Jemez y Sangre
Regional Water Planning Council

Charlie Nylander, Chair
11 Abierto Way
Santa Fe, New Mexico 87506

January 8, 2010

Estevan Lopez, Director
New Mexico Interstate Stream Commission
Bataan Memorial Building
Santa Fe, New Mexico 87501

Subject: Jemez y Sangre Phase II Update Report Transmittal

Dear Mr. Lopez:

The Jemez y Sangre Regional Planning Council has reviewed and accepted the Phase II Update Report prepared by Amy Lewis, Consultant, and Daniel B. Stephens & Associates, Inc., and we request that you place the electronic version of this report on the Interstate Stream Commission (ISC) website under regional water planning, Region 3.

This Update Report addresses four (4) topical areas, as recommended by the Jemez y Sangre Regional Planning Council. These topics have been researched by the authors of the report, and the resulting document presents updated information and recommendations regarding the topics. Please note that the Council had originally requested technical assistance from ISC toward providing professional consulting assistance in addressing the four topical areas, and we appreciate the funding support provided by ISC to prepare the enclosed report. The four topical areas include San-Juan Chama Reliability, Climate Change, Aquifer Viability through 2060, and Changes in Water Use by the Agricultural Sector.

A summary of the authors' findings for the four selected topics are as follows:

San Juan-Chama Reliability

- No change in the firm yield estimate for San Juan-Chama project water is necessary for water planning purposes. The Navajo Settlement should not impact the firm yield estimate; however, no surface water supply is risk-free because a series of droughts could occur that result in shortage

Climate Change

- Temperature is predicted to increase 5 to 10°F by 2100.
- Precipitation is predicted to decrease 10 to 20%, except for one study that shows a 5% increase.
- Streamflow is predicted to decrease by 10 to 30% by 2080.
- Spring run-off is predicted to occur 20 days earlier.
- Evapotranspiration is predicted to increase.
- Extreme precipitation events are predicted to increase.
- Precipitation is predicted to fall more as rain and less as snow.
- Climate change will put great stress on crops (weeds and insect problems increase with higher temperatures).

Aquifer Viability through 2060

- A reliable groundwater model of the aquifer systems in the region is needed to adequately address the viability of the aquifer.
- The Santa Fe County Model has stability problems in Layer 1, and pumping stresses need to be reassigned to deeper layers.
- Recharge estimates in the North Galisteo Sub-basin are much higher than other water budget estimates for the sub-basin.
- The region needs to define what is meant by "sustainable."
- The region should continue to refine/calibrate the groundwater model.

Changes in Water Use in the Agricultural Sector

- Information available is not adequate to detect changes in water use for the agricultural sector.
- The Office of the State Engineer's 1995 and 2005 estimates for the Jemez y Sangre Region are about 1% different, although more was estimated for the Velarde sub-basin and less for Pojoaque-Nambe sub-basin.
- Farms not reporting to the Farm Service Agency are not included in Office of the State Engineer's estimates.

In reviewing the enclosed report, the Jemez y Sangre Regional Planning Council has the following comments regarding the document.

Aquifer Viability through 2060. Under the section on Aquifer Viability through 2060, the reader should note the authors' caution regarding the stability of Layer 1 of the model (the uppermost layer in the 5-layer model). This layer contains numerous dry modeling cells at the onset of the model run, and the model does not differentiate between an existing dry cell at the onset of pumping and a dry cell resulting from actual water level declines due to pumping. Layer 1 starts with dry cells in the southeast part of Los Alamos County and in the area south of Santa Fe in the vicinity of Sunlit Hills. In these cells, the top of the water table is below the bottom of Layer 1. Thus Layer 1 model results may suggest general trends, but may not accurately represent true field conditions.

Climate Change. The Jemez y Sangre Regional Planning Council does not have a great deal of confidence regarding the conclusion that the Jemez y Sangre region can expect decreased precipitation in the forecast period. The Council understands that there are problems and issues associated with applying regional global climate models on a local scale. In all fairness to the author, the art of climate modeling, and the inherent limitations found in the current climate change literature, the Council recommends that the reader of this report focus on the statement by Dr. David Gutzler that is quoted by the authors on page 32 of the report:

> "Precipitation scenarios show periods of wet and dry, but no clear trend for New Mexico."

The Council, as well as the larger community of water planners, should not ignore the possibility of decreased precipitation, but should consider the possibility in the context of the lack of modeling at the local scale and the need for improved research in this area of science. The Council recognizes the need for such research and encourages the ISC to support such research in the future.

On behalf of the Jemez y Sangre Regional Planning Council, I wish to thank you and the Interstate Stream Commission for your support of the Jemez y Sangre Regional Water Plan, Phase II Update Report.

Sincerely,

Charlie Nylander

Charlie Nylander, Chair
Jemez y Sangre Regional Planning Council

Selected Topics
Jemez y Sangre Regional Water Plan
Phase II Update

Prepared for **Jemez y Sangre Water Planning Council**

December 22, 2009

Daniel B. Stephens & Associates, Inc.

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Acknowledgements

DBS&A would like to acknowledge the contributions of numerous individuals who provided assistance in the preparation of this report:

- John Whipple, Tanya Trujillo, and Estevan Lopez of the New Mexico Interstate Steam Commission reviewed drafts and met with Amy Lewis and Mark Miller on the availability of San Juan-Chama water.

- Robert Vocke, previous member of the Jemez y Sangre Water Planning Council, brought to light numerous climate change publications, Sig Silbur identified a discrepancy in an important publication by Hurd and Coonrod (2008), and Brian Hurd of New Mexico State University was very helpful in providing information on the climate change estimates for New Mexico.

- Karen Torres, Santa Fe County Hydrologist, in a very short time-frame performed the aquifer modeling used for Task 3.

- Molly Magnuson, New Mexico Office of the State Engineer, Pat Torres, Santa Fe County Extension Agent, Tony Valdez, Rio Arriba County Extension Agent, and Thomas Gonzales, District Conservationist with the USDA-NRCS Española Field Office, were very helpful in explaining the procedures used to estimate agricultural acreage.

Introduction

On behalf of the Jemez y Sangre (JyS) Water Planning Council (WPC), Daniel B. Stephens & Associates, Inc. (DBS&A) has investigated and summarized information available on four topics relative to the water resources and planning in the JyS region. The topics were identified based on issues and recommendations identified in the JyS regional water plan 2007 update report (JyS WPC, 2008):

- Task 1: San Juan-Chama Project water reliability
- Task 2: Climate change impacts on water resources of the JyS Region
- Task 3: Aquifer viability through 2060
- Task 4: Changes in water use of agricultural sector

This report was funded by the Interstate Stream Commission Water Planning Section, and the project was initiated on March 23, 2009.

1. San Juan-Chama Project Reliability

The reliability of San Juan-Chama (SJC) Project water was investigated in light of the Navajo Nation Water Rights Settlement for the San Juan River Basin (NM OSE, 2005) and bypass requirements, to determine potential impacts on the firm yield of the SJC Project water. Firm yield is defined as "[t]he estimated amount of SJC water that can be provided from Heron Reservoir with reasonable certainty each year" (USBR, 2007).

Public Law (PL) 87-483 in 1962 authorized the SJC Project to divert up to a total of 270,000 acre-feet per year (ac-ft/yr) in any year, not to exceed 1,350,000 acre-feet in any period of 10 consecutive years, from three streams in the San Juan River Basin in Colorado for use in the Rio Grande Basin in New Mexico (Figure 1-1). The Navajo, Little Navajo, and Blanco rivers are tributary to the San Juan River in Colorado above Navajo Reservoir, and the SJC Project diversion dams on these three streams are operated to meet bypass flow requirements to protect fish and aquatic life downstream and to avoid impairment to water rights in Colorado, including for any future water development on these streams that Colorado is entitled to under the Upper Colorado River Basin Compact. If not diverted by the SJC Project or used downstream, streamflow in these three streams would flow to Navajo Reservoir.

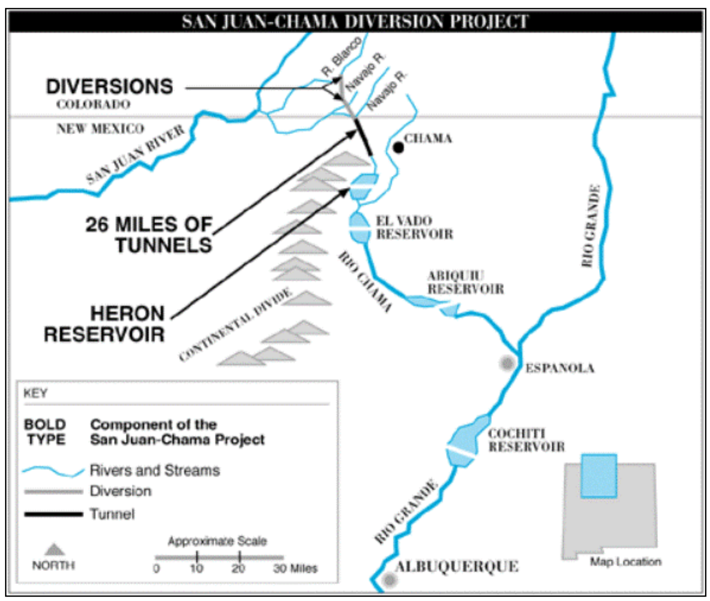


Figure 1-1. San Juan-Chama Project
Source: Earp et al., 2006

Pursuant to PL 87-483, the SJC Project must share in any shortages in the Navajo Reservoir Supply in the San Juan River Basin with the contractors for water from the reservoir. The Navajo Reservoir Supply includes all water originating above Navajo Dam to which the United States is entitled, including water to supply the SJC Project. Demands on the Navajo Reservoir Supply will increase with implementation of the Navajo-Gallup Water Supply Project, authorized as part of the San Juan River Basin in New Mexico Navajo Nation Water Rights Settlement approved by

PL 111-11. Also, Navajo Reservoir is now operated to provide flow regimes recommended by the San Juan River Basin Recovery Implementation Program (SJRIP) for the San Juan River below Farmington for the protection of critical habitat and the support of all life stages of the river populations of Colorado pikeminnow and razorback sucker, both listed as endangered under the Endangered Species Act (ESA). The SJRIP has dual goals to recover the San Juan River populations of the endangered fish species and to continue with water development in the San Juan River Basin in accordance with federal and state laws and the United States' trust responsibilities to the Indian tribes in the basin.

Since operation of the SJC Project began, sufficient water has been available to meet Project contractor demands at Heron Dam in the Rio Grande Basin. To date, the storage capacity of Heron Reservoir has been able to serve as a buffer to mitigate impacts to the water supply by low-flow periods in the San Juan River Basin when diversions were much below average. A review of available documents and consultation with the U.S. Bureau of Reclamation (USBR) and New Mexico Office of the State Engineer (OSE) and Interstate Stream Commission (ISC) indicates that no adjustment in the estimates of firm yield is needed. However, the reliance on contracted water from the SJC Project is not without some risk, because a series of dry years could occur that might be worse than the critical hydrologic period of record used in yield studies for the project.

1.1 San Juan-Chama Project Background

The SJC Project was authorized in 1962 and began diverting water in 1971 from the watersheds of the Navajo, Little Navajo, and Blanco river tributaries that are part of the San Juan Basin in Colorado. Figure 1-1 shows a map of the SJC Project. Water is diverted from the three tributaries through a series of tunnels, one of which passes under the Continental Divide (the Azotea tunnel) to Willow Creek in New Mexico. The water flows down Willow Creek and is stored in Heron Reservoir, which was constructed to store and regulate SJC Project diversions, which might vary greatly from year to year, for the purpose of providing a more uniform or constant annual yield to SJC Project contractors in the Rio Grande Basin. Heron Reservoir fills during wet periods and is drawn down during dry periods as needed to make contract deliveries when the SJC Project diversions would otherwise not be sufficient (such as in 2002 when only about 6,300 acre-feet could be diverted through the Azotea Tunnel). The SJC Project is allocated an average 135,000 ac-ft/yr) of diversions and has an estimated reliable diversion yield of 107,500 ac-ft/yr from the three tributaries. The firm yield of the SJC Project at Heron Dam is 96,200 ac-ft/yr (USBR, 2007), which is contracted to the entities listed in Table 1-1. Figures 1-2a and 1-2b show the historical diversions of SJC Project water and the historical total releases of SJC Project water to the SJC contractors, respectively.

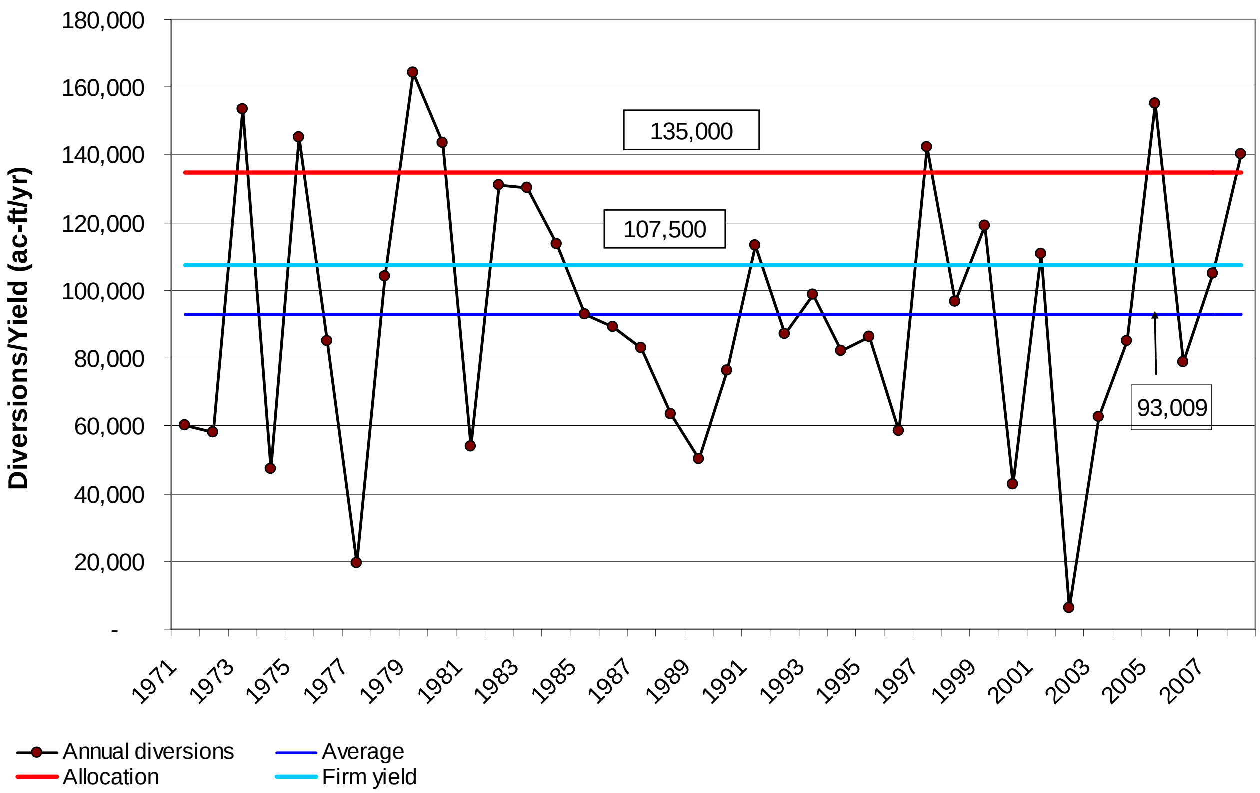
Table 1-1. San Juan-Chama Project Water Contracts

Contractor	Annual Contract Amount (acre-feet)
Municipal, domestic, and industrial supplies	
City of Albuquerque	48,200
Jicarilla Apache	6,500
City of Santa Fe	5,230
County of Santa Fe	375
County of Los Alamos	1,200
City of Española	1,000
Okay Owingeh (San Juan Pueblo)	2,000
Town of Belen	500
Village of Los Lunas	400
Village of Taos	400
Town of Bernalillo	400
Town of Red River	60
Taos Ski Valley	15
Irrigation supplies	
Middle Rio Grande Conservancy District	20,900
Pojoaque Valley Irrigation District	1,030
Other	
Cochiti Reservoir Evaporation Offset	4,300
Taos Pueblo [a]	2,621
Aamodt [b]	1,079
Total	96,200

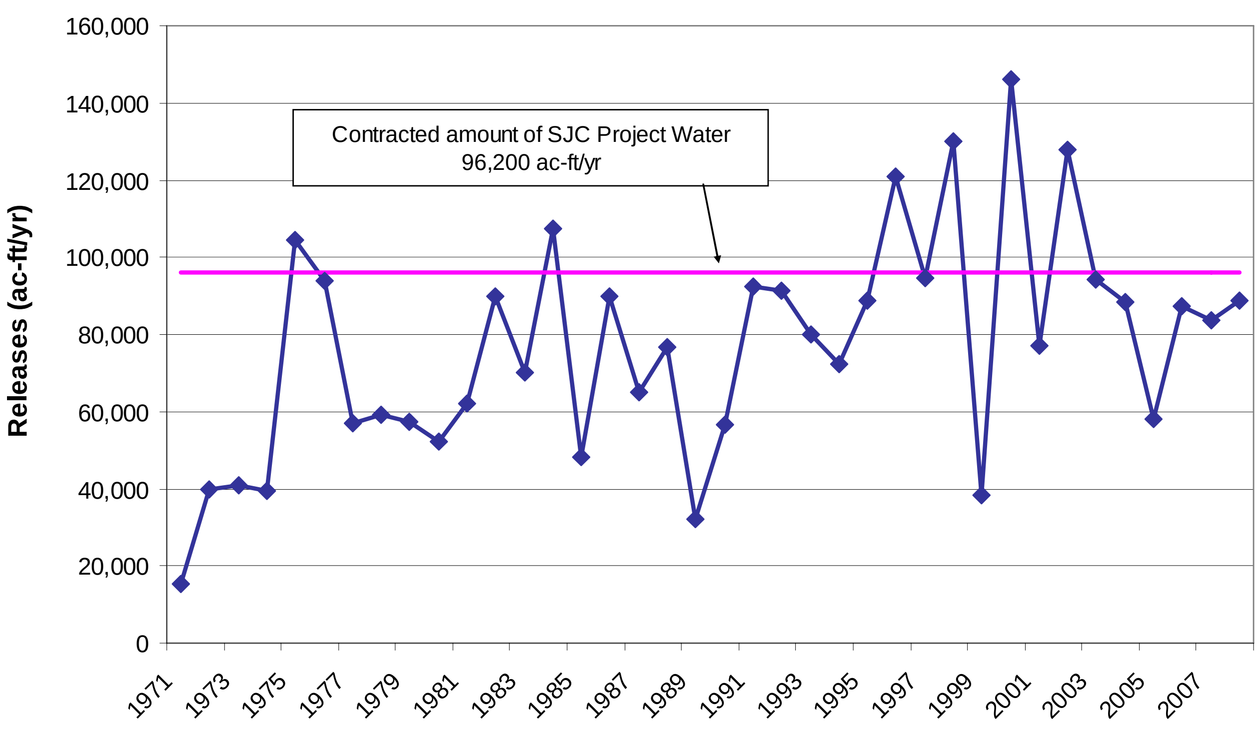
[a] Pending Taos Pueblo Settlement (Federal legislation S. 965). Section 9(b) allocates 2,215 acre-feet per acre (ac-ft/ac) of SJC water for the Pueblo, 366 ac-ft/ac for the Town of Taos, and 40 ac-ft/ac for El Prado.

[b] Pending Aamodt Settlement (Federal legislation S. 1105). Section 103(a)(2) allocates 1,079 ac-ft/ac of SJC water for the Pueblos through the regional water system.

a. Historical Diversions of San Juan-Chama Water through the Azotea Tunnel



b. Historical Releases of San Juan-Chama Project Water from Heron Reservoir, 1971-2008



Source: Flanigan, 2009

JEMEZ Y SANGRE PHASE II UPDATE

Historical Diversions and Releases
San Juan-Chama Project

Daniel B. Stephens & Associates, Inc.

6/27/09

Figure 1-2

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Heron Reservoir has a capacity of about 400,000 acre-feet, which is dedicated to operational storage of the SJC Project water. Heron Reservoir is operated by the USBR in compliance with applicable federal and state laws, including the SJC Project authorization and the Rio Grande Compact. Under these laws, only imported SJC Project water may be stored in Heron Reservoir; there are no provisions for storing native Rio Grande water. Thus, all native Rio Grande water entering Heron Reservoir is released to the river below Heron Dam.

Contracts for SJC Project water require that the water allocated to each contractor must be delivered each year by releases from Heron Reservoir. Annual water allocations must be used each year by December 31 or be forfeited by the contractor. Unused water will be reallocated the following year. No carry-over storage is available in Heron Reservoir for individual allocations (without a waiver), and no other conservation storage capacity is available. A waiver can be granted to allow for temporary storage of water, usually for unused water not needed in the later part of the year.

Table 1-2 provides statistics for the average annual SJC Project diversions from the San Juan River Basin into Heron Reservoir and for contract deliveries to SJC Project contractors at Heron Dam for the period 1971 through 2008. The average annual diversion for the SJC Project has been 93,000 ac-ft/yr for the period of record from 1971 through 2008. Note that historical diversions are not equivalent to yield, because the diversions were curtailed in many years to avoid a spill at Heron Dam and such conditions would occur less frequently in the future with a full demand at Heron.

Table 1-2. Summary of San Juan-Chama Diversion Allocations and Actual Yields

Description of Diversion Allocation or Yield	Annual Diversion at the Azotea Tunnel Outlet (ac-ft/yr)	Releases from Heron (Project Yield) (ac-ft/yr)
Maximum single-year diversion	270,000	—
Allocated 10-year average diversion	135,000	—
USBR estimated annual yield	107,500	96,200
Maximum actual diversion	164,000 (1979)	146,300 (2000)
Minimum actual diversion (1975-2008)	6,311 (2002)	32,000 (1989)
Average annual diversion past 37 years (1971-2008)	93,000	76,800
Median annual diversion past 37 years (1971-2008)	88,100	78,600

ac-ft/yr = Acre-feet per year
— = Not applicable
USBR = U.S. Bureau of Reclamation

1.2 Shortage Sharing Requirements and Agreements

The SJC Project is required to share in shortages according to PL-483 (which is described in Section 1.2.1), and the SJC Project contractors voluntarily signed shortage sharing agreements for the years 2003 through 2008. The Navajo Settlement (signed in 2009) now clarifies how shortage sharing will be calculated. This section describes both the required sharing of shortages and the 2003 through 2008 voluntary agreements (although the latter may no longer be relevant).

1.2.1 Shortage Sharing Requirement

The original legislation creating the SJC Project in 1962 (PL 87-483) required that the SJC Project share in shortages with the Navajo Indian Irrigation Project (NIIP), a project that is continuing to be developed for additional irrigated acreage with increased diversions, and with other contractors for water from the Navajo Reservoir Supply. The NIIP contractors include the Navajo Nation, Jicarilla Apache Nation, Hammond Conservancy District, and Williams Gas Company. Under the PL 87-483 that authorized the SJC Project and NIIP, in any year in which the Secretary of the Interior "anticipates a shortage, taking into account both prospective runoff originating above Navajo Reservoir and the available water in storage in Navajo Reservoir . . . the prospective runoff shall be apportioned between the contractors diverting above and those diverting at or below Navajo Reservoir in the proportion that the total normal diversion requirements of each group bears to the total of all normal diversion requirements." The water available to the Secretary for apportionment does not include inflow to the reservoir that is bypassed to meet senior downstream water rights to divert from the direct flow of the San Juan River or to meet the SJRIP's flow recommendations.

The Navajo Water Rights Settlement Agreement of April 19, 2005 (approved by President Barack Obama on March 30, 2009 by signing the Northwestern New Mexico Rural Water Projects Act, part of the Omnibus Public Land Management Act of 2009 [PL 111-11]) does not change the shortage apportionment provisions of PL 87-483, but it does include clarifications as to how to determine the normal diversion requirement for each contractor and the SJC Project. PL 111-11, Section 10402 (f)), states that the "Secretary of the Interior shall determine the quantity of any shortages and the appropriate apportionment of water using the normal diversion requirements on the flow of the San Juan River originating above Navajo Dam." The criteria for establishing a shortage include determining water demand based on cropping plans, non-irrigation demands, and an "annual normal diversion demand of 135,000 acre-feet for the initial stage of the San Juan-Chama Project authorized by Section 8, which shall be the amount to which any shortage is applied."

The institutional processes and computational procedures for implementing the shortage sharing are detailed in a memorandum from John Whipple (Whipple, 2005b). This memorandum provides an example computation and apportionment of shortages and supplies for water originating above Navajo Dam according to the 1962 Act (Section 11) and the Navajo Settlement (Sections 403 and 404). The example shows what is and isn't included in the shortage (for instance, water stored in Heron reservoir is not included, whereas available water in Navajo Reservoir is). In the event of a shortage of 21.6 percent, as used in this example, SJC water available for diversion would be 105,878 acre-feet (135,000 acre-feet less 21.6 percent of 135,000). This is just an example; conditions in the future could be different and not necessarily lead to the 105,878–acre-foot result depending on others' demands, even with same hydrology.

Given that (1) the firm yield of the SJC project is already below the "annual normal diversion" specified in the Navajo Settlement and (2) the formula does not include water stored in Heron Reservoir, the example indicates that shortage sharing is unlikely to impact the available diversions to the project. Whipple (2005a) concludes that the "formula . . . for allocating the supply available above Navajo Dam to the San Juan-Chama Project . . . favors water uses under the San Juan-Chama Project . . .." Whipple concludes that the "San Juan-Chama Project in years of shortage would receive . . . an annual allocation amounting to about 25% or more of the runoff above Navajo Reservoir. . . " and ". . . years of shortage . . . are expected to occur only rarely, and in such years, the actual current year demands for water from Navajo Reservoir under Navajo Reservoir water supply contracts would have to be shorted by a substantial amount before the . . . San Juan-Chama Project is allocated less water than the . . . water delivery demand for the project." He further states that the project is designed to divert water when available and the water in storage at Heron Reservoir should be able to offset shortages in a particular year, but the shortages are most likely to be created by bypass requirements, not shortages in the Navajo Reservoir Supply.

Under the 1962 Act, shortages are defined as predictive determinations of anticipated shortages, with some associated uncertainty in runoff amounts. The U.S. Secretary of the Interior determines when a shortage is anticipated, based on the prospective runoff and storage in Navajo Reservoir. Because the NIIP diversion is directly from Navajo Reservoir, a shortage for NIIP occurs when the reservoir level falls below the elevation of the NIIP diversion.

The USBR has developed a surface water model of the San Juan River Basin that has gone through several generations. The first version was developed in the late 1990s and used in the development of the SJRIP's flow recommendations for the San Juan River. The second generation model was used for water planning and environmental compliance activities associated with the Navajo-Gallup Water Supply Project (Whipple, 2009). The USBR is currently working on a third version of the surface water model of the San Juan River to incorporate additional hydrologic data and other model improvements that will increase the reliability of modeling for water planning purposes, including evaluating the potential for future shortages. The latest version of the model, Generation 3, is not finalized due to ongoing technical work and discussion and negotiation among stakeholders in the basin regarding several aspects of the model. The revised model will not be available for several years (Grantz, 2009).

The availability of water in the San Juan Basin at Navajo Reservoir is dependent on there being sufficient San Juan River flows for Navajo Reservoir operations to meet ESA requirements. Flow requirements for the San Juan River are currently addressed under the SJRIP, which recommended a flow regime to protect habitat needed for recovery of the San Juan River populations of the endangered Colorado pikeminnow and razorback sucker. The recommended flow regime basically mimics a natural hydrograph, with large peak flows during the spring snowmelt runoff period and low target base flows during the remainder of the year (SJRBRIP, 1999).

Preliminary modeling conducted for the SJRIP flow recommendations report (SJRBRIP, 1999) found that operating Navajo Dam to meet both the recommended flow statistics for spring peak flows in the San Juan River at Four Corners and additional water development in the San Juan River Basin could lead to water shortages to meet the demands in the basin (USBR, 2002; Keller-Bliesner and USBR, 2004). The modeling evaluated various scenarios of additional water depletions in the basin (SJRBRIP, 1999) and showed that increasing depletions by 122,000 ac-ft/yr above current levels could be sustained, but that increasing depletions by 210,000 ac-ft/yr or more above current levels resulted in water shortages to the Navajo Reservoir Supply.

1.2.2 San Juan River Operations Agreement

Prior to 2003, sufficient water had historically been available to meet all of the system demands from Navajo Reservoir for the period of record from 1936 to 2003 (Whipple, 2007a). In 2002, however, severe drought resulted in Navajo Reservoir storage being substantially drawn down. In response, from 2003 through 2008 the ten largest water users on the San Juan River system entered into annual San Juan River Operations and Administration agreements recommending self-imposed diversion limitations and provisions for a sharing of available water supplies in the event of shortage, without differentiation between the Navajo Reservoir Supply and the direct flow rights. No river administration agreement was made for 2009. These agreements were accepted by the USBR and the State Engineer, but are not binding on them in the future or on other water users, including the SJC Project.

The San Juan River sharing agreement for 2003 (USBR, 2003; USFWS, 2003) specifies that:

> In the event of shortage, the parties also request that Reclamation limit its annual SJC Project diversion for 2003 to an amount equal to the 107,500 acre-feet less the percentage shortage calculated by Reclamation.

This may not be applicable for the future now that PL 111-11 has clarified the apportionment formula, which uses 135,000 acre-feet as the basis for use by SJC Project. In 2003, sharing was implemented based on the projected minimal flow; however, the actual runoff was closer to the maximal probable flow (Page, 2009). Based on the projected shortage, irrigation in 2003 was delayed by one month. The sharing agreement specifies the percentage of diversions by month, and the month of April was equivalent to 10 percent of the total annual diversion.

The sharing agreement would not have impacted the SJC Project in 2003 because the bypass requirements already limited the SJC Project diversions to well below the amount that the sharing agreement would have required. Under the sharing agreement in 2003, the SJC Project water would be reduced to "107,500 acre-feet less the percentage shortage calculated by Reclamation," which in 2003 was estimated to be 10 percent based on the minimal probable inflow (Page, 2009), or 96,750 acre-feet (107,500 acre-feet minus 10,750 acre-feet). In 2003, the amount of water potentially available for diversion under the bypass requirements was 64,435, well below the limit that would have been imposed by the sharing agreement.

1.3 Bypass Requirements

The SJC Project diversions are allowed from the Navajo, Little Navajo, and Rio Blanco when minimum flow requirements are met at the points of diversion. The diversions are operated according to the 1962 Act, which requires bypass flows for protection of fish and aquatic life. The bypass flows are "specified as the minimum daily flow that has to be bypassed [not diverted] during a given month" (USBR, 2009). The bypass flows vary monthly for each tributary as shown in Table 1-3. Diversions occur primarily during spring runoff and summer storm events, and available stream flows are often less than the bypass requirement during fall and winter.

Table 1-3. Minimum Bypass Flow Requirements for the San Juan-Chama Diversions

Month	Minimum Bypass Flow (cfs)		
	Rio Blanco	Little Navajo River	Navajo River
January	15	4	30
February	15	4	34
March	20	4	37
April	20	4	37
May	40	27	88
June	20	27	55
July	20	27	55
August	20	27	55
September	20	27	55
October	20	4	37
November	20	4	37
December	15	4	37

cfs = Cubic feet per second

1.4 San Juan-Chama Project Design Capacity

The diversion capacity of the SJC Project is limited by the capacity of the three diversions, the connecting tunnels, and the Azotea Tunnel (Table 1-4). The combined diversion capacity of the three diversion dams exceeds the conveyance capacity of Azotea Tunnel, which must carry the combined flow. The Azotea Tunnel capacity therefore sets the upper limit on the maximum diversion rate, even when flows in the tributaries may be higher.

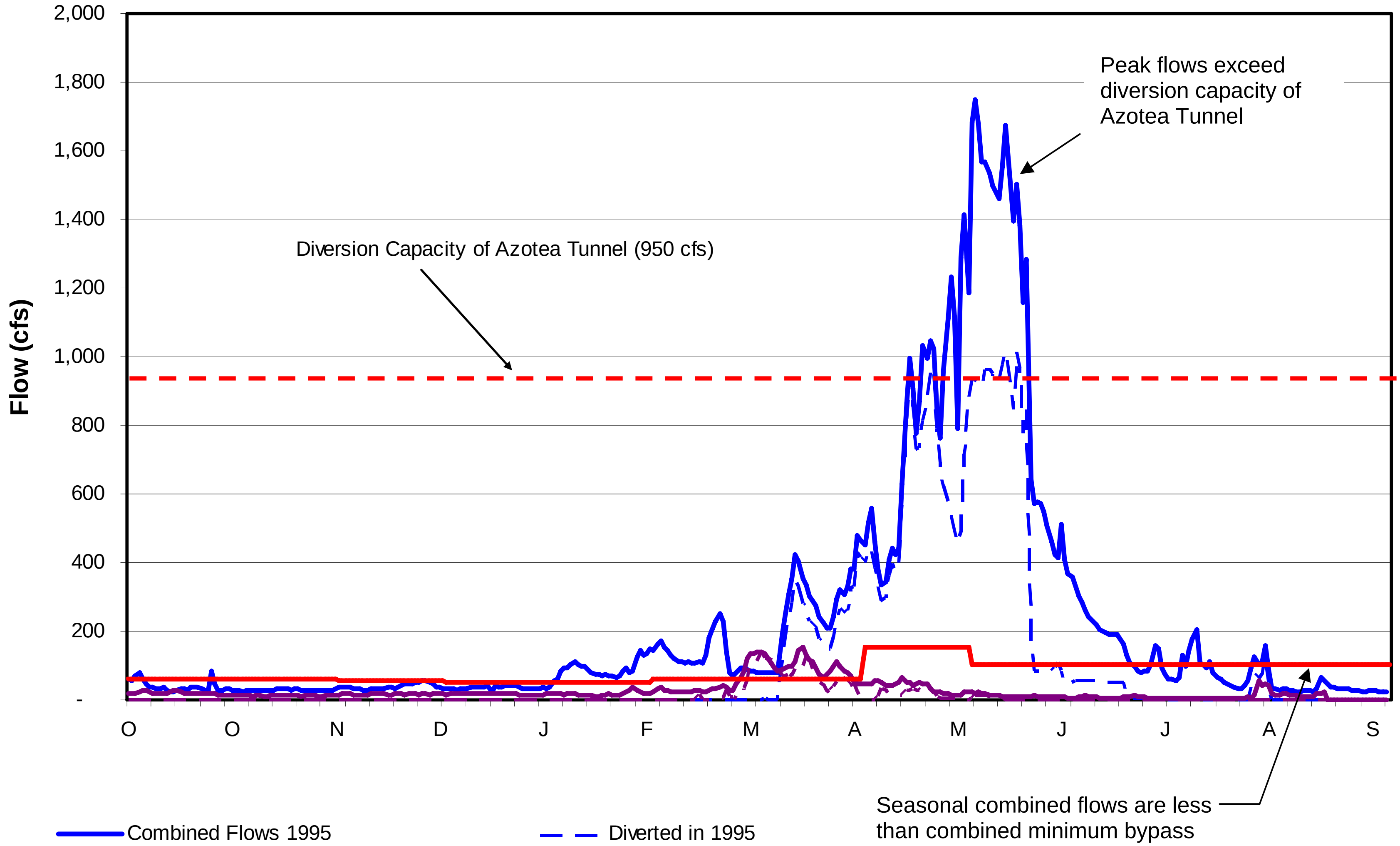
Table 1-4. San Juan-Chama Diversion Design Capacity

Diversion/Conveyance Structure	Diversion Feeder Capacity		Conduit Capacities	
	cfs	ac-ft/d	cfs	ac-ft/d
Rio Blanco Diversion	520	1,030	550 [a]	1,090 [a]
Little Navajo Diversion (Little Oso Siphon)	150	300		
Navajo River Diversion (Oso Siphon) [b]	650	1,290	NA	NA
Azotea Tunnel [c]	NA	NA	950	1,880

[a] Oso tunnel capacity (conveys the combined Blanco plus Little Navajo diversions from the Little Oso to the Oso diversion dams)
[b] The Navajo River does not have a conveyance capacity because it and the Oso tunnel join at the head of the Azotea tunnel.
[c] The Azotea Tunnel conveys the combined diversions from the three diversion structures; the Azotea Tunnel capacity is therefore a limiting factor for maximum diversion rate. The limiting factor at any one time may be the capacity of the diversion or conveyance from one of the streams or the available hydrology. The maximum diversion rate in the spring often exceeds the Azotea tunnel "capacity" due to diurnal flow surges.
cfs = Cubic feet per second ac-ft/d = Acre-feet per day NA = Not applicable

The USBR operates the project to maximize diversion rates (USBR, 2009), which are constrained between the minimum bypass flows and the maximum diversion capacity. The SJC Project diversions can take place only at times when natural tributary flows exceed the bypass requirement and can then occur only up to the limit of system design capacity. High flows in the tributaries that exceed the design capacity of the diversions cannot be fully captured. The capacity of Azotea tunnel is set at 950 cfs as an operational target maximum, which can and has been exceeded for short periods of time (Whipple, 2009). The tunnel is not designed to sustain flows above 950 cfs for an extended period of time without damage to the structure.

Figure 1-3 shows the combined limitations for diversion, the combined daily flow from the three tributaries (Navajo, Little Navajo and Blanco), and the actual daily diversions through Azotea Tunnel for a wet year (1995) and a dry year (2002). Note that even in a wet year like 2005, the



Note: Based on combined total tributary flows above the three diversions for water years 1995 (wet) and 2002 (very dry)

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Water Available for Diversion in Representative Wet and Dry Years

Daniel B. Stephens & Associates, Inc.

6/27/09

Figure 1-3

flows in winter months are below the bypass requirements. While the combined flow may not exceed the combined bypass requirement, giving the appearance that no flow is available for diversion, the bypass requirement may be met on one tributary and not the others, thus allowing for diversions. For instance, in 2002, the bypass requirement on the Rio Blanco was exceeded most of the year.

1.5 SJC Project Diversion Potential

The historical diversions of SJC Project water from 1971 through 2008 have been less than their potential diversions. John Whipple of the New Mexico ISC assessed the potential amount of water available for the SJC project given the historical record of flows, legal constraints, and the physical capacity of the system (Whipple, 2007a). SJC Project diversions are dependent on several limitations. First, as discussed in Section 1.3, the minimum bypass flows to protect aquatic life and water rights must be allowed to pass the gages where the flow is recorded below each diversion. Streamflows exceeding the minimum bypass may then be diverted, up to the diversion capacity of each diversion structure and the capacity of tunnels connecting the diversion structures and leading to Heron Reservoir (Section 1.4). The flow actually diverted depends on diversion operations, storage space available in Heron Reservoir, and timing of releases for SJC contractors.

To estimate potentially available flow, Whipple (2007a) conducted the following steps:

- Adjusted the gaged diversion records for the three project diversions for the period of record from October 1970 to September 2005 to match the measured flow at the Azotea Tunnel outlet (which is more accurate than the sum of the diversions from the individual tributaries).

- Estimated pre-1971 flows by correlating with flows in nearby tributaries that had been measured to obtain an historical period of record for October 1936 to February 1971.

- Estimated flows available above the daily bypass requirements.

- Adjusted available flow to account for gage error, short-duration flow surges in the Azotea Tunnel exceeding the 950-cfs capacity, delays in making gate adjustments at the diversions dams in response to changes in hydrologic conditions, sediment sluicing requirements, and other factors.

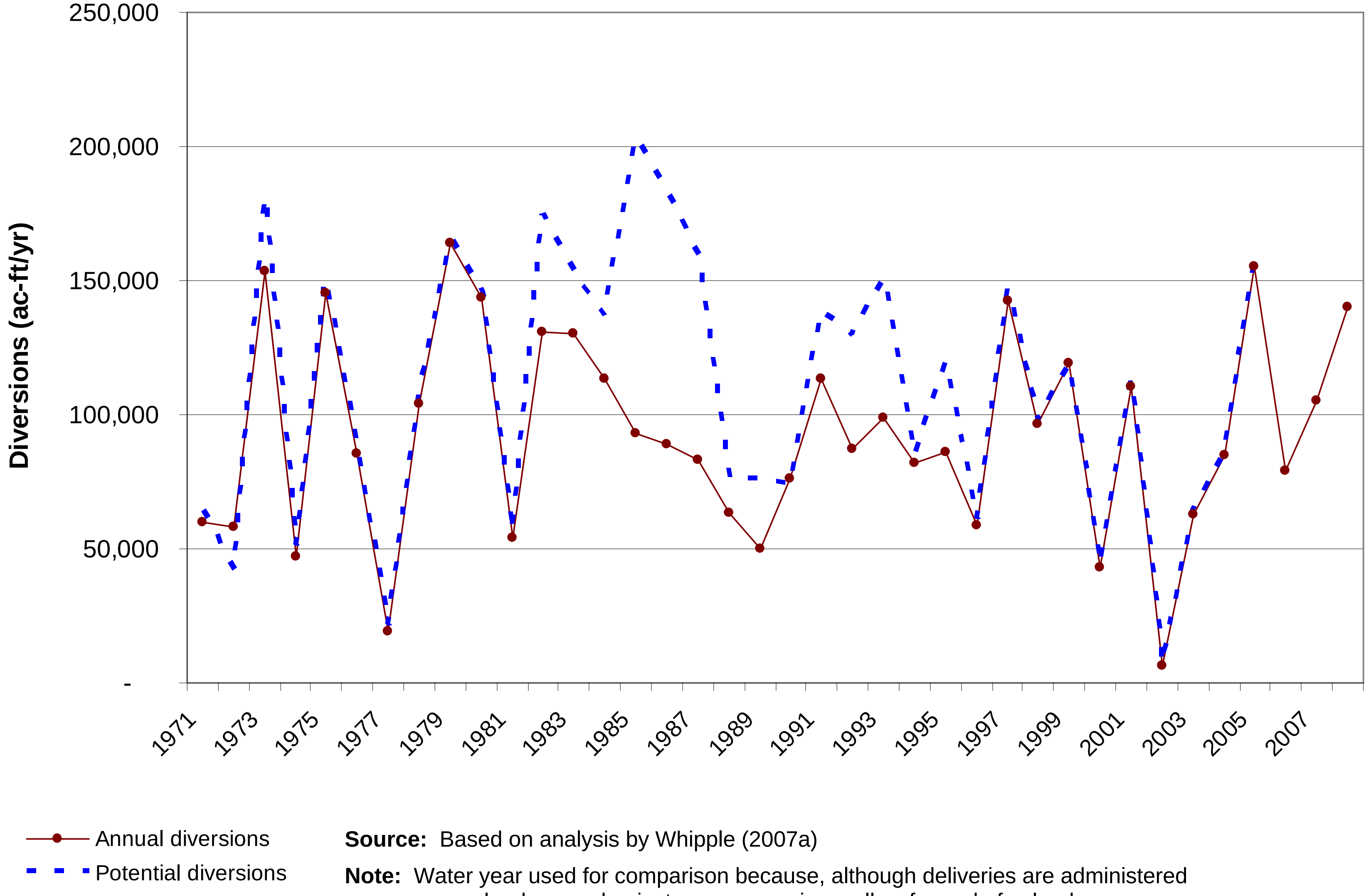
- Adjusted potential project diversion to avoid spills from Heron Reservoir, considering evaporation, sedimentation (current and future), and timing of releases.

- Reduced the potential diversions to the maximum allowable 1,350,000 acre-feet in any 10-year period when higher diversions were possible.

Figure 1-4 shows the results of Whipple's analysis, which compares actual calendar year diversions with the potential available diversions based on the water year. Whipple concludes that "The results of the reservoir operations studies indicate that with a demand at Heron Dam of 96,200 acre-feet annually and assuming 1936-2005 period hydrology, there would be no water supply shortages to project uses in the Rio Grande Basin under either historic 1984 or projected 2070 storage sedimentation conditions in Heron Reservoir."

Due to inherent operating efficiencies at the diversions (e.g., it is not always possible to adjust the diversions during a brief storm event), actual diversions typically are less than the total diversion potential. In addition, actual diversions have been less than potential diversions in past years when Heron Reservoir storage has been near capacity.

The potential diversion calculations show that operational changes may increase the yield of SJC Project diversions. The flows available for diversion that have not been captured during past operations average approximately 18,000 ac-ft/yr due to Heron Reservoir capacity limitations. Past diversions resulted in Heron being near capacity a higher percentage of the time than anticipated in the future because full demand on Heron did not occur until 1996 (Whipple, 2009). Past diversions have captured approximately 88 percent of the potentially available diversion. If diversion operations could capture 95 percent of the potentially available diversion, the average annual diversion could be raised from the recorded average of 93,000 ac-ft/yr to 105,200 ac-ft/yr, the firm yield of the project.



Source: Based on analysis by Whipple (2007a)

Note: Water year used for comparison because, although deliveries are administered on a calendar year basis, temporary waivers allow for end of calendar year [October through December] deliveries to be applied to the following year.

JEMEZ Y SANGRE PHASE II UPDATE

Comparison of Potential and Actual Flows Available for San Juan-Chama Project Diversions

Daniel B. Stephens & Associates, Inc.

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Figure 1-4

1.6 Firm Yield Conclusions

Firm yield estimates for the SJC Project have remained at 96,200 ac-ft/yr, although the amount available for diversion from the three tributaries has varied as the available historical record increases. Table 1-5 summarizes the historical estimates of project diversions through the Azotea Tunnel and contract deliveries from Heron Reservoir. The USBR has determined that the average annual diversions from the three tributaries are approximately 107,500 ac-ft/yr and that the firm yield of the project from Heron Reservoir is 96,200 ac-ft/yr. All of the firm yield for the SJC Project is currently contracted. While the demand for water in the San Juan River Basin is projected to increase, which may result in shortages for the users below Navajo Reservoir, no impact on the SJC Project is predicted by ISC or the USBR (assuming historical hydrology).

Table 1-5. Estimates of Firm Yield for the San Juan-Chama Project

Source	Years of Analysis	Firm Yield (ac-ft/yr)	
		Azotea	Heron Dam
USBR 1964 Definite Plan Report [a]	1935-1957	NA	101,800
USBR 1986 Hydrology Report San Juan-Chama Yield Update [a]	1935-84	108,800	94,200
USBR 1999 Draft Hydrology Report, Revised San Juan-Chama Firm Yield, October 1999 [a]	1935-97	114,900	95,800
USBR Model (Generation 2) [b]	1929-1993	107,500	96,200
USBR Fact Sheet 2007 [c]	NA	NA	96,200
ISC estimate [b]	1936-2005	105,200	96,200

[a] As cited by Aspen, 2006, p. 1
[b] Whipple, 2007a
[c] USBR, 2007

ac-ft/yr = Acre-feet per year
NA = Information not available

The USBR is currently working on a model of the San Juan River Basin, but the parties have not yet agreed on aspects of the model assumptions. Whipple (2007a, 2007b) discusses the problems with the Generation 3 model, which shows a reduction in the firm yield estimates based on assumed greater depletions in the future on the tributaries above the SJC Project diversions, which Whipple argues are not likely to occur. The USBR has not revised the firm yield estimate for the SJC Project, which remains at 96,200 ac-ft/yr (Towne, 2009).

Whipple (2007b, p. 10) states that "the maximum long-term average annual diversion from the San Juan River Basin by the SJC Project will decline from about 105,500 acre-feet per year under 1984 conditions to about 105,200 acre-feet per year under 2070 conditions, assuming historic hydrology for the period 1936-2005." Whipple's estimate of 105,500 ac-ft/yr is less than USBR's estimate of 107,500 ac-ft/yr available for diversions. Both Whipple and the USBR estimate that the project has a firm yield delivery of 96,200 ac-ft/yr at Heron Dam based on the observed historical period of record from 1936 to 2005. However, if increased water use on the San Juan River and a series of consecutive droughts occur that are more severe than those observed historically, the SJC Project could experience water shortages. In addition, climate change may increase the risk of future droughts, as discussed in Section 2.

2. Climate Change Impacts on Water Resources of the JyS Region

The original JyS regional water plan (DBS&A and Lewis, 2003) compared average water supply to current and projected demand and discussed the variability of surface water supplies during historical drought periods. Recent climate change models, however, show that the region may not be able to depend on the historical record for predicting the future variability of streamflow and aquifer recharge. The new “average” supply may be lower, and droughts may be more severe. The objective of this task is to review current scientific information on climate change studies and discuss potential impacts to the JyS region that have implications on precipitation, temperature, and change in runoff and recharge that impact the region’s water supplies. This section concludes with potential actions that the Council can undertake to help the region prepare to address climate change issues.

Recent scientific literature regarding global climate change, as well as studies focused on the southwestern U.S. including New Mexico, are listed in Table 2-1, along with a brief summary of some of the key issues identified in each report. Many of the reports listed in Table 2-1 used information and models prepared by the Intergovernmental Panel on Climate Change (IPCC), which is a scientific intergovernmental body set up by the World Meteorological Organization and the United Nations Environmental Programme (Bates et al., 2008). The IPCC’s role is to assess on a comprehensive, objective, open, and transparent basis the latest scientific, technical, and socioeconomic literature produced worldwide relevant to understanding the risk of human-induced climate change, its observed and projected impacts, and options for adaptation and mitigation (IPCC, 2009).

In the United States, the U.S. Climate Change Science Program integrates federal research on climate change as sponsored by 13 federal agencies and overseen by the Office of Science and Technology Policy, the Council on Environmental Quality, the National Economic Council, and the Office of Management and Budget (USCCSP, 2007).

Table 2-1. Studies of Climate Change in North America
Page 1 of 5

Title	Citation	Comments
Changes Toward Earlier Streamflow Timing across Western North America	Stewart et al., 2005	Statistical analysis of data from stream gages showing the shift in mass of annual runoff earlier in the spring
An Overview of Potential Economic Costs to New Mexico of a Business-As-Usual Approach to Climate Change	Niemi, 2009	Summarizes the expected costs to families, businesses, and communities in New Mexico if no action is taken to address climate change
Climate Change and Its Implications for New Mexico's Water Resources and Economic Opportunities	Hurd and Coonrod, 2008	Uses three climate change scenarios across two future time periods (2030 and 2080), selected to represent the range of conditions based on 18 global climate models (GCMs) using the A1B emissions scenario (a scenario seen as neither too optimistic or too pessimistic). The six climate change scenarios were then used to predict runoff changes in the Rio Grande watershed using the WATBAL hydrologic model and building on the Rio Grande Hydro Economic Model (RGHE).
Climate Change Wizard	Nature Conservancy et al., 2009	An online tool created by the Nature Conservancy to show predicted changes in climate worldwide based on the IPCC climate models. Several general circulation models were used to provide a range of expected climate change scenarios. Maps of predicted temperature changes are also included. The worldwide predictions can be zoomed to focus on an area of interest. The mapped predicted changes indicate approximate reductions in precipitation in the 10 to 20% range for the Jemez y Sangre (JyS) region for most of the climate change scenario models that were included.
New Mexico Forestry and Climate Change Workshop	Forest Guild, 2008	Climate projections specific to New Mexico developed by Dr. David Gutzler of the University of New Mexico. The projections were based on IPCC projection A1B, which assumed rapid economic growth, population decline after 2050, rapid implementation of new and efficient technologies, and a balance of fossil and alternative energy use. Supporting graphs from Dr. Gutzler's presentation show an annual temperature increase of about 6° F between 2000 and 2100 for the A1B scenario. The publication quotes Julie Coonrod predictions of 7.5°F increase in summer temperatures and 5.8° F increase in winter temperatures for 2100. Precipitation scenarios presented by Dr. Gutzler show periods of wet and dry but no clear trend. The climate predictions were used by work groups to assess potential impacts on various forest ecosystems in New Mexico. The publication quoted Dr. Craig Allen in indicating that climate change may exacerbate other forest threats such as insects and that there may be abrupt thresholds in ecosystem response even if climate is changing gradually. Dr. Allen's presentation showed predicted summer temperature increases of about 7°F in 2100.

Table 2-1. Studies of Climate Change in North America
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Title	Citation	Comments
Potential Effects of Climate Change in New Mexico	ATWG, 2005	Climate change predictions by mid- to late 21st century include air temperatures warmer by 6 to 12°F (more at winter, at night, and at high elevations), more episodes of extreme heat, fewer episodes of extreme cold, more intense storms and flash flooding, and more winter precipitation falling as rain rather than snow. Higher evaporation rates will at least partially offset any possible increases in precipitation due to climate change. Changes in average precipitation are uncertain, could increase or decrease.
The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources	NM OSE, 2006	Global temperatures are rising, as evidenced by decreased icepack and snowfields and retreat of glaciers. This global warming is thought to be due to the presence of greenhouse gases, concentrations of which are continuing to increase. In New Mexico, wintertime average temperatures have increased statewide by about 1.5° F since the 1950s. Increased temperatures lead to high evapotranspiration, lower soil moisture, and a greater potential for drought. More intense but probably less frequent storms could lead to more extreme flooding events. The study indicated that New Mexico-specific modeling has not been completed, but that work on the Colorado River Basin had indicated that increased evapotranspiration would cause diminished streamflows, and similar conditions could be expected here. An average of 18 GCM scenarios indicated more than a 5°F average temperature increase by the end of the century. Annual precipitation is subject to greater uncertainty and there is poor representation of the North American monsoon processes.
Citizens Guide to Colorado Climate Change	Colorado Foundation for Water Education, 2008	A good overview of GCMs. Indicates that GCMs do a poor job of predicting precipitation in the Rockies because the large grid size blurs the effect of precipitation due to steep terrain. The reported range of expected temperature increases based on IPCC data is 3.2 to 7.2°F relative to the 20th century average. Precipitation projections for the American Southwest range from increases of 19% to decreases of 27%.

Table 2-1. Studies of Climate Change in North America

Title	Citation	Comments
Climate Change and Water	Bates et al., 2008	Report focused on climate change impacts on water resources. Anticipated changes include increasing atmospheric water vapor, changing patterns in precipitation frequency and intensity, reduced snowpack, reduced glacial ice, and shifts in the amplitude and timing of snowmelt and glacial runoff. Increased precipitation intensity and variability are likely to increase the risk of both flooding and drought. Water resources stresses will have an impact on food security. Adaptive management will need to address both supply- and demand side-issues. This is a global report and even the regional analysis doesn't look in detail at the JyS region; however, trends specific to the Southwest in general identified in the report are decreasing mountain snow water equivalent, decreasing annual precipitation, decreasing runoff and streamflow, increasing water temperature, and increasing periods of drought. In general, projected changes in temperature extremes are greater than changes in mean precipitation. Report cites a need to improve climate change observations and modeling at a scale relevant to decision-making.
Global Climate Change Impacts in the United States	USGCRP, 2009	Provides summaries of climatic impacts by region for the U.S. Information summarized here is for the Southwest (including but not exclusive of New Mexico). Global average temperature has risen by abut 1.5° F since 1900 and is expected to rise another 4 to 10°F by 2100. The key findings indicate that water resources will be stressed in the Southwest. Warmer air holds more water evaporating from the world's oceans and lands, and precipitation patterns are changing. For the U.S. Southwest, the report indicates that recent warming is among the greatest in the nation. The Southwest needs to be prepared for severe droughts that may be exacerbated by climate change impacts on top of natural drought cycles. Climate change impacts on forest fire will vary locally, but in general, the area burned is expected to increase. Increased frequency and altered timing of flooding will increase risks to people, ecosystems, and infrastructure. The increase of rain on snow events will result in higher flooding risk.

Table 2-1. Studies of Climate Change in North America
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Title	Citation	Comments
Land Use Planning in the Changing Climate of the West	Carter, 2009	If land use policies identified in westerns state-level climate action plans are fully implemented, greenhouse gas emissions could be reduced by 20%. Implementation of these policies is usually with local governments and land use planners. Pertinent policies include green-energy-efficient buildings, transit policies, alternative energy, open space, urban forestry, and wildland-urban interface policies. Plans analyzed included those developed by Arizona, California, New Mexico, Montana, and Washington. Green building and transportation policies were found to be the most effective in reducing greenhouse gas emissions.
The Colorado River: The Story of the Quest for Certainty on a Diminishing River	Kuhn, 2007	Primarily a policy analysis that provides background information on the Colorado River Compact and relevant lawsuits. Also describes the State of Colorado Interbasin Roundtables. Both the in-state and interstate issues create a need to understand the certainty of the Colorado River supply. Includes some historical summaries of water use, streamflow, and lake levels. A chart illustrating the paleohydrologic records illustrates that the Compact was negotiated during a historical wet period. A general discussion indicated that climate change could further reduce flows in the Colorado River, but no specific scientific evaluation was included.
The Effects of Climate Change on Agriculture, Land Resources, Water Resources and Biodiversity in the United States	USCCSP, 2008a	Report prepared by USCCSP with USDA as the lead agency; focuses on anticipated changes in agriculture, land resources, water resources, and biodiversity. The main focus is the recent past and predictions for 25 to 50 years in the future. The Southwest is likely to become drier. Forest fires and insect outbreaks are increasing. The spread of invasive species is likely to continue. Where earlier snowmelt peaks have been observed, this trend is likely to continue. Water quality is sensitive to both increased temperatures and changes in precipitation. Water temperature increases will be most notable during low-flow periods when aquatic ecosystems are particularly sensitive. Essentially no aspect of the current hydrologic observation system was designed to monitor climate change. Data collection efforts are obsolete and inadequate.
Widening of the tropical belt in a changing climate	Seidel et al., 2007.	This article describes the poleward movement of the tropical belt and the resulting changes in the global climate, including drier conditions in the southwestern United States.

Table 2-1. Studies of Climate Change in North America
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Title	Citation	Comments
Thresholds of Climate Change in Ecosystems	USCCSP, 2009	Identifies ecological thresholds (leading to potentially irreversible changes) resulting from climate change. The report reviews North American ecological thresholds that are potentially caused by climate change and recommends strategies for land managers to address these changes. Recommendations include continued research, better information sharing, and various adaptive management techniques.
Abrupt Climate Change	USCCSP, 2008c	Synthesis and assessment product (needed to further understand climate change impacts) that addresses abrupt climate change by synthesizing current research and providing information for decision support. The report addresses the potential for rapid changes in glaciers and ice sheets, hydrologic variability, potential for abrupt change in the Atlantic Meridional Overturning Circulation (AMOC), and the potential for abrupt changes in atmospheric methane.
Climate Change and Water Resource Management	Brekke et al., 2009	Prepared at the Federal level; does not focus on New Mexico or the Southwest. The report indicates that climate change will likely affect all aspects of water resource management and that long-term monitoring networks are needed to detect changes. Recommended improved methodologies, decision-making and adaptive management strategies are provided.
Decision-Support Experiments and Evaluations Using Seasonal-to-Interannual Forecasts and Observational Data: A Focus on Water Resources	USCCSP, 2008b	Focuses on linking the ability to predict climate on a seasonal to interannual (SI) basis to water resource management decisions. A number of research priorities are identified including improving climatic and hydrologic forecasting, improving communication of uncertainties, enhancing monitoring, improving scientific-decision maker interactions, and others. The role of long-term climate change in the SI forecasting is discussed, but new climate forecasts are not included.

2.1 Global Perspective

The U.S. Global Change Research Program (USGCRP), a program correlated with the U.S. Climate Change Science Program, prepared the report *Global Climate Change Impacts in the United States* (USGCRP, 2009), which looked at current research as well as past studies conducted by scientific researchers. A synopsis of the current understanding of global climate change can be extracted from the key findings of the report:

- Global warming is unequivocal and primarily human-induced.
- Climate changes are underway in the U.S. and are projected to grow.
- Widespread climate-related impacts are occurring now and are expected to increase.
- Climate change will stress water resources.
- Crop and livestock production will be increasingly challenged.
- Coastal areas are at increased risk of sea level rise and storm surge.
- Threats to human health will increase.
- Climate change will combine with many social and environmental stresses (i.e., pollution, population growth, etc.) to create larger impacts.
- Rapid, irreversible, and unanticipated changes are likely as key thresholds are crossed.
- Future climate change and its impacts depend on choices made today.

The IPCC (Bates et al., 2008) indicated that observed warming over several decades has been linked to several changes in the hydrologic cycle, including:

- Increased atmospheric water vapor
- Changing patterns in precipitation frequency and intensity, which is likely to increase the risk of both flooding and drought
- Reduced snowpack and reduced glacial ice
- Shifts in the amplitude and timing of snowmelt and glacial runoff

The global predictions of climate change are based on general circulation models (GCMs), which divide the planet into grids and solve equations that simulate wind, heat transfer, radiation, relative humidity, and surface hydrology to simulate global oceanic and atmospheric circulation. Coupled oceanic-atmospheric GCMs are the commonly used method for simulating global climate change. The IPCC has developed a number of scenarios for emissions and other factors such as population that simulate a potential range of possible climate change impacts. There is general confidence in the models because they are based on physical principles and have been able to simulate observed conditions, though confidence in the models is higher for temperature than it is for precipitation (Solomon et al., 2007)

The U.S. Geological Survey (USGS) (Brekke et al., 2009) describes some of the problems with downscaling global models to predict local climate conditions. Local climate conditions, such as the slope and aspect of a mountain, are not well represented in the global models.

2.2 Impacts to the Southwestern United States

A National Oceanic and Atmospheric Administration (NOAA) study by Seidel et al. (2007) explains how the widening of the tropical belt is likely to bring even drier conditions to the southwestern U.S. (and Mexico, Australia, and parts of Africa and South America). The study warns that there are grave implications for the many millions of people living in dry, subtropical regions bordering the tropics, which are at risk of becoming even more arid because of changes to rainfall patterns and wind directions. The poleward movement of large-scale atmospheric circulation systems, such as jet streams and storm tracks, could result in shifts in precipitation patterns affecting natural ecosystems, agriculture, and water resources.

The USGCRP (2009) summarizes the projected increase in temperatures in the southwestern U.S. if greenhouse gas emissions continue at a high level or are reduced. Under the worst case, temperature changes could increase an additional 8.5°F by 2090 in the Southwest, above the average observed temperature from 1961 through 1979. Under a lower emissions scenario, temperatures are predicted to increase by 6°F by 2090. The study predicts less precipitation in all seasons in the Southwest, including up to 30 percent less in the spring by 2090 based on 15 climate models. Over the past 50 years (1958 through 2007), the USGCRP study shows a 9 percent increase in the amount of precipitation that is falling in very heavy precipitation events.

Heavy downpours that are now 1-in-20 year events are predicted to occur every 4 to 15 years by the end of the 21st Century.

2.3 Studies Specific to New Mexico

Studies specific to climate change in New Mexico are listed in Table 2-2. In New Mexico, wintertime average temperatures have increased statewide by about 1.5°F since the 1950s (NM OSE, 2006). The increased temperatures lead to higher evapotranspiration, lower soil moisture, and a greater potential for drought. Predictions of annual precipitation are subject to greater uncertainty “given poor representation of the North American monsoon processes in most GCMs” (NM OSE, 2006). However, we can expect more intense and probably less frequent storms, which could lead to more extreme flooding events. According to the OSE study (NM OSE, 2006), the following effects of global climate change are likely to occur in New Mexico:

- Temperature is expected to continue to rise.
- A greater percentage of precipitation is expected to fall as rain rather than snow.
- The amounts of snowpack and snow water equivalency are expected to decrease.
- Smaller spring snowmelts and/or earlier runoff are expected to diminish supplies of water for irrigation and ecological health (including increased risk of wildfires).
- Reservoir and other open water evaporation is expected to increase.
- Evapotranspiration is expected to increase due to higher temperatures and longer growing seasons.
- The severity of droughts and floods is expected to be more extreme.
- Higher temperatures and evapotranspiration and a longer growing season will increase water demand on irrigated lands.

In a study of the economic impacts to New Mexico due to climate change, Niemi (2009) states that the higher temperatures will also reduce the habitat of coldwater fisheries, reducing trout populations (trout require water temperatures below 20°C to reproduce).

Table 2-2. Climate Change Studies Relevant to New Mexico

Title	Citation	Precipitation	Streamflow Quantity	Timing of Run-Off	Temperature	Crop Requirements
Changes toward Earlier Streamflow Timing across Western North America	Stewart et al., 2005	NA	NA	5 to 20 days earlier than observed from 1945 to 2002	NA	NA
Climate Change and Its Implications for New Mexico's Water Resources and Economic Opportunities	Hurd and Coonrod, 2008	+5.7% to –15.6%	Predicted stream-flow in 2080 is –8% to –29% for the Rio Grande	30 days earlier by 2080	+5 to 8°F	Increased
Climate Change Wizard	Nature Conservancy et al., 2009	–10 to –20% in the State of New Mexico based on average of models	NA	NA	+8°F	NA
New Mexico Forestry and Climate Change Workshop	Forest Guild, 2008	No trend	NA	NA	+6 to 8°F between 2000 and 2100	NA
Potential Effects of Climate Change in New Mexico	ATWG, 2005	More in winter but as rain; more intense storms. Annual total may not change	NA	Earlier	+6 to 12°F	Increased evapotrans-piration
The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources	NM OSE, 2006	More precipitation will fall as rain, not snow; fewer storm events, but more intense	Decrease	Early snowmelt	+1.5°F since 1950; expect continued increase, predict a 5°F increase by 2100	Increased evapotrans-piration
Global Climate Change Impacts in the United States	USGCRP, 2009	Decrease, up to 45% less in the spring	Predicted stream-flow in 2041-2060 is –10% to –20% for New Mexico	Observed 20 days earlier	Increase 4 to 8°F by 2090	Increased stress, decreased yields

NA = Not addressed

Quantitative estimates for New Mexico of the predicted changes in temperature, precipitation, and run-off are provided by five studies:

- The OSE (NM OSE, 2006) study summarized results from an average of 18 GCM scenarios

- Climate change prediction scenarios were presented by Dr. David Gutzler, Dr. Julie Coonrod, and Dr. Craig Allen at a New Mexico Forest Guild workshop (Forest Guild, 2008).

- Hurd and Coonrod (2008) used three different water balance models to represent the range of outcomes projected for the Rio Grande in New Mexico: (1) The Hadley model was used to simulate the Wet scenario, (2) the Commonwealth Scientific and Industrial Research Organisation-Atmospheric Research Australia (CSIRO) model for the Middle scenario, and (3) the NOAA model for the Dry scenario. The models were run using six different climate change scenarios to predict changes in temperature and precipitation in New Mexico.

- The USGCRP (2009) study provides climate projections based on careful analysis of outputs from global climate models using different scenarios of human activity that lead to increases in heat-trapping emissions. The report shows maps of the United States with predictions of changes in temperature, precipitation, heavy rainfall events, and the quantity and timing of run-off.

- The Climate Wizard (http://www.climatewizard.org/) is a tool developed through collaboration between The Nature Conservancy, The University of Washington, and The University of Southern Mississippi, that downscales GCMs, allowing the user to easily visualize the projected changes in temperature and precipitation based on an average of the GCMs.

2.3.1 Temperature

The five studies with specific predictions for temperature changes in New Mexico are summarized in Table 2-3. The predicted range of temperature increase is from 5 to 10°F by the end of the century.

Table 2-3. Predicted Changes in Temperature in New Mexico

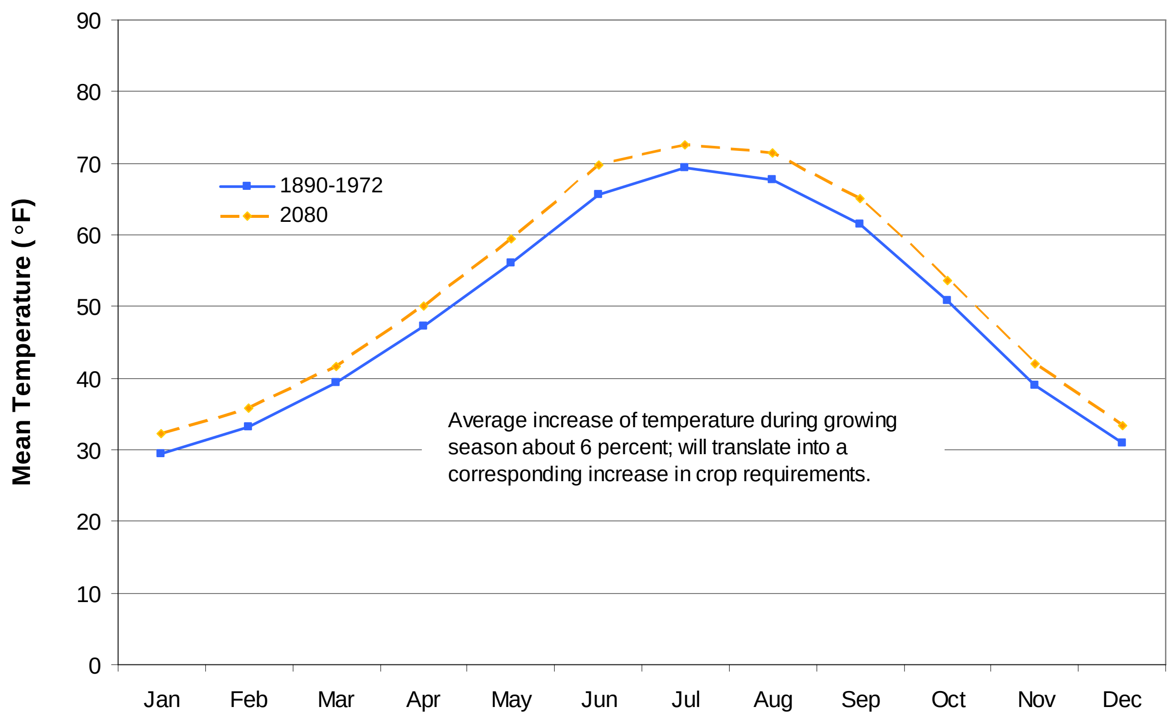
Source	Temperature Change (°F)	Scenario	Season	Year	Comparison Year
NM OSE (2006)	5	Average of 18 GCMs	Annual	2100	1971-2000
David Gutzler (Forest Guild, 2008)	6	A1B	Annual	2100	1971-2007
Julie Coonrod (Forest Guild, 2008)	7.5	Average of 18 GCMs	Summer	2100	1901-2007
	5.8	NA	Winter		
Craig Allen (Forest Guild, 2008)	7 to 8	NA (cites Hoerling and Eischeid of NOAA)	Summer	2091-2100	1971-2000
Hurd and Coonrod (2008)	6	Wet	Annual	2080	1971-2000
	5.4	Middle			
	8	Dry			
USGCRP (2009, p 29)	4 to 6	Low emissions	Annual	2080-2099	1961-1979
	8	High emissions			
Climate Wizard (http://www.climatewizard.org)	7.5	Average of GCMs	Annual	2100	1971-2000

°F = Degrees Fahrenheit
GCM = General circulation model
NA = Not applicable

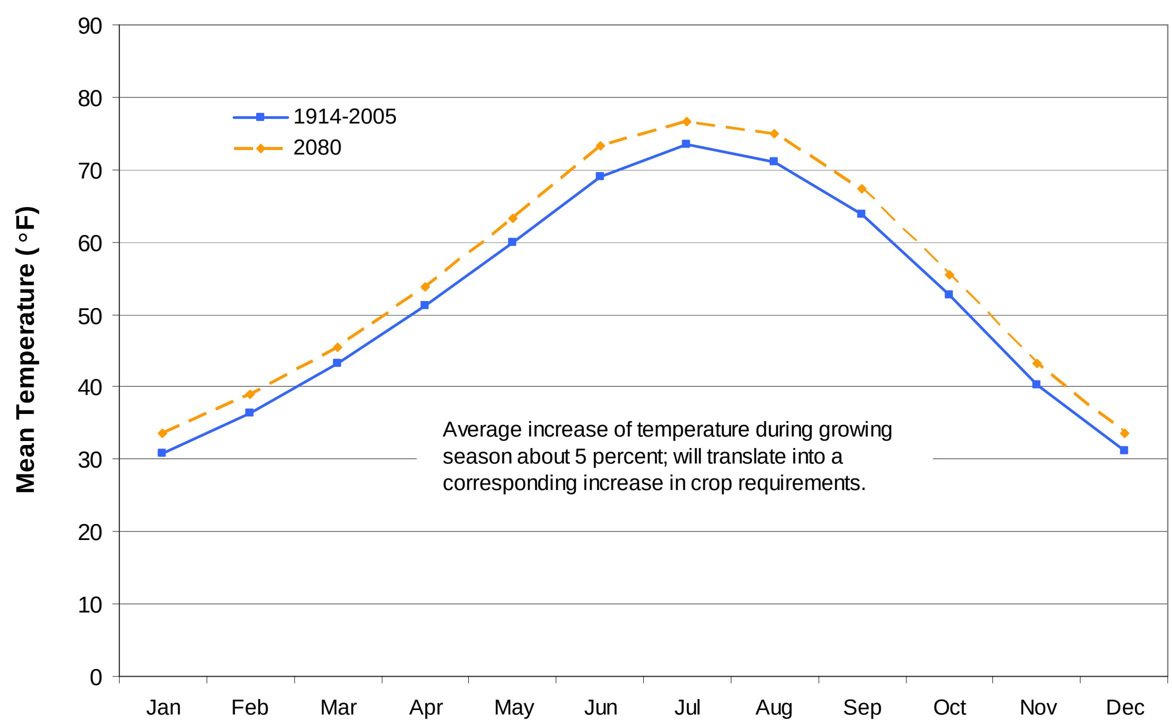
Climate change prediction scenarios were presented by Dr. David Gutzler, Dr. Julie Coonrod, and Dr. Craig Allen at a New Mexico Forest Guild workshop (Forest Guild, 2008). Supporting graphs from Dr. Gutzler's presentation show an annual temperature increase of about 6°F between 2000 and 2100 for the A1B scenario. The workshop summary quotes Julie Coonrod as predicting a 7.5°F increase in summer temperatures and a 5.8°F increase in winter temperatures for 2100. Dr. Craig Allen is quoted as indicating that climate change may exacerbate other forest threats such as insects and abrupt thresholds in ecosystem response may occur even if climate is changing gradually. Dr. Allen's presentation showed predicted summer temperature increases of about 7 to 8°F in 2100.

Hurd and Coonrod (2008) predict that temperature will increase by 6.0°F, 5.4°F, and 8°F, respectively, for the Wet, Middle and Dry scenarios, respectively, by 2080. Using these increases in mean monthly temperatures projected by Hurd and Coonrod (2008), DBS&A estimated the projected changes for two communities in the JyS region (Figure 2-1). The mean

a. Santa Fe New Mexico



b. Española, New Mexico



Note: Based on Hurd and Coonrod (2008), Middle scenario

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JEMEZ Y SANGRE PHASE II UPDATE
Projected Monthly Temperatures

Figure 2-1

monthly temperatures during the growing season are projected to rise by 5 percent in Espanola and 6 percent in Santa Fe by 2080 under the Middle scenario. This temperature increase will result in a corresponding increase in crop demands and riparian evapotranspiration.

The Climate Wizard projected that temperature will increase by 8°F throughout the state by the end of the century.

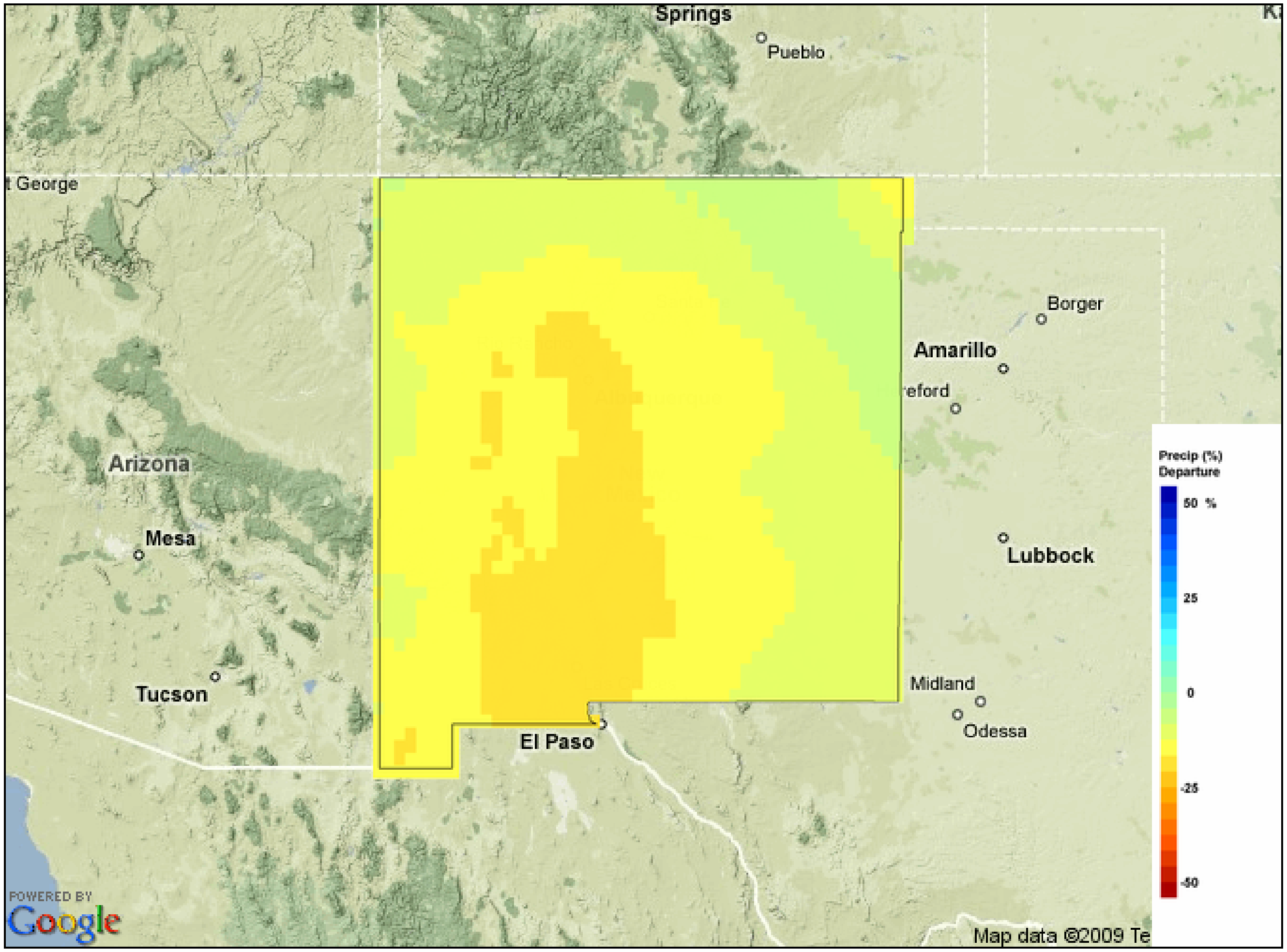
2.3.2 Precipitation

Though the models are in general agreement about predicted temperature trends, there is still uncertainty in climate change modeling. In addition to the uncertainty in how greenhouse gas emissions will proceed over the next century, there is some uncertainty in physical responses, particularly at a local level, or in predicting climatic conditions at any particular point in time (beyond short-term forecasts). In particular, likely precipitation patterns during summer monsoons in the southwestern U.S. are not well understood, and there is therefore uncertainty regarding trends in annual precipitation. Table 2-4 shows the predicted changes in precipitation in New Mexico, which vary from a 5.7 percent increase to a 20 percent decline for the annual average and up to a 45 percent decline in spring precipitation. Precipitation scenarios presented by Dr. Gutzler at the Forest Guild workshop show periods of wet and dry, but no clear trend for New Mexico. As shown in Figure 2-2, the Climate Wizard predicts a decline in precipitation of 10 to 20 percent in the JyS Region.

Table 2-4. Predicted Changes in Precipitation for New Mexico

Source	Precipitation Change (%)	Scenario	Season	Year	Comparison Year
David Gutzler (Forest Guild, 2008)	No trend	IPCC's A1B	Annual	2100	1971-2007
Hurd and Coonrod (2008)	+5.7	Wet	Annual	2080	1971-2000
	–10.6	Middle			
	–15.6	Dry			
USGCRP (2009, p130)	–10 to –15	Low emissions	Spring	2080-2099	1961-1979
	–35 to –45	High emissions			
Climate Wizard (http://www.climatewizard.org)	–10 to –20	Average of GCMs	Annual	2080	1971-2000

Model: Ensemble Average, SRES emission scenario: A2



Data Source: Base climate projections downscaled by Maurer, et al. (2007). We also acknowledge the following groups for providing the WCRP CMIP3 multi-model dataset available: Program for Climate Model Diagnosis and Intercomparison, The WCRP's Working Group on Coupled Modeling,and the Office of Science, US Department of Energy

Santa Clara University

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JEMEZ Y SANGRE PHASE II UPDATE

Projected Decline in Average Annual Precipitation in New Mexico by 2100

Figure 2-2

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6/27/09

Figure 2-3 shows the average annual precipitation in 2080 for the three scenarios projected by Hurd and Coonrod (2008) for three communities in the JyS region:

- In Los Alamos average annual precipitation for the period of record 1910 to 2008 is over 18 inches (WRCC, 2009), but is projected to decline 2 inches by 2080 under the Middle scenario.

- In Española, the average annual precipitation is just under 10 inches for the period of record from 1914 to 2005 (WRCC, 2009) and projected to decrease about an inch under the Middle scenario.

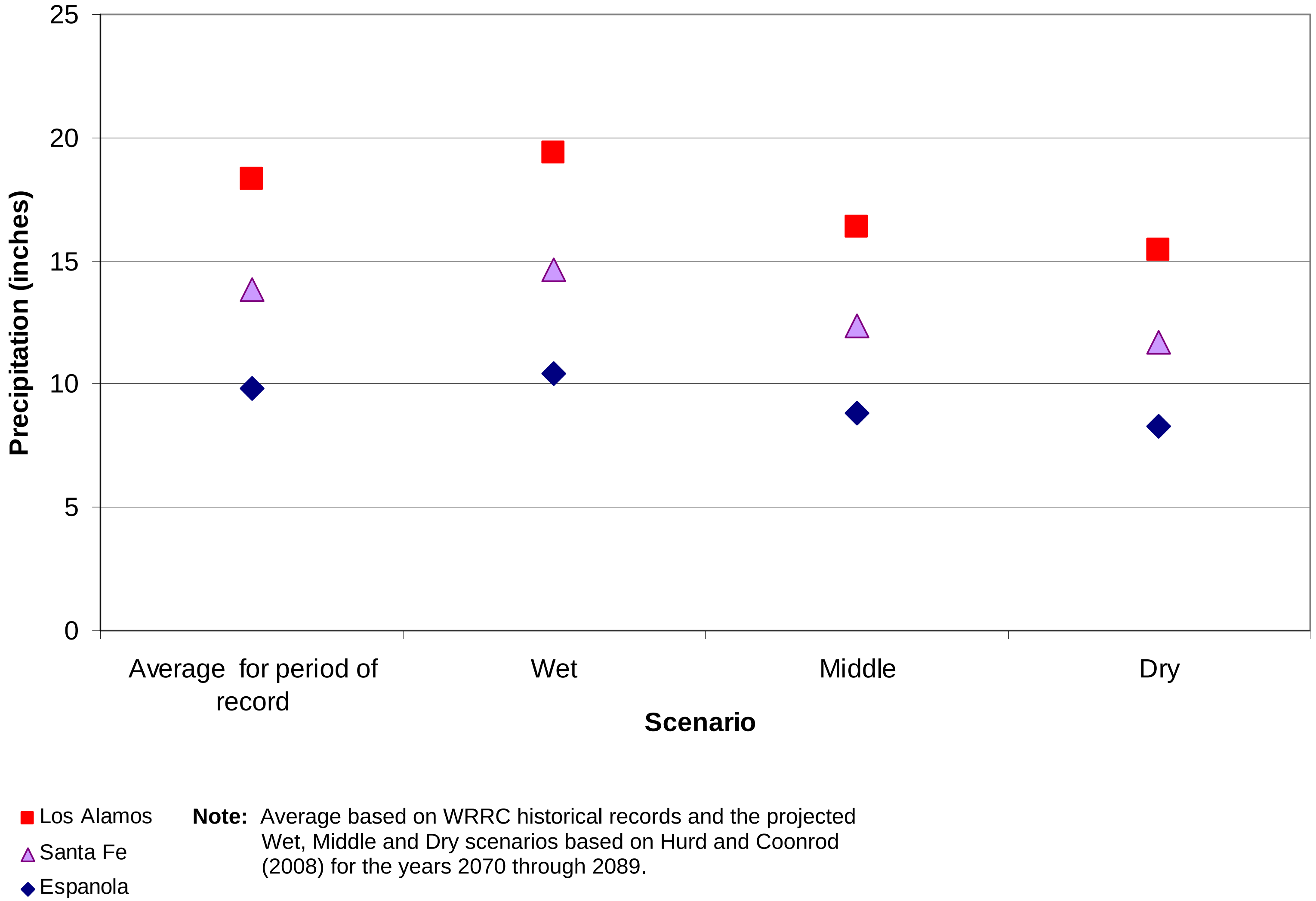
- In Santa Fe the average annual precipitation of just under 14 inches for the period of record 1980 to 1972 (WRCC, 2009) is projected to decline to 12.4 inches by 2080. (WRCC does not extend the record to 2008 because the precipitation station for Santa Fe has moved several times since 1972 to areas with different elevations).

2.3.3 Streamflow

With the estimates of changes in temperature and precipitation, Hurd and Coonrod (2008) performed a series of simulations using the Rio Grande Hydro-Economic Model to predict the changes with and without climate change. Each simulation for the climate change scenarios required adjustments to streamflow, runoff, reservoir evaporation rates, agricultural consumptive water use (reflecting increased irrigation requirements), and urban water demand due to population growth.

The results of the Hurd and Coonrod (2008) study indicated reduced streamflows for all scenarios; the probable change in streamflow for 2080 were –8 percent for the Wet, –23 percent for the Middle, and –29 percent for the Dry scenarios. They state that “Although there is a potential for summer monsoonal activity to increase . . . [under the wet scenario] . . . this is not likely . . . to offset the losses from diminished snowpack in the headwater regions.”

The USGCRP (2009) study also shows a predicted decline in runoff of 10 to 20 percent in New Mexico for the median run-off in 2041-2060 as compared to 1901 to 1970. The USGCRP



Note: Average based on WRRC historical records and the projected Wet, Middle and Dry scenarios based on Hurd and Coonrod (2008) for the years 2070 through 2089.

JEMEZ Y SANGRE PHASE II UPDATE

Projected Average Annual Precipitation for Three Communities in the Jemez y Sangre Region

Daniel B. Stephens & Associates, Inc.

7/9/09

Figure 2-3

projected time frame is in-between two projection ranges presented by Hurd and Coonrod (2008). The two studies are showing the same range of predicted declines. Table 2-5 summarizes the predicted changes in surface water yield from the two reports.

Table 2-5. Projected Change in Average Annual Run-Off in New Mexico for Different Time Periods

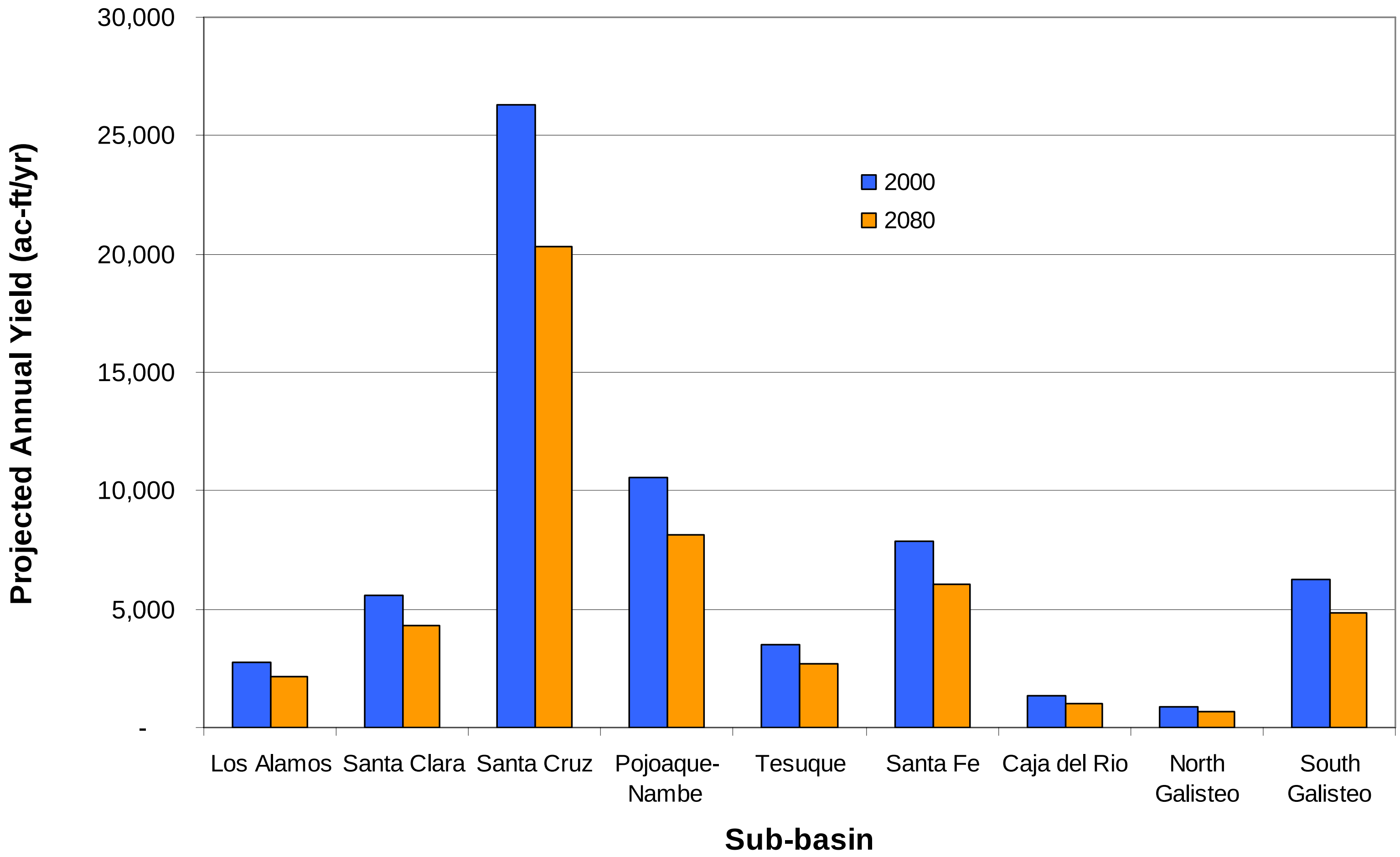
Source	Streamflow Change (%)	Scenario	Year	Comparison Year
Hurd and Coonrod (2008)	–6.3	Wet	2020-2039	1971-2000
	–3.5	Middle		
	–13.7	Dry		
USGCRP (2009, p 45)	–10 to –20	In between high and low emission scenarios	2041-2060	1901-1970
Hurd and Coonrod (2008)	–8.3	Wet	2070-2089	1971-2000
	–22.8	Middle		
	–28.7	Dry		

The annual yield of tributaries in the JyS region as presented in the water budgets of the 2003 water plan (DBS&A and Lewis, 2003) were adjusted to reflect predictions by Hurd and Coonrod (2008). Figure 2-4 shows the annual yield presented in the water plan with the projected 22.6 percent decrease in streamflow for the Middle scenario 2080 projection. The flow in the Rio Grande for the Velarde sub-basin (not shown on this figure because the scale is so different) is projected to decrease from an average of 593,580 acre-feet to 458,200 acre-feet at the Embudo Station gage.

Additional work by Hurd (2008b) indicated that by 2080, the peak in run-off will be 30 days earlier (Figure 2-5). A study by Stewart et al. (2005) of streamflow data from 1948 to 2002 in the western United States, including data from gages in New Mexico, projected that the spring pulse of runoff in some New Mexico streams will occur up to 20 days earlier than in past years.

2.4 Conclusions and Recommendations

The available literature on climate change indicates that the JyS region can expect warmer temperatures, less precipitation, less runoff, greater evapotranspiration, and earlier snowmelt.



Note: 2080 yield is based on a projected decline of 22.8% (Hurd and Coonrod, 2008, Middle scenario) of the 2000 yield, as reported in the JyS water plan.

JEMEZ Y SANGRE PHASE II UPDATE

Projected Change in Surface Water Inflow in Tributaries to the Rio Grande

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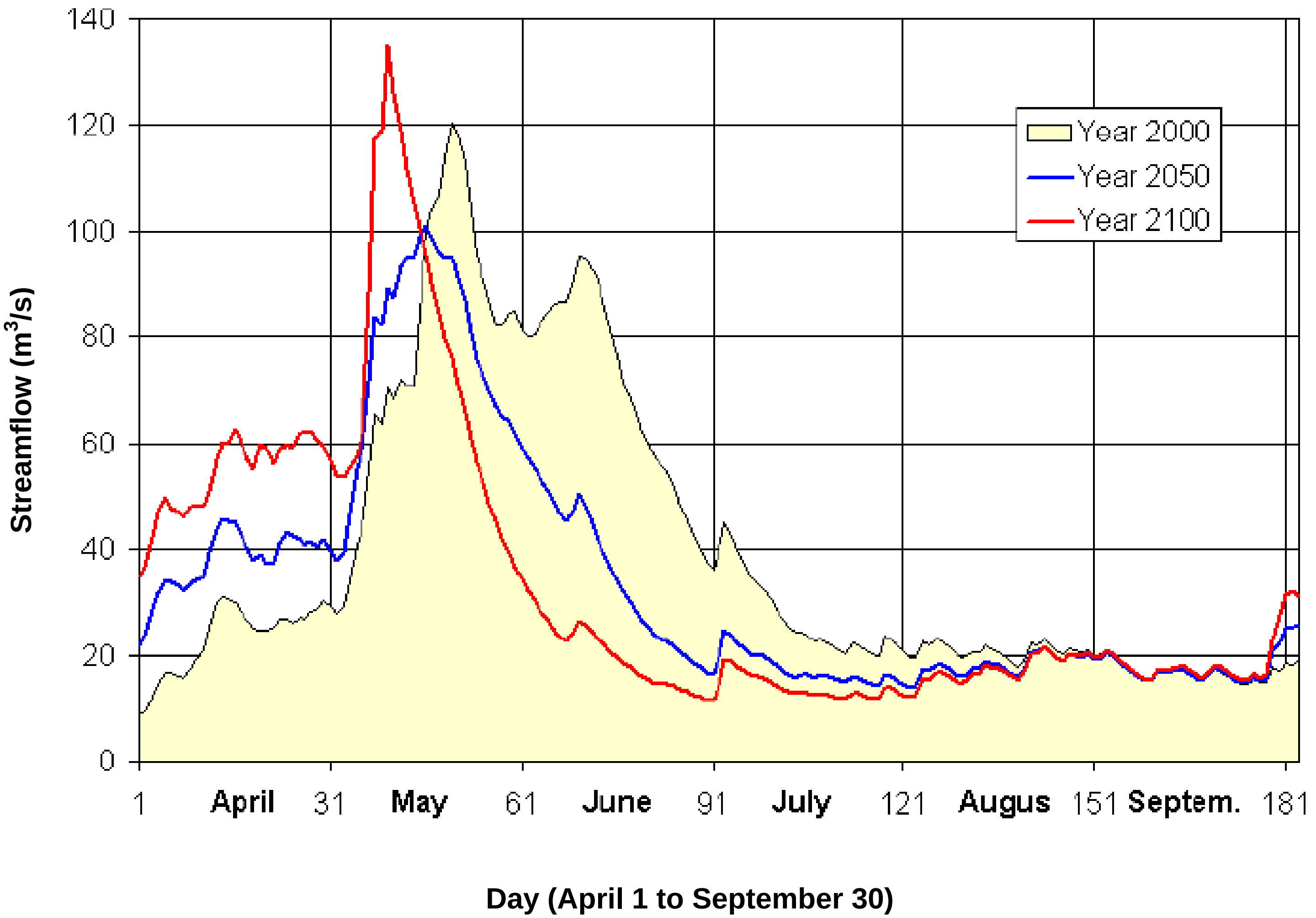
6/27/09

Figure 2-4



Source: Hurd, 2008b

JEMEZ Y SANGRE PHASE II UPDATE

Projected Change in Streamflow
Rio Grande at Del Norte

Daniel B. Stephens & Associates, Inc.

6/27/09

Figure 2-5

While none of the studies specifically addressed recharge to aquifers, the predicted decline in precipitation and increase in evapotranspiration is expected to result in declining recharge as well. In light of these changes, it would be prudent for the JyS Water Planning Council and the individual entities to revisit their water supply and demand forecasts.

The USGS Circular 1331 (Brekke et al., 2009) provides an excellent description of how to plan for climate change. They suggest developing the most robust system through scenario analysis. Ideally, a coupled groundwater-surface water model could be developed for the region to evaluate the resilience of the water systems to provide water and protect the ecosystem.

Even without rigorous analysis of scenarios, some conditions can reasonably be anticipated at some point in the future, and it will be prudent to develop contingency plans for these potential scenarios. Based on the current research regarding likely future conditions, even with a range of uncertainty, it is recommended that contingency planning for the JyS region focus on four key areas: drought, extreme precipitation events (including flooding and water quality impacts), land use issues including crop requirements, and watershed health (particularly risk of catastrophic forest fires). These are all issues that can benefit from good planning, regardless of uncertainty that exists in predicting climate change impacts. The potential for worsening conditions due to climate change impacts increases the urgency of preparing for these conditions. The 20 white papers in the JyS plan (DBS&A and Lewis, 2003) describe alternatives that address many of these issues.

Recommendations for consideration by the JyS Water Planning Council for each of these four areas are provided in Sections 2.4.1 through 2.4.4.

2.4.1 Prepare for Drought

The JyS region is familiar with drought, and the original plan includes a white paper, Manage Drought, that discusses approaches to preparing for drought, focusing on increasing storage capacity and reducing demand. White papers were also developed for other alternatives that will increase the resilience of a community to sustain drought periods, including Conjunctive Use of Surface and Groundwater, Bank Water, Optimize Reservoir Management/Increase Allowable Storage, Efficiently Convey Water To Reduce Loss, and Wastewater Reuse.

Increased frequency and severity of drought is one of the greatest concerns regarding global warming. Research consistently indicates that snow-water equivalents available to support spring runoff are likely to be lower in the future in much of the Southwest, particularly in the lower elevations and further south regions of existing snowpack in New Mexico. Rainfall, particularly monsoonal rainfall, is not as easy to predict. Nonetheless, given higher temperatures and evapotranspiration rates, it is prudent that the region be prepared to address potentially more long-term and severe drought periods than have been observed in the historical record.

The major public water suppliers in the region are undertaking efforts to make use of San Juan-Chama Project water through the Buckman Direct Diversion (City of Santa Fe and Santa Fe County) and through future additional diversion projects (City of Española and Los Alamos County). These projects all involve a conjunctive management strategy that allows for use of renewable surface water when it is available and preservation of groundwater for times of drought. Each entity will need to make sure that it has contingency plans that are adequate to carry the community through periods of extended drought. The many smaller water systems in the JyS region also need to be prepared to address potential drought scenarios.

The water supply shortages are likely to increase for acéquias along the Rio Grande tributaries as temperatures continue to rise, and earlier snowmelt may contribute to drier conditions for a greater part of the growing season, even during normal precipitation years. These surface water users do not generally have any backup groundwater supplies for use during times of drought.

Possible areas for further work by the JyS Water Planning Council to address drought include:

- Review the Manage Drought white paper, which describes what is involved in developing drought management plans.

- Compile existing drought contingency plans from the municipal and smaller water systems in the region and review them to develop an understanding of the cumulative drought preparedness in the region.

- Assist smaller systems that do not have drought contingency plans in seeking funding and developing plans.

- Provide educational materials on drought preparedness to the general public.

- Review and update alternatives from the original plan that can help to address drought impacts.

2.4.2 Prepare for Extreme Precipitation

Extreme precipitation events are a likely consequence of global warming, even if conditions are hotter and drier in the long-term average. Heavy rainfall and associated flash flooding may lead to dangerous conditions and damage to infrastructure from high water, as well as increased erosion and associated water quality impacts. Contingency planning for extreme precipitation events needs to focus on three primary areas: minimizing the risk of flood damage, minimizing the risk of water quality impacts, and optimizing the storage of high flows for use during times of drought.

Alternatives from the original JyS plan that addressed extreme precipitation are:

- Manage Storm Water from Short Duration Precipitation Events Using Catchment Basins in Urban Areas

- Appropriate Flood Flows During Spill Years

These along with additional new strategies may be needed to optimize preparedness for addressing extreme precipitation events in the future.

Possible areas for further work by the JyS Council to address extreme precipitation include:

- Review the two JyS white papers listed above, which describe the legal and physical issues involved in improving management of high flow events and high yield years.

- Coordinate with New Mexico Environment Department (NMED) regarding current water quality issues facing the region, particularly the potential for water quality deterioration during flood events.

- Provide educational materials on flood preparedness to the general public.

- Encourage communities to implement stormwater management plans.

2.4.3 Evaluate Vulnerability of Agricultural Sector

The agricultural sector is particularly vulnerable to climate change for several reasons. Although higher levels of carbon dioxide may have a positive impact for crops, a series of conditions put a strain on agriculture (USGCRP, 2009):

- The increased temperatures will increase evapotranspiration and increase the growing season, both of which will increase the consumptive use of the crops.

- The projected melting of the snowpack earlier and faster in the spring will reduce the availability of the water supply later in the season. Without adequate storage, some agricultural lands may be unable to meet crop demands.

- Intense precipitation events can damage crops.

- Higher temperatures benefit weeds and pests, putting additional stress on crops.

The JyS white paper Optimize Reservoir Management/Increase Allowable Storage describes the legal and physical constraints to increasing storage capacity in the JyS region. The white paper on Gaining Water Use Efficiency includes a discussion of the issues associated with improving irrigation efficiency.

In the 2008 regional water plan update, the Jemez y Sangre water supply was compared to demand, and new gaps were calculated using similar methods to those used for the original Jemez y Sangre regional water plan. While detailed water budgets were prepared for all of the five subregions (which include ten sub-basins) in the JyS planning region, the focus of the supply-demand gap was to identify projected demand, based on population growth, and to determine if there was adequate supply for those uses. The gap between supply and projected demand was analyzed for each of the five subregions, and graphs were prepared that compared projected demand for municipal and domestic supply to sources of supply.

As the agriculture sector was not identified as a growing sector that needed to find new water supplies, it was not the focus of the supply-demand analysis. A potential task to be undertaken would be to revise the projected water demand for the existing acreage under cultivation based on increased temperatures (and therefore increased evapotranspiration) and a longer growing season. The ability of surface water supplies to meet agricultural needs should then be evaluated using the revised agricultural demand numbers. This should include an analysis of the impact of the change in timing of runoff and the available storage capacity. Once the degree of vulnerability is established, methods for adapting (e.g., diversifying crops, increasing storage) can be developed.

2.4.4 Improve Watershed Health

Higher temperatures and evaporation rates could diminish watershed health and ecological functions of riparian areas and could increase the risk of catastrophic fires in the large forested areas present in the planning region. The original JyS plan included a white paper (Restore and Manage Forests, Piñon-Juniper Woodlands, and Riparian Systems) that addresses approaches and benefits of restoring watershed health. Many of the entities in the JyS region are actively pursuing these actions, such as thinning forests and working on specific stream reaches to improve the riparian area. The JyS update (JySWPC, 2008) summarizes the activities that are underway. The Council could review this list and consider whether it wants to become involved in any further watershed initiatives. Continued action in this category is of paramount importance to sustaining the impacts of both flood and drought periods anticipated due to climate change.

In summary, there are a number of possible alternatives that could be further developed to improve the preparedness for addressing climate change impacts in the JyS region.

3. Aquifer Viability Through 2060

Groundwater supplies about 80 percent of the JyS region's water supply for municipal, community, commercial, and industrial use. As stated in the JyS Regional Water Plan Phase 1 Update, a water plan for this region needs to address "the amount of water in the region's aquifers and the long-term viability of the aquifers as they impact available water supply" (JySWPC, 2008). The original JyS water plan compared the projected demand to the available supply to determine the future gap in water supply (DBS&A and Lewis, 2003). However, the comparison assumed that the current groundwater supply would continue to be available. If the aquifer cannot continue to support existing demands, then the projected gap would be greater than predicted. In this analysis, viability is defined as adequate groundwater being available without regard as to whether the water level declines or surface water impact are within a range that the JyS community can live with. Once our region has defined the impacts it can live with, then the question of groundwater sustainability can be evaluated.

The approach taken by this analysis was to:

1. Choose an appropriate groundwater model (Section 3.1).

2. Model the future groundwater impacts of continuing current (2008) groundwater withdrawals through 2060 (Section 3.2).

3. Compare the recharge component of the County groundwater model with the recharge calculated in the 2003 JyS Water Plan (Section 3.3).

4. Present the modeled impacts on groundwater in 2060 (Section 3.4).

3.1 Groundwater Models

To answer the question about future viability of the aquifers, a numerical model that simulates future conditions is the best tool. However, modeling simulations are by their very nature based on multiple model input variables, and any model may be subject to significant degrees of uncertainty. Several groundwater models for the region are available or under construction, such as those developed by the USGS (Hearne, 1985; McAda and Wasiolek, 1988; Frenzel, 1995), Los Alamos National Laboratory (LANL) (Keating et al., 2002), Eldorado Water and Sanitation District (Shomaker et al., 2001), and two under construction by consultants to the City of Santa Fe (CDM, 2002) and Santa Fe County (Intera, 2006). The OSE's administrative model (Core, 1996) for the southern part of the JyS region is a superposition version of the McAda and Wasiolek (1988) model, modified to identify impacts on the springs in the La Cienega area. This superposition model was further refined by Barroll and Keyes (2005) to address a discrepancy between the calibrated and superposition models.

For the JyS analysis, the County's groundwater model (Intera, 2006) was chosen by the JyS Council because it represents one of the latest modeling efforts, although it is in the process of being reviewed by other governmental agencies in the JyS region and has not yet been approved by the OSE as a regional administrative model. The original model (Intera, 2006) was modified by Santa Fe County to include actual stresses from 2003 through 2008 (current water demand) for comparison to those projected in the year 2060.

The Santa Fe County groundwater model covers 77 percent of the JyS region area; all of the Velarde sub-basin and parts of the Santa Clara and Santa Cruz sub-basins are not included in the model. The model consists of five layers, the lower four of which total 1,800 feet in thickness (Section 3-4). Layer 1 represents the uppermost unconfined layer with variable thickness due to variations in the elevation of the water surface.

3.2 Pumping for the Year 2008

The model scenario assumed that 2008 water diversion quantities continue to be pumped from all wells through 2060, except in the Buckman well field (Table 3-1). A plausible future City of Santa Fe water resource management scenario for the Buckman well field, which was used for this analysis, is presented in Table 3-2.

Table 3-1. Simulated Pumping by Stress Period and Model Input File

Year	Stress Period	Well Pumping Input (ac-ft/yr)
2003	1	22,798
2004	2	19,941
2005	3	17,624
2006	4	20,359
2007	5	17,222
2008	6	17,025
2009	7	21,460
2010	8	21,460
2011	9	17,555
2012	10	17,555
2013	11	17,555
2060	58	17,555

Table 3-2. Projected Annual Pumping from City of Santa Fe Wells

Year	Annual Pumping (ac-ft/yr)	
	Buckman Wells	Town Wells
2009	5,790	3,577
2010	5,790	3,577
2011	4,776	3,577
2012 to 2060	1,881	3,577

The Santa Fe County groundwater model (Intera, 2006) simulated depletions from 2003 to the year 2060 using a projected pumping rate totaling 17,554 ac-ft/yr for all of the sub-basins within the model. This total is approximately equal to the amount estimated for seven of the sub-basins in the groundwater budgets developed for the JyS Water Plan. The rate of groundwater use for the JyS sub-basins outside the Santa Fe County groundwater model boundaries (Velarde, Santa Clara, and Santa Cruz) were not included, nor were they analyzed separately. A total of 17,755 ac-ft/yr for the year 2000, including irrigation, domestic, self-supplied, and public supply wells, was estimated in the JyS Water Plan's groundwater budgets for the area within the model boundaries. Therefore, the model is simulating about 200 acre-feet less (about 1 percent) than the amount in the JyS groundwater budgets.

The simulated pumping for the years 2003 through 2013 and to the end of the simulation (2060) are shown in Table 3-1. Pumping for the years 2003 through 2008 are based on records of pumping for the region. The projected pumping from 2008 to 2060 is the same for all wells, except the Buckman wells. The projected pumping from the Buckman wells was set at a higher rate until 2012, when the Buckman Direct Diversion is planned to be operational (Table 3-2) (Borchert, 2009). Pumping rates are simulated to be constant after the year 2011.

Pumping from each well is applied to the appropriate layer or layers depending on the well depth and construction. A well that is open to more than one layer is simulated as pumping from multiple layers.

3.3 Recharge

The quantity of annual recharge assumed in any groundwater model will affect the degree to which groundwater levels are impacted. Table 3-3 compares recharge estimates in the JyS Water Plan’s budgets with modeled recharge in the sub-basins included in the Santa Fe County model. Only recharge from mountain front, areal, and stream losses is included in the comparison; recharge from adjacent sub-basins, return flow from irrigation, and seepage from septic tanks are not included in this comparison.

For the areas covered by the model, the simulated overall recharge is about 133 percent more than the recharge estimated in the JyS Water Plan’s groundwater budgets, although the discrepancy varies widely among the sub-basins. Recharge is substantially higher (500 percent greater) in the North Galisteo sub-basin but much less in the South Galisteo sub-basin (11 percent) than assumed for the JyS water budgets. Recharge in the Los Alamos sub-basin is twice as much in the model as compared to the hydrologic budgets developed in the JyS Water Plan. In those basins where the budget is not in balance, further investigation into the groundwater budgets, including recharge, is merited; the model indicates that significant groundwater mining is occurring in the Caja del Rio, North Galisteo, and Los Alamos sub-basins.

Table 3-3. Comparison of Recharge Components in the JyS Water Plan and the Santa Fe County Model

Component	Source [a]	Recharge Estimate (ac-ft/yr)											
		Sub-basin										Total JyS Region	Total Within Model Boundary
		Velarde	Santa Cruz River	Santa Clara	Los Alamos	Pojoaque-Nambe	Tesuque	Caja del Rio	Santa Fe River	North Galisteo Creek	South Galisteo Creek		
JyS Water Plan Groundwater Budget Recharge Components													
Mountain front recharge	JyS	2,100	3,080	3,760	3,820	4,500	2,460	0	5,050	0	5,500	30,270	18,516
Stream loss	JyS	1,800	5,190	510	400	5,000	2,500	1,150	6,330	770	0	18,920	15,930
Total recharge [b]		3,900	8,270	4,270	4,220	9,500	4,960	1,150	11,380	770	5,500	49,190	34,446
Santa Fe County Groundwater Model Recharge Components													
Mountain front recharge	Intera	—	3,573	241	9,173	9,571	3,661	0	7,883	3,845	387	38,334	38,334
Stream loss	Intera	—	0	0	0	1,739	1,956	0	3,600	0	200	7,495	7,495
Total recharge [b]		—	3,573	241	9,173	11,310	5,617	0	11,483	3,845	588	45,829	45,829
Percentage of JyS water plan (DBS&A and Lewis, 2003) estimate		—	43%	6%	217%	119%	113%	0%	101%	499%	11%	93%	133%
Percentage of basin within model boundary		0%	45%	18%	77%	69%	75%	100%	95%	95%	69%	77%	100%

[a] Sources: JyS = DBS&A and Lewis, 2003
Intera = Intera, 2006

[b] Not including return flow or flow from adjacent basins

ac-ft/yr = Acre-feet per year
— = Not available

3.4 Projected Water Level Declines

The simulation of current levels of pumping from the year 2003 until the year 2060 shows drawdown primarily in the vicinity of the City of Santa Fe and Town of Los Alamos. Drawdown is insignificant (<10 feet) for the remainder of the model area. The drawdown predictions for Layers 1 through 5 are included in Appendix A. The thicknesses of the model layers are shown in Table 3-4 along with a summary of the predicted drawdown. The drawdown predicted by the model is in addition to drawdown that has already occurred from historical pumping up to 2003.

Table 3-4. Range of Water Level Drawdowns Predicted by Santa Fe County Groundwater Model

Model Layer	Layer Thickness (feet)	Maximum Drawdown 2003 to 2060 (feet)	
		Vicinity of Santa Fe	Vicinity of Los Alamos
1	Variable [a]	Dry cells	Dry cells 40 feet near wells
2	275	140	50
3	325	170	55
4	475	132	54
5	725	56	46

Source: Torres, 2009
[a] Variable due to elevation of starting head

The drawdown shown in Table 3-4 represents the decline in pressure head and does not necessarily represent the dewatering of the pore space, except for Layer 1, which is primarily unconfined. For Layers 2 through 5, the drawdown most likely does not represent any dewatering of the aquifer, only a change in the height the water would rise to, for instance, in a piezometer screened across the entire thickness of a particular layer.

Model Layer 1 contains numerous dry modeling cells at the onset of the model run, and the model does not differentiate between an existing dry cell at the onset of pumping and a dry cell resulting from actual water level declines due to pumping. Layer 1 starts with dry cells in the southeast part of Los Alamos County and in an area south of Santa Fe in the vicinity of Sunlit Hills. In these cells, the top of the water table is below the bottom of Layer 1. Thus, Layer 1 model results may suggest general trends, but may not accurately represent the true groundwater conditions.

The elongated cone of depression in the vicinity of Santa Fe extends north toward Tesuque Pueblo and to the south of El Dorado. The drawdowns are deepest in the vicinity of Santa Fe, with dry cells occurring in Layer 1 near the City of Santa Fe wells. Drawdown is up to 140 feet in Layer 2, up to 170 feet in Layer 3, up to 132 feet in Layer 4, and almost 60 feet in Layer 5. Drawdown in the vicinity of El Dorado is between 20 and 50 feet for Layers 1 through 3 and less than 20 feet for Layers 4 and 5.

A water level rise is predicted in all layers between Santa Fe and the Rio Grande, presumably due to the projected reduction in pumping from the Buckman wells. A water level rise is also shown east of Santa Fe in Layer 1, but this is an artifact of recharge accumulating upgradient of cells that have gone dry. The model code does not allow for re-wetting of the cells; thus recharge cannot flow to the dry cells.

Water level declines in the vicinity of Los Alamos are between 10 and 50 feet for Layers 1 through 5. Layer 1 in southern Los Alamos County shows dry cells where no wells are present.

Because the model does not allow for re-wetting of cells once they are dry, the desired pumping rate may differ from the simulated pumping rate. This can occur because some wells may be located in a dry cell. The goal of the model simulation was to determine if the aquifer can sustain the current level of pumping. The dry cells might appear to suggest that the pumping rate is not sustainable at the locations of the dry cells. However, it is important to examine the timing of the cells going dry and the locations of wells in the dry cells. To assess the magnitude of the pumping designated in dry cells, the projected pumping was compared to the simulated pumping.

The projected pumping rate was designated in a well input file. The amount of pumping for each stress period that was simulated by the model was compared to the well input file to assess the performance of the model (Table 3-5). The difference between these two numbers may indicate that some cells are dry and therefore not simulating the pumping. From the outset, the first stress period shows that some of the pumping is designated in dry cells. Review of the output file shows that the cells in the southern part of Los Alamos County are dry in Layer 1 by the first time step, and some of the wells in the vicinity of Sunlit Hills are also dry in Layer 1. As the stress periods proceed to the year 2009, additional cells are dry, resulting in 744 ac-ft/yr out of Layer 1 not being simulated in the model for the remainder of the simulation. From 2009 to 2060, no additional cells go dry.

Table 3-5. Simulated Pumping by Stress Period and Model Input File

Year	Stress Period	Pumping (ac-ft/yr)		
		Model Simulation	Well Input File	Difference Between Well Input and Model Simulation [a]
2003	1	22,647	22,798	151
2004	2	19,790	19,941	151
2005	3	17,473	17,624	151
2006	4	20,207	20,359	152
2007	5	17,070	17,222	152
2008	6	16,516	17,025	509
2009	7	20,716	21,460	744
2010	8	20,716	21,460	744
2011	9	16,811	17,555	744
2012	10	16,811	17,555	744
2013	11	16,811	17,555	744
2060	58	16,811	17,555	744

[a] Pumping wells in dry cells ac-ft/yr = Acre feet per year

These results of groundwater decline are useful as a first step in evaluating aquifer viability and in directing the next analytical step. Given the contradictory results, a review of the model's hydrologic parameters and calibration, especially in the area of dry cells and high drawdown rates, is prudent. For example:

- The model predicts a dewatering of Layer 1 in some locations before 2009, which has not occurred.

- The model shows dry cells in Layer 1 throughout the Sunlit Hills area (in the vicinity of Seton Village); however, the water levels in the Sunlit Hills Water System have steadily recovered since the drought years from 2001 to 2004, exceeding water levels observed at the time the wells were drilled in the 1960s (Vail, 2009).

- The impact of the simulated ponding of water upgradient of dry cells needs to be addressed.

- The discrepancy between the model-assumed recharge and the recharge used in the JyS Water Plan should be addressed.

- A more conservative analysis would use the lower recharge estimates.

The model, therefore, is not performing adequately to assess the long-term groundwater viability in these areas, particularly in Layer 1.

3.5 Conclusions

The Santa Fe County groundwater model simulations indicate that the region could continue the current level of pumping (with the anticipated reduction at the Buckman well field) until the year 2060. However, the recharge in the North Galisteo sub-basin is much higher than in the groundwater budgets developed for the JyS Water Supply Report (Duke Engineering, 2001). The basis for the increase in recharge has not been reviewed in this summary. If the level of recharge is over-estimated in the model, then the predicted drawdowns would be less and the viability of the aquifer would not be adequately predicted. Furthermore, the instability of Layer 1, which resulted in dry cells, ultimately prevented the simulation of projected pumping in those dry cells. Therefore, the actual stresses on the aquifer in the vicinity of the dry cells were not simulated, and drawdown in the layers beneath and adjacent to the dry cells was less than it would be if pumping were simulated in those dry cells.

To prevent an underestimate of aquifer drawdown, a detailed assessment of the pumping stresses by sub-basin should be performed along with an evaluation of the performance of the model in each sub-basin. In some areas the cells are dry within the first few years of simulation (2003 through 2005), which is not consistent with the observed performance of the aquifer. Continued development of this model or other models will also be a valuable tool to assess other aspects of groundwater development on the region, such as impacts to streams and springs.

The JyS Water Planning Council could also work together to develop a definition of what is considered "sustainable." For instance, it is theoretically possible to design well fields that intercept most of the recharge and thus would be able to "sustain" the designed pumping rate. However, intercepting all recharge ultimately captures water that would have flowed to the Rio Grande or tributaries of the Rio Grande, an outcome that may not be desirable, even if it could be legally implemented.

4. Changes in Water Use of the Agricultural Sector

A critical aspect of water planning includes tracking changes in water use by the agricultural sector, a sector that diverts about 70 percent of the water used in the JyS region. Agricultural water use in the western U.S. has generally been declining, in part due to increased urban populations inhabiting once irrigated pastures, transfers of irrigated acreage to municipal and industrial uses, or fallowing of lands due to declining interest in the low profit margins of agriculture. To assess whether any of these changes have occurred in the JyS region since the plan was completed in 2003, irrigated acreage estimates used in the JyS water plan were compared to the most recent estimates. Unfortunately, estimates of irrigated acreage vary greatly, making it difficult to determine actual trends.

The estimates of water use by the agricultural sector reported in the JyS water plan were based on the OSE water use report for 1995 and other available sources. Table 4-1 lists the irrigated acreage estimates, by sub-basin, reported in the plan. For the most part, agricultural diversions are not metered, and estimates are instead developed based on first estimating the acreage of various crops in production and then assuming a certain per-acre diversion and/or consumptive use for each type of crop. These methodologies leave considerable uncertainty, and due to the wide range of values provided by the different sources, little confidence can be had in the estimates of water use by the agricultural sector. Nevertheless, a recently released OSE water use report for 2005 includes updated water use estimates for all sectors, including agriculture. Figure 4-1 compares the OSE estimates for 1995 to the latest estimates for 2005.

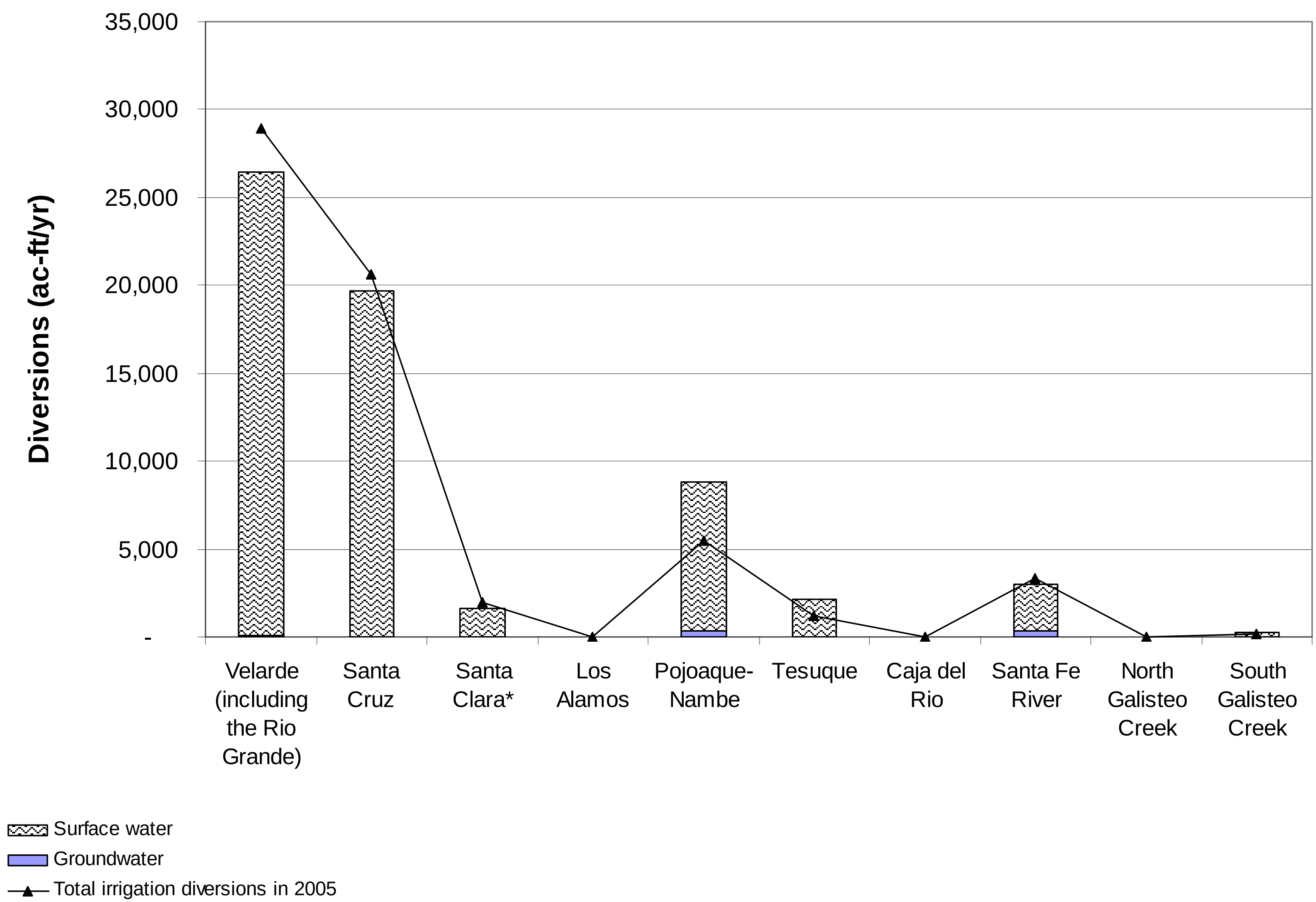
OSE bases their estimates of irrigated acreage on reports from the Farm Service Agency (FSA) (Magnuson, 2009). The FSA estimates in turn are based in part on acreage reported by the farmers who have registered with the FSA (to qualify for farm programs and crop insurance). Irrigation by Pueblos is treated differently and does not appear to be included in the estimates used by the OSE. Extension Agent Pat Torres, who is responsible for estimating acreage for Santa Fe County, does not conduct areal or land surveys to determine acreage (Torres, 2009), basing his estimates instead on conversations with farmers. Rio Arriba County Extension Agent Tony Valdez does not attempt to estimate acreage (Valdez, 2009), relying only on the estimates reported by registered farmers.

Table 4-1. Irrigated Acreage Estimates Included in 2003 Jemez y Sangre Water Plan

Sub-Basin	Irrigated Acreage by Information Source			
	Rio Arriba County Planning Office	1992-Landsat Image	Wilson and Lucero (1997)	Hydrographic Surveys
Velarde				
Velarde area	1,815	3176	2,870	—
Rio de Truchas area	3,258	334	2,925	2,064.3 [a]
Velarde total	5,073	3,510	5,795	2,064.3
Santa Cruz				4,780 [a]
Rio Arriba County	1,326	1,010	4,155	—
Santa Fe County	—	910	5,735	—
Santa Cruz total	1,326	1,920	9,888	4,780
Santa Clara	699	545	—	—
Los Alamos	—	0	0	0
Pojoaque-Nambe	—	957	2,375 [c]	3,538 [b,c]
Tesuque	—	170	0 [d]	0 [d]
Caja del Rio	—	0	0	0
Santa Fe River	—	306	965	485 [e]
North Galisteo Creek	—	0	0	0
South Galisteo Creek	—	88	—	0
Total	7,098 [f]	7,496	19,023	10,867

Source: Duke, 2001 (Table 3-12)
— = No estimate provided

[a] Hydrographic survey conducted during 1970
[b] Hydrographic survey conducted during 1966
[c] Includes Tesuque estimate
[d] Included in Pojoaque-Nambe estimate
[e] Hydrographic survey conducted during 1976
[f] Rio Arriba only



JEMEZ Y SANGRE PHASE II UPDATE

Comparison of Irrigation Diversions in 1995 and 2005
Jemez y Sangre Planning Region

Daniel B. Stephens & Associates, Inc.

6/27/09

Figure 4-1

The FSA method of estimating irrigated acreage in the JyS region does not include acreage in some sub-basins, and therefore, OSE does not include these demands in their water use reports. Specific omissions include:

- The acreage irrigated in the South Galisteo sub-basin that was identified in the 1992 Landsat imagery (and currently visible on Google Earth) was not included in the estimates for Santa Fe County because the irrigation is new (Torres, 2009).

- The land irrigated by Santa Clara Pueblo in the Santa Clara sub-basin is estimated to be 950 acres in 2008 (Gonzales, 2009), but this acreage is not included in OSE's estimates for Rio Arriba County.

- The amount of land irrigated by Ohkay Owingeh in the Velarde sub-basin is estimated to be 1,200 acres but does not appear to be included in the OSE estimates, which are about 1,000 acres less than acreage visible in the Landsat image for 1992.

Regardless of whether the FSA and OSE numbers are inclusive of all acres, the method has remained the same from 1995 to 2005, providing a valid basis for comparison, and the overall irrigated acreage estimates have declined by about 12 percent (Figure 4-1).

Estimated diversions and depletions were calculated based on OSE estimates (Longworth et al., 2008) and estimates of irrigated acreage for Pueblos and the South Galisteo area by the USDA and County Extension agents. Because OSE's new estimates (Longworth et al., 2008) do not include return flow estimates for the agriculture sector, return flow was estimated based on the irrigation efficiencies reported by Longworth et al. (2008) and the incidental depletions reported by Wilson and Lucero in 1997. Table 4-2 shows the updated estimates of irrigation diversions, depletions, and return flows. As indicated in this table, the estimated total amount of diversions has changed (increased) less than 1 percent. However, the error margin of the original estimate and the latest estimates may be too great to place any meaning on the estimated change.

Table 4-2. Estimated Irrigation Diversions, Depletions, and Return Flows, 2005

Sub-Basin	Irrigated Land [a] (acres)		Consumptive Irrigation Requirement [a] (ft/yr)		Efficiency [a] (dimensionless): On-Farm Irrigation		Efficiency [a] (dimensionless): Off-Farm Conveyance		Total Diversion [b] (ac-ft/yr)		Incidental Depletion Fraction [c] (dimensionless)		Total Depletion [d] (ac-ft/yr)		Return Flow [e] (ac-ft/yr)	
	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water	Surface Water	Ground-water
Velarde																
Velarde and Vicinity	3,653 [f]	35	1.62	1.16	0.5	0.85	0.7	NA	16,908	48	0.168	0	6,912	41	9,996	7
Rio de Truchas	2,888	0	1.16	0	0.4	0	0.7	NA	11,965	0	0.113	0	3,729	0	8,236	0
Subtotal	6,541	35	NA	NA	NA	NA	NA	NA	28,873	48	NA	NA	10,641	41	18,232	7
Santa Cruz																
Rio Arriba County	4,222	0	0.8	0	0.55	0	0.7	NA	8,773	0	0.179	0	3,982	0	4,791	0
Santa Fe County	4,425	5	0.94	1.47	0.5	0.85	0.7	NA	11,884	9	0.179	0	4,904	7	6,980	1
Subtotal	8,647	5	NA	NA	NA	NA	NA	NA	20,657	9	NA	NA	8,886	7	11,771	1
Santa Clara	950 [g]	0	0.8	0	0.55	0	0.7	NA	1,974	0	0.179	0	896	0	1,078	0
Los Alamos	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
Pojoaque-Nambe	1,184 [h]	145	1.84 [i]	0.95	0.55	0.85	0.75	NA	5,281	211	0.14	0.11	2,484	153	2,798	58
Tesuque	296 [h]	0	1.84 [i]	0.95	0.55	0.85	0.75	NA	1,165	0	0.14	0.11	621	0	544	0
Caja del Rio	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
Santa Fe River																
Drip Irrigation	0	20	0	0.97	0	0.85	0	NA	0	23	0	0	0	19	0	3
Flood Irrigation	590	110	1.75	1.75	0.5	0.5	0.7	NA	2,950	385	0.179	0.15	1,217	221	1,733	164
Subtotal	590	130	NA	NA	NA	NA	NA	NA	2,950	408	NA	NA	1,217	241	1,733	167
North Galisteo Creek	0	0	0	0	0	0	0	NA	0	0	0	0	0	0	0	0
South Galisteo Creek	40 [j]	0	1.75	0	0.5	0	0.7	NA	200	0	0.179	0	82.53	0	117.47	0
Total JyS Region	18,498	315	NA	NA	NA	NA	NA	NA	61,100	675	NA	NA	24,827	442	36,273	234
Total JyS Region [k] JyS Plan (DBS&A and Lewis, 2003)	19,627	305	NA	NA	NA	NA	NA	NA	61,221	730	NA	NA	25,523	452	35,695	279

[a] Source: Longworth et al. (2008), unless otherwise noted
[b] Total diversion = (irrigated acreage x CIR)/[(on-farm irrigation efficiency) x (off-farm irrigation efficiency)].
[c] Source: Wilson and Lucero (1997)
[d] Total depletion = (irrigated acreage x CIR) x (1 + incidental depletion fraction).
[e] Return flow = total diversion – total depletion
[f] Longworth et al. (2008) plus 1,200 acres estimated for Okay Owingeh (Valdez, 2009)
[g] Irrigated acreage in the Santa Clara sub-basin based on information provided by the USDA District Conservationist (Gonzales, 2009).
[h] Irrigated acreage in the Pojoaque-Nambe sub-basin assumed equal to 80% of amount estimated by Longworth et al. (2008) for combined area of Pojoaque-Nambe and Tesuque sub-basins
[i] Consumptive irrigation requirement in the Pojoaque-Nambe sub-basin based on an Order of the Court in the Aamodt adjudication case (U.S. District Court, 1994)
[j] Torres (2009)
[k] DBS&A & Lewis, 2003

ft/yr = Feet per year
ac-ft/yr = Acre-feet per year
NA = Not applicable
JyS = Jemez y Sangre

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Appendix A

Results of Pumping Simulations

Appendix A. Results of simulating 2008 pumping to 2060 using the Santa Fe County Groundwater Model developed by Intera (2006)

Figure A-1. Location of wells in the OSE WATERS Database

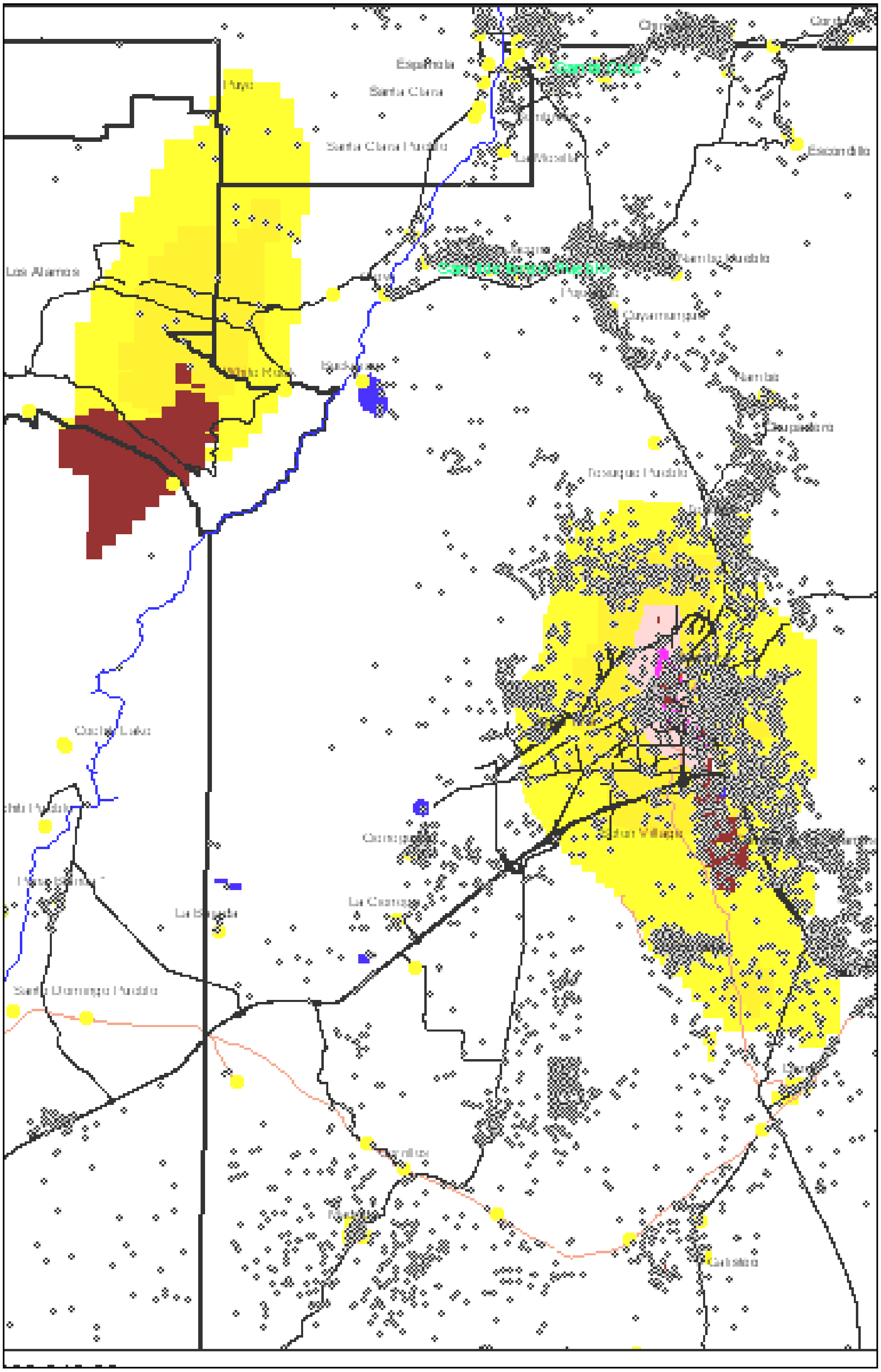
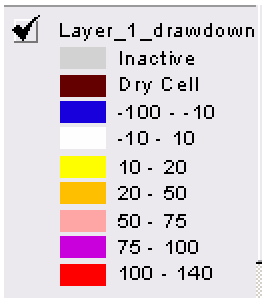
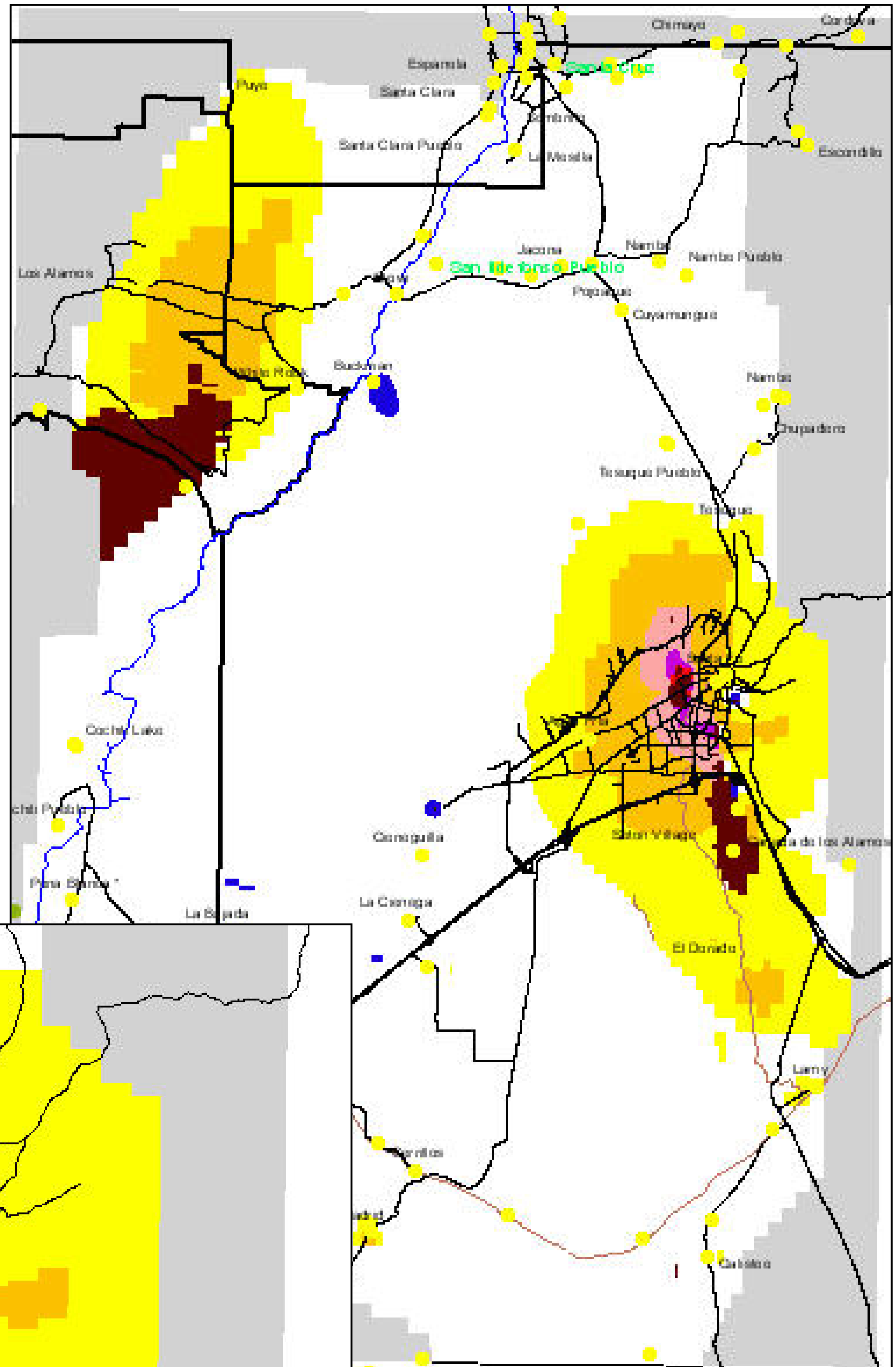


Figure A-2 Drawdown in Layer 1 in year 2060 showing detail for Santa Fe area.





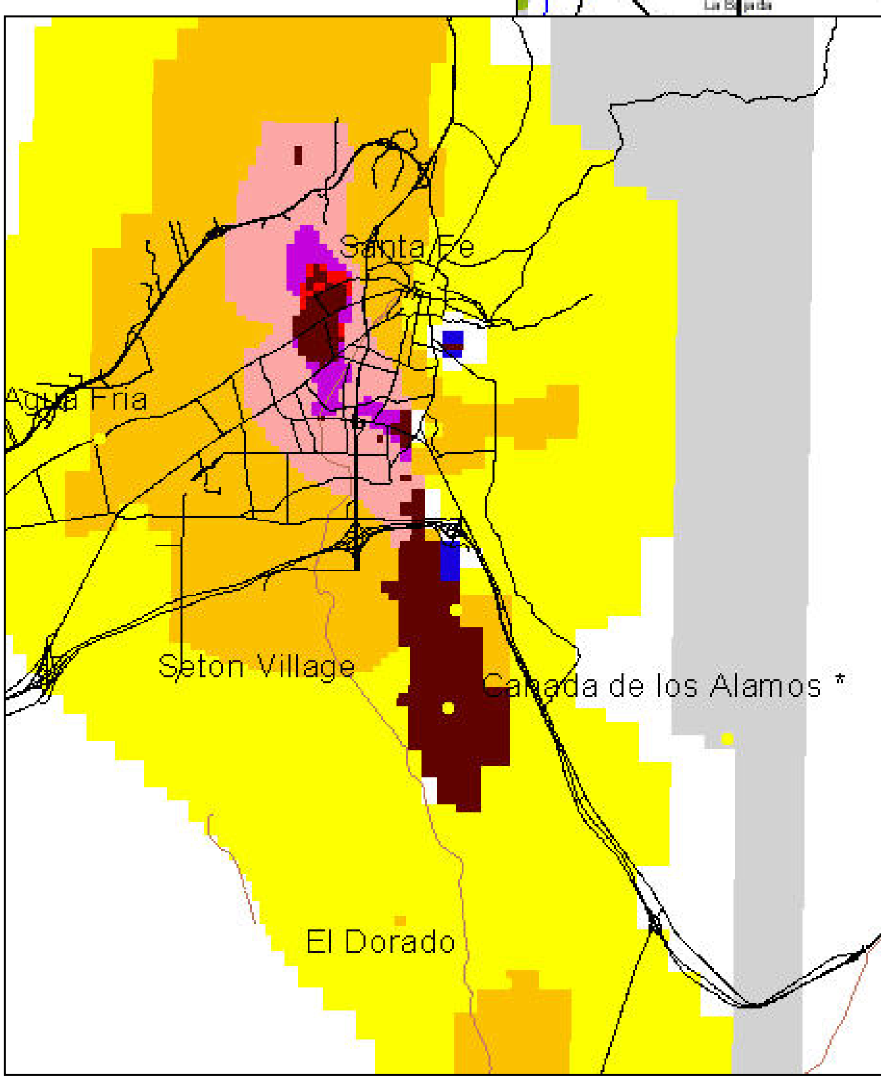
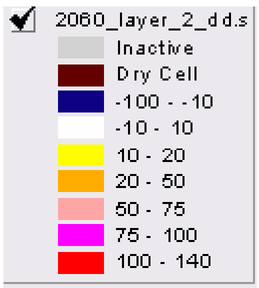
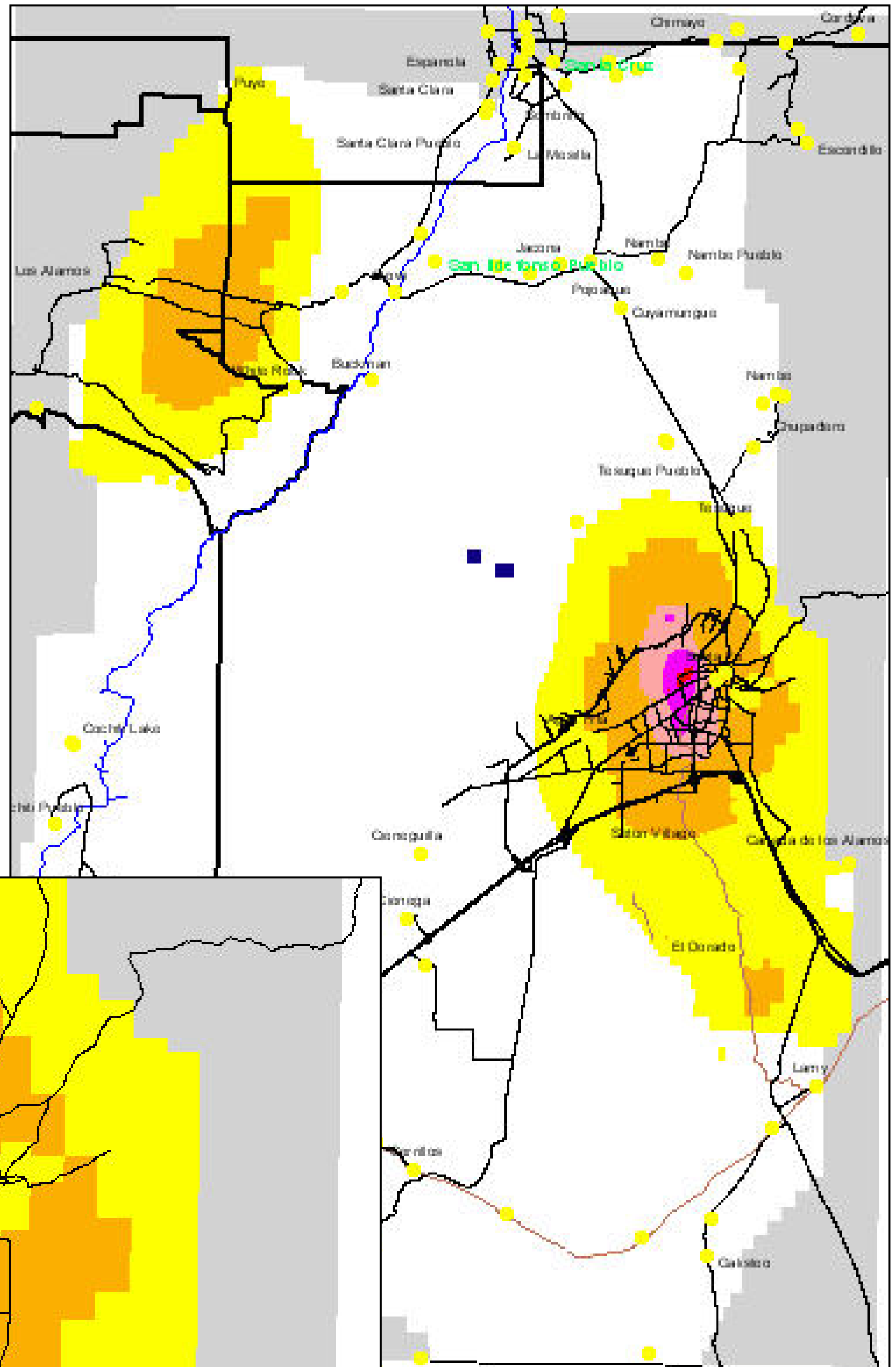


Figure A-3. Drawdown in Layer 2 in year 2060 showing detail for Santa Fe area.





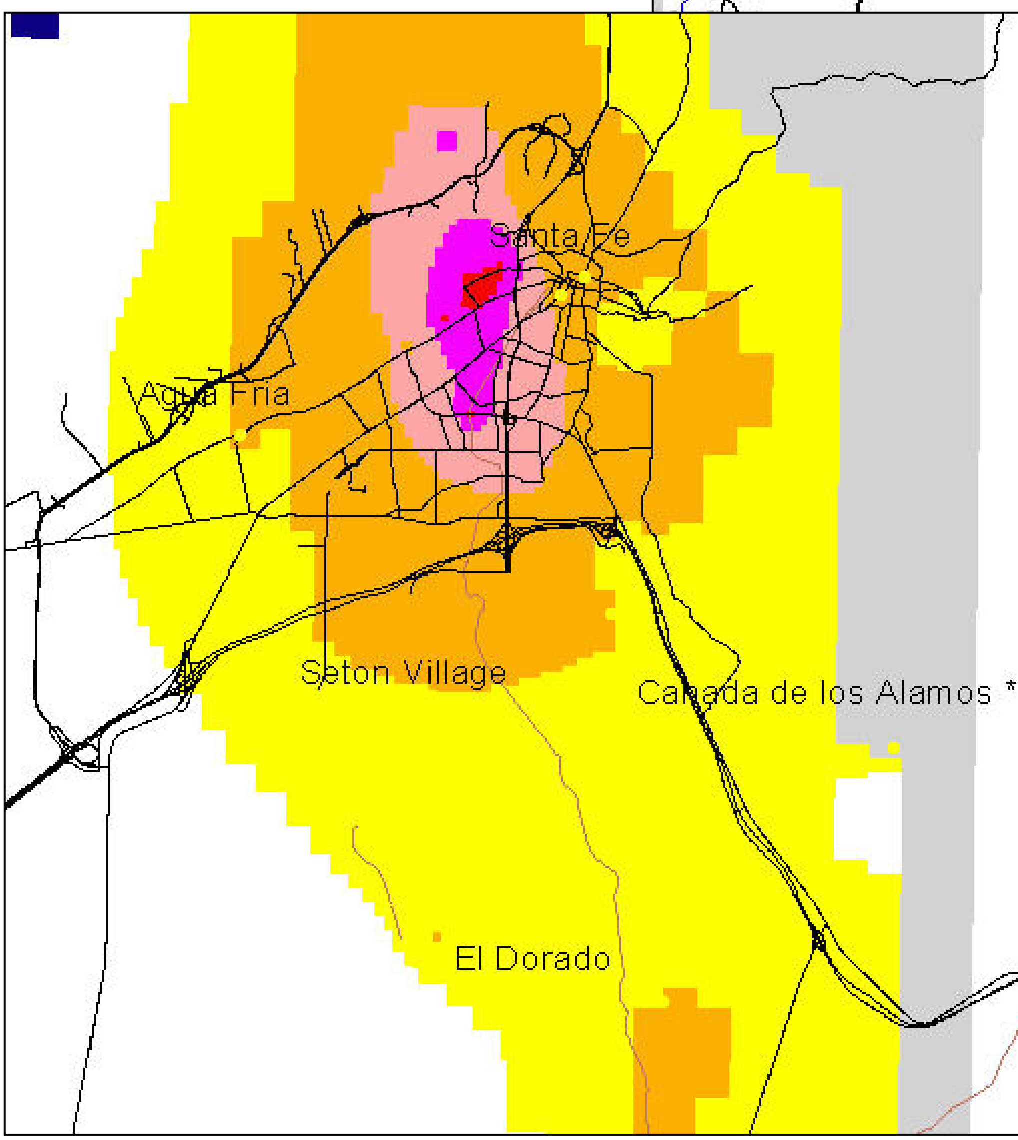
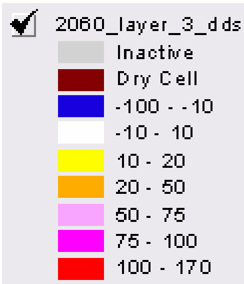
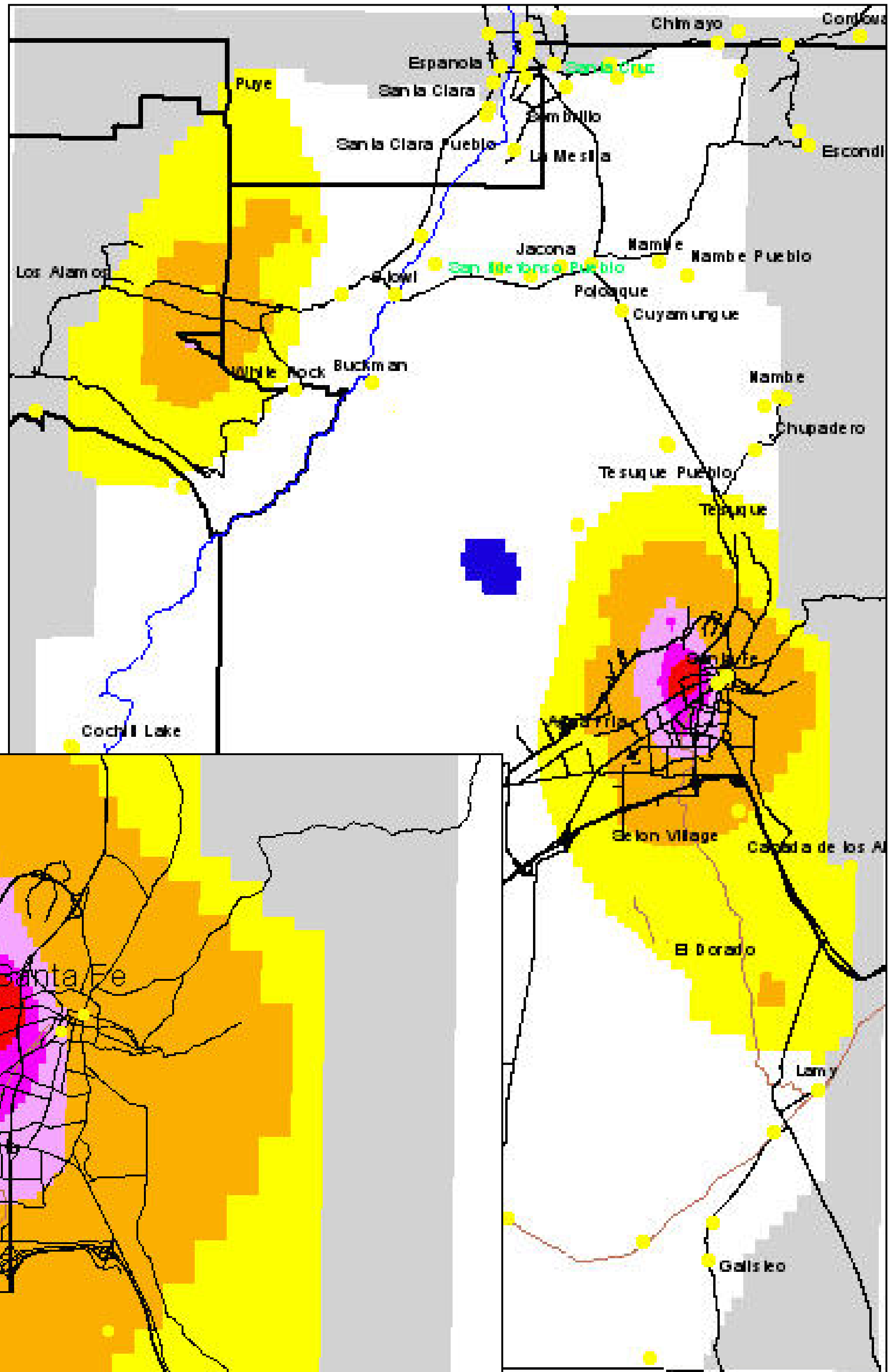


Figure A-4. Drawdown in Layer 3 in year 2060 showing detail for Santa Fe area.





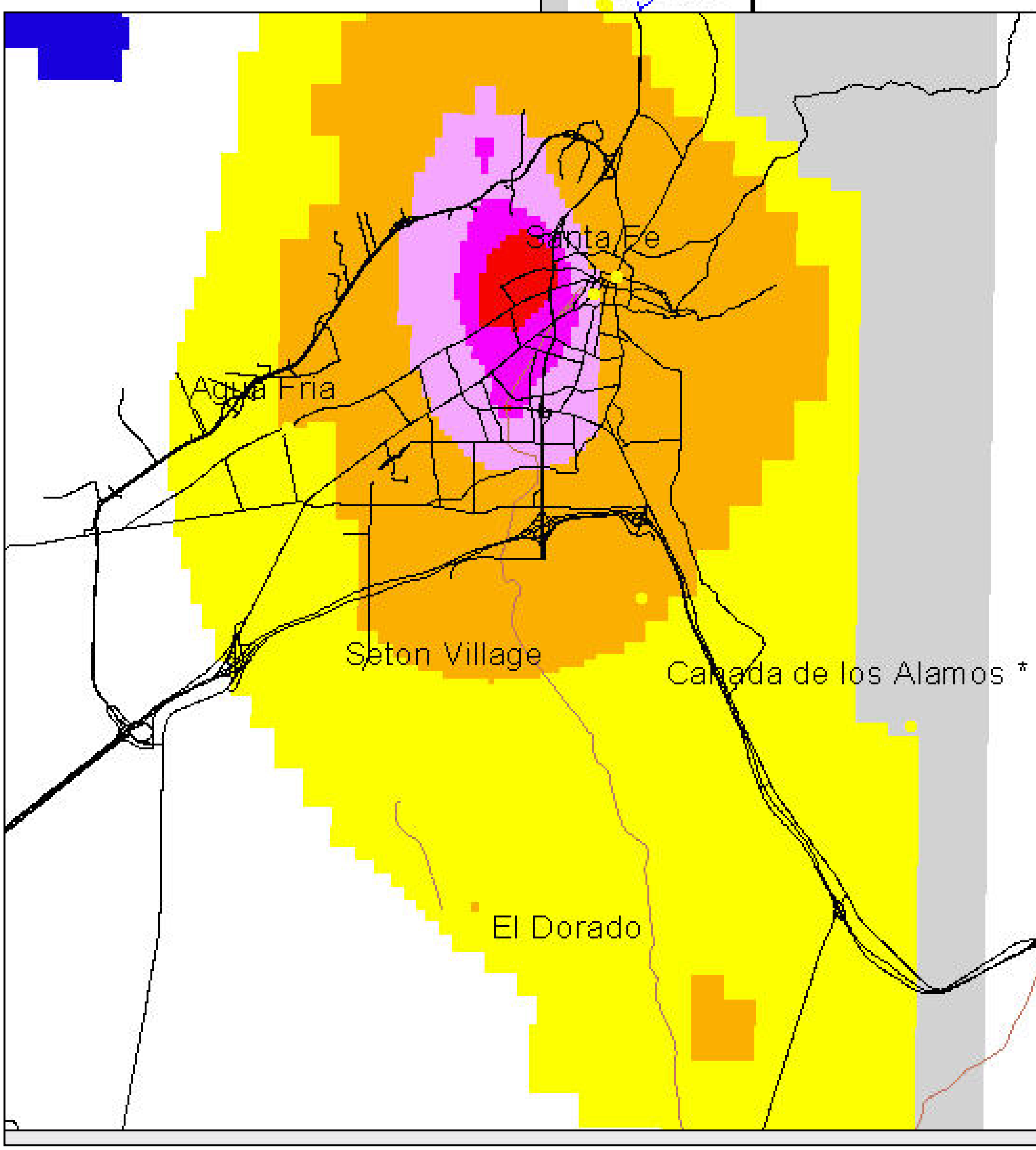
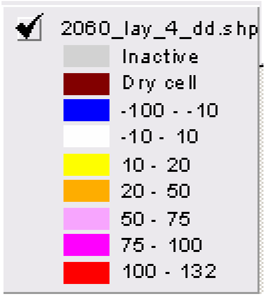
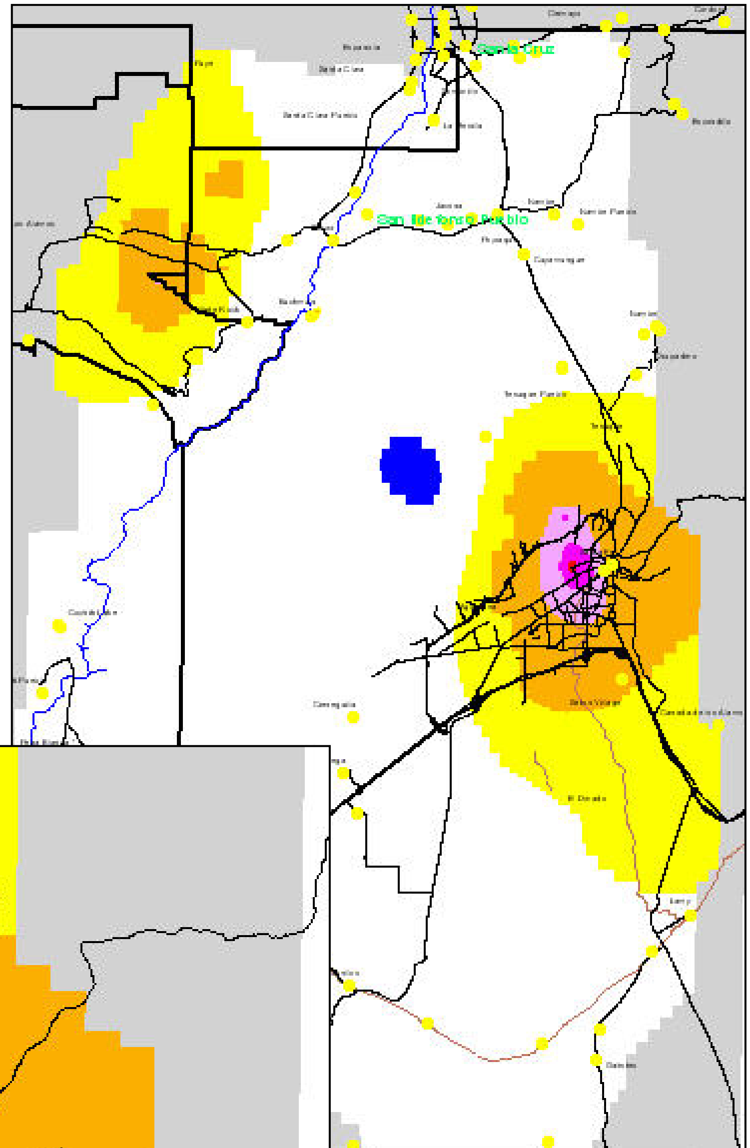


Figure A-5. Drawdown in Layer 4 in year 2060 showing detail for Santa Fe area.





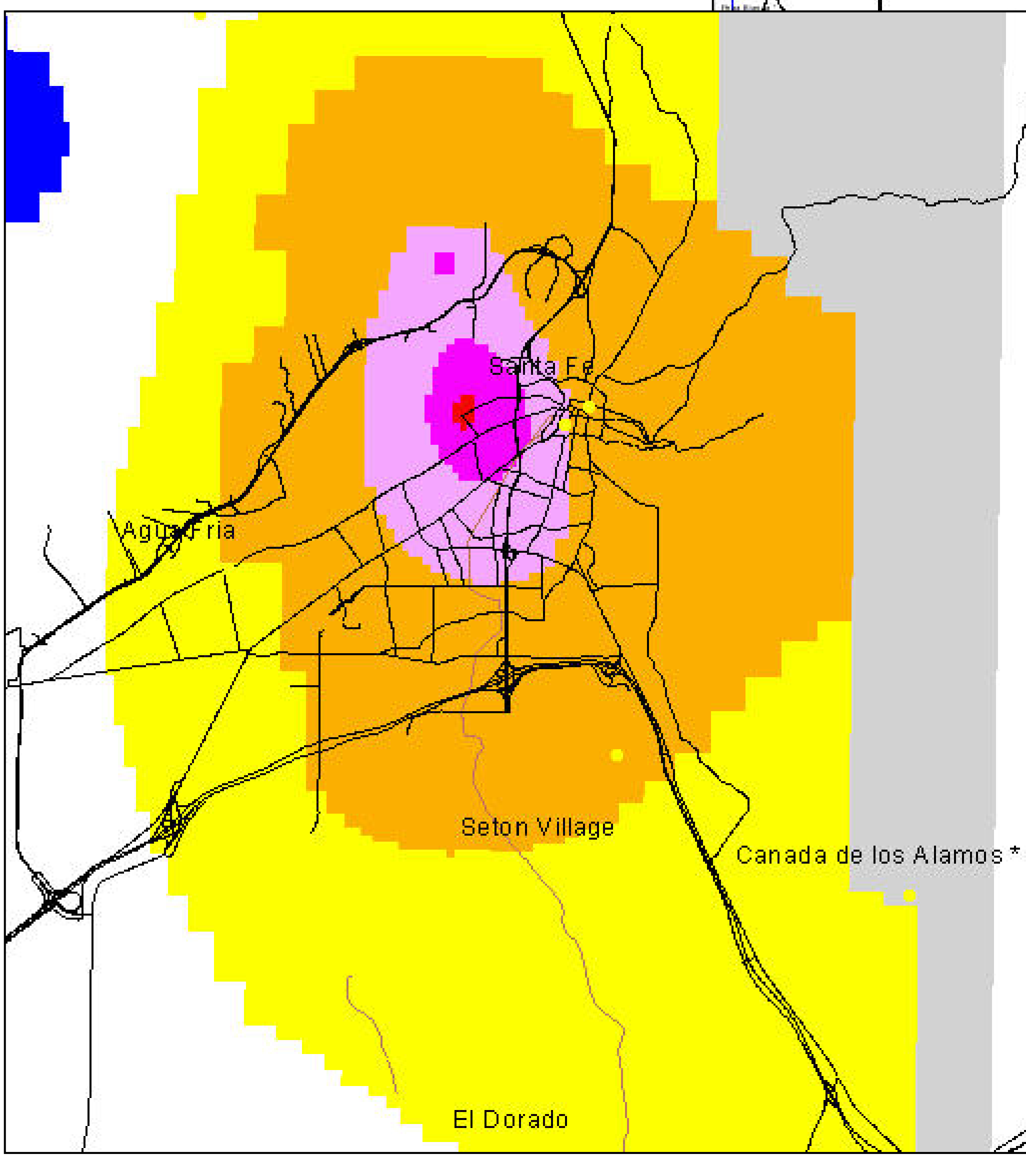


Figure A-6. Drawdown in Layer 5 in year 2060 showing detail for Santa Fe area.