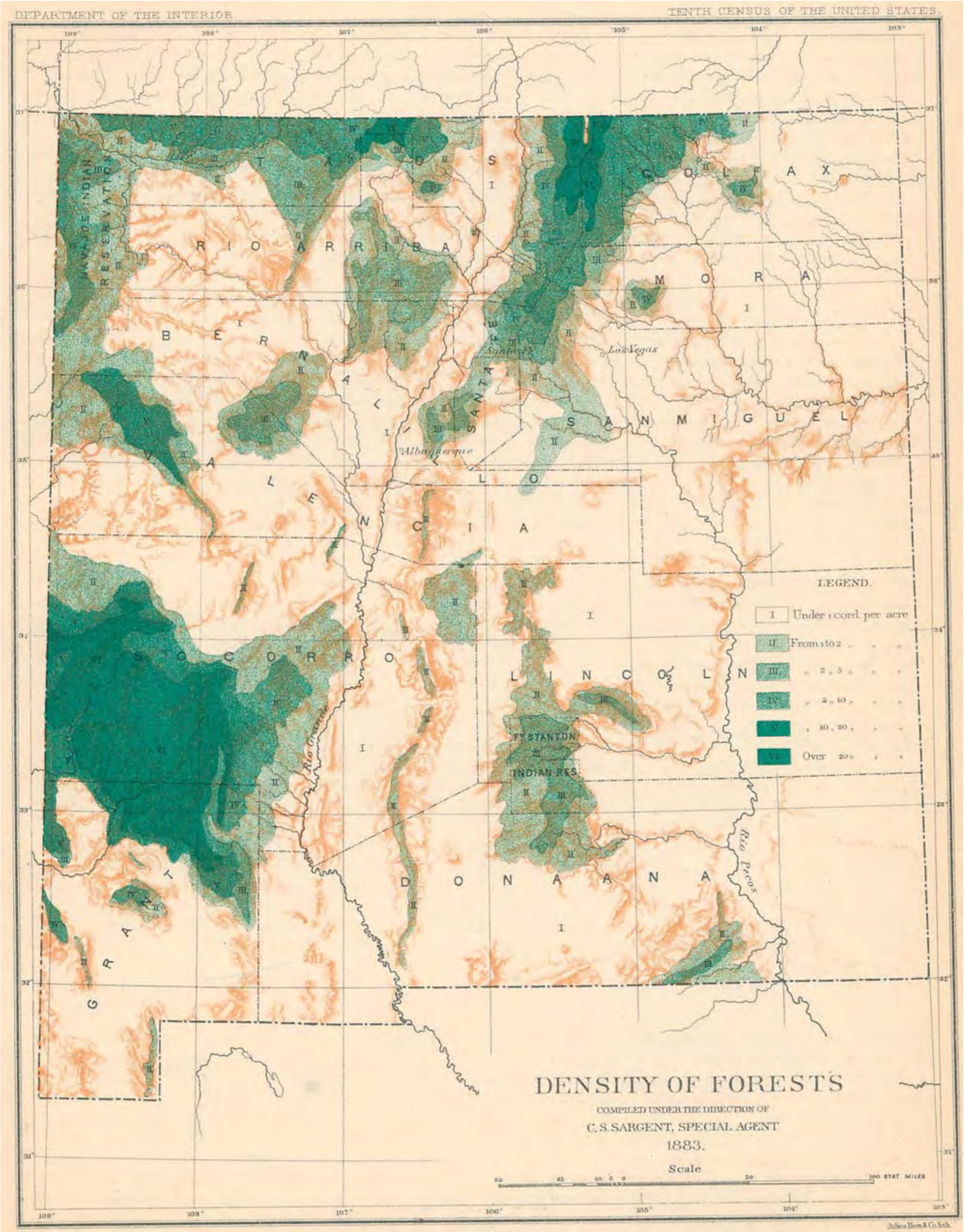
VEGETATION AND BIOLOGICAL DIVERSITY

During the early 1900s dramatic changes in the landscape of the Sacramento Mountains began to take place. Developers opened the mountains to the timber industry by building a railroad to Cloudcroft, with spurs up many of the adjacent canyons. The big, old trees were logged and removed. Settlers’ livestock kept the grass short. With the removal of widespread, low-lying ground cover, low-intensity ground fires were no longer able to maintain the delicate balance between old-growth trees and open grasslands. The natural balance between trees, grass, animals, and water, developed over thousands of years, became skewed.

The most significant vegetation changes in the last 100 years have been marked by a reduction in species diversity and an increase in tree density. In the logged stands, each original tree has since been replaced by dozens of smaller trees. The intervening grassy savannahs have also been filled with trees, at the expense of the lush grasses of the open forest floor and the original biological diversity. Riparian plants along streams and wet areas have largely disappeared, as the forest vegetation shifts toward a monoculture of evergreen species. Most significantly, the change from open stands of large conifer trees and associated deciduous trees to dense stands of small, monotypic conifer trees has altered the water balance in mountain watersheds.

The territory occupied by fir trees has significantly expanded into lower elevations during the last century, and firs now dominate many hillsides where the majestic old ponderosa pines once reigned. The current drought, combined with pests, disease, and a thick understorey of juniper, has also displaced old ponderosa pines from lower elevations. Although these old pines were on the fringe of their adapted range in the Sacramento Mountains, they had prospered here for several hundred years.

The piñon-juniper zone has also undergone dramatic changes associated with the recent drought. Piñon pine has suffered a massive die-off in the foothills of the Sacramento Mountains, primarily because it is drought intolerant and less competitive than juniper. Its shallow roots generally extend no more than 21 feet into the ground, increasing its susceptibility to pests and disease during stressful drought periods.



This map showing availability of firewood in the territory of New Mexico was published in 1883 in the Tenth Census of the United States. The Department of the Interior survey depicts a landscape of low density, open woodland, and forest in the Sacramento Mountains.

Many trees that have lived and thrived here for over two centuries recently succumbed to the killer combination of drought, pests, and competition. The current drought will alter the composition of our woodlands. Small alligator junipers or one-seeded junipers are already positioned to fill the void left by dying piñon. As these junipers grow, they will eventually dominate the foothills, creating a monoculture and decreasing the habitat value for wildlife. Juniper trees also use more water than piñon pine, thus increasing consumptive use of water in this vegetation zone.

In this photo of piñon-juniper woodland, the dead trees are piñon, whereas the junipers are still healthy.

Changes in plant diversity affect the water balance in mountain watersheds. Evergreen trees use water in the winter because they never go dormant, as do grass and deciduous plants. The extensive root systems of evergreens allow them to use most of the summer and winter precipitation. Mature ponderosa pine roots can extend to a depth of 15–79 feet, and large pines use over 250 gallons of water per day in the summer. Juniper roots can extend to a depth of 80–200 feet. A 12-inch-diameter juniper can use 34 gallons of water per day in the summer and 14 gallons per day in the winter.

As conifer populations dominate the landscape, both deciduous trees and grasses are choked out. Conifers are displacing aspen and oak, deciduous species that use much less water than conifers and are dormant in the winter, allowing snow and precipitation to contribute to recharging the water table. Trees use from 4 to 17 times more water than grass to produce a pound of biomass. The transition from a mosaic of deciduous trees, grasses, junipers, and conifers to monotypic stands of conifers has sacrificed both water and biological diversity.

WATER AVAILABILITY

A forest is a living thing; changing one part will influence other parts. The tree-covered hills we see today are a result of unnatural forest growth that has followed logging and fire suppression during the last century. Water is an indispensable part of any healthy forest, and in the Sacramento Mountains its availability has steadily and dramatically decreased in our lifetimes. Many springs and streams that were perennial during the last century have become intermittent sources of water in the last 20 years, flowing seasonally and only during years with high precipitation. Several streams have completely dried up, including the Agua Chicuita, Cuevo, La Luz Creek, Three Rivers Creek, and the Sacramento River.

The Agua Chicuita stream has been dry for over ten continuous years. Investigations along its upper course reveal reservoirs and old ditches that were once used to store water for irrigation. Maps from the Office of the State Engineer show that many people have water rights along this ex-stream. Descendants of homesteaders describe it as a dependable source of water that had dried up only twice in their lifetimes. Photos taken in the early 1900s portray the Agua Chicuita as a substantial stream.

The Sacramento River played an important role in the development of the watershed. In the early 1900s a railroad company built a pipeline from the river above Timberon to Orogrande in the Tularosa Basin to supply water for its steam engines. The springs feeding this small river provided water for the Orogrande pipeline, as well as for fishing at Timberon, as recently as the 1970s. The U.S. Geological Survey stream gage on the Sacramento River was closed in 1989 when the river dried up. Orogrande is presently tying into a pipeline near Chaparral for its water supply because the spring at their water intake location on the Sacramento River is also dry.

Carrisa Spring, which once supplied the community of Timberon with water, dried up in September of 2000 for the first time since flow records have been kept for the spring. The spring yielded as much as 600 gallons of water per minute when the Sacramento River valley was settled in the late 1800s. A 10-inch flow meter was installed on the main spring in 1986, measuring its flow at an average of 108 gallons per minute that year. The flow during the 1990s ranged from a high of 124 gallons per minute in 1990 to a

	Piñon–juniper woodland		Ponderosa pine		Mixed conifer	
	circa 1900	**circa 2000**	**circa 1900**	**circa 2000**	**circa 1900**	**circa 2000**
Trees/acre	19–25	1,300 above 1"	20–50	180–220 >5" dbh	40–70	200–250
Basal area	Multi-aged	> 120	Multi-aged	110–120	Moderate, open stand	120–140
Site water	Limited seeps and springs	Depleted, minor water available	Seeps, springs, moderate ground water recharge	Diminished 10–30%	Active seeps, springs	Diminished 10–30%
Soil	Thin, but intact with dense grass	Very unstable, lack of cover	Dense grass, some shrub cover	Unstable, minimal ground cover	Intact and stable, dense grass and forbs	Unstable, minor grass cover
Fire interval	Low intensity, frequent 5–15 years	60% of stand at risk of crown fire	Low intensity frequent ground fire 3–10 years	65% of area at risk of crown fire	4–15 years	Larger crown fire potential

Summary of research findings by M3 Research relating to tree density and other forest components.

low of 66 gallons per minute in 1994. In early 2000 the flow was 69 gallons per minute, then the spring declined steadily until it dried up altogether.

Timberon residents are now trying to find more water by deepening existing wells, but they are having difficulty finding adequate water in a watershed already drained by acres of heavy timber. The aquifer in the San Andres Limestone that supplies Timberon is one that readily transmits water through enlarged fractures and holes in the rock, but it also has a relatively small storage capacity. In other words, it must be continually recharged. The combination of the current drought and thick timber on the upper slopes has altered the water balance dramatically and dried up springs, streams, and the ribbon of riparian habitat once used by both man and wildlife

INVESTIGATIONS AND RESTORATION

A historic reconstruction of vegetation type, size, and density has recently been completed for the Lincoln National Forest. Early logging records and other U.S. Forest Service records were used to recreate woodland landscapes present in the Lincoln Forest Reserve in 1902. These records indicate a tree density of 20–70 trees per acre, with trees ranging from 25–45 feet apart. Now average woodland densities are 200–250 trees per acre for trees measuring more than 5 inches in diameter at breast height. The average distance between trees is 3–10 feet if trees less than 5 inches in diameter are also counted.

The Otero Soil and Water Conservation District (Otero SWCD) and the Natural Resources Conservation Service (NRCS) recently completed a grant proposal for watershed investigations and restoration in the Sacramento Mountains. The principal component of the proposal is to map the hydrogeology in the Sacramento Mountains to determine where recharge zones for the springs and streams are located. The map will be used to delineate areas where vegetation thinning could have the most positive impact on restoring surface and ground water sources. Another component of the proposal includes the development of a watershed model to predict the effects of various resource alternatives on the water balance in these mountain watersheds.

A coalition of state, federal, and local government entities recently initiated a study of the Sacramento River and its watershed. The Otero SWCD, Otero County Commission, residents of Timberon, the U.S. Forest Service, and the NRCS have joined forces to participate in the endeavor. The hydrogeology, early written history, photographic reconstruction, and a watershed model are all components of the study. In addition, the Otero SWCD recently received a grant through the U.S. Bureau of Reclamation to monitor static water levels in six wells in the watershed.

Focusing thinning and restoration efforts in recharge zones for streams and springs has proven to be a successful approach for restoring surface water on Mescalero Apache tribal lands. In 1998 the Mescalero Apaches noticed that the flow of Whitetail Spring had diminished dramatically until it was barely able to fill the adjacent storage pond. This spring system supplies water through 25 miles of pipeline to both cattle and large wildlife populations. The tribe requested assistance from the NRCS to restore and conserve the spring. After mapping the recharge area for the spring, the U.S. Bureau of Indian Affairs immediately began timber sales in the recharge zone to replenish subsurface flow to the spring. The forest management plan identified 1,225 acres of the 2,400-acre recharge area to be thinned by Mescalero Forest Products crews. Trees were thinned to a density of about one 12-inch tree every 40 feet. Two 20- to 25-acre blocks were clear cut to make parks or forest openings. More sunlight in the parks has allowed grasses and shrubs used as browse by wildlife to increase. Thinning proceeded for about 18 months before flows in Whitetail Spring visibly increased. Thinning of the last units will be completed in 2003. Whitetail Spring is still flowing and filling the pond and pipeline system, even though the drought has intensified. The Mescalero Apache Tribe has asked that the same process be initiated for Encino Spring, which is now in jeopardy. Similar hydrogeologic surveys are planned for springs throughout the Sacramento Mountains.

SUMMARY

If we wait for watershed health to improve, it probably won't. All the streams in the Sacramento Mountains are now discharging substantially less water than they were during the 1980s. Springs have been disappearing for decades, but the rate has accelerated during the current drought. The communities of Cloudcroft, Ruidoso, and Alamogordo all have serious water supply problems that are intensified by declines in their watershed yields. Most municipal residents do not realize that they have traded their water for trees. At least 65 rural wells have also dried up, and in some instances, water was not available even when the wells were deepened. The impact to wildlife populations, livestock producers, and mountain residents has been substantial. Proactive management of tree stands is the only alternative available to sustain the lifeblood of these mountains—water.

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Managing Forests and Woodlands for Increasing Water Yields

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Over the past century forest density has generally increased in New Mexico due to fire suppression, reduced grazing rates, and reduced harvest of timber for fuel wood and other products. The problem is that the increase in forest density may increase the risk of high-severity wildfires during unusually dry periods. High-severity wildfires generally have a much greater effect on runoff and water quality than forest harvest or thinning operations using best management practices. Data from the Cerro Grande and other fires show that such high-severity fires greatly increase surface erosion rates and the size of peak flows, induce channel scour and bank erosion, cause downstream sedimentation, and adversely affect water quality. Hence there is increasing interest in reducing forest vegetation density, but the justification and effects of these treatments will vary by forest type.

The effect of fire suppression is particularly marked in lower-elevation forests where fire historically was relatively frequent. Because annual precipitation in these lower-elevation forests is generally less than 18–20 inches, any reduction in vegetation to reduce fire risk will have little or no effect on annual water yields. The last century of fire suppression has had much less effect in higher-elevation forests because the several hundred-year natural fire recurrence interval in these forests is longer than the period of suppression. There is much less justification for thinning in these higher-elevation forests, but these are the forests where harvesting or heavy thinning has the potential to increase water yields.

Efforts to reduce fire risks in lower-elevation areas or alter the density of tree cover in piñon-juniper woodlands involve a variety of social, legal, and economic considerations, and these may make it difficult to implement larger-scale treatments. Similarly, social and physical considerations may severely limit efforts to increase water yields from the higher-elevation forests.

MANAGEMENT EFFECTS ON RUNOFF PROCESSES AND WATER YIELD

Piñon-Juniper Woodlands The historic record indicates that there has been an increase in the density of piñon pine and/or juniper in piñon-juniper woodlands and a corresponding decline in the abundance of broad-leafed plants and grasses. Although tree removal may reduce interception and transpiration losses, these are offset by a corresponding increase in soil evaporation and transpiration from the denser understory. Hence it is virtually impossible to increase water yields through tree removal in piñon-juniper woodlands, where annual precipitation is below the 18–20 inch threshold. Predicting the effects of management actions in piñon-juniper woodlands is particularly difficult because there can be such large differences in runoff processes and management effects between the canopy and intercanopy areas.

In some cases removing the tree canopy may affect the timing and quality of stream flow, even though there is no change in the annual water yield. A critical issue is how overstory removal affects the amount of surface cover and surface roughness. Runoff and erosion rates generally are much lower under the tree canopy than in the intercanopy areas. If removing the woody vegetation results in less surface vegetation, there can be an increase in the amount of overland flow and surface erosion, and this may reduce the amount of groundwater recharge and the magnitude of base flows. On the other hand, if management increases the amount of surface cover and roughness—especially in the intercanopy areas—the resulting increase in infiltration may reduce the size of peak flows and cause some streams to flow on a more regular basis. This shift in runoff processes may reduce total annual runoff while improving the timing and the quality of the runoff.

Similarly, a reduction in grazing intensity may increase herbaceous cover and reduce the amount of overland flow by increasing infiltration rates. Although most of this additional infiltration would be lost to evapotranspiration, this shift in runoff processes again could result in lower peak flows and more sustained stream flows.

The effects of wild and prescribed fires on runoff rates are difficult to predict. In general, a higher-severity fire should have a proportionally greater effect on runoff rates because of the greater loss of surface cover.

Forests Forests in New Mexico include lower-elevation ponderosa pine forests, mid-elevation mixed conifer forests, and higher-elevation spruce-fir forests. In areas where annual precipitation is greater than 18–20 inches it may be possible to increase water yields by large-scale reductions in the number and density of trees. The social, political, and physical constraints on forest harvest imply that water yield increases associated with removing forest vegetation will be relatively small.

In general, only a small portion of a watershed can be subjected to forest harvest, and this limits the potential increases in water yields. For example, only 24 percent of the 4,100-acre Coon Creek basin in Wyoming's Medicine Bow National Forest could be harvested due to various management constraints, and the observed initial increase in annual water yield was 3.0 inches per unit area harvested, or 0.7 inches when averaged over the entire watershed. This increase in annual water yield is consistent with the results of other watershed studies in the central Rocky Mountains. At a yet larger scale, intensive management of national forest lands in the California Sierra Nevada was predicted to cause a sustained water yield increase of only 0.1 inch, as much of the land is not suitable for timber harvest or is subject to other management constraints.

A more recent study estimates that the increase in forest density since the late 1800s on national forest land in the North Platte River basin in Colorado has decreased water yields by approximately 160,000 to 185,000 acre-feet per year. This is slightly less than 2.0 inches of water per unit area of forest land or approximately 1.6 inches of water over the entire watershed. Approximately 54 percent of the total area, or 66 percent of the forested area, is classified by the USDA Forest Service as land suitable or potentially suitable for timber harvest. Intensive forest management on these lands could yield an average of 55,000 acre-feet of additional water per year. The 55,000 acre-feet converts to 0.9 inch per unit of suitable forest land, or 0.5 inch per unit of total forest land. This is slightly more than one-third of the "losses" that are currently occurring as a result of the increase in forest density.

The values from the North Platte River basin study probably represent the upper boundary on water yield changes that might be expected from forested areas, as two-thirds of the national forest in the North Platte River basin were classified as suitable or potentially suitable for timber harvest. Furthermore, forest types with a high potential for increasing water yields (spruce-fir and lodgepole pine) accounted for nearly 85 percent of the forested area; while forest types with a lower potential for increasing water yields (ponderosa pine and aspen) occupied only 13.5 percent of the forested area.

In most cases, a reduction in forest density by prescribed burning will not increase water yields. Most prescribed burns are designed primarily to remove brush and suppressed trees, and are not intended to kill a significant proportion of the overstory. There is little reason to expect an increase in water yields unless there is a substantial reduction in vegetation density over the entire watershed.

Though field data from New Mexico are scarce, hydrologic response to forest treatment in New Mexico is expected to follow the patterns seen in studies of similar forest types elsewhere. Importantly, in New Mexico only small portions of the larger river basins are occupied by the higher-elevation forests that have sufficient annual precipitation to even consider the potential for increasing annual water yields.

MANAGEMENT EFFECTS ON EROSION, WATER QUALITY, AND FOREST HEALTH

Piñon-Juniper Woodlands Management goals for piñon-juniper woodlands are typically to increase the amount of forage and vegetative ground cover, reduce erosion, and re-establish native riparian species. Aggressive treatments such as chaining are generally not acceptable because of excessive ground disturbance and potential increases in erosion. The most significant management issue in the piñon-juniper zone is the intensity, timing, type, and location of grazing activities. Although the effects of grazing can be highly variable, the scientific literature generally indicates that high-intensity grazing causes a significant reduction in plant cover and infiltration rates, potentially leading to an increase in runoff and surface erosion, and a decrease in site productivity and water quality. Light to moderate grazing has much less effect in terms of soil compaction, surface erosion, the degradation of riparian areas, and adverse changes in water quality and stream channel characteristics.

Cattle tend to concentrate in riparian areas because of the better forage, water for drinking, and shade. The concentration of cattle in riparian areas usually causes a more direct and largely adverse effect on aquatic resources than high-intensity grazing outside the riparian area, as a much higher proportion of sediment and animal wastes is likely to be delivered directly into the stream network. If cattle or other animals concentrate in the riparian areas, the resultant trampling and reduction of riparian vegetation can destabilize the stream banks and further increase the amount of sediment being delivered to the stream.

Some of the adverse effects of grazing can be alleviated by simply reducing the number of animals, but the total number of animals is often not as much of a problem as the distribution of animals within the areas being grazed. A combination of fencing, herding, and providing salt, shade, and watering points away from streams can help ensure a more even distribution of grazing pressure and reduce the concentration of animals in the riparian zone.

Forests The primary forest management options include commercial harvest, commercial and noncommercial thinning, and prescribed burning. An extensive program of forest harvest or thinning could increase erosion rates and adversely affect water quality as a result of increased turbidity and sediment loads. The magnitude of these effects will depend more on the methods used to gather and remove the woody material than on the harvest itself, as roads and skid trails are the primary sources of sediment from well designed and carefully executed forest management programs. The increase in erosion from harvested areas and the accompanying adverse impacts on water quality usually can be minimized by applying Best Management Practices. The design, construction, and post-harvest treatment of the road and skid trail system is critical to minimizing the generation and concentration of overland flow, and hence the amount of surface erosion. The use of buffer strips along both ephemeral and perennial streams can greatly reduce the delivery of overland flow and sediment to the stream network. Maintaining riparian vegetation is the best means to minimize increases in water temperatures.

The primary advantage of reducing forest density is the lower risk of high-severity fires. In the absence of any effort to reduce forest density, one can expect a continuing (or gradually increasing) risk for high-severity wildfires in forested areas. Such fires are of considerable concern because of the potential to destroy property and greatly increase runoff and erosion rates. The increase in runoff from wildfires is usually regarded as a negative effect because high-severity fires can increase the size of peak flows by as much as a factor of 10. Erosion rates from forested sites burned at high severity can increase by a factor of 100 or more. These changes can have severe effects in terms of downstream flooding, reservoir sedimentation, and degradation of aquatic habitat.

Prescribed fires generally have minimal effects on runoff and water quality, as the fire severity is mostly low to moderate, resulting in much less soil water repellency than high-severity fire. Areas burned at moderate or low severity also have much lower percentages of bare ground; recent research shows that erosion rates are strongly correlated with the percent of bare ground. As long as the percent bare ground is less than approximately 20–30 percent, post-fire erosion rates should be very low and therefore pose little threat to water quality and downstream aquatic resources.

REGULATORY AND LEGAL CONSIDERATIONS

High-elevation forests present greater opportunities for increasing water yields than piñon-juniper woodlands or riparian zones. Two different sets of laws affect the potential to manage these forests for increased water yields.

The first set of laws governs land management practices and the protection of surface waters. Most of the constraints placed by these laws relate to the planning, studies and administrative procedures for deciding what management activities are appropriate. The National Forest Management Act restricts the methods and locations of logging and road building on national forest lands. The National Environmental Policy Act requires federal agencies to consider the potential environmental impacts of any proposed policy or action. The Clean Water Act may limit activities through state-specific water quality criteria. The Endangered Species Act may limit actions in areas with threatened or endangered species, or in areas that might be suitable habitat for these species. The National Historic Preservation Act and the American Indian Religious Freedom Act may limit land disturbance near sites of historical, cultural, or religious significance.

The second set of laws governs the use and ownership of water. Water use generally is subject to the prior appropriation doctrine, which means the person with the most senior water right has the first claim, and the most junior claim can receive water only when all senior water rights have been satisfied. Any "additional" runoff created by watershed management becomes part of the public water supply and is subject to the prior appropriation system. Hence a person or entity that increases the amount of runoff would not be able to claim that water except by obtaining a new and very junior water right, so there is no direct incentive for a person or agency to manage for increasing water yields. Some states explicitly preclude anyone from claiming the rights to water generated by a reduction in vegetation density.

ECONOMIC AND SOCIAL CONSIDERATIONS

The costs of a program to manage or restore piñon-juniper woodlands will be much greater than the direct economic benefits. Piñon-juniper woodlands are used primarily for fuelwood and livestock production. Past practices included chaining followed by seeding, but this was costly, induced severe erosion in some areas, and engendered considerable public resistance. Broadcast burning often is not feasible because there is not enough fuel to carry the fire during the conditions conducive for controlled burns. Overall, the costs of trying to alter or intensively manage piñon-juniper woodlands have far exceeded the potential returns, so many efforts have been discontinued.

Efforts to reduce vegetation density and increase water yields in forested zones generally will require a net investment of public funds. Commercial forest harvest or thinning is more economically feasible in areas with less than 30 percent slope and an existing road network. In other areas, thinning is much more difficult unless it also includes some harvest of the larger trees that have more economic value. In some areas the thinned material may be used for poles, posts, or fuelwood, and this can help offset some of the costs of the thinning. If there is not a commercial market for the harvested material, the thinnings have to be chipped and scattered, piled and burned, or broadcast burned. In the Upper South Platte watershed southwest of Denver, thinning costs for ponderosa pine are approximately $1600 per acre.

Local residents may support efforts to manage and restore woodlands and forests because of the potential to improve watershed conditions, reduce fire risks, and provide short-term employment. However, some of the management actions may encounter local opposition. Piñon and juniper are the preferred fuel wood in many areas, and any program or action that would limit access or supply might encounter local opposition. Grazing of sheep and cattle is a tradition and a source of livelihood in many communities, and efforts to restrict or control the number of animals in piñon-juniper woodlands may be opposed by local communities. Efforts to harvest or thin public forests often engender considerable opposition, even though these actions may reduce the risk of high-severity wildfires and improve wildlife habitat while having few negative effects on water quality.

An important concern in the case of prescribed fire and broadcast burning is the effect on air quality. Fires in forested areas produce a large number of particulates that are a hazard to human health, and the regulatory agencies may limit the number of permits for prescribed burning because of the temporary reductions in air quality. Smoke is visually unappealing and this can be an important concern for communities dependent on tourism. For these reasons prescribed burning programs often encounter considerable public resistance.

To be successful, restoration and management plans must be designed in collaboration with local communities to generate local support. Local communities can directly benefit from restoration and management efforts through contracts for forest harvest and thinning, prescribed burning, erosion control, and other stewardship work. If much of the cost has to be met by public funds, these efforts will require broad public support.

SUMMARY OF POTENTIAL AND PITFALLS OF FOREST MANAGEMENT

Advantages of manipulating the vegetative cover in forests and woodlands include the following:

- Reduced risk of wildfires;
- Reduced surface runoff, surface erosion, and channel incision in piñon-juniper woodlands;
- Improved range and riparian conditions in piñon-juniper woodlands and possibly improvements in water quality;
- Increased amount and quality of forage;
- Improved habitat for native riparian and aquatic species at lower elevations;
- Potential for small increases in water yield from higher-elevation forests, especially in wetter years.

Disadvantages of actively managing the vegetative cover in forests and woodlands include:

- Limited potential to increase water yields; coupled with the need to store a water yield increase until it is needed;
- Smaller water yield increases in dry years;
- Poor cost/benefit ratios;
- Potential declines in air quality and threats to human health from increased particulates from prescribed fires;

- Considerable public opposition to forest harvest and thinning;
- Difficulty of balancing the needs of different resources and user groups.

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Surface Water Quality Monitoring in the Lower Pecos River Watershed

David Hogge and Neal Schaeffer, *New Mexico Environment Department*

New Mexico recognizes the value of surface waters as a public resource. Surface waters irrigate croplands, water livestock, and, as live streams (the "thin green lines" in the desert), support a variety of wildlife and places where people can fish, swim, watch and photograph wildlife, or simply find peace and relaxation. These "designated uses" are the management goal of the Surface Water Quality Bureau of the State of New Mexico. Our mission is "to preserve, protect and improve New Mexico's surface water quality for present and future generations."

The lower Pecos River and some of its tributaries (including the Rio Peñasco) do not currently support these goals. The causes include disruption of both hydrologic and sediment regimes. These kinds of impairments can be seen throughout New Mexico. Disruption of the hydrologic regime includes changes in the runoff characteristics of the watershed, such as unnatural changes in the vegetation (like forest overgrowth), increased impermeable surfaces (like asphalt), or poorly designed bar ditches along roads. These changes tend to make watersheds more "flashy," resulting in less water soaking into the ground—ground waters that would otherwise support stream flow in dry times. Flashy streams also tend to downcut. Excessive diversion of stream flow such as for irrigation is another way to disrupt the hydrologic regime; the diminished flows can jeopardize the survival of the fish in these streams.

Rio Peñasco below the mouth of Cox Canyon (showing recent channel excavations and levee rebuilding).

Rio Peñasco below the mouth of Cox Canyon (showing recent channel excavations and levee rebuilding). Recent flood debris in side channel from burned area.

Disruption of the sediment regime involves changes to the stream's sediment supply. Watershed impairments such as those described above often increase the supply of fine-grained sediment or silt. A gravel stream bed by its very nature usually has spaces between the gravels that serve as habitat for and support aquatic insects (which fish eat) and even fish eggs. Oxygenated water usually circulates through these gravels. When these spaces are filled with silt, this habitat and (eventually) the fishery are destroyed.

TOTAL MAXIMUM DAILY LOAD

One measure of the standards that are set for water quality throughout the state is "total maximum daily load" (TMDL), which can best be described as a watershed or basin-wide budget for pollutant influx to a watercourse. TMDLs may also be established for a portion or segment of a watershed. A TMDL, in actuality, is a planning document. Through scientific study the allowable budget—the amount of pollutants that can be assimilated without causing the stream to exceed the water quality standards set to protect the stream's designated uses—is first determined. Once

Some Background on TMDLs

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The federal Clean Water Act requires states to determine whether water bodies meet water quality standards and protect beneficial uses. In instances where water bodies do not meet a particular water quality standard, states must identify that water body as impaired and determine the total maximum daily load (TMDL) of the pollutant that the water body can receive and still meet water quality standards. The state then allocates that TMDL among both point and nonpoint sources discharging to the water body, with the objective of reducing pollutants and improving water quality. However, because states lacked data and resources to accomplish this objective, neither the U.S. Environmental Protection Agency (EPA) nor the states historically used the TMDL program to address water quality problems—until the EPA was barraged by citizen lawsuits.

In 1997 one such lawsuit in New Mexico (*Forest Guardians and Southwest Environmental Center v. Carol Browner*, Administrator, U.S. EPA, Civil Action 96-0826 LH/LFG) resulted in a federal court monitored consent decree and settlement agreement between the EPA and environmental groups concerning development of TMDLs in New Mexico. This consent decree laid out an ambitious schedule for the development of TMDLs throughout the state. TMDLs summarize identified wasteload allocations for known point sources and load allocations for nonpoint sources at a given flow. TMDLs must also include a margin of safety to account for uncertainty in the calculation of the pollutant allocations.

A TMDL is not a regulatory document; it is a planning document that contains recommended actions intended to protect or restore the health of the water body. In 1999 the New Mexico Environment Department, Surface Water Quality Bureau developed 26 TMDLs on 11 different reaches in four watersheds throughout the state. These TMDLs were determined for a variety of pollutants such as stream bottom deposits, turbidity, total phosphorous, total ammonia, fecal coliform, and temperature. After TMDLs are developed, there is a legitimate expectation that they will be implemented. The Surface Water Quality Bureau has started implementing TMDLs in several watersheds.

—Excerpted from *Water, Watersheds, and Land Use in New Mexico*, Peggy S. Johnson, editor, 2001 Decision-Makers Field Guide, New Mexico Bureau of Geology and Mineral Resources.

Lower Pecos River (main stem) 2003 Intensive Water Quality Survey.

this is done, sources of the pollutants are considered. Both point and nonpoint sources must be included. Once all the sources are accounted for, the pollutants are then allocated or budgeted among the sources in a manner that will describe the limit (the total maximum load) that can be discharged into the river without causing the stream standard or budget to be exceeded. Nonpoint sources are grouped into a load allocation and point sources are grouped into a wasteload allocation. By federal regulation, the budget must also include a margin of safety. TMDLs can therefore be described by the following equation:

TMDL = sum of nonpoint sources + sum of point sources + margin of safety

TMDL ASSESSMENT FOR THE LOWER PECOS RIVER WATERSHED

An intensive water quality survey for the lower Pecos River watershed is in progress and will be finished in early fall 2003. The lower Pecos River watershed is defined for this survey as the Pecos River from Fort Sumner Dam south to the New Mexico–Texas border; it includes the Rio Ruidoso, Rio Hondo, and Rio Peñasco drainages. The data from the survey are expected to be back to the Surface Water Quality Bureau by summer 2004. The data will undergo a thorough check to ensure that the results are not erroneous. Once this is done, the watershed will be assessed for impairment and listing on the State's 303(d) list, which is a compilation of all impaired surface waters statewide. If it is determined that portions of the lower Pecos River watershed are impaired by one or more pollutants, then TMDLs will be written for those pollutants in 2006–2007.

Drought in New Mexico: History, Causes, and Future Prospects

David S. Gutzler, *University of New Mexico*

Ecosystems and human societies have adapted to New Mexico's desert climate. During prolonged drought periods, however, life in the desert can become extraordinarily harsh and difficult. Drought in New Mexico causes dry riverbeds, widespread plant and wildlife mortality, failed crops, and may have contributed to the collapse of prehistoric civilizations in the not-so-distant past. It behooves us to study the history of drought to get an idea of what is in store for us when the next major drought event befalls us.

We don't have a thorough understanding of what causes long-term drought episodes. Recent research on the variability of the world's oceans offers insights into possible causes of drought, but our limited knowledge is not yet sufficient to provide reliable forecasts of when the next huge drought will occur, or (perhaps more importantly) to predict when an existing drought might end. As we will discuss, however, there are ominous signs that the current dry conditions may not abate soon and that New Mexico could be in for dry times for the next few years.

DROUGHT INDICES

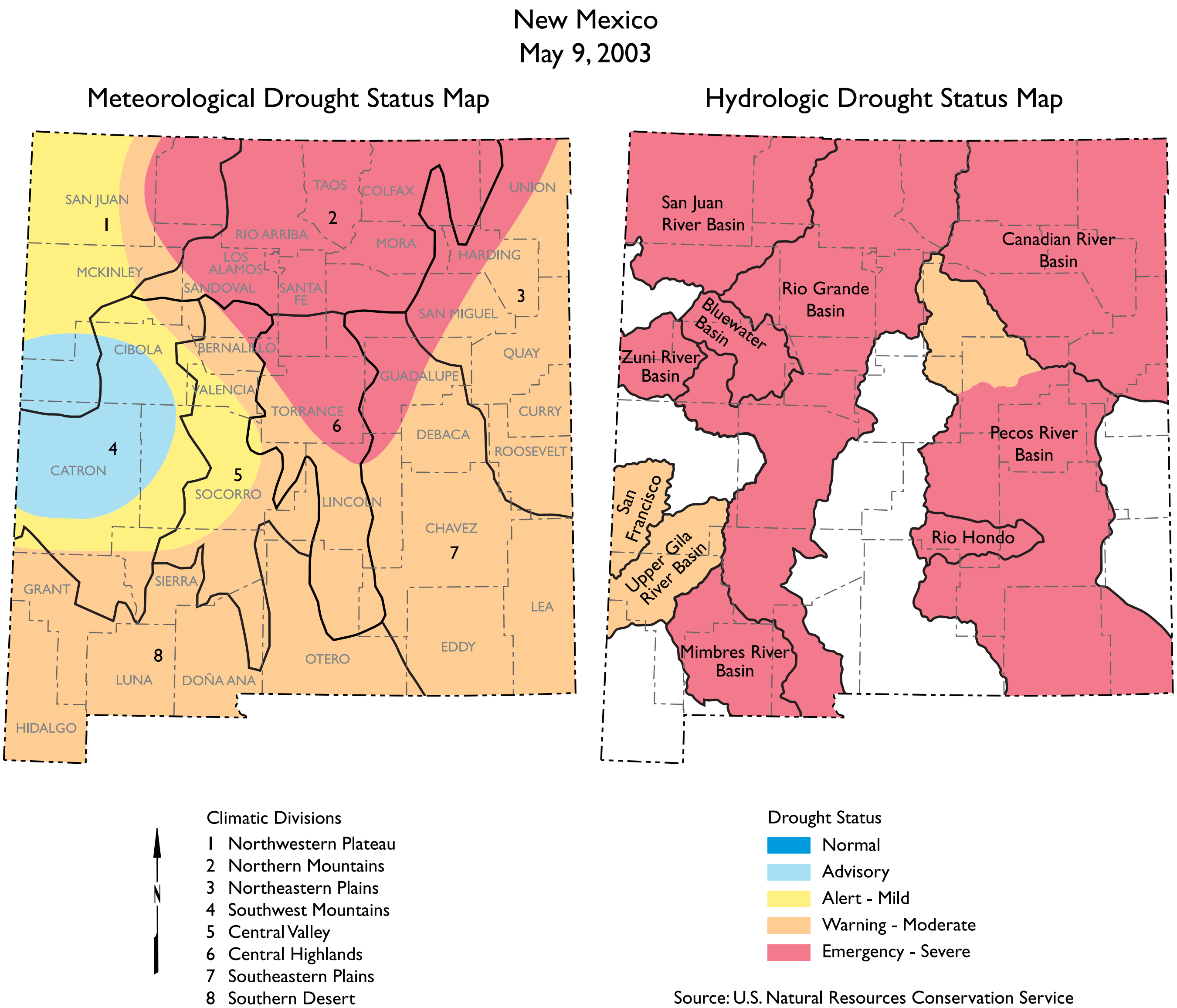
There is no standard quantitative or legal definition of "drought." The term refers to an extended period of time of below-normal precipitation, generally long enough to have pronounced effects on plants, rivers, or reservoirs. Thus, drought refers not just to persistent dry weather, but also to the various impacts that go along with dry weather. These impacts vary regionally. Three weeks without rain in a desert, coniferous forest, or wheat-growing region would have different effects in different seasons; they would have quite different consequences in a place that depends on precipitation replenishing a local reservoir than they would on a major, snow-fed river in a different location.

The National Drought Mitigation Center at the University of Nebraska defines three different "types" of drought: *meteorological* drought, defined strictly in terms of less than normal precipitation; *agricultural* drought, defined in terms of water-stressed crops or rangeland and anomalously dry soil; and *hydrologic* drought, measured in terms of shortages of surface water supplies (low reservoir levels and/or diminished stream flow). Meteorological drought affects ecosystems and economic activities that depend directly on local precipitation. Forested hillslopes, non-irrigated agriculture, and landscape watering in cities are examples. Agricultural drought generally refers to longer time scales than meteorological drought. Hydrologic drought affects large-scale waterworks and river flows, taking into account factors such as reservoir levels (which are affected by consecutive years of drought) and winter snowpack at the headwaters of large river drainages.

At present (June 2003) most of New Mexico has received near-normal precipitation for the water year that began in October 2002, hence in a formal sense we are not suffering from short-term meteorological drought. The Palmer Drought Severity Index, probably the single most commonly cited measure of drought conditions, is currently near zero (i.e., normal conditions) across most of New Mexico.

However, the Palmer Index is based entirely on local weather history. Dry conditions prevailed for several years before last autumn, and neither rangelands nor reservoirs have recovered from very poor conditions. Thus, indices of agricultural drought (such as soil moisture estimates) or hydrological drought (such as reservoir levels) indicate that New Mexico is deep in a long-term drought.

Recognizing the multiple components of drought, in spring 2003 the New Mexico Drought Task Force (which reports to the governor) switched from using the Palmer Index as its principal drought indicator to a two-component set of maps on the next page. The task force regards parts of the state to be in the midst of a long-term meteorological drought (the map on the left), emphasizing the multi-year precipitation deficit that has built up since the late 1990s. The map on the right shows the absolutely dire situation in the state with regard to hydrological drought in both the Rio Grande and Pecos drainage basins. Reservoir levels are very low (as a result of very dry years in 2001 and 2002), and current forecasts call for minimal river flows in the Rio Grande and Pecos River following a deficient winter snowpack in northern New Mexico and southern Colorado.

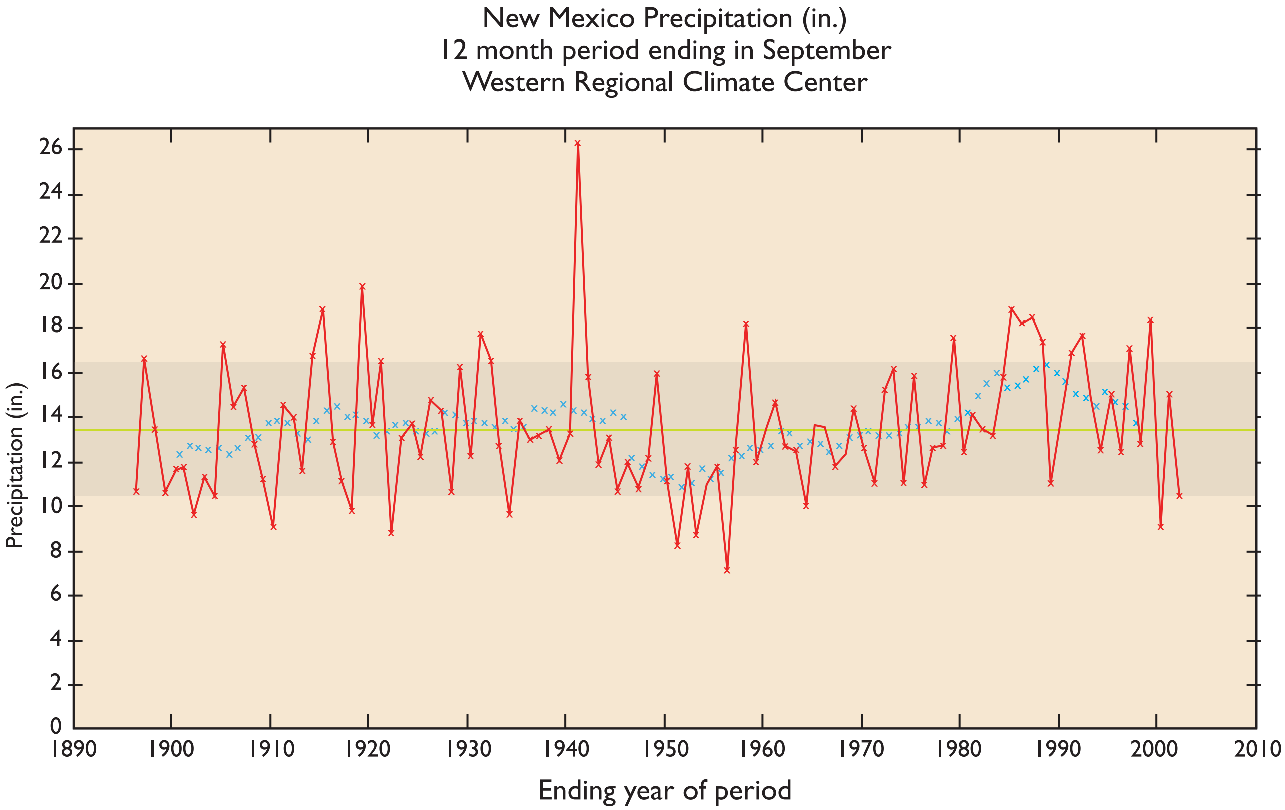


Drought status maps (issued May 9, 2003) from the New Mexico State Drought Task Force, available online from the New Mexico Climate Center at http://weather.nmsu.edu/drought/ (a) Status of "meteorological drought"; (b) Status of "hydrological drought." Color scheme is the same in both maps, ranging from blue ("normal" or no drought) to deep red ("emergency" or severe drought). Hydrologic drought is defined only for selected river basins; areas between these basins are left blank.

PREVIOUS DROUGHTS IN NEW MEXICO

Instrumental precipitation records in New Mexico extend back to the nineteenth century. A time series of annual precipitation averaged over the entire state since 1896, shown in the figure on the opposite page, is based primarily on a network of several hundred volunteer "cooperative observers" spread throughout the state organized by the U.S. National Weather Service. (Even today this network of citizens—ranchers, park rangers, backyard weather enthusiasts, etc.—none of whom receives payment for this effort—forms the backbone of our nationwide climate observing system.) Each annual value contains considerable uncertainty: there are large gaps between weather stations, and high mountain regions are undersampled, so the data in this figure probably underestimate the "true" statewide average. The solid green line shows the century-average annual precipitation in the state, about 13.5 inches.

Large inter-annual fluctuations of precipitation occur routinely. However the severe drought of the



Time series of annual water-year (October–September) precipitation averaged across New Mexico from 1896 to 2002. Red line shows annual data points; blue x's show 10-year running average; yellow line shows average annual precipitation for the entire period of record. Data and plotting routine are available online from the Western Regional Climate Center at http://www.wrcc.dri.edu

1950s clearly stands out as something unique in the twentieth century. For seven consecutive years, 1950–1956, annual precipitation was less than 12 inches. In three of those years (1951, 1953, 1956) the annual value was less than 9 inches, an amount lower than any year in the half century since then (although 2001 came close).

The 1980s and 1990s were years of plentiful rainfall by comparison. Precipitation failed to exceed 12 inches only one year in those two decades. These were decades of explosive population growth in the state. It is imperative for policy makers to understand that recent climatic conditions in the 1980s and 1990s were not "normal" by any standard. The 1980s and 1990s were just as anomalously wet as the 1950s were anomalously dry.

To put the drought of the 1950s and the wet spell of the 1980s and 1990s into long-term perspective, plots like the figure on this page can be extended backward in time using biological or geological indices that are known to correlate with climate in recent data. The most common such proxies for continental climate variability of the last 1,000–2,000 years are the annual growth rings in old trees, analyzed using a technique called dendrochronology. Trees in New Mexico have yielded a wealth of information on droughts and wet spells during the past millennium.

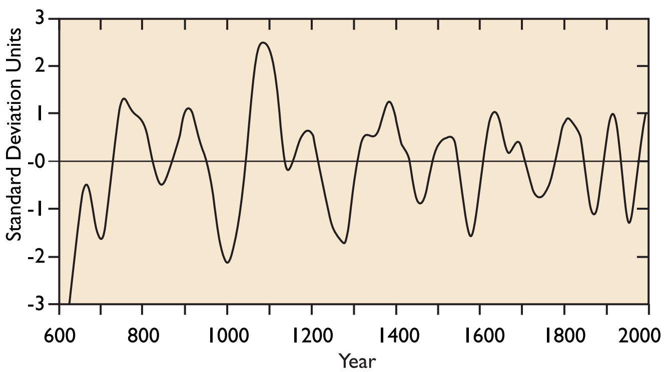
The dendrochronological record shown on the next page, for the period from A.D. 622 to 1994, is from a set of trees in south-central New Mexico. The graph shows the time series of reconstructed annual precipitation anomalies after a low-frequency smoother has been applied to emphasize long-period fluctuations, so short-term (one- or two-year) dry or wet spells are smoothed out. Several features are worth emphasizing:

- The 1950s drought was very substantial, but previous droughts (e.g., around A.D. 1000 and in the late thirteenth and sixteenth centuries) were both longer and drier.
- The late twentieth century wet spell is truncated by the smoothing function, but it is clearly a wet spell of historic proportions.

- Frequency analysis of this curve indicates that severe droughts occur at least once every century, with an average of approximately 60–80 years between droughts. An average drought periodicity between 50 and 100 years is observed in similar records throughout the Mountain West, suggesting that the next severe drought episode in New Mexico is due anytime within the next couple of decades.

CAUSES OF MULTI-YEAR CLIMATE ANOMALIES

What could cause precipitation to remain lower than normal for months, years, or a decade or more? The dendrochronological record shows that droughts have occurred in New Mexico for centuries, long before people were plentiful enough to disrupt the climate system. Research during the past several decades has pointed to slow variations in ocean temperature and currents, especially in the Pacific Ocean, as a major cause of wintertime climate variability across North America. The causes of prolonged summer droughts are not well understood at this time, but severe long-term winter droughts seem to span the seasons.



Reconstructed precipitation in south-central New Mexico, A.D. 622–1994, derived from tree ring records obtained in the Magdalena, San Mateo, and Organ Mountains. The annual precipitation values have been smoothed to emphasize multi-decadal fluctuations. From Grissino-Mayer, H., C.H. Baisan, and T.W. Swetnam, 1997, *A 1,373 year reconstruction of annual precipitation for the southern Rio Grande basin*: Final report for the Legacy Program.

The El Niño cycle is the best known, and best understood, oceanic phenomenon that modulates drought in New Mexico. El Niño is an enormous tongue of anomalously warm Pacific Ocean surface water extending along the equator westward from the South American coast. The mirror-image cold phase is typically called La Niña. The cycle is not periodic, but extreme warm and cold phases each tend to occur several years per decade, reaching maximum amplitude in the Northern Hemisphere winter season.

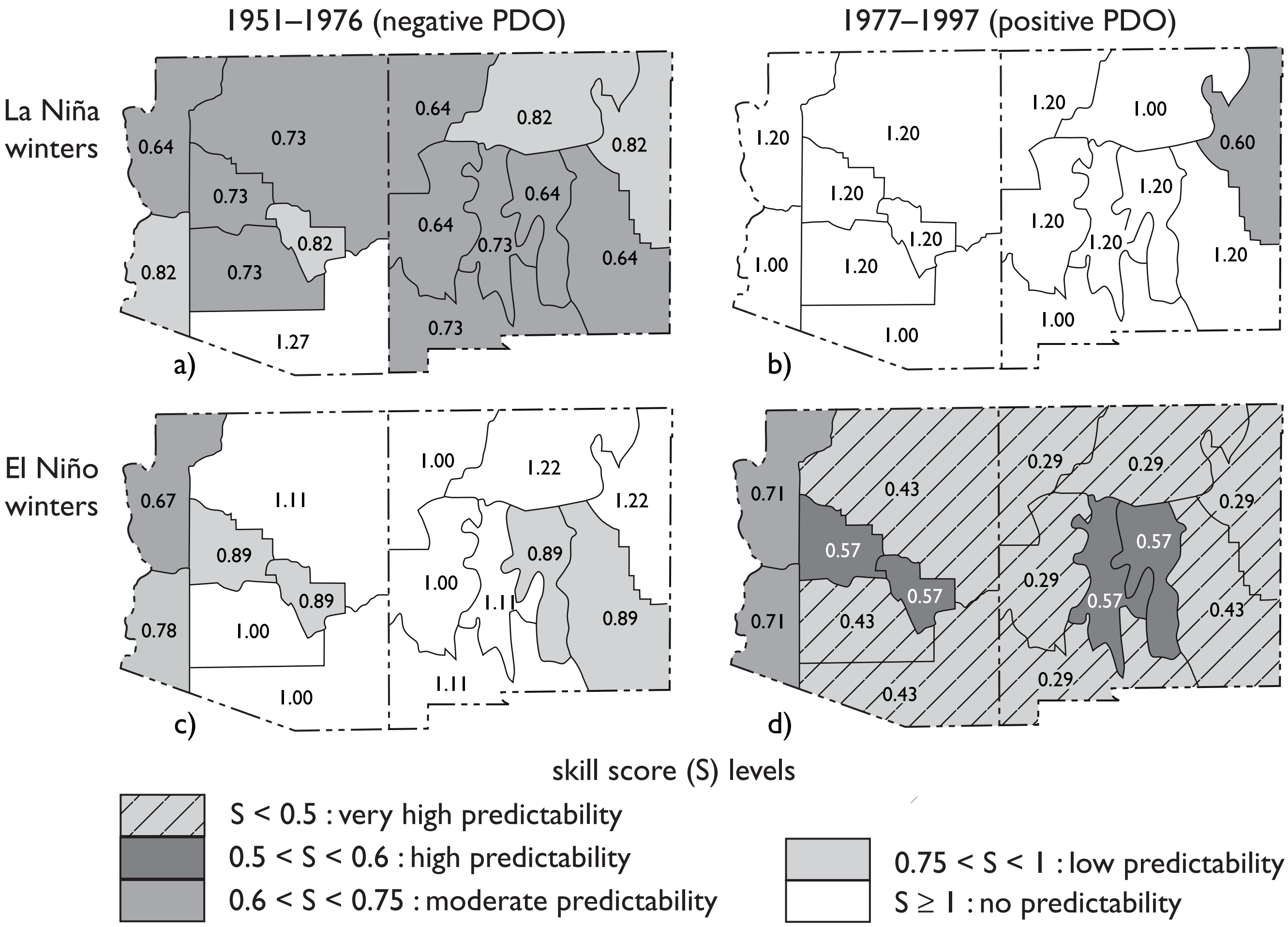
El Niño affects winter and spring precipitation by influencing the atmospheric jet stream across the Pacific Ocean. El Niño pulls the Pacific jet stream, and the storms that spawn off it, southward toward California and the southern U.S. Thus New Mexico tends to receive more precipitation than normal during an El Niño winter. La Niña has the opposite effect, pushing the jet stream northward and leaving New Mexico drier than normal.

Recent research shows that longer multidecadal fluctuations in the North Pacific Ocean also affect precipitation across southwest North America. In particular, North Pacific Ocean temperatures seem to vary more slowly than El Niño-related anomalies. This "Pacific decadal oscillation" (or PDO) seems to modulate the effects of El Niño, such that in its negative phase the effects of La Niña are amplified and the effects of El Niño are suppressed, whereas in the PDO's positive phase the opposite modulation occurs. The PDO was in a negative phase during the 1950s (when persistent drought plagued New Mexico), then abruptly flipped in 1977 so that the wet decades of the 1980s and 1990s took place during a PDO-positive period.

El Niño / La Niña extrema are the principal source of skill for current seasonal forecasts. When we see El Niño or La Niña forming in the summer and autumn we can be nearly certain that the ocean anomalies will persist through the winter. The PDO is currently not predictable, but it appears to have flipped back to a negative phase following the huge El Niño event of 1997–98. This ominous development may have contributed to the failure of last winter's El Niño event to generate abundant snowpack and break the current drought. Major research initiatives now in progress seek to gain better understanding of El Niño and PDO variability with the aim of improving long-range predictions of continental climate a year or more in advance.

CURRENT STATUS OF DROUGHT: SUMMER 2003

At the time this chapter is being written (June 2003) New Mexico is poised on the cusp of what could become the worst drought since the 1950s. Reservoir levels, streamflows, and rangeland-quality indices all indicate that the state is deep in agricultural and hydrological drought already. Unfortunately, current Pacific Ocean conditions are consistent with continuation of



Predictability of winter precipitation across Arizona and New Mexico derived from knowledge of El Niño or La Niña conditions the previous autumn (Gutzler et al., 2002). The plotted values represent a statistical measure of predictive skill, with 0 representing perfect predictability and 1 or greater representing no predictive skill at all. The top row of maps (maps a,b) show predictive skill associated with La Niña; the bottom row (c,d) depicts predictive skill associated with El Niño. The left column (a,c) is based on years between 1951 and 1976, when the PDO was in its negative phase. The right column (b,d) is based on years between 1977 and 1997 during a positive phase of the PDO. Thus La Niña effects (dry winters) were enhanced in the earlier period (a), and El Niño effects (wet winters) were enhanced in the later period (d). Pacific Ocean data since 1998 suggest that the PDO may have flipped back into its negative phase, whence the Southwest could be especially vulnerable to dry La Niña winters. From Gutzler, D., D. Kann, and C. Thornbrugh, 2002: Modulation of ENSO-based long-lead outlooks of Southwest U.S. winter precipitation by the Pacific Decadal Osicillation, Weather and Forecasting, vol. 17, pg. 1163–1172.

drought in New Mexico: Initial hints of the next La Niña event have been observed in the tropical Pacific, and the Pacific Decadal Oscillation seems to have shifted back into the phase that reinforces La Niña when it next occurs. Decision makers should anticipate the increasing likelihood that drought conditions in New Mexico will get worse in the near future.

SUGGESTED READING

Wilhite, D., editor, 2000, Drought—A global assessment (in 2 volumes): New York, Routledge.