Groundwater, Economic, and Legal Analysis of a Proposed Diversion from the San Agustin Basin of New Mexico

by

David J. Reese

Water Resources Program
University of New Mexico
Albuquerque, New Mexico 87131-0001
www.unm.edu/~wrp

December 2012

NOTE: This publication is the Professional Project report of David J. Reese, submitted in partial fulfillment of the requirements for the Master of Water Resources degree at the University of New Mexico (December 2012). The project was supervised and approved by the following committee: Dr. Bruce M. Thomson, Water Resources Program and Department of Civil Engineering, UNM (Chair); Dr. Janie Chermak, Department of Economics, UNM; and Dr. Vincent C. Tidwell, Sandia National Laboratories.

Committee Approval

The Master of Water Resources Professional Project Report of **David Reese,** is approved by the committee:

Bruce M Thomson 11/1/2012

Chair Date

11/01/2012

Vincent Tidwell 11/1/2012

Table of Contents

Appendices

List of Tables

List of Illustrations

Abstract

A private corporation has proposed to export up to 54,000 acre-feet per year of groundwater from the San Agustin basin of central New Mexico for use within the Rio Grande basin. This water would be used for eleven stated purposes. Concerns have been expressed regarding the hydrologic, economic, environmental, and legal consequences. Sustainability of the water supply is an issue, as are effects on the neighboring Rio Grande and Gila River watersheds. A system dynamics model of groundwater and its relationship to the local economy in the basin was developed to explore some of these issues. Subsurface flow between six subbasins was modeled as well as flow to two neighboring groundwater basins. Simulation runs occur on an annual time-step over a 40-year period. Two simulations are presented: 1) no-development based on historic precipitation and evapotranspiration, and 2) development, which includes a 54,000 acre-foot per year appropriation. Model results indicate that effects are measurable. Pumping is sustainable over 40 years. Basin-wide groundwater resources decline 1.76%. Water levels decline 11 feet. Twenty-eight active wells are projected to become dry. Water volume decreases 4.78% or 46 feet in the subbasin where the proposed wells would be located. Water table decreases are averaged for each of six subbasins; wells closer to the pumping center are impacted more than distant wells. Subsurface discharge to the Gila River and Alamosa Creek watersheds decreases 2.93% and 30.2%, respectively. Sensitivity analyses were conducted using hydrologic values suggested in other studies, *viz.* recharge, hydraulic conductivity, volume, climate change, and water price figures. Basin-wide groundwater volume decreases 1.56-3.87%. Water levels decline 10.6-24.7

feet. Water volume decreases 4.02-10.35%, or 38.8-100 feet in the subbasin where the wells would be located. Subsurface discharge to the Alamosa and Gila River watersheds decreases 21.7-73.7% and 1.67-7.86%, respectively. Examples of costs include drilling 37 wells and constructing associated pipeline, deepening existing wells, and impacts on endangered species. Net costs over 40 years to basin residents and endangered species are projected to be $587,156 and $12.4 million, respectively, the latter assuming water decreases are not offset or replaced. Economic benefits would come primarily through marketing water outside of the basin. Net earnings from water sales range from $1.43 billion to $1.88 billion before taxes. Legal analysis utilizes groundwater and economic results. As New Mexico Office of the State Engineer Application No. RG-89943 is currently being appealed, any future application may need greater specificity, as well as firmly show proof of demand, contractual arrangements, and an absence of harm to basin residents.

1.0 Introduction

New Mexico has limited water resources for its growing population; consequently, there is considerable interest in developing new sources of water as well as increasing usefulness of existing water rights. Augustin Plains Ranch, LLC, in October 2007 filed Application No. RG-89943 with the New Mexico Office of the State Engineer (OSE) for a permit to appropriate 54,000 acre-feet of groundwater per year (AFY) from the San Agustin basin of west-central New Mexico. The company proposes "domestic, livestock, irrigation, municipal, industrial, commercial, environmental, recreational, subdivision and related, replacement and augmentation" uses for the water in seven New Mexico counties (Appendix A). The resource would be developed by drilling up to 37 wells with 20-inch casings up to 3000 feet deep then pumping the water to end users as far as Santa Fe County (Augustin Plains Ranch, 2011) (Figure 1).

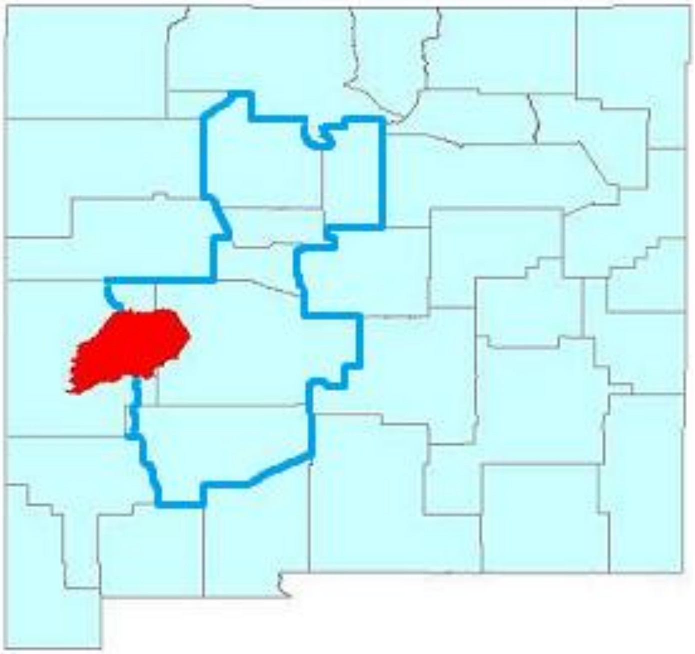


Figure 1. San Agustin Basin and potential diversion service areas.

The San Agustin basin totals 1965 square miles within Socorro and Catron counties of central New Mexico. Being a closed basin, surface water drains inward to the gently sloping, largely featureless San Agustin Plains. Ranging between 6800 to 7500 feet above sea level, and at about 54 miles in length with a maximum width of about 21 miles, the plains are bounded largely by mountains reaching 8000-10,000 feet in elevation. Groundwater seeps under this divide may provide flow to the Tularosa River-San Francisco River-Gila River watershed. Water may also drain southeast to Alamosa Creek, a Rio Grande tributary (Blodgett and Titus, 1973) (Myers et al., 1994).

The application was denied in April 2012 (OSE, 2012), but without prejudice, meaning the ranch is able to re-file. Instead, it has chosen to appeal to the New Mexico Seventh Judicial District Court (Draper, 2012), where the application resides as of October 2012.

There is considerable opposition to this plan. The San Augustin Water Coalition and Catron County Water Coalition were organized and hundreds of formal protests have been filed. The principal concern is that the basin cannot sustain large-scale pumping. Many protestants claim their senior water rights would be impaired, and that at the very least, they would need to drill deeper wells at their own expense. Some claim it would amount to a monopolization of basin water (OSE, 2011b). However, data have been lacking in formal protest letters and in the debate in general. The primary objective of this project is to provide an estimate of the impacts the proposed project would have on the volume of groundwater in the basin, the amount of drawdown that would occur, and the economic consequences of this development.

Hydrogeologic information on the basin is very limited. A 1973 graduate student thesis (Blodgett and Titus) and a U.S. Geological Survey (USGS) report (Myers et al., 1994) are, according to the latter, the only two extensive hydrogeology studies of the basin. Other sources include Office of the State Engineer well data, a Catron County USGS investigation (Basabilvazo, 1997), first-hand professional estimates, two New Mexico Interstate Stream Commission regional water plans, and more.

Groundwater and economic modeling is accomplished using a system dynamics approach using Powersim Studio® 9 software. A lumped parameter groundwater model was developed consisting of six subbasins, or blocks, with water exiting to the Gila River and Alamosa Creek-Rio Grande watersheds. This modeling approach does not predict drawdowns in individual wells but instead simulates responses to block water levels as a result of groundwater development. Two different scenarios are presented: 1) no-development scenario, and 2) appropriation scenario, consisting of the proposed 54,000 acre-foot per year inter-basin transfer. Sensitivity analysis considers different figures considered possible by other studies, *viz.*, recharge, volume, climate change, and water lease rates. Simulation runs occur on an annual time-step over a 40-year period.

Economic costs to the ranch would include drilling wells, building pipeline and associated infrastructure, operations, and maintenance of the project. Revenue would be produced by leasing water. Basin residents may need to drill new wells, deepen existing wells, and pay higher electric costs, but would benefit from construction and maintenance-related economic activity. In addition, New Mexico places an economic value on endangered species (Berrens et al., 2000) (Loomis and White, 1996), several of which might be impacted by significant reductions in subsurface flow to the adjacent Gila River basin and Alamosa Creek basin.

Based on modeling results, an analysis is provided of legal and policy concerns this and any future applications may face. It draws from New Mexico Statutes Annotated (1978), OSE policy, and case law, among other sources.

2.0 Research Methods

This report considers groundwater, economic, and policy/legal impacts of OSE Application No. RG-89943, or similar pumping, on the water resources of the San Agustin Underground Water Basin. Standard research methods are employed.

Guidance is taken primarily from previous studies of the basin completed as part of the Water Resources: Models graduate course during Spring Semester 2008 at the University of New Mexico in Albuquerque. Much of the class centered on teaching students the fundamentals of Powersim Studio® 7 modeling software, using the San Agustin basin proposal as a case study. The class was divided up into groups of three to four students and each group prepared a groundwater model and an economic model.

Each group's report has different strengths and weaknesses. A strength is that several inputs are considered. For example, many consider evaporation, precipitation, aquifer characteristics, and flow between subbasins. The weaknesses of the group reports are principally due to the short duration available to complete the models and the limited data available regarding the basin. Most reports are vague to an extent and have little discussion regarding why certain inputs are used. Several inputs cannot be verified. The reports are also now outdated to an extent. For example, the amended May 2008 application states wells would be drilled up to 3000 feet, increased from 2000 feet as originally proposed. My project gathers verifiable data of each model and uses the best features of each. Several other inputs are added, such as irrigation of 4440 acres of ranch land (Appendix A), and effects on endangered riparian species. Uncertainty is reduced, but is unavoidable, due in large part to a limited understanding of the characteristics of basin aquifers.

There are few studies of the basin; hence, other sources must be utilized. As discussed in the Literature Review, these consist of OSE water usage data, New Mexico Interstate Stream Commission regional water plans, Federal Register postings on endangered species, U.S. Census data, U.S. Geological Survey studies, first-hand professional estimates, and others. Each primary source contributes to the model.

Potential legal issues are considered, drawn from New Mexico Statutes Annotated (1978), OSE Application No. RG-89943, case law, interstate compacts, as well as other sources.

3.0 Literature Review

Empirical hydrogeological data and literature are perhaps more lacking for the San Agustin basin than any other significant New Mexico watershed. A 1973 graduate study thesis (Blodgett and Titus, 1973) and a 1994 USGS study (Myers et al., 1994) are the only two substantial hydrological studies of the entire basin. These are the primary sources for most other studies regarding the San Agustin basin.

Blodgett and Titus' report is an informative master's thesis, but it has limitations in relation to this study. First, it is in large part a water quality study, which is of limited concern for this project. Its emphasis is particularly on the San Agustin Plains rather than the entire basin. It is also nearly 40 years old. Population has increased from 700 to about 1057 (Blodgett and Titus, 1973) (U.S. Census, 2010), a small but statistically significant increase. Precipitation and potential evapotranspiration (PET) are figured by assuming San Agustin PET is exactly one-half of a 1937 estimate for the high plains of New Mexico and Texas, a speculative assumption based by comparing the high plains with only one New Mexico weather station, near but outside of the San Agustin basin. Also, a hydrologic budget is developed based on precipitation and PET, but not on vegetation or soil conditions.

Nonetheless, it generally seems to use the best data available for the period and is valuable in part because there has been little development in the basin since 1973. Field tests were performed which provide evidence of a static water table from 1952-1972. Evidence is presented in support of southward subsurface leakage, such as large hydraulic gradients as well as little loss due to pumping, phreatophytes, and evaporation. Subsurface flow directions toward the Gila River basin appear thoroughly defended.

Myers et al. (1994) described a USGS investigation of the basin which studied the hydrogeology of the basin. However, more modern data allows for more accurate estimates. They differentiate between the Gila and Alamosa basins more than Blodgett and Titus. They present some initial volume data and discuss basin recharge. They state that there is little to no percolation and evaporation occurring at the playa lakes. Saline water is largely limited to the area beneath the western playa. Information is given regarding the bolson-fill aquifer where the proposed 37 wells would be drilled, including information on aquifer thickness, specific yield, and transmissivity. However, comparable data is not available outside the plains.

Basabilvazo (1997) authored a USGS study similar to Myers et al. (1994), but limited its scope to Catron County water resources. It draws very much from Myers et al. but is helpful in clarifying current knowledge about the basin's relationship to the Tularosa River-San Francisco River-Gila River basin. Roybal (1991) provides a similar USGS study regarding Socorro County resources.

Other information is available. Two Interstate Stream Commission regional water plans, 2010 U.S. Census data, Federal Register postings, and other sources help. Amended OSE application RG-89943 (Appendix A) and a promotional document issued by Augustin Plains Ranch, LLC (2011) describe the proposed project. Current well information, in particular depth of well and depth to water, has been obtained from the OSE (OSE, 2011b). Well locations are also provided, allowing for differentiation of water levels and purposes of use by block. New Mexico Statues Annotated 1978 is regularly referenced in a legal analysis. State court cases are also referenced.

4.0 Problem Statement

As population and economic activity increases, more and more demand is being placed on the limited water resources of the Middle Rio Grande region of New Mexico. The state's largest and fastest-growing region, growth here has outpaced water supply. Water in much of the state is over-appropriated. New Mexico Rio Grande basin surface waters have been considered fully allocated since the Rio Grande Compact, ratified in 1939, quantified water deliveries to Texas (RGC, 1939). No new surface diversions are allowed (OSE, 2000). There are Rio Grande silvery minnow instream flow requirements.

As a result, New Mexico in the past has had to retire agriculture lands, pay fines to Texas for delivery shortfalls, and immerse itself in costly lawsuits. Some public utilities have experienced difficulty complying with requirements to offset pumping effects on the river (D.B. Stephens, 2005). An extended drought would exacerbate stresses. Solutions are limited.

5.0 Application No. RG-89943

There are also groundwater development restrictions. In the Middle Rio Grande Administrative Area (MRGAA), groundwater withdrawals are administered as having an effect on Rio Grande flow. Various restrictions result (OSE, 2000). Therefore, it may be more attractive to develop water resources in locations within the Rio Grande Underground Water Basin yet outside MRGAA boundaries, such as the San Agustin basin. Pumping in such areas could nonetheless still affect Rio Grande flow.

Such a proposal exists in the form of OSE Application No. RG-89943. Initially filed by Augustin Plains Ranch, a New Mexico LLC, on October 12, 2007, it seeks approval for a permit to appropriate and consumptively use 54,000 acre-feet per year

(AFY) of water from the basin (Figure 1). Denied on April 2, 2012 (OSE, 2012), the ranch has chosen to appeal the decision (Draper, 2012).

This is a large sum of water—in comparison, the Jemez River has averaged 53,999 AFY since 1954 (USGS, 2011). Considering that New Mexico imports an average of 94,200 AFY of San Juan-Chama Project water, river flow entering Elephant Butte Reservoir (as measured at San Marcial) averages about 923,000 AFY (Kelly, 2007), and that demand in the Middle Rio Grande region has exceeded annual supply by about 55,000 acre-feet (Water Assembly, 2004), 54,000 AFY would significantly increase water resources to the basin.

The amended application states that Augustin Plains Ranch seeks to drill 37 wells on ranch property up to 3000 feet then transport water via pipeline as far as Santa Fe County, ostensibly to "reduce the current stress on the water supply of the Rio Grande basin" (Appendix A) "while managing this scarce resource for the common good" (Augustin Plains Ranch, 2011). Water quality is generally good in the eastern plains, where drilling would occur (D.B. Stephens, 2003) (Myers et al., 1994) (Roybal, 1991).

6.0 Concerns

According to opponents of the project, the proposed diversion would create many problems. These include requiring existing users to drill new or deeper domestic wells, land subsidence, pipeline construction expenditures, declines in endangered species, potentially less water in the Rio Grande above the pipeline terminus, and more. Any new groundwater withdrawal except domestic wells within the Rio Grande Underground Water Basin must obtain valid water rights sufficient to offset any impact its diversions would have on Rio Grande surface flow (OSE, 2000). In this case, if not available for purchase, water for offsets must be taken from the 54,000 AFY appropriation. An application can only be approved if the State Engineer finds that the proposed appropriation "would not impair existing water rights from the source, is not contrary to conservation of water within the state and is not detrimental to the public welfare of the state" (NMSA 1978 § 72-12-3(E)). There are also interstate issues over possible reduced discharge to the Gila River basin and Rio Grande basin through subsurface flow out of the San Agustin basin.

6.1 Opposition

Upon receipt of Application No. RG-89943, the OSE published a notice in at least one newspaper of each county that could be affected by the water use. Individuals, organizations, and others believing they could be affected were required to file a formal protest with the OSE within ten days of publication of the final notice (Appendix B).

The number of protestants with standing is currently about 150. Those with their own legal representation include the Bureau of Indian Affairs, Bureau of Reclamation, Catron County, U.S. Department of Agriculture, Kokopelli Ranch, Middle Rio Grande Conservation District (MRGCD), Navajo Nation, New Mexico (NM) Commissioner of Public Lands, NM Department of Game and Fish, NM Interstate Stream Commission, University of New Mexico; the Pueblos of Acoma, Isleta, Kewa, Sandia, San Felipe, Santa Ana, and Zuni; and others. Eighty-two others have chosen *pro bono* (free or reduced-cost) representation by the New Mexico Environmental Law Center. There are 44 *pro se* (on one's own behalf) protestants. Most within this group have mailing addresses within the basin. Augustin Plains Ranch, LLC is represented by a Santa Fe-based law firm (OSE, 2010).

One protestant stated that a diversion would have “a direct negative effect on the people who have existing wells” and harm natural springs “which could dry up altogether.” “Why should the citizens of Catron County be isolated” to provide water? “If you grant this application…you will destroy both a way of life and an environment…that are unique and irreplaceable” (OSE, 2008).

7.0 Background: San Agustin Basin

7.1 Topography

The San Agustin watershed totals 1965 square miles within Socorro and Catron counties of west-central New Mexico. Of this, 1540 square miles are within Catron County (D.B. Stephens, 2005). Being a closed basin, surface water drains inward.

Figure 2. San Agustin Plains. Image source: Google Earth®, accessed 7/29/12.

Water may reach two playas lying within a gently sloping, largely featureless area at the basin center known as the San Agustin Plains (Figure 2). Ranging between 6800 to 7500 feet above sea level, and at about 54 miles in length with a maximum width of about 21 miles, the plains are bounded largely by mountains reaching 8000-10,000 feet in elevation. In particular, bordering ranges include the Datil (north), Gallinas (northeast), San Mateo (southeast), Luera (south), Tularosa (southwest), and Mangas (west) mountains. The northwest, west, and southwest boundaries correspond to the Continental Divide. As suggested by hydraulic gradients, groundwater seeps under this divide may provide flow to the Gila River watershed. Hydraulic gradients also suggest drainage southeast to Alamosa Creek, a Rio Grande tributary (Blodgett and Titus, 1973) (Myers et al., 1994) (OSE, 2008).

7.2 Land Use

The basin is characterized by significant rangeland, few roads, minimal agriculture, and the absence of urban development (Cartron et al., 2002). Population is about 1057. Datil is the only sizeable community (U.S. Census, 2010). The principal occupation is cattle ranching. Land designations that surround the proposed drill sites are largely private, New Mexico, and U.S. Bureau of Land Management and Forest Service land. U.S. Route 60 and State Highway 12 are the only paved public roads. The former bisects the proposed well locations.

7.3 Climate and Vegetation

The climate is continental semi-desert, with cold winters and mild summers. Precipitation averages 13.63 inches. Most of this results from summer monsoonal storms and winter moisture. The growing season at the San Agustin Plains averages slightly more than 100 days (Blodgett and Titus, 1973) (Myers et al., 1994).

Vegetation is indicative of elevation, soils, and water availability. Three distinct vegetative zones compose the watershed. As delineated from Griffith et al. (2006), these zones are: 1) plains-mesa grasslands, 2) coniferous-mixed woodlands, and 3) montane-coniferous forests (Figure 3).

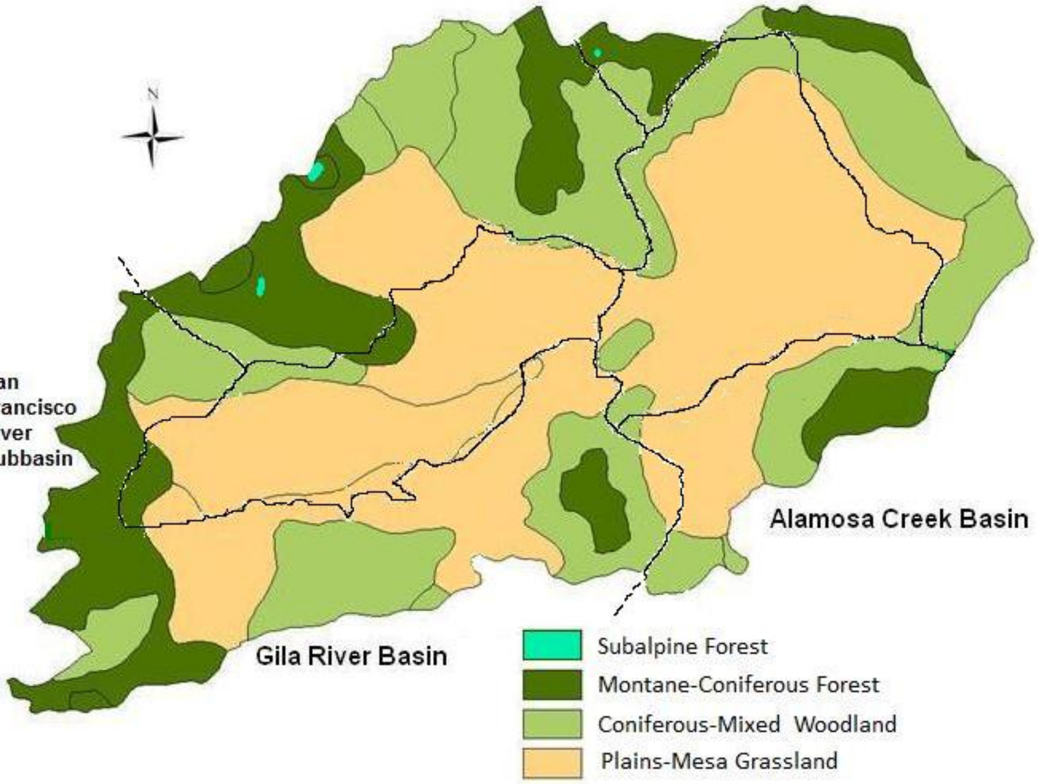


Figure 3. Vegetation zones.

Plains-mesa grasslands consist of dry-land grasses and short shrubs at lower elevations. Dominant grasses and shrubs include blue grama grass, greasewood, alkali sacaton, and fourwing saltbush. These are found particularly in low, sandy areas. Other grasses and shrubs are sand dropseed, galleta, winterfat, Indian ricegrass, western wheatgrass, and chamisa. Higher slopes may have piñon, juniper, blue grama, bottlebrush squirreltail, and Indian ricegrass (BLM, 2007) (Griffith et al., 2006). There are no extensive phreatophytes (Blodgett and Titus, 1973).

Coniferous-mixed woodlands are located in the mid-elevation regions of the basin. They largely consist of piñon-juniper woodlands, with some ponderosa pine at higher elevations. These regularly intermingle with grasslands and shrublands (Griffith et al., 2006).

Montane-coniferous forests, dominated by ponderosa pine, Gambel oak, mountain mahogany, and serviceberry, are found generally from 7000-9500 feet in the mountains surrounding the basin. At the highest elevations, above 9500 feet, New Mexico subalpine forests predominate. These are characterized by Engelmann spruce, corkbark fir, blue spruce, white fir, and aspen (Griffith et al., 2006). Being by far the smallest ecoregion in the watershed, it is combined with the montane-coniferous forest for modeling purposes.

7.4 Wildlife

Basin vegetation provides habitat for a variety of wildlife, including pronghorn, mule deer, Rocky Mountain elk, as well as numerous species of amphibians, reptiles, birds and rodents (BLM, 2007). Regional animals of concern include the Mexican spotted owl, Mexican wolf, peregrine falcon, northern aplomado falcon, and black-footed ferret (USFWS, 1996).

San Agustin basin groundwater levels may affect the adjacent Alamosa Creek and Gila River basins (Basabilvazo, 1997) (Blodgett and Titus, 1973) (Myers et al., 1994) (D.B. Stephens, 2005). Alamosa Creek courses southeast to the Rio Grande at Elephant Butte Reservoir. The Rio Grande upstream of Elephant Butte to Cochiti Dam serves as critical habitat for endangered Rio Grande silvery minnow (*Hybognathus amarus*) (Endangered and Threatened Wildlife and Plants, 2010) and southwest willow flycatcher (*Empidonax traillii extimus*) (Endangered and Threatened Wildlife and Plants, 2011).

The Alamosa Creek basin contains critical habitat for one federally endangered species, the Alamosa springsnail (*Tryonia alamosae*), and one federally threatened vertebrate species, the Chiricahua leopard frog (*Lithobates chiricahuensis*). The Gila River basin within New Mexico serves as habitat for two threatened and three endangered vertebrate species, respectively the Chiricahua leopard frog, Gila trout (*Oncorhynchus gilae*), Gila chub (*Gila intermedia*), loach minnow (*Tiaroga cobitis*), and spikedace (*Meda fulgida*).

Listed in 1991, the endangered Alamosa springsnail (*Tryonia alamosae)* survives only in the Alamosa Creek basin (Burton and Metzinger, 1994). It is a small mollusk that requires fresh, flowing, and thermally-heated water to survive. The springsnail is established in five individual thermal springheads that discharge into Alamosa Creek at Alamosa Warm Springs. These thermal springs are within one-half mile of each other and are believed to receive water from the same groundwater source. Any activity that would interrupt flow of spring water, lessen the quantity of aquatic habitat, or degrade water quality could threaten its existence (Burton and Metzinger, 1994). Hydraulic gradients (Blodgett and Titus, 1973) (Myers et al., 1994) (OSE, 2011b) suggest a connection to the San Agustin Basin.

The threatened Chiricahua leopard frog (*Lithobates chiricahuensis*) inhabits portions of the Alamosa Creek and Gila River basins. Its habitat extends into central and southeastern Arizona, west-central to southwestern New Mexico, and Mexico, but is absent from approximately 75% of its historical range largely due to habitat modification and destruction. Its presence can be found along lakes, reservoirs, and streams. Critical habitat of 10,346 acres includes habitat designated for the Alamosa springsnail at

Alamosa Warm Springs, where an isolated but “robust breeding” frog population occurs (Endangered and Threatened Wildlife and Plants, 2012b).

The endangered loach minnow (*Tiaroga cobitis*) and spikedace (*Meda fulgida*) have critical habitats of 610 miles and 630 miles, respectively, including New Mexico reaches of the Gila River. Both need perennial streamflow with moderate to swift currents (Endangered and Threatened Wildlife and Plants, 2012a).

The Gila trout (*Oncorhynchus gilae*) is a threatened species found largely near Gila River headwaters (Endangered and Threatened Wildlife and Plants, 2006). The Gila chub (*Gila intermedia*) is an endangered species found in Arizona and near Gila River headwaters (Endangered and Threatened Wildlife and Plants, 2005).

7.5 Hydrogeology

The San Agustin basin, on the northeast edge of the Mogollon Plateau, formed largely due to middle-Tertiary (43-21 million years ago) intrusive volcanic activity and more recent Basin and Range faulting (21 mya-present). The plains occupy the Gallinas Embayment and the northeast-trending San Agustin Graben. Erosion, alluvial-fan, and fluvial processes have since reduced by the graben’s original relief of 4000 feet by half (Stearns, 1962) (Myers et al., 1994). The San Agustin Plains were flooded by pluvial Lake San Agustin during the pre-Wisconsin and Wisconsin glaciations of the Pleistocene era (Hawley, 1993). Lacustrine features such as clay beds, wave-cut notches, beaches, bars, and spits are remnant features of the ice-age lake (Griffith et al., 2006). The drainage basin for the lake roughly corresponds to present-day basin boundaries (Allen, 2005).

There are three main aquifers in the basin: 1) shallow upland aquifers, 2) the Datil aquifer, and 3) the bolson-fill aquifer (Figure 4). The bolson-fill aquifer largely corresponds to the area underneath the San Agustin Plains. In addition, a basalt/basaltic andesite unit atop the Datil Group and the Baca Formation along the northern edge of the San Agustin basin yield some water to wells. All are largely unconfined (Basabilvazo, 1997). The Alamosa Creek shallow upland aquifer and Gila Conglomerate yield small to moderate amounts of water.

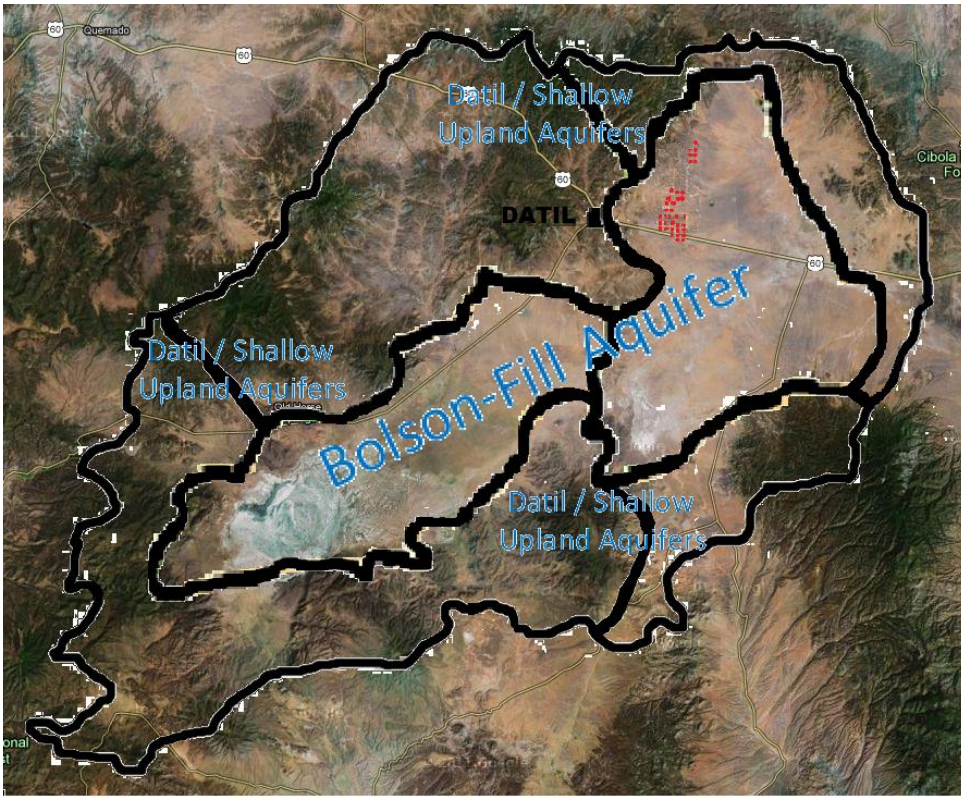


Figure 4. Basin aquifers.

Shallow upland aquifers are located in Quaternary alluvial fill in arroyos and canyon bottoms and consist largely of alluvial clay, silt, sand, and gravel (Myers et al., 1994). They are also found in some mountainous areas at the upper portions of the underlying bedrock. Thickness is usually less than 100 feet. Recharge occurs mostly from precipitation but may include inflow from the Datil aquifer (Basabilvazo, 1997). They yield small to moderate amounts of water, often little more than 10 gallons per minute (Myers et al., 1994).

Datil aquifer recharge occurs from: 1) precipitation directly on the outcrops in the mountains surrounding the San Agustin Plains, 2) groundwater flow from the shallow upland aquifers to the Datil aquifer, and 3) groundwater flow from the bolson-fill to the Datil aquifer south of the San Agustin Plains. At its higher elevations it consists primarily of erosional remnants of Quaternary and Tertiary volcanic rocks, often basalt or basaltic andesite. Typically several hundred feet thick with a maximum thickness of 2500 feet, these yield small volumes of water, often about 10 gallons per minute. Beneath or interbedded with this lies the Datil Group, consisting of volcaniclastic rocks that range from rhyolite to andesite (Blodgett and Titus, 1973) (Myers et al., 1994). Ranging from 98-5000 feet thick, portions may be confined at depth (Basabilvazo, 1997). Well yields here are small to moderate, measuring 1.5-15 gallons per minute south of the San Agustin Plains (Basabilvazo, 1997) or averaging about 10 gallons per minute (Myers et al., 1994). Roybal (1991) lists yields of 2.5-80 gallons per minute. Although these are small, Tertiary formations and the Datil Group are a significant water source in the San Agustin basin and Alamosa Creek basin (Roybal, 1991).

The majority of San Agustin basin groundwater is located in alluvial, bolson-fill, and other surficial deposits of unconsolidated gravel, sand, silt, and clay, dating from Quaternary and middle-Tertiary volcanic activity (Anderson et al., 1997) (Myers et al., 1994) (Basabilvazo, 1997). Maximum thickness of the bolson fill in the eastern plains is 3300 feet and 4600 feet in the western plains (Myers et al., 1994). One test well drilled on Augustin Plains Ranch property in the San Agustin Plains indicates alluvium/bolson-fill to 800 feet, basalt/rhyolite/tuff to 920 feet, alluvium/bolson-fill to 1290 feet, and basalt/rhyolite/tuff to 1510 feet. A second only lists shallow alluvium/bolson-fill for a 3500-foot well (OSE, 2011b) (Figure 5). It is unknown whether the lower aquifer beneath the plains consists of bolson-fill or Datil Group volcaniclastic deposits (Basabilvazo, 1997).

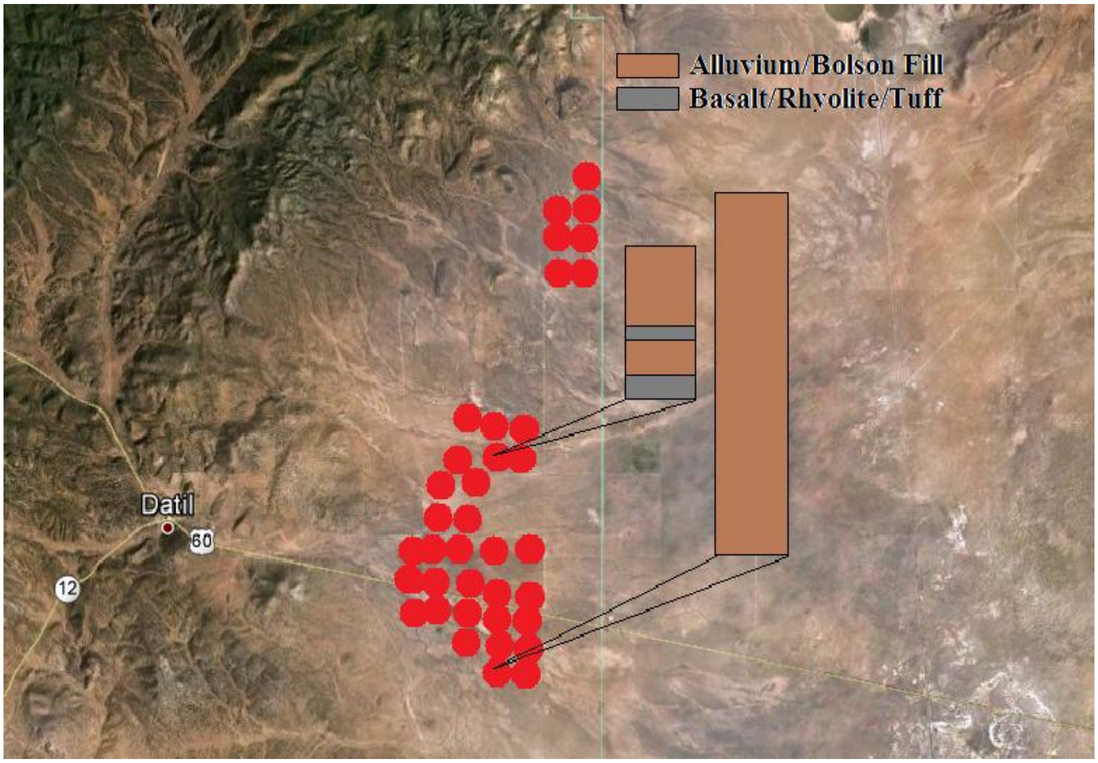


Figure 5. Test well geologic profile and ranch proposed well/irrigation plots. Image source: Google Earth®, accessed 12/20/11.

Bolson-fill well yields are moderate to large at up to 975 gallons per minutes in several places. The aquifer is recharged by: 1) precipitation on areas with permeable soils, 2) shallow upland aquifers, 3) the Datil aquifer, and 4) runoff from the uplands infiltrating into moderately to well-drained soils generally located at the edge of the plains. It is primarily at these edges that runoff from the uplands percolates to the water table. Soils along the edge of the bolson-fill deposits tend to be moderately to well-drained. Water is largely fresh except beneath the playa lake of the western plains, where 8.9 million of 28 million acre-feet are saline (Myers et al., 1994). Soils at the playa lakes tend to be poorly to moderately drained clays that are greater than 60 inches in depth (Myers et al., 1994), have a "mesic temperature regime, an aridic moisture regime, and mixed mineralogy" (BLM, 2007).

Aquifers extend to the west and south into the San Francisco and Gila River basins. Each river is perennial, with baseflow supplying most streamflow during drier periods. Alluvium is up to about 100 feet thick at Reserve, with water levels 15-28 feet below the surface. Beneath the alluvium is Quaternary to Tertiary Gila Conglomerate (Basabilvazo, 1997). This consists of locally-derived volcanic sandstone and conglomerate (Myers et al., 1994). Maximum thickness values range from 600-820 feet according to Basabilvazo (1997), or 2000 feet according to Myers et al. (1994). It is mostly unconfined, but the lower portions may be confined at depth. Two wells here yield 5 gallons per minute. Beneath and sometimes interspersed with the conglomerate is andesite. Thickness is commonly 100-500 feet. Yields from three wells have been measured at 5 gallons per minute. Tertiary Datil Group sedimentary and volcanic deposits likely underlie Gila Conglomerate and andesite (Basabilvazo, 1997).

The Alamosa Creek basin upstream of Monticello Box is an alluvial valley centered on the north-south Cuchillo Negro Graben. The shallow upland aquifer consists of varying proportions of unconsolidated alluvium ranging from clay to gravel less than 100 feet thick. The Quaternary-Tertiary basalt to basaltic andesite unit and Datil Group lie beneath and alongside the graben, as does pre-Tertiary sedimentary rock. Gila

Conglomerate is minimal. The Monticello Box area is the site of several hot and cold springs where the water table intersects the surface. Well yields are small to moderate at 2-100 gallons per minute. Shallow groundwater is interconnected with aquifers of the Rio Grande basin but a connection at depth is uncertain based on available data (Myers et al., 1994).

8.0 Surface Influence on Aquifers

There are no perennial streams or surface-water bodies today (Blodgett and Titus, 1973) (Myers et al., 1994) because evapotranspiration (ET) at free-water surface bodies here exceeds the rate of inflow due to precipitation, runoff, and groundwater discharge (Allen, 2005). Runoff typically infiltrates into alluvial fans at the base of the surrounding mountains. During periods of heavy precipitation, ephemeral streams may spill floodwaters into the basin. Consequently, playa lakes at the west and east ends of the elliptical plains occasionally contain water (Blodgett and Titus, 1973) (Myers et al. 1994). These cover approximately 55.5 and 6.5 square miles respectively.

Blodgett and Titus (1973) argue that because the water table is deeper than 10 feet and the playas are largely impermeable, it is likely that minimal groundwater beneath the playas is lost to evaporation. Myers et al. (1994) find that the high clay content and depth of the soils here “probably inhibits percolation of ponded water to groundwater, as well as evaporation of groundwater.” The model therefore ignores infiltration and evaporation of groundwater in the vicinity of the playa lakes.

9.0 Groundwater Stability

Based on their examination of well records from 1952 to 1972, Blodgett and Titus (1973) conclude that “change in groundwater storage [is]…considered to be nil” (20).

More recent monthly measurements of 21 wells between 1996 and 2001 further demonstrate little change in well levels. Some levels even increased (Shomaker et al., 2002). Groundwater pumping in the basin is minimal at less than 10,000 AFY (OSE, 2011b). Water levels fluctuate but there appear to be no trends indicating depletion (D.B. Stephens, 2003).

The stability of the water table can be explained by the belief that groundwater recharge is balanced largely by outflow from the basin to the south (Blodgett and Titus, 1973). The model therefore maximizes groundwater stability for the no-development scenarios, excepting additional domestic pumping as a result of population growth. However, it is possible the ongoing drought of the past decade may have had an adverse impact, with the region currently experiencing a moderate to severe drought (Svoboda, 2012). Decreases in precipitation could be related to long-term climate change (Seager et al., 2010). As a result, climate change is accounted for in a model sensitivity analysis.

10.0 Model Description

The objective of the groundwater model was to determine the impact of an Augustin Plains Ranch appropriation on the groundwater and economic resources of the San Agustin, Alamosa Creek, and Gila River basins.

Groundwater modeling is accomplished using a system dynamics approach. The model is a compartmental block model that represents the groundwater system as a network of interconnected cells or compartments through which water is transferred. This model contains eight compartments, one for each subbasin (block) within the San Agustin basin, and one each for the Gila River and Alamosa Creek subbasins. This modeling approach does not predict drawdowns in individual wells but instead simulates responses to area-wide (block) water levels as a result of groundwater development. In this respect it is similar to the groundwater modeling done in the middle Rio Grande basin (Passell et al., 2003).

The model uses an annual time-step from 2018 to 2058. Forty years were chosen as this is the maximum water use planning period allowed for municipalities, counties, and other public entities as established under New Mexico Statutes Annotated 1978 (NMSA) § 72-1-9; the related 40-year period used to determine possible impairment in OSE Critical Management Areas such as those within the Middle Rio Grande Administrative Area (OSE, 2000) and Tularosa Underground Water Basin (OSE, 1997); and the ruling of *Mathers v. Texaco, Inc.* (77 N.M. 239, 421 P.2d 771 (1966)), in which the New Mexico State Supreme Court upheld an OSE plan to withdraw up to two-thirds of a local aquifer over 40 years. A start date of 2018 was chosen due to it being a reasonable time pumping could begin if current legal challenges are overcome, permits and easements secured, and infrastructure constructed. Two different scenarios are presented:

- **No-development scenario.** Assumes historic precipitation and recharge/discharge over the 40-year January 2018 through December 2057 modeling period, totaling 101,993 AFY of recharge/discharge.

- **Appropriation scenario.** Same as the no-development scenario but including a 54,000 acre-foot per year appropriation of groundwater applied to the eastern bolson-fill subbasin.

- **Sensitivity analyses of no-development and appropriation scenarios.** Considers separately: a) Doubled recharge/discharge b) Halved recharge/discharge c) Reduced (49,908,000 acre-foot) basin-wide volume d) Climate change (linear 3% decrease of precipitation) e) Combination of halved recharge/discharge, reduced basin-wide volume, and climate change f) water leased at $100/afcu (as opposed to $500) appreciating at 2% annually.

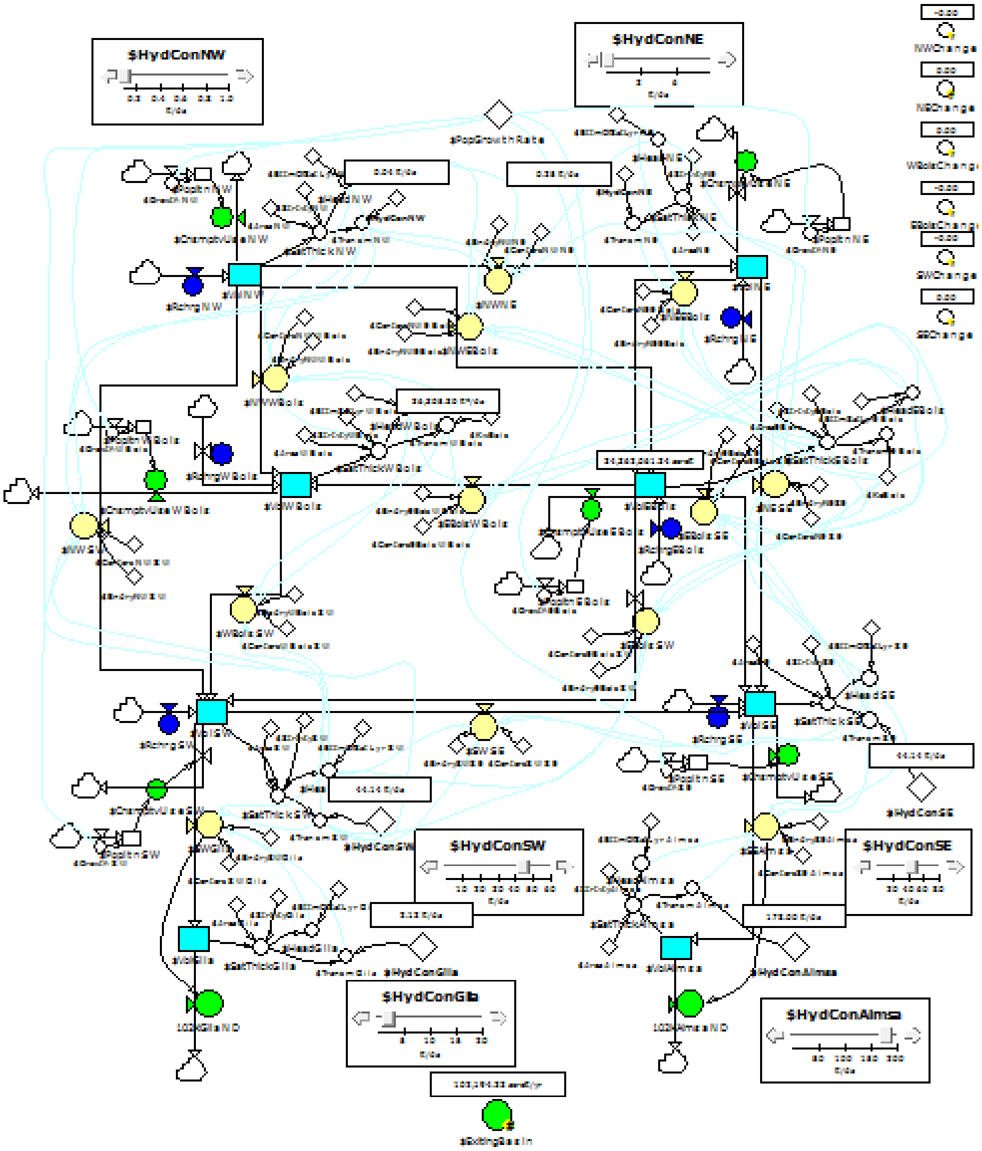


Figure 6. Powersim Studio® 9 model diagram.

10.1 Basin-wide Parameters

The groundwater model is based on the water balance equation for each sub-basin

$$\Delta S = P - ET - D,$$

where ΔS is the change in storage, P is precipitation, ET is evapotranspiration, and D is groundwater discharge, including pumping. Contemporary basin precipitation measurements are scarce and vary widely based on elevation. Blodgett and Titus (1973) believe basin-wide precipitation to average 14 inches per year. However, Myers et al. (1994) state it as 13.25 inches. This model averages both studies, assuming overall precipitation to be 13.63 inches per year. Based on their precipitation rate of 14 inches per year and potential evapotranspiration rate of about 35 inches per year, Blodgett and Titus (1973) estimated a recharge and discharge rate of 1 inch per year, or 104,800 acre-feet per year. Based on the adjusted precipitation rate, recharge and discharge are adjusted accordingly to 101,993 acre-feet per year, or 0.973 inches per year for both scenarios. Assuming no change in storage (i.e. groundwater elevations remain constant), evapotranspiration equals precipitation minus present discharge, or 12.65 inches per year. The climate change analysis reduces precipitation, and thus discharge. Discharge may also be reduced by increasing evapotranspiration, as argued by some climate models. Due to historically stable well levels (Blodgett and Titus, 1973) (Shomaker et al., 2002) (D.B. Stephens, 2003), basin heads and discharge during model calibration (in which there is no population growth) remain as close to initial values as possible.

Blodgett and Titus (1973) state that recharge could be higher or lower by a factor of two. Therefore, sensitivity analysis considers recharge rates of 203,986 AFY and 50,996 AFY, with discharge rates adjusted accordingly (due to historically static water levels). These sensitivity analyses address concerns over accuracy of precipitation, evapotranspiration, infiltration, and other highly uncertain data. As explained later, population growth has a very small impact on groundwater volumes, and so is not factored during sensitivity analysis.

10.2 Groundwater Block Delineation

The San Agustin basin is not one homogeneous unit. The model includes six distinct groundwater units, or blocks (Figure 7), based on a Quaternary and Tertiary geologic feature map of the basin (Anderson et al., 1997), available information from

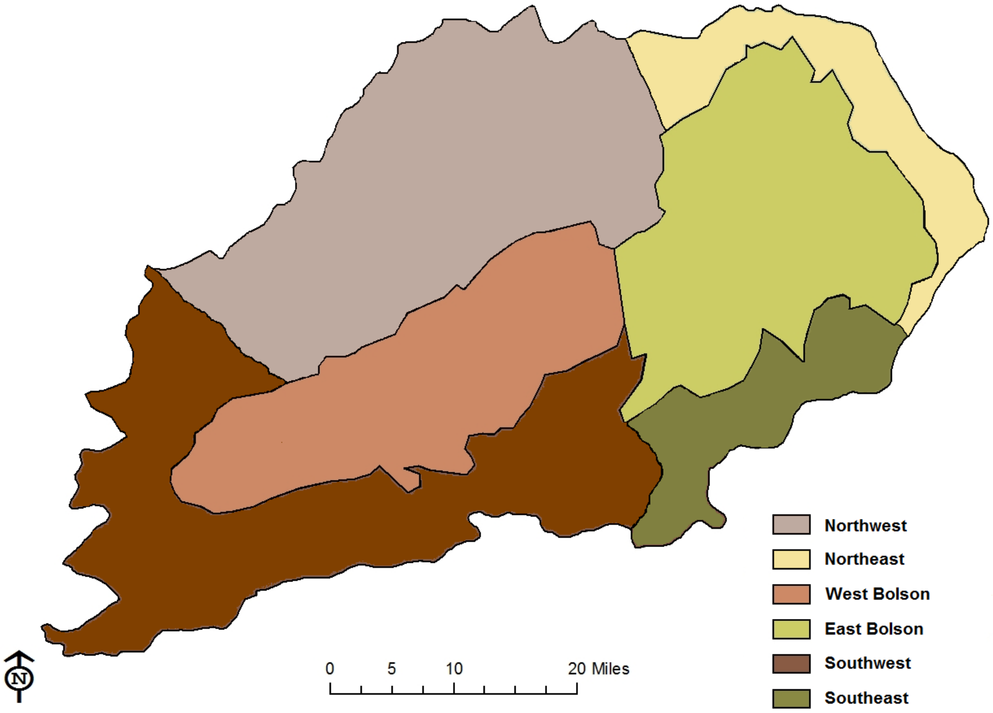


Figure 7. San Agustin basin groundwater blocks.

Myers et al. (1994) and Basabilvazo (1997) on the extent of the bolson-fill aquifer, Alamosa Creek and Gila-San Francisco drainage boundaries, and a New Mexico Resource GIS Program image. Delineation is accomplished in ESRI® ArcGIS 9.3©. The bolson-fill aquifer underlying the San Agustin Plains is divided in two due to the elongated elliptical nature of the aquifer and low ridge which roughly bisects the plains (Myers et al., 1994). The remainder of the basin is divided into four blocks, each of which contains both the Datil and shallow upland aquifers.

10.3 Calculating Block Recharge (Q_R)

Blodgett and Titus (1973) used a crude approach to estimate recharge and discharge at 104,800 acre-feet per year. Based on the adjusted precipitation rate, recharge and discharge are proportionally adjusted to 101,993 acre-feet per year in both scenarios. This may differ in sensitivity analysis. Vegetation composition, precipitation, and evapotranspiration data are used to estimate recharge.

10.3.1 Runoff

Surface runoff results from mountain ranges surrounding the basin. This water either infiltrates to recharge groundwater resources or is lost to evaporation. Total annual basin runoff which infiltrates to the water table was estimated at 5% of precipitation. This amounts to 71,395 AFY of 1,427,900 AFY of precipitation. Although highly speculative, this is typical for mountain ponderosa pine watersheds in the western United States (Dortignac, 1960) (Osborn and Laursen, 1973). The recharge coefficient at a site within the neighboring Rio Salado basin measured at 3.9-20.4% of precipitation using one method and 20.7% to a 153 cm depth (54% to 122 cm) using a second method (Stephens and Knowlton, 1986). Due in part to this uncertainty, one sensitivity analysis sets runoff-derived infiltration at 2.5% of precipitation.

The model requires each groundwater block's share of runoff-derived recharge to be determined. According to Blodgett and Titus (1973) and Myers et al. (1994), moderately to well-drained soils are generally located at alluvial fans at the edge of the plains; it is primarily in these areas that runoff from the uplands percolates to the water table. These essentially follow the boundary of the bolson-fill aquifer. There is nothing to prevent rapid infiltration of this relatively small amount of water except small playa lakes which occasionally contain runoff. Therefore, the model apportions the 71,395 acre-feet per year between the blocks in proportion to each block's share of a border with the bolson-fill aquifer blocks. One-half of this, 35,698 AFY, is apportioned among the two bolson-fill blocks, with the other half divided among the other four blocks in proportion to their shared boundaries with the bolson-fill blocks.

The half allocated to the bolson-fill aquifers accounts for playa lake area. Blodgett and Titus (1973) argue that because the water table is deeper than 10 feet and the playas are largely impermeable, minimal groundwater at the playas is lost to evaporation. Myers et al. (1994) find that the high clay content and depth of the soils there "probably inhibits percolation of ponded water to groundwater, as well as evaporation of groundwater." Proportionally, this amounts to 3431 AFY of runoff reaching the playa lakes, leaving 67,964 AFY to infiltrate to aquifers.

There remain 34,029 AFY of recharge not due to runoff, but from direct infiltration of precipitation. Surface area, precipitation data, and evapotranspiration data are used to apportion this among the blocks.

10.3.2 Precipitation

Although basin-wide precipitation is assumed to average 13.63 inches per year, relative precipitation differences of the plains-mesa grassland, coniferous-mixed woodland, and montane-coniferous forest vegetative zones are determined in order to estimate relative precipitation rates of blocks. Precipitation averages are gathered from National Weather Service Cooperative Observer Program stations (NOAA, 2012). Precipitation data includes all years in the period of record in which no month is missing more than 5 days of data.

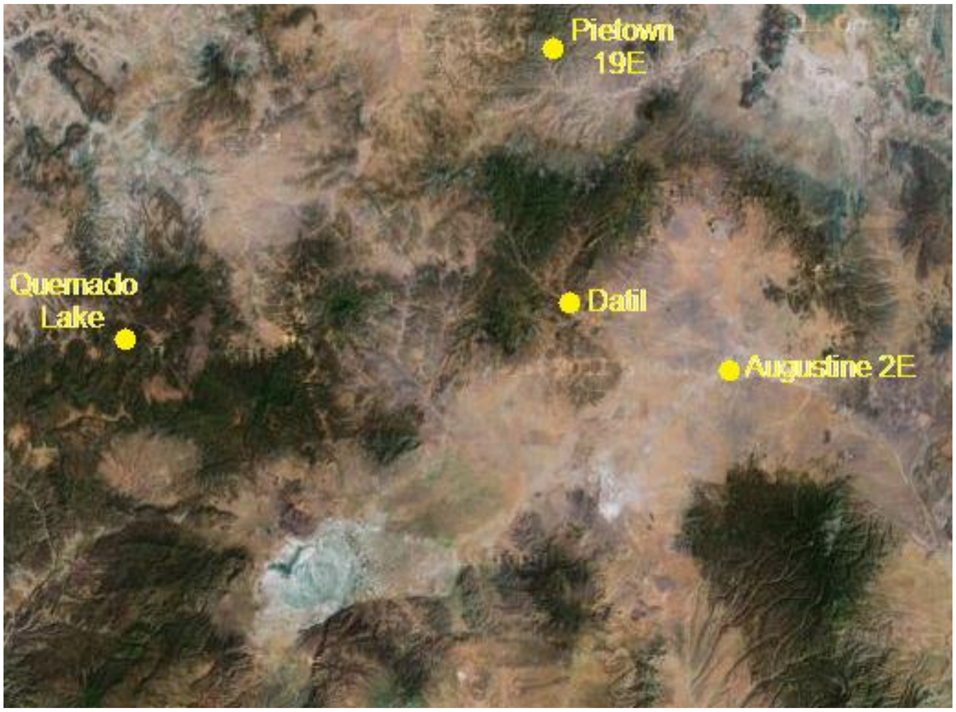


Figure 8. Selected NWS Cooperative Observer Program stations.
Image source: Google Earth®, accessed 12/13/11.

Data from four weather stations are utilized (Figure 8). For the plains-mesa grasslands, data is derived from the Augustine 2E (COOP 290640, el. 7001 feet) station at the east end of the plains. It has an 84-year period of record. Precipitation here has averaged 11.27 inches per year. For the coniferous-mixed woodland zone, the model utilizes the Datil (COOP 292367) station at 7104.2 feet. Precipitation has averaged 12.42 inches over 47 years. There are no weather stations in the montane-coniferous forest region within the basin, so data is used from the nearby Quemado Lake (COOP 297191) and Pietown 19 NE (COOP 296812) stations at 7658 feet and 7959 feet, respectively. Precipitation at the former averaged 16.7 inches per year from 1986-1993. At the latter station, north of Datil, precipitation averaged 14.15 inches from 1988-2009. Together they average 15.43 inches per year (NOAA, 2012).

The watershed according to these stations averages 12.6 inches per year. This is not the 13.63 inches used in the model, but the difference is minor. Of importance for modeling purposes are relative precipitation differences between groundwater blocks. Block precipitation rates are estimated by knowing each block's vegetation zone composition as well as the precipitation rate for each vegetation type. Next, rates are uniformly scaled upward to form a basin-wide average of 13.63 inches per year (Table 1).

	Preliminary Precipitation	**Adjusted Precipitation**
Plains-Mesa Grassland	11.27	12.19
Coniferous-Mixed Woodland	12.42	13.43
Montane-Coniferous Forest	15.43	16.69
San Agustin Basin	12.60	13.63

Table 1. Precipitation (in/yr).

10.3.3 Evapotranspiration

Evaporation and transpiration together compose evapotranspiration (ET). Evapotranspiration reduces aquifer recharge by returning water to the atmosphere before it reaches the water table.

Blodgett and Titus (1973) estimate basin-wide potential evapotranspiration (PET) to be about 35 inches per year, but this is an educated guess. It can also be estimated using the Blaney-Criddle or Penman-Monteith equations. The former is regarded as unreliable but somewhat more accurate long-term. The latter, while believed to be more accurate, requires input data which are not available for the San Agustin basin. The Blaney-Criddle formula, as used to predict potential evapotranspiration, is:

$$PET_o = p \cdot (0.46 \cdot T_{mean} + 8),$$

in which:

PET_o is the reference evapotranspiration [mm day^{-1}],
T_{mean} is the mean daily temperature [°C] given as $T_{mean} = (T_{max} + T_{min})/2$,
p is the mean daily percentage of annual daytime hours.

Data is again derived from the Augustine 2E, Datil, Quemado Lake and Pie Town 19 NE COOP stations (NOAA, 2012). Combining the latter two into the montane-coniferous forest region, PET rates for the vegetation zones are, respectively: 48.02 in/yr, 47.12 in/yr, and 46.76 in/yr, for a basin-wide average of 47.44 in/yr.

However, these are potential evapotranspiration rates. Actual evapotranspiration is typically no greater than precipitation on non-irrigated soil (Hendricks, 1985). Therefore, 12.6518 inches per year is initially used, as determined by rearranging the closed-basin water balance equation as $ET = P - D$, in which discharge includes pumping, and no change in storage occurs. For dry climates, the ratio ET/P is close to unity, in this case 0.9286. It is believed that 85-95% of precipitation is evaporated or consumed by vegetation in many semiarid to arid watersheds (Brooks et al., 2003). The effects of climate change were simulated by decreasing precipitation 3% over the 40-year modeling period, thereby reducing recharge. Recharge may also be reduced by increasing ET.

As with precipitation, the model differentiates ET between the six blocks based on area and vegetation type. It is therefore necessary to know relative evapotranspiration rates between vegetation types.

Woodhouse (2008) claims the following ET rates: 2.8-23 in/yr (12.9 in/yr average) for grasslands in the adjacent Middle Rio Grande region, 16 in/yr for mid-elevation pinon-juniper woodlands in northern Arizona, and 20 in/yr for high-elevation northern Arizona ponderosa pine forests. Applied to the San Agustin basin, this equates to a basin-wide average of 15.53 inches per year. Playa lake surfaces, where little to no

ET or percolation occurs (Blodgett and Titus, 1973) (Myers et al., 1994), are taken into account. Adjusting to the average of 12.65 in/yr, ET for each vegetative type is uniformly scaled downward, and is used in the model (Table 2):

	Preliminary ET	**Adjusted ET**
Plains-Mesa Grassland	12.9	10.51
Coniferous-Mixed Woodland	16	13.03
Montane-Coniferous Forest	20	16.29
San Agustin Basin	15.53	12.65

Table 2. Evapotranspiration (in/yr).

10.3.4 Synthesis

Recharge is the same as percolation to the water table for modeling purposes. Recharge equals 101,993 acre-feet per year. Sources (Dortignac, 1960) (Osborn and Laursen, 1973) (Stephens and Knowlton, 1986) state that 5% of precipitation in the basin, in this case 71,395 AFY, is a reasonable estimate of runoff which infiltrates. However, due to playas near or at the bolson-fill border, 3431 AFY does not reach the water table. This leaves 34,029 AFY of precipitation which reaches the water table through direct infiltration rather than runoff. This is apportioned to each block based on the following formula, which also accounts for playas:

Direct Infiltration Recharge (AFY) = (Adjusted Precipitation – Adjusted Evaporation) / (Basin Adjusted Precipitation – Basin Adjusted Evaporation) * Non-Playa Share of Watershed * 34029 AFY

Recharge figures by block are found in Table 3:

	NW	NE	W Bolson	E Bolson	SW	SE	Total
Runoff Recharge	10347	8623	13685	18582	12761	3966	67964
Infiltration Recharge	5620	1910	7934	8271	8197	2097	34029
Total	**15967**	**10533**	**21619**	**26853**	**20958**	**6063**	**101993**

Table 3. Initial recharge by block (AFY).

10.4 Calculating Block Discharge (Q_D)

Blodgett and Titus (1973), Shomaker et al. (2002), and Daniel B. Stephens & Associates (2003) state that basin water levels are currently largely static, meaning recharge equals discharge. Therefore, the no-development scenario has the total amount of water lost to subsurface leakage and existing well withdrawals to be 101,993 AFY (or the appropriate figure in sensitivity analysis).

Based on New Mexico OSE data, 9383 AFY in the basin is currently appropriated for consumptive use, primarily for irrigation, livestock, and domestic purposes. Most of these appropriations are decades old (OSE, 2011b). This leaves 92,616 AFY to exit the basin via subsurface leakage (adjusted in sensitivity analysis). Water flows from blocks with higher heads (h) to neighboring blocks with lower heads. Water ultimately discharges to the Gila River and Alamosa Creek watersheds to the south.

10.4.1 Water Table Delineation

Groundwater potentiometric (head) data is derived using an OSE geodatabase, which combines point of diversion permit data from the New Mexico Water Rights Reporting System as of February 2008 (OSE, 2008) with geospatial shape files. Groundwater permits are retrieved for the San Agustin basin by formulating a spatial select (Figure 9).

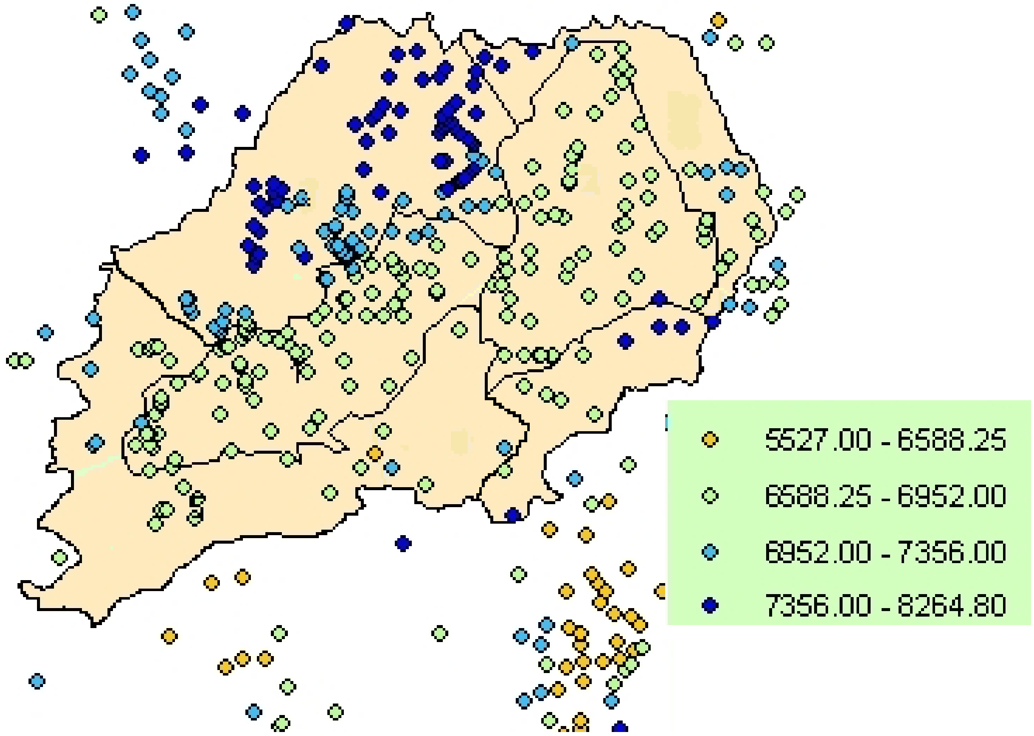


Figure 9. Groundwater heads as of 2008 (feet) (OSE, 2008).

Kriging interpolation utilizes these points to form a water table for each block (Table 4) (Figure 11). Table 4 also lists the water table as measured at well locations (no interpolation), as well as mean depth to water for each well (OSE, 2011b). These figures are helpful in estimating the economic impact of any appropriation. Depth-to-water numbers are in general agreement with those reported by Roybal (1991), and suggest negligible evaporation from the water table.

	NW	**NE**	**W Bolson**	**E Bolson**	**SW**	**SE**
Interpolated Water Table	7276	6922	6791	6818	6772	6760
Well Location Mean Water Table	7413	7257	6837	6847	6949	7080
Well Location Mean Depth to Water	129.9	280.3	136.9	265	310	412

Table 4. Initial water table (feet) and depth to water.

10.4.2 Flow Direction

Based on potentiometric heads in Table 4, it can be inferred that groundwater currently flows as shown in Figure 10, i.e., from north to south and generally east to west. Myers et al. (1994) suggest a south to southwest direction of flow in the eastern plains, southwest direction in the ridge area in the mid-plains, and south to east direction along the northern edge of the western plains.

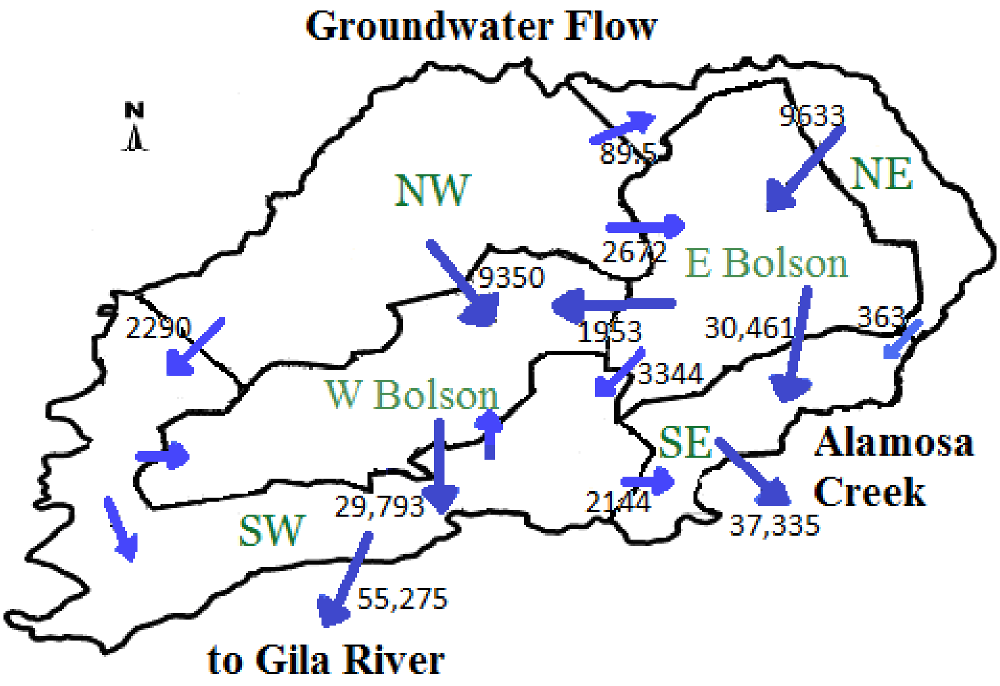


Figure 10. Initial groundwater directions and flow (AFY).

Water exits to the Gila River basin (6621’) through the Southwest block and to the Alamosa basin (6736’) through the Southeast block (Figure 11). The relationship between the San Agustin basin and the neighboring Gila and Alamosa Creek basins is currently not well-understood. Subsurface drainage via both basins is possible, as existing research suggests.

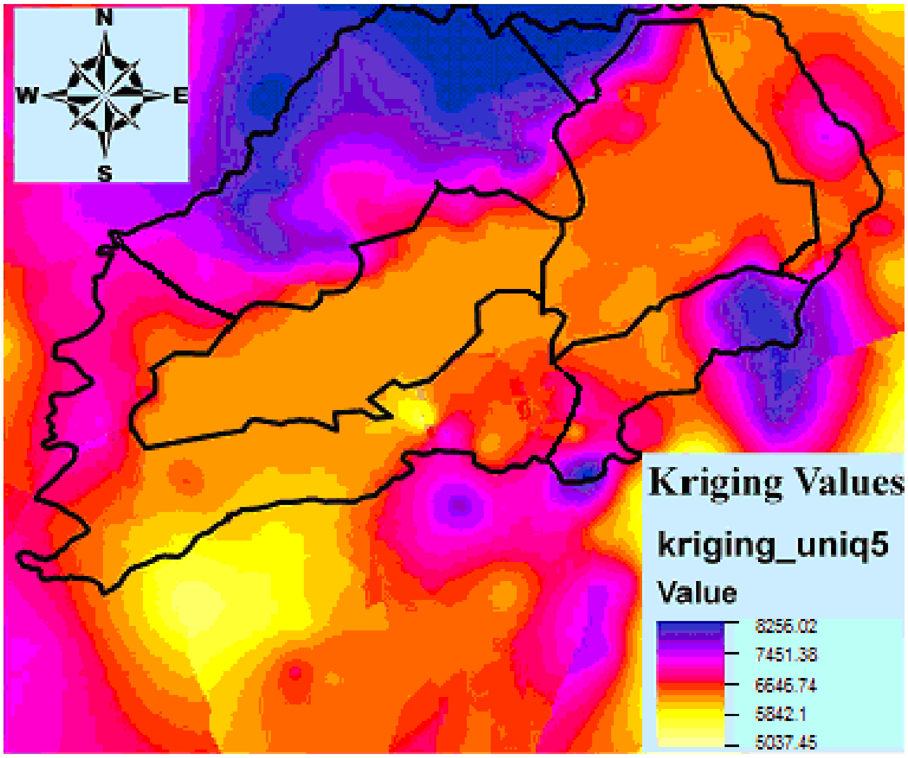


Figure 11. Interpolated water table.

Blodgett and Titus (1973) argue for southwest subsurface outflow beneath the Continental Divide. They note a “gentle rise” in the water table from the southwest plains to the Gila River drainage, which then slopes southward at 30 feet per mile. They state that if there is minimal subsurface outflow, then the static water table may be accounted for only through playa evaporation. However, this is minimal. Myers et al. (1994) state hydraulic gradients of 20 feet per mile in the southwest basin and into the Gila River basin. They conclude some recharge to the Alamosa Creek basin “may occur as flow from the Datil aquifer in the surrounding uplands.” Basabilvazo (1997) suggests brackish and saline water beneath the western playa as an indication of little to no flow from here to the southwest Datil aquifer.

Figures 9 and 11 support each study. Subsurface outflow exits primarily from the West Bolson block to the Gila block via the Southwest block, as well as from the East Bolson block to the Alamosa block by way of the Southeast block. Hydraulic gradients do not appear to support subsurface flow to the San Francisco River, water levels being highest along a ridge approximating the Continental Divide from the southwest corner to the northwest corner of the Southwest block. A similar situation exists along the south edge of the basin near the intersection of the Southwest, Southeast, Gila, and Alamosa blocks, as well as at the east edge of the Southeast block along its boundary with the Alamosa block beneath the San Mateo Mountains (Figure 11). Drainage occurs through a 19.1-mile segment of the Alamosa Creek basin. Perimeter lengths between blocks are adjusted according to such interfaces. The Alamosa Creek basin for modeling purposes covers 400 square miles as measured upstream of Monticello Box (Myers et al. 1994), while the Gila block, with a border to the basin 1.4 times larger, covers 562 square miles.

10.4.3 Flow between Blocks

In addition to head, various other inputs are used to determine the volume of water moving between blocks and out of the basin (Figure 9). Summarized in Table 5, each input is subsequently discussed.

Groundwater Block	Initial Volume (acre-feet)	Area, *A* (acres)	Init. Satrtd. Thickness, *b* (ft)	Initial Head, *h* (ft)	Init. Hydlc. Cond., *K* (ft/day)	Storativity, *S*	Initial Trnsmsty, *T* (ft2/day)
NW	15,162,376	314,880	963	7276	0.04	0.05	38.5
NE	5,365,385	111,424	963	6922	0.25	0.05	240.8
W Bolson	28,000,000	219,200	960	6791	37.75	0.133	36255
E Bolson	34,400,000	193,600	966	6818	37.54	0.184	36255
SW	20,518,020	333,568	1230	6772	44.15	0.05	54308
SE	5,235,141	84,928	1233	6760	44.15	0.05	54424
Gila River	26,976,000	359,680	1500	6621	2.13	0.05	3195
Alamosa	19,200,000	256,000	1500	6736	178	0.05	267000

Table 5. Hydrologic parameters by block.

Storativity (*S*) is the value of water released from storage per foot decline in hydraulic head. It is usually about equal to specific yield (*Sy*) in unconfined aquifers. Myers et al. (1994) list specific yield values for the bolson-fill blocks. A storativity number of 0.05 is used for the other blocks and is provided by a regional hydrologist (Tidwell, 2008). This is similar to the 0.04 storativity listed in the Southwest New Mexico Regional Water Plan for the Datil block region (D.B. Stephens, 2005).

Saturated thickness (*b*) is the difference between the top of the water table and bottom of the aquifers. The initial elevation of each saturated layer is determined by land surface elevation and depth to water (OSE, 2011b).

Initial volumes for the bolson-fill aquifer blocks are provided by Myers et al. (1994). Initial volumes for the other blocks are calculated by finding the product of saturated thickness (*b*), area (*A*), and storativity (*S*):

$$V = b*A*S.$$

Area and storativity are constants but saturated thickness and volume increase or decrease with the other:

$$\Delta b = \Delta(V/A*S).$$

Based on volume and storativity estimates of Myers et al. (1994), initial saturated thicknesses for the west and east bolson-fill aquifers are calculated to be 960 feet and 966 feet, respectively. These are a fraction of overall aquifer thickness values (3300 feet in the West Bolson block, 4600 feet in the East Bolson block) they provide, but agree with a saturated thickness map of the bolson-fill aquifer (Fig. 9).

No saturated thickness data for the rest of the basin is available, except for the Socorro-Sierra Regional Water Plan (D.B. Stephens, 2003) which lists Datil saturated thickness as 225-425 feet, based on a $^{+}/_{-}$ 100 foot adjustment of well depths recorded by Roybal (1991). Stearns (1962) and Blodgett and Titus (1973) believe the Datil aquifer to have a maximum thickness of 3000 feet, stated by Myers et al. (1994) to be up to 5000 feet in places. Averaging these, aquifer thickness is nearly equal to that of the bolson-fill aquifer. Therefore, the model conservatively assumes initial saturated thicknesses to be equal to the average of the two bolson-fill blocks, or 963.06 feet. However, Blodgett and Titus (1973) list Alamosa Creek aquifer saturated thickness at the San Agustin basin border to be 1500 feet, so this number is averaged with East Bolson saturated thickness to determine a Southeast Block initial thickness of 1233 feet. Gila block saturated thickness is assumed to be the same as Alamosa Creek block thickness. The average of this and West Bolson block saturated thickness is 1230 feet, which is applied to the Southwest block.

For modeling purposes, head (*h*) increases or decreases directly with saturated thickness. In accordance with Darcy's Law, groundwater flows from blocks with higher heads to blocks with lower heads. Flow direction reverses if and when the potentiometric head in one block becomes higher than a neighboring block which previously had the higher head.

Transmissivity (*T*, ft^2/day) in the model is the product of hydraulic conductivity (*K*, ft/day) and the thickness of the formation (*b*, ft). It is a measure of the resistance to flow through the saturated media. Thus an aquifer with a high *T* can transport large volumes of water with small differences in head, while a tight formation (low *T*) is an unproductive aquifer.

Measured transmissivity values in the San Agustin basin are few; only seven estimates are available (Basabilvazo, 1997). Six of these are from Myers et al. (1994), who conducted aquifer recovery tests on six irrigation wells in the northern part of the basin. Five were completed on irrigation wells in the North Lake area along the East Bolson-Northeast block boundary. These range from 20,900-48,400 ft^2 per day for an average 36,160 ft^2 per day. Tests varied from 80-158 minutes. The sixth well, 12 miles to the south, had an estimated transmissivity of 2400 ft^2 per day from a test duration of 100 minutes (Myers et al. 1994). The seventh test occurred in the bolson-fill deposits of the southeastern plains in 1978. This measured 70,588 ft^2 per day (Basabilvazo, 1997). Together, the seven measurements average 36,255 ft^2 per day.

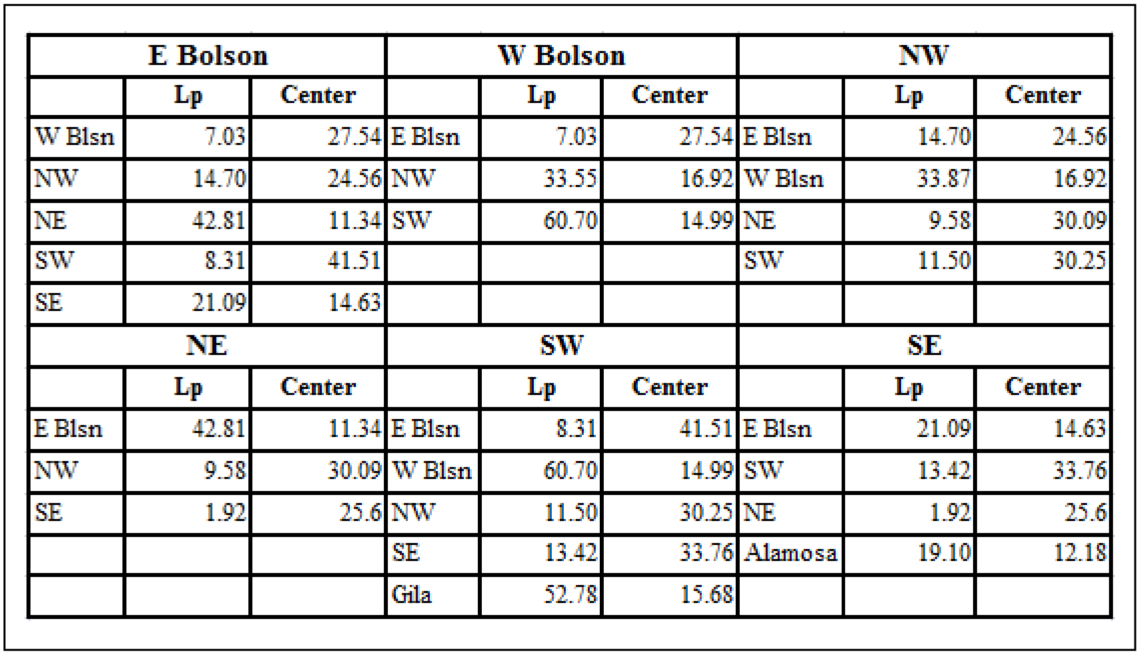
No hydraulic conductivity (*K*) values for the basin are available (Johnson, 1990). Bolson-fill transmissivity averages 36,255 ft^2 per day when hydraulic conductivity is approximately 37.8 and 37.5 feet per day for the west and east bolson-fill blocks, respectively. Bolson-fill deposits are composed largely of either clean sands (Blodgett and Titus, 1973) or a mix of varying amounts of surficial deposits of unconsolidated gravel, sand, silt, and clay (Myers et al. 1994) thousands of feet thick. These numbers are within range of the 0.9-898 feet per day range for clean sands and 0.09-89.8 feet per day range for silty sands as determined by Freeze and Cherry (1979), as well as near the 49.9 feet per day estimate for sands and 44.3 feet per day estimate for loamy sands by Clapp and Hornberger (1978).

Transmissivity and hydraulic conductivity figures for the Datil or shallow-upland aquifers are not available. These are therefore estimated using soil permeability as a proxy. Shallow upland aquifers may consist of unconsolidated gravel, sand, silt, and clay, usually less than 100 feet thick. These yield small to moderate amounts of water, often little more than 10 gallons per minute. Underneath are soils which are primarily erosional remnants of Quaternary and Tertiary volcanic rocks, often basalt or basaltic andesite. Several hundred feet thick, these yield small volumes of water, often about 10 gallons per minute. Beneath these lies the Datil Group, consisting of volcaniclastic rocks that range from rhyolite to andesite. It is as much as 5000 feet thick. Yields are small to moderate.

Considering that bolson-fill well yields regularly approach 975 gallons per minute, and well yields elsewhere are often about 10 gallons per minute (Myers et al. 1994), hydraulic conductivity in these areas must also generally be much less. Approximating historical static water levels (Blodgett and Titus, 1973) (Shomaker et al., 2002) (D.B. Stephens, 2003), values were adjusted during model calibration to ensure that no-development block discharge approximates (within 0.5%) block recharge.

Calibration results in values necessarily ranging from 0.04 feet per day in the mountainous Northwest block to 178 feet per day in the Alamosa block, which largely agree with the 0.0028-89.7 feet per day range for fractured igneous rocks and 0.028-2835 feet per day range for permeable basalt as determined by Freeze and Cherry (1979). Values range up to 210 feet per day (203,986 AFY analysis for the Alamosa block).

Groundwater flow between blocks is calculated using a form of Darcy's Law, $Q = -TL_P(\Delta h/\Delta x)$, in which Q is the volumetric groundwater flow, T is the geometric mean of the transmissivity of the two blocks, L_P is the length of the perimeter or boundary between the two blocks, and $\Delta h/\Delta x$ is the hydraulic gradient, as determined by head and the distance between block center points (Table 6). Water exits the Gila and Alamosa blocks at the rate it enters.



E Bolson			**W Bolson**			**NW**		
	Lp	**Center**		**Lp**	**Center**		**Lp**	**Center**
W Blsn	7.03	27.54	E Blsn	7.03	27.54	E Blsn	14.70	24.56
NW	14.70	24.56	NW	33.55	16.92	W Blsn	33.87	16.92
NE	42.81	11.34	SW	60.70	14.99	NE	9.58	30.09
SW	8.31	41.51				SW	11.50	30.25
SE	21.09	14.63						
NE			**SW**			**SE**		
	Lp	**Center**		**Lp**	**Center**		**Lp**	**Center**
E Blsn	42.81	11.34	E Blsn	8.31	41.51	E Blsn	21.09	14.63
NW	9.58	30.09	W Blsn	60.70	14.99	SW	13.42	33.76
SE	1.92	25.6	NW	11.50	30.25	NE	1.92	25.6
			SE	13.42	33.76	Alamosa	19.10	12.18
			Gila	52.78	15.68			

Table 6. Perimeter length (Lp) between blocks and distance between geographic center points (miles).

10.4.4 Pumping (Q_P)

The amount of water withdrawn from domestic wells depends on population. Other pumping occurs for livestock, irrigation, and miscellaneous uses.

10.4.4.1 Population Estimates

U.S. Census 2010 data in the San Agustin basin is available on a county-wide basis only, excepting Datil. The basin is within Catron and Socorro counties. The Catron County portion covers 1540 mi^2, or 78.4% of the 1965 mi^2 basin (Blodgett and Titus, 1973). County 2010 population is 3725 (up 5.14% from 3543 in 2000) while Socorro County population is 17,866 (down 1.17% from 18,078 in 2000). The 2010 population of the Catron County portion of the basin (828) is based on its share of the 6928 mi^2 county (U.S. Census, 2010). The Socorro County portion assumes a population density similar to that of Catron County, for a population of 229. Total population, then, is 1057. A weighted population growth rate is 3.77% every ten years. This is assumed by the model, which begins January 2018.

10.4.4.2 Current Pumping

Pumping demand is derived using a geodatabase which combines point of diversion permit data from the New Mexico Water Rights Reporting System (WATERS) as of July 2011 (OSE, 2011b) with geospatial shape files. Groundwater permits are retrieved for the San Agustin basin by formulating a spatial select. This selection yields 1027 groundwater permits. Ancillary information includes groundwater volumes and purpose of use for each permit (Figure 12). It should be noted that OSE WATERS data have not been verified.

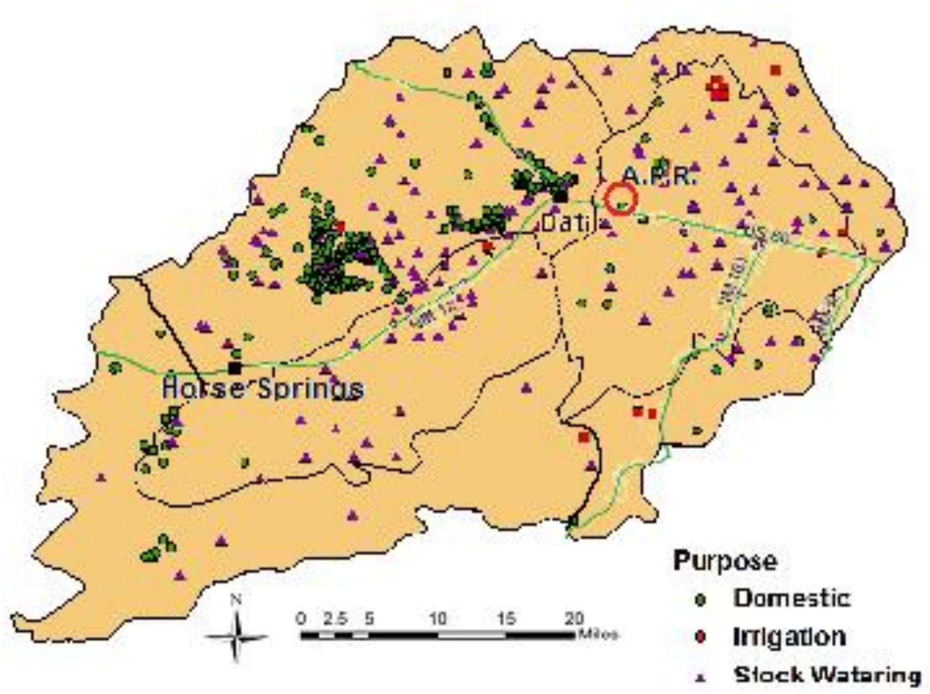


Figure 12. Permitted wells (OSE, 2008).

Currently, groundwater is primarily used for irrigation, livestock watering, and domestic use. Because there has been little change in population or land use in the basin and groundwater levels are static (Blodgett and Titus, 1973) (Shomaker et al., 2002) (D.B. Stephens, 2003), irrigation, livestock, and other non-domestic values are assumed to be constants unaffected by population growth. Annual pumping demands from each block and purpose of use are delineated in Table 7 (OSE, 2011b):

Groundwater Block	Non-Domestic	Domestic	2011 Total
NW	853	1055	1908
NE	560	27	587
W Bolson	798	112	910
E Bolson	4406	57	4463
SW	74	36	110
SE	1390	15	1405
Basin Total	**8081**	**1302**	**9383**

Table 7. 2011 well rights by groundwater block (AFY).

Domestic water use is affected by population growth. Use increases linearly with population at 3.77% per decade, the 2000-2010 basin weighted growth rate (U.S. Census, 2010). Year 2010 (July) population is used to project 2011 (July) population. Year 2011 domestic use and 2011 population are used to calculate a per capita pumping rate. Basin-wide, this is 1.23 acre-feet per person. Finally, in accordance with the 2018-2058 modeling period, January 2018 population (1088) and domestic use (1336 AFY) are estimated.

10.4.4.3 Future Pumping

The model multiplies per capita water use with block population for each year to determine total domestic water use for each block. Irrigation use remains constant, except in the appropriation scenarios, which include Augustin Plains Ranch irrigation.

Augustin Plains Ranch, LLC has applied for 54,000 acre-feet per year of consumptive use. However, it is important to note that not all of this is for export from the basin. Its application states a proposed use of irrigating 120 acres of land within a 1290-foot radius of each of 37 proposed wells (Appendix A) (Figure 5). This totals 4440 acres. In comparison, Basabilvazo (1997) states that irrigated lands within the Catron County portion of the plains totaled 561 acres in 1990.

Economic analysis concludes that Augustin Plains Ranch's return on investment would be greater if water is diverted to the Middle Rio Grande rather than applied to farmland, so the model minimizes irrigation use for the 4440 acres. Irrigation requirements for various land management practices at nearby Datil are available from the U.S. Natural Resource Conservation Service. For normal precipitation, net irrigation requirements range from 6.36 in/yr for winter wheat to 17.51 in/yr for oat hay (USDA, 2005). These numbers factor in carryover from previous irrigation. Therefore, the model assumes the ranch will plant winter wheat, needing 6.36 in/yr for 4440 acres, or 2352 AFY. The model assumes water is transpired by the wheat or evaporates rather than infiltrates to the water table. This leaves 51,648 acre-feet available for export.

Once the water is pumped from the aquifer, a pipeline would have to be installed to transport water out of the basin. The application for permit does not state a route for a pipeline, but only that a pipeline would be used to transport water for use in Catron, Sierra, Socorro, Valencia, Bernalillo, Sandoval, and Santa Fe counties (Appendix A). However, Augustin Plains Ranch has since specified a potential corridor (Figure 13).

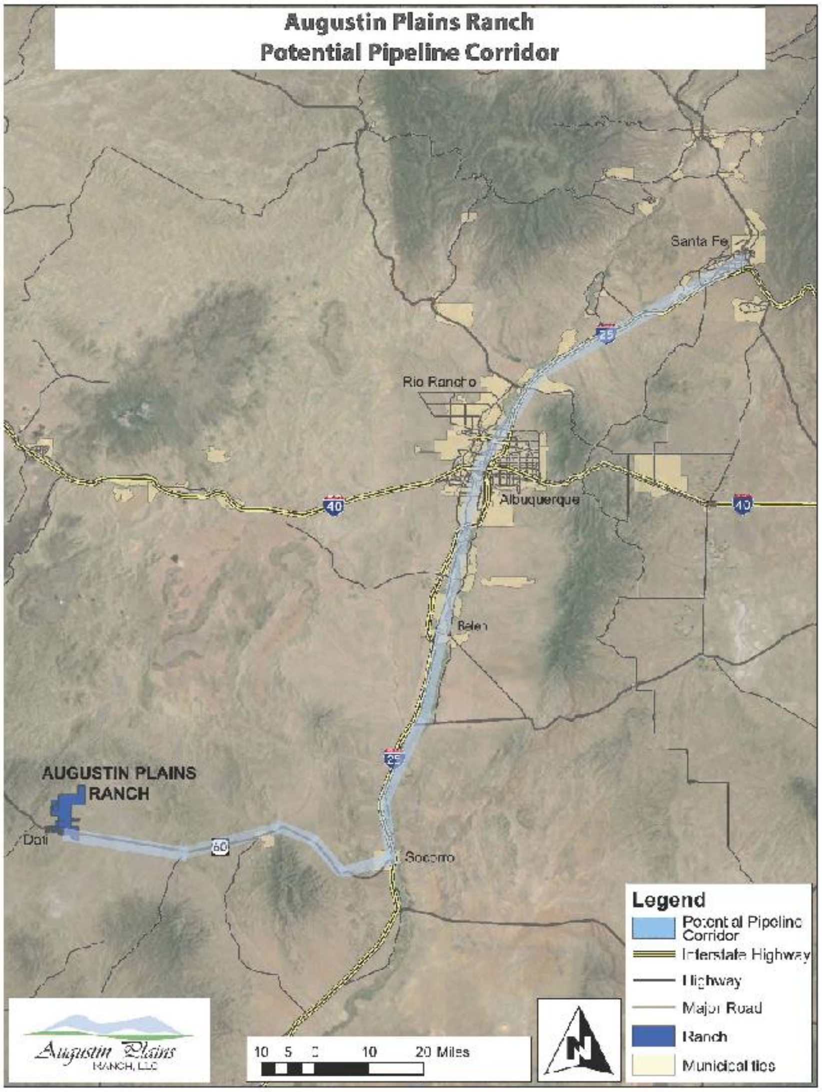


Figure 13. Potential pipeline corridor (Augustin Plains Ranch, 2011).

This route parallels U.S. Route 60 for 53 miles from the wells to Socorro, continues approximately 99 miles along the Rio Grande to near the Angostura Diversion Dam, after which it parallels Interstate 25 for 40 miles to central Santa Fe, for an approximate total of 192 miles of pipeline. An economic and legal analysis shows this to be the most practicable route, and so was used to develop an estimate of pipeline costs. There appear to be five other pipeline routes to the Rio Grande, each believed to have such significant physical, economic, legal, and/or environmental issues that they are not considered. However, each is discussed in Appendix C.

10.5 Calibration

Model calibration is required to assure that the conceptual model and the hydraulic parameters used in the model (Tables 5-7) agree with observed hydrology in the basin. Calibration essentially assumes a continuation of past conditions of largely static water table levels (Blodgett and Titus, 1973) (Shomaker et al., 2002) (D.B. Stephens, 2003).

Based on the water balance equation for a closed basin, $\Delta S = P - ET - D$, and with no change in San Agustin Basin storage, recharge (precipitation minus evapotranspiration) equals discharge. Calibration involved adjustment of model parameters under the no-development scenario and with no population growth to produce a water balance within 0.5% of the estimated recharge for each block.

Basin field data as used in model calibration includes precipitation data from four National Weather Service Cooperative Observer Program stations (NOAA, 2012), OSE water right permit records (OSE, 2011), aquifer recovery tests on irrigation wells in the northern part of the basin performed by Myers et al. (1994), and data from numerous sources on known basin hydrogeologic characteristics, as performed or relayed by Blodgett and Titus (1973), Myers et al., and Basabilvazo (1997).

As discussed previously, recharge is the same as percolation to the water table for modeling purposes. Recharge equals 101,993 acre-feet per year. Sources (Dortignac, 1960) (Osborn and Laursen, 1973) (Stephens and Knowlton, 1986) state that 5% of precipitation in the basin, in this case 71,395 AFY, is an acceptable number for runoff which infiltrates. However, due to playas near or at the bolson-fill border, 3431 AFY does not reach the water table. This leaves 34,029 AFY of precipitation which reaches the water table through direct infiltration rather than runoff. This is apportioned to each block based on the following formula, which also accounts for playas:

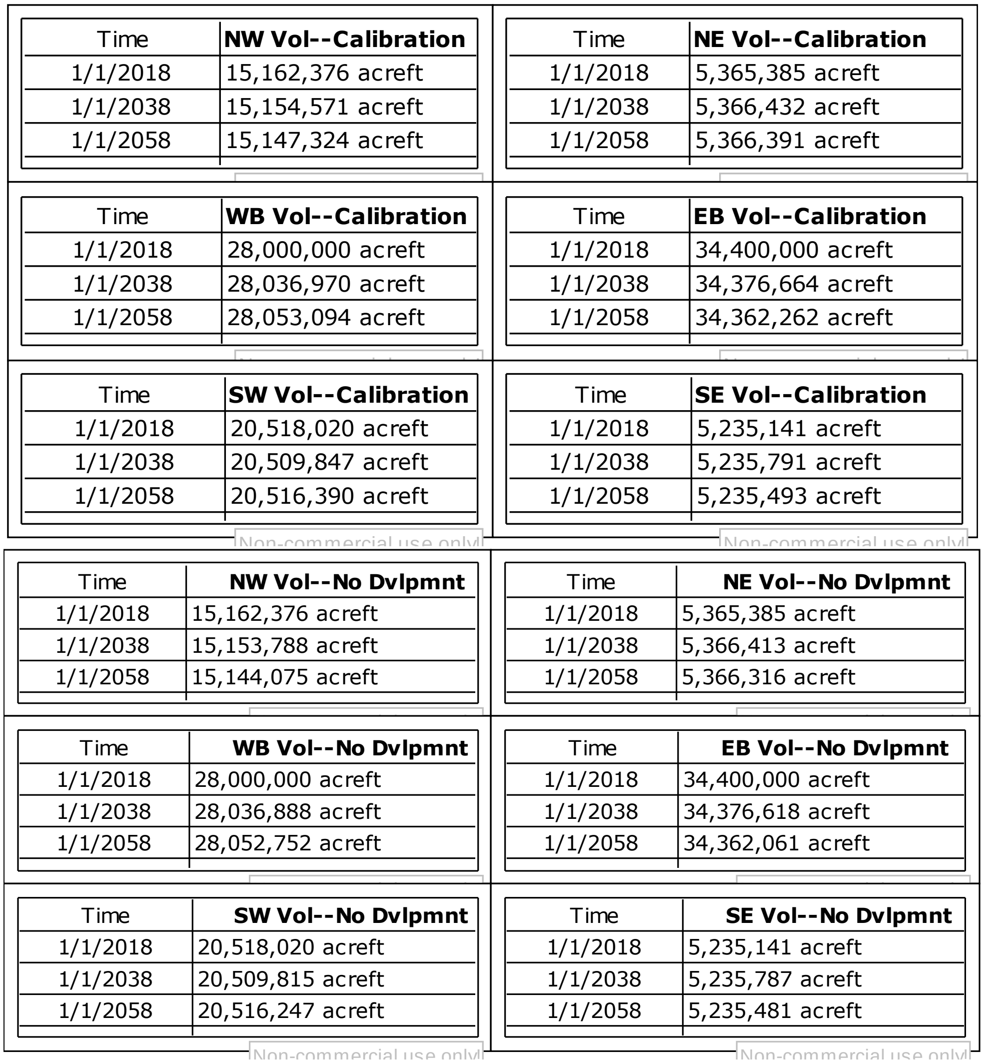
Direct Infiltration Recharge (AFY) = (Adjusted Precipitation – Adjusted Evaporation) / (Basin Adjusted Precipitation – Basin Adjusted Evaporation) * Non-Playa Share of Watershed * 34029 AFY.

Recharge by block is shown in Table 3.

Discharge is dependent on existing pumping and basin characteristics previously discussed and as shown in Tables 5-7. To ensure discharge greatly approximates recharge, hydraulic conductivity values, of which no empirical data is currently available, were adjusted within acceptable ranges. These values range from 0.04 feet per day for the Northwest block to 178 feet per day for the Alamosa block.

Excepting population growth, hydraulic conductivity and other values are the same in calibration as the no-development scenario. Population growth rates are set to zero to negate possible hydrological effects of population growth.

Results show that population growth has minimal effect on groundwater volumes. Overall domestic use increases from 1336 AFY in 2018 to 1538 AFY in 2058. The greatest effect of population growth is on the Northwest block, with 99.98% of the 2058 volume of the same block under calibration (Table 8).



Time	NW Vol--Calibration
1/1/2018	15,162,376 acreft
1/1/2038	15,154,571 acreft
1/1/2058	15,147,324 acreft

Time	NE Vol--Calibration
1/1/2018	5,365,385 acreft
1/1/2038	5,366,432 acreft
1/1/2058	5,366,391 acreft

Time	WB Vol--Calibration
1/1/2018	28,000,000 acreft
1/1/2038	28,036,970 acreft
1/1/2058	28,053,094 acreft

Time	EB Vol--Calibration
1/1/2018	34,400,000 acreft
1/1/2038	34,376,664 acreft
1/1/2058	34,362,262 acreft

Time	SW Vol--Calibration
1/1/2018	20,518,020 acreft
1/1/2038	20,509,847 acreft
1/1/2058	20,516,390 acreft

Time	SE Vol--Calibration
1/1/2018	5,235,141 acreft
1/1/2038	5,235,791 acreft
1/1/2058	5,235,493 acreft

Time	NW Vol--No Dvlpmnt
1/1/2018	15,162,376 acreft
1/1/2038	15,153,788 acreft
1/1/2058	15,144,075 acreft

Time	NE Vol--No Dvlpmnt
1/1/2018	5,365,385 acreft
1/1/2038	5,366,413 acreft
1/1/2058	5,366,316 acreft

Time	WB Vol--No Dvlpmnt
1/1/2018	28,000,000 acreft
1/1/2038	28,036,888 acreft
1/1/2058	28,052,752 acreft

Time	EB Vol--No Dvlpmnt
1/1/2018	34,400,000 acreft
1/1/2038	34,376,618 acreft
1/1/2058	34,362,061 acreft

Time	SW Vol--No Dvlpmnt
1/1/2018	20,518,020 acreft
1/1/2038	20,509,815 acreft
1/1/2058	20,516,247 acreft

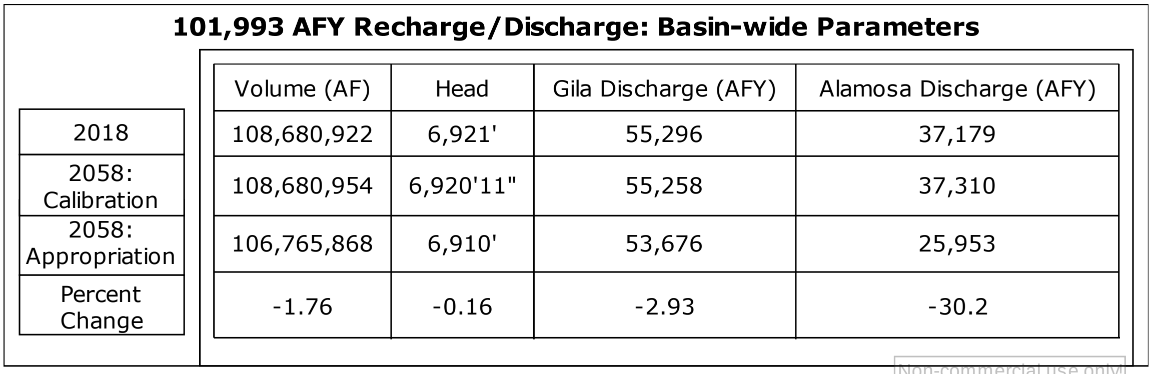
Time	SE Vol--No Dvlpmnt
1/1/2018	5,235,141 acreft
1/1/2038	5,235,787 acreft
1/1/2058	5,235,481 acreft

Table 8. Volume by block under calibration (no population growth) and no development (with population growth) scenarios.

Due to this small effect of population growth on water levels, population growth is not accounted for in sensitivity analysis. Instead, results under an appropriation scenario are analyzed against comparable numbers under the no-development scenario (Appendix E).

11.0 Model Results

After model calibration was completed, a 54,000 AFY appropriation was applied to the basin, specifically the East Bolson block. Results show basin-wide groundwater declining 1,915,054 acre-feet or 1.76%, resulting in a regional decline of the water table of 11.02 feet (Appendix D) (Table 9).

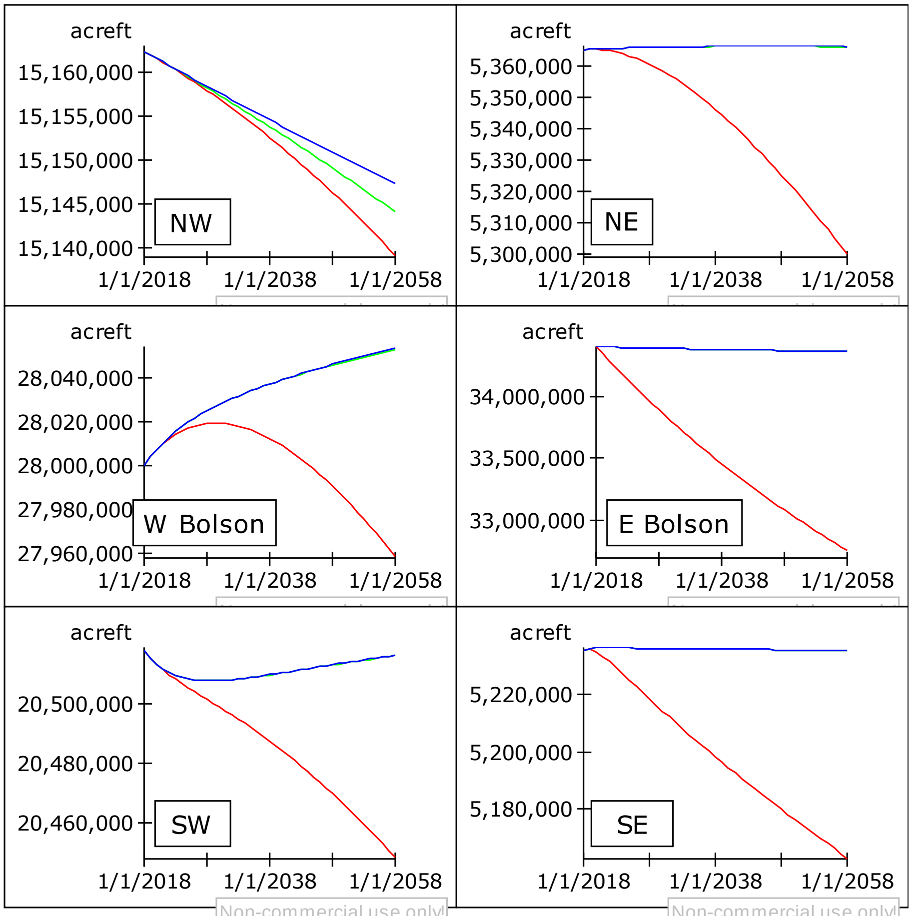


101,993 AFY Recharge/Discharge: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	108,680,922	6,921'	55,296	37,179
2058: Calibration	108,680,954	6,920'11"	55,258	37,310
2058: Appropriation	106,765,868	6,910'	53,676	25,953
Percent Change	-1.76	-0.16	-2.93	-30.2

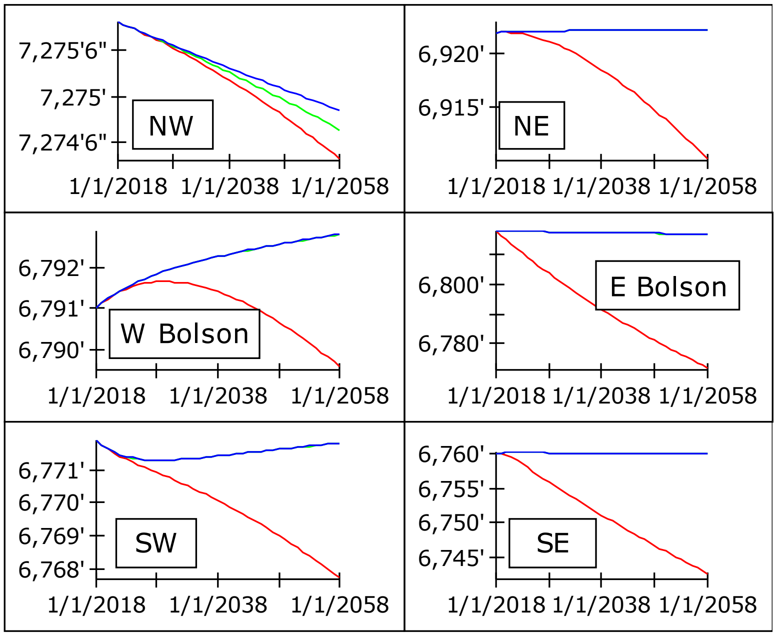
Table 9. Volume, head, and discharge: 101,993 AFY analysis.

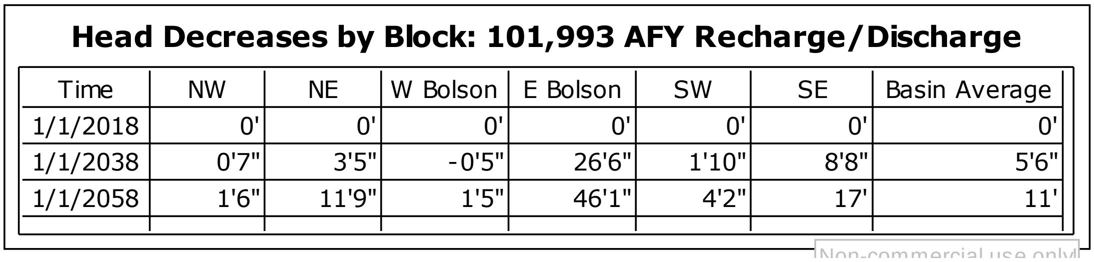
The 37 wells proposed by Augustin Plains Ranch are located in the East Bolson block. Its volume decreases 1,643,011 acre-feet, 4.78%, or 46.12 feet (Appendix E) (Figure 14) (Table 10). Modeling results by block (Appendix E) are uniform despite variability within each. Cone of depression effects are possible in the vicinity of the wells despite unconfined conditions of the basin, particularly of the bolson-fill (Basabilvazo, 1997).



Blue = Calibration, Green = No-Development, Red = Appropriation

Figure 14. Volume decreases by block.





Head Decreases by Block: 101,993 AFY Recharge/Discharge

Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	0'7"	3'5"	-0'5"	26'6"	1'10"	8'8"	5'6"
1/1/2058	1'6"	11'9"	1'5"	46'1"	4'2"	17'	11'

Table 10. Head decreases by block.

Regarding discharge, the proposed Augustin Plains Ranch diversion will decrease discharge to the Gila River basin by 1620 AFY (2.93%) at the end of the 40-year modeling period. Discharge to the Alamosa Creek basin will decrease by 11,226 AFY (30.2%) (Appendix D) (Table 9) after 40 years. The USGS San Francisco River Near Glenwood, NM gage has averaged 62,670 AFY since 1928, and the Gila River Below Blue Creek Near Virden, NM gage has averaged 151,844 AFY since 1932 (1978-1980 excluded). Alamosa Creek (at the Alamosa Creek Near Monticello, NM gage) averaged 5985 AFY over 1932-1941 and 1959-1971 (USGS, 2011). While the relationship between surface water and groundwater flows in the Alamosa Creek basin is not known, the large reduction in groundwater flow to this basin will almost certainly result in a dramatic reduction in surface water flow in the creek. For modeling purposes it is assumed that surface water flow is affected proportionally with changes in subsurface recharge.

Twenty-eight of 1027 total wells in the San Agustin basin are projected to become dry, 27 in the East Bolson block. All wells are active. It should be noted that water table decreases are averaged for each block; if accounted for, cone of depression effects would result in wells closer to the pumping center being impacted more than distant wells, despite unconfined aquifer conditions.

12.0 Sensitivity Analysis

Some inputs necessary for groundwater modeling are either lacking or suspect in the case of the San Agustin basin. These include, but are not limited to, data on precipitation, evaporation, transpiration, runoff-derived recharge, and outside the San Agustin Plains—hydraulic conductivity, storativity, and saturated thickness. Therefore, some of the hydrological parameters in the model are, of necessity, educated estimates.

Sensitivity analysis simulations utilize parameters considered possible by existing literature. Sensitivity analyses include:

1) Doubled (203,986 AFY) recharge and discharge
2) Halved (50,996 AFY) recharge and discharge
3) Reduced basin-wide (49,908,000 acre-foot) volume
4) Climate change (steady decrease of precipitation by 3% over 40 years)
5) Combination of halved recharge/discharge, reduced basin-wide volume, and climate Change, and
6) Water lease rate of $100 per acre-foot of consumptive use.

Unlike the standard 101,993 AFY model, simulations are not run using a calibration (no population growth) scenario. Instead, due to the minimal impact of population growth, each appropriation scenario is compared with its no-development (includes population growth) scenario. Basin-wide results are in Appendix D. Results by block are in Appendix E.

12.1 Doubled Recharge and Discharge

Based on a precipitation rate of 14 inches per year and potential evapotranspiration rate of about 35 inches per year, Blodgett and Titus (1973) calculate a recharge rate of 104,800 acre-feet (1 inch basin-wide average) per year. However, they recognize the inherent inaccuracies of this estimate, stating that recharge could be higher or lower by a factor of two. For this reason, model runs were conducted in which the annual recharge was doubled and decreased by half. Discharge is about equal due to historically static groundwater levels.

If the estimated Blodgett and Titus recharge rate is doubled, the annual infiltration rate becomes 203,986 AFY. Recharge is doubled by doubling the difference between precipitation and evapotranspiration, accomplished by reducing evapotranspiration to 0.923 of its original amount. Precipitation figures are only altered in the climate change and combination analyses. The new *ET/P* ratio is 0.857, agreeable with Brooks et al. (2003). As suggested by Dortignac (1960), Osborn and Laursen (1973), and Stephens and Knowlton (1986), runoff-derived recharge remains 5% of precipitation, thus greatly increasing the share of other sources of recharge. Basin discharge in the no-development scenario must also double to keep water levels static. This is modeled by increasing hydraulic conductivity, perhaps the least understood variable in the basin, of non-bolson-fill blocks up to 210 feet per day. Initial volume and other parameters remain the same.

Model calculations show that, with an appropriation, groundwater in the basin decreases 1,700,624 acre-feet, 1.56%, or resulting in a regional decline of the water table of 10.6 feet (Appendix D) (Table 11). This is the smallest regional decline of any of the sensitivity analyses. The 37 wells proposed by Augustin Plains Ranch are located in the East Bolson block. It decreases by 1,381,513 acre-feet, 4.02%, or 38.8 feet (Appendix E), the smallest East Bolson block decline of any sensitivity analysis. Twenty-two of 1027 total wells are projected to become dry, 21 in the East Bolson block. Regarding discharge, an appropriation decreases it by 4403 AFY, or 3.76%, over 40 years to the

Gila River basin. Discharge to the Alamosa Creek basin decreases 16,741 AFY, or 21.7% (Table 11) (Appendix D), the least decline of any sensitivity analysis.

203,986 AFY Recharge/Discharge: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	108,680,922	6,921'	117,199	77,025
2058: No Development	108,680,475	6,920'11"	117,246	77,351
2058 Appropriation	106,980,298	6,910'5"	112,796	60,284
Percent Change	-1.56	-0.15	-3.76	-21.7

Head Declines by Block: Appropriation

Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	0'2"	7'11"	-0'9"	24'2"	2'7"	7'8"	5'6"
1/1/2058	0'10"	19'10"	1'7"	38'9"	5'4"	14'2"	10'7"

Table 11. Volume, head, and discharge: Doubled Recharge/Discharge analysis.

12.2 Halved Recharge and Discharge

The low recharge/discharge simulation for the sensitivity analysis is one-half of 101,993 AFY, or 50,996 AFY. This is based on the low-end of recharge considered possible by Blodgett and Titus (1973).

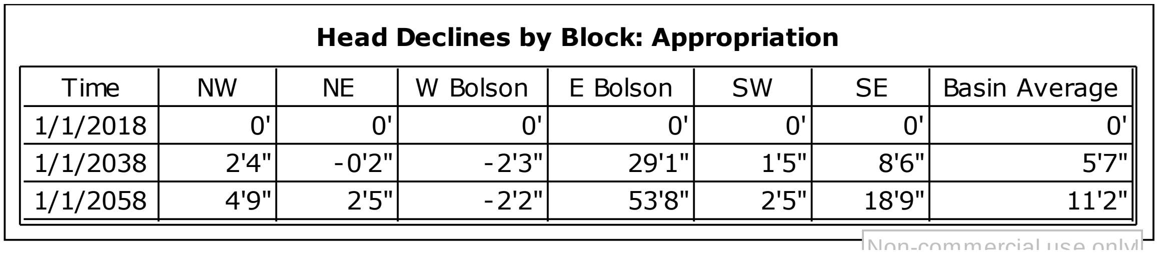
It is believed that 85-95% of precipitation is evaporated or consumed by vegetation in many semiarid to arid watersheds (Brooks et al., 2003). In this analysis, recharge necessarily amounts to 3.57% of precipitation, the only analysis in which this is less than 5%. The Southwest New Mexico Regional Water Plan (D.B. Stephens, 2005) claim that approximately 1.9% of precipitation recharges Catron County groundwater in the basin (27,130 AFY if applied basin-wide), with 97.5% of outflow lost to evapotranspiration (0% to subsurface discharge), is therefore not modeled here.

Recharge is halved by halving the difference between precipitation and evapotranspiration. Evapotranspiration is increased to 1.04 of the standard 101,993 AFY scenario amount, increasing the *ET/P* ratio to 0.964. Runoff-derived recharge is only 2.5% of precipitation because 5% of precipitation is 71,395 AFY, a number higher than 50,996 AFY. As a result, relatively less water reaches the bolson-fill blocks. Discharge is halved by reducing hydraulic conductivity of the four southernmost blocks to 3.11 feet per day.

Model results indicate that an appropriation would result in basin groundwater declining 2,056,337 acre-feet and 1.89%, resulting in a regional decline of the water table of 11.18 feet (Appendix D) (Table 12). The 37 wells proposed by Augustin Plains Ranch are located in the East Bolson block. It decreases 1,912,409 acre-feet, 5.56%, or 53.7 feet (Appendix E). Thirty of 1027 total wells are projected to become dry, 29 in the East Bolson block. Regarding discharge, an appropriation decreases it by 420 AFY, or 1.67%, over 40 years to the Gila River basin, the lowest of any sensitivity analysis. Discharge to the Alamosa Creek basin decreases 5940 AFY, or 36.5% (Table 12) (Appendix D).

50,996 AFY Recharge/Discharge: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	108,680,922	6,921'	25,161	16,277
2058: No Development	108,680,896	6,920'7"	25,163	16,251
2058: Appropriation	106,624,585	6,909'10"	24,741	10,337
Percent Change	-1.89	-0.16	-1.67	-36.5



Head Declines by Block: Appropriation

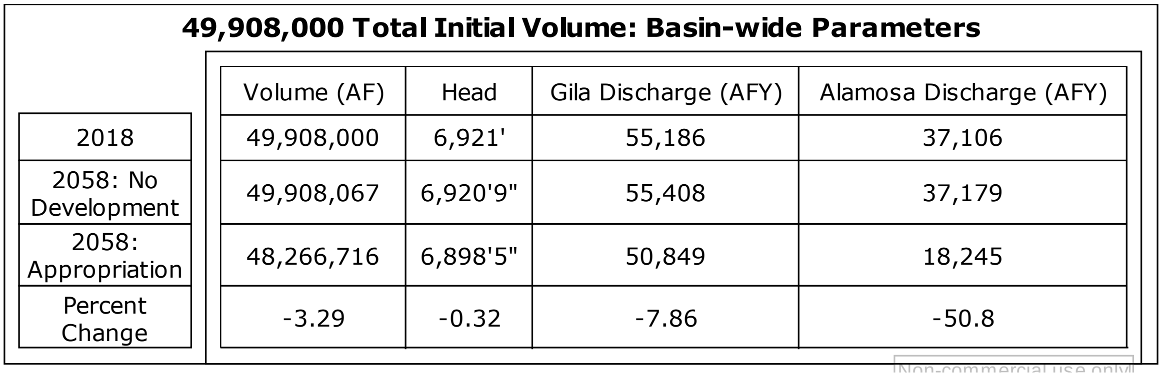
Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	2'4"	-0'2"	-2'3"	29'1"	1'5"	8'6"	5'7"
1/1/2058	4'9"	2'5"	-2'2"	53'8"	2'5"	18'9"	11'2"

Table 12. Volume, head, and discharge: Halved Recharge/Discharge analysis.

12.3 Reduced Basin-Wide Initial Volume

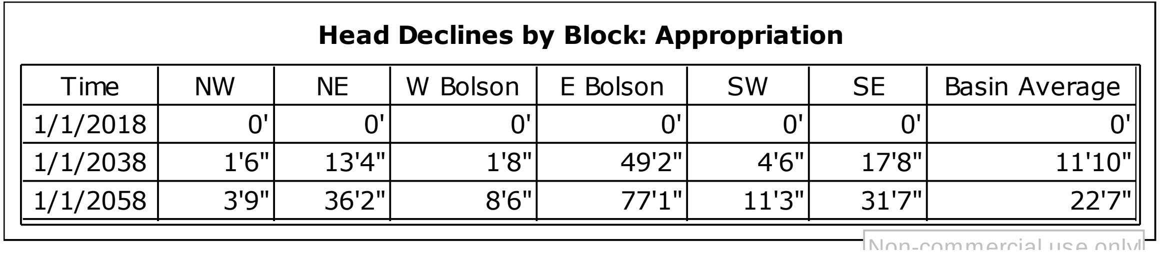
Myers et al. estimate the total volume of water in the bolson-fill aquifer to be 62.4 million acre-feet (1994). Volumes for the rest of the basin are not explicitly provided. However, the Southwest New Mexico Regional Water Plan (D.B. Stephens, 2005) estimates the volume of groundwater in the *entire* basin to be 49,908,000 acre-feet. Therefore, storativities for all blocks are uniformly lowered until overall initial volume is 49,908,000 acre-feet. This is 46.6% of the initial volume utilized in other analyses (excepting the Combination analysis). No other values are changed.

Lowering aquifer volume results in increased effects of an appropriation. Model calculations state that with an appropriation, groundwater in the basin decreases 1,642,084 acre-feet, or 3.29%, resulting in a regional decline of the water table of 22.6 feet (Appendix D) (Table 13). East Bolson block volume decreases 1,260,564 acre-feet, 7.98%, or 77.1 feet (Appendix E). Thirty-seven of 1027 total wells are projected to become dry, 34 in the East Bolson block. Regarding discharge, an appropriation decreases discharge by 4337 AFY, or 7.86%, over 40 years to the Gila River basin. Discharge to the Alamosa Creek basin decreases 18,861 AFY, or 50.8% (Table 13) (Appendix D).



49,908,000 Total Initial Volume: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	49,908,000	6,921'	55,186	37,106
2058: No Development	49,908,067	6,920'9"	55,408	37,179
2058: Appropriation	48,266,716	6,898'5"	50,849	18,245
Percent Change	-3.29	-0.32	-7.86	-50.8



Head Declines by Block: Appropriation

Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	1'6"	13'4"	1'8"	49'2"	4'6"	17'8"	11'10"
1/1/2058	3'9"	36'2"	8'6"	77'1"	11'3"	31'7"	22'7"

Table 13. Volume, head, and discharge: Reduced Basin-Wide Initial Volume analysis.

12.4 Climate Change

Climate models indicate that the climate of the American Southwest will become drier in the coming decades. These include an ensemble of 18 global climate models participating in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, or IPCC (2007) (Seager et al., 2010). Climate change is therefore modeled in sensitivity analysis.

The U.S. Global Change Research Program, organized to coordinate and integrate federal research on global environmental change, predicts changing precipitation patterns in much of the United States. The American Southwest is projected to experience less precipitation, more so than any other region, in part due to changing atmospheric circulation patterns (USGCRP, 2009).

Weiss (2007) utilizes IPCC (2007) average projections in changes for temperature and precipitation through 2091/2100, under the A2 or “business as usual” approach, and relates them to temperature and precipitation averages from 1971-2000, as provided by NOAA researchers. Figure 15 shows projected precipitation changes. At the San Agustin basin this is approximately a 7% decrease over 100 years. Considering the 40-year modeling period, this is scaled down to a linear 3% decrease. This reduction in precipitation reduces discharge. Other parameters remain unchanged.

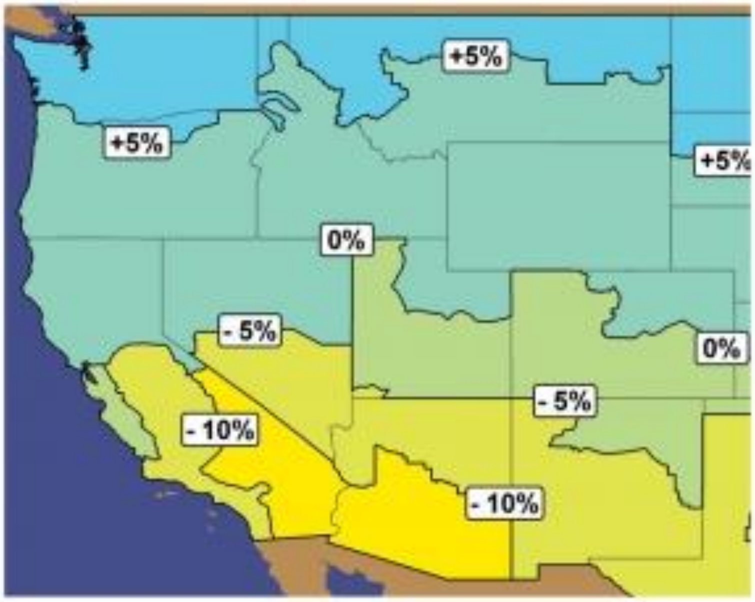
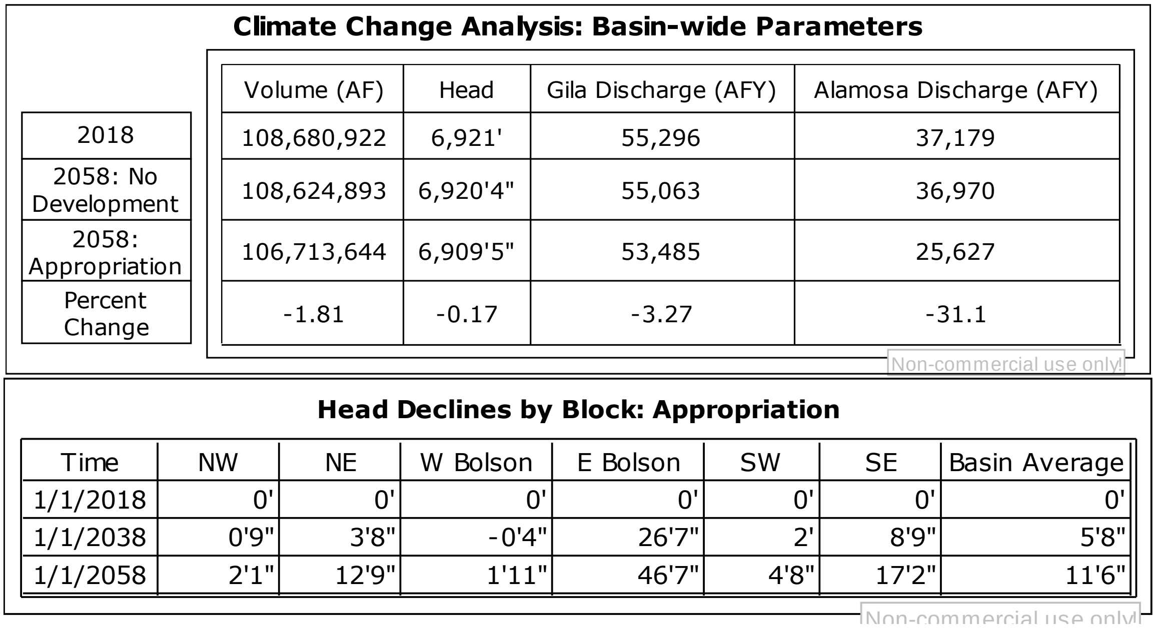


Figure 15. Projected annual precipitation changes from 1971-2000 averages to 2091/2100 (Weiss, 2007).

Results indicate that, with an appropriation, groundwater in the basin decreases 1,967,278 acre-feet, 1.81%, or resulting in a regional decline of the water table of 11.5 feet (Appendix D) (Table 14). East Bolson block volume decreases 1,658,214 acre-feet, 4.82%, or 46.5 feet (Appendix E). Regarding discharge, an appropriation decreases it by 1811 AFY, or 3.27%, over 40 years to the Gila River basin. Discharge to the Alamosa Creek basin decreases 11,552 AFY, or 31.1% (Table 14) (Appendix D).



Climate Change Analysis: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	108,680,922	6,921'	55,296	37,179
2058: No Development	108,624,893	6,920'4"	55,063	36,970
2058: Appropriation	106,713,644	6,909'5"	53,485	25,627
Percent Change	-1.81	-0.17	-3.27	-31.1

Head Declines by Block: Appropriation

Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	0'9"	3'8"	-0'4"	26'7"	2'	8'9"	5'8"
1/1/2058	2'1"	12'9"	1'11"	46'7"	4'8"	17'2"	11'6"

Table 14. Volume, head, and discharge: Climate Change analysis.

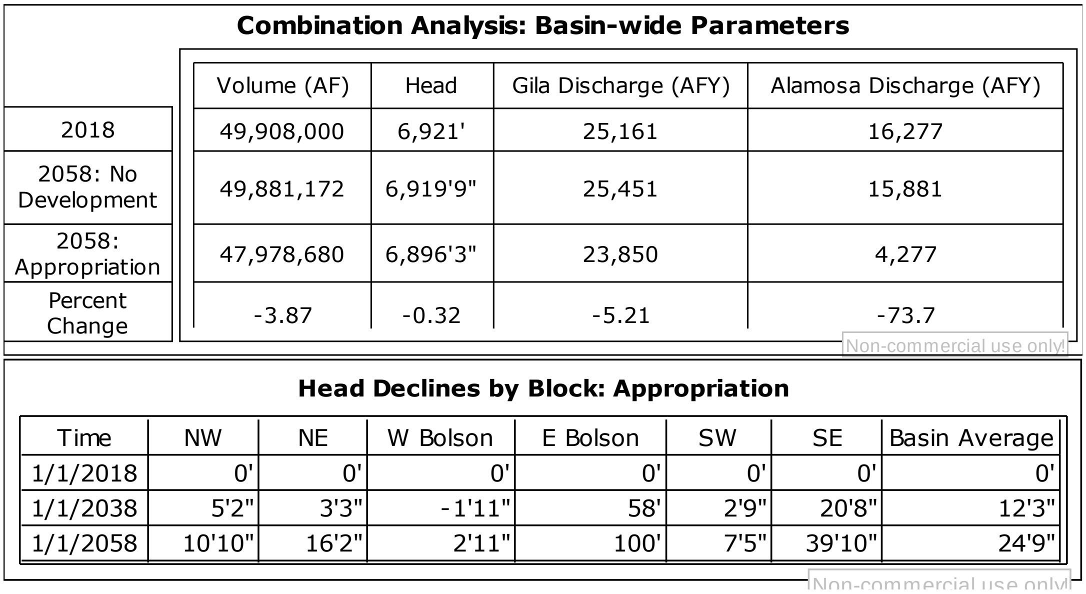
Compared to the 101,993 AFY appropriation model, a climate change appropriation reduces basin groundwater volume a further 52,224 acre-feet, 0.048%, or 5 inches, and in the East Bolson block, 16,941 acre-feet, 0.05%, or 6 inches. No additional wells are projected to become dry. Discharge to the Gila River basin decreases a further 191 AFY, or 0.35%, and to the Alamosa Creek basin, a further 326 AFY, or 0.88%.

12.5 Combination Analysis

This analysis models the maximum potential impact of an Augustin Plains Ranch appropriation. This is done by combining other analyses, *viz.*, halved recharge/discharge, reduced basin-wide volume, and climate change. Storativity values are the same as for the reduced basin-wide volume analysis.

Effects of an appropriation are greatest under this analysis. Results show that groundwater in the basin decreases 1,929,320 acre-feet, 3.87%, or resulting in a regional decline of the water table of 24.7 feet (Table 15). East Bolson block volume decreases

1,635,397 acre-feet, 10.35%, or 99.97 feet (Appendix E). Forty-seven of 1027 total wells are projected to become dry, 41 in the East Bolson block. Regarding discharge, an appropriation decreases it by 1311 AFY, or 5.2%, over 40 years to the Gila River basin. Discharge to the Alamosa Creek basin decreases 12,000 AFY, or 73.7% (Table 15) (Appendix D).



Combination Analysis: Basin-wide Parameters

	Volume (AF)	Head	Gila Discharge (AFY)	Alamosa Discharge (AFY)
2018	49,908,000	6,921'	25,161	16,277
2058: No Development	49,881,172	6,919'9"	25,451	15,881
2058: Appropriation	47,978,680	6,896'3"	23,850	4,277
Percent Change	-3.87	-0.32	-5.21	-73.7

Head Declines by Block: Appropriation

Time	NW	NE	W Bolson	E Bolson	SW	SE	Basin Average
1/1/2018	0'	0'	0'	0'	0'	0'	0'
1/1/2038	5'2"	3'3"	-1'11"	58'	2'9"	20'8"	12'3"
1/1/2058	10'10"	16'2"	2'11"	100'	7'5"	39'10"	24'9"

Table 15. Volume, head, and discharge: Combination analysis.

13.0 Economic Analysis

Potential water projects must be workable and reasonable. An economic analysis must be conducted to determine if a project is cost effective. The economic impacts of the proposed Augustin Plains Ranch project would affect basin residents, the general public, and endangered species. This analysis is intended as a preliminary estimation of project costs and benefits. No project-specific engineering studies have yet been published.

Cost-benefit analysis is regularly used to determine if a proposed project is an economically efficient use of resources. To do so, economists typically extrapolate future costs and benefits back to the present day. Discounting is accomplished using acceptable discount rates. For example, with a 4.3% annual discount rate, $1 available in one year would be worth $0.959 available today ($1/[1.00+0.043]). This does not account for inflation. Therefore, this project incorporates a 4.3% annual inflation rate, the average from 1972-2011 (BLS, 2012). In this case, $1 available today would be worth $0.959 in one year. The two rates thus offset each other in economic analysis.

13.1 Augustin Plains Ranch, LLC

Augustin Plains Ranch, LLC proposes to drill 37 wells and export most of the produced water to the Rio Grande basin, with the remainder for irrigation (Appendix A). The ranch has stated the project would be funded entirely by private investment, with an estimated cost of $300 million (Augustin Plains Ranch, 2011). However, model analysis herein estimates ranch initial costs to total $581 million. Over 40 years, expenditures could run over $1 billion with revenue over $1.88 billion.

13.1.1 Wells

Well cost estimates are based on a federal study of the Department of Energy (DOE) Yucca Mountain site of Nevada, which has a similar geologic profile, well diameter, and depth (EPA, 2001) (OSE, 2011b). That study bases costs on a 4” casing, which are then scaled for area using a 0.7 power function. This includes drilling, pumps, power source, associated infrastructure, and miscellaneous costs. Augustin Plains Ranch, LLC plans to use 20” casings, 1.65 the area of the 14” casing of a modeled 3450-foot EPA well. Cost per well is reduced from $1,117,670 for the EPA well to $971,887 based on a depth of 3000 feet, then multiplied by 1.648 to $1,601,670. Final cost is reached by adjusting for inflation since 2001 (BLS, 2012). This is $2,074,592 each or $76,759,913 for 37 wells. It is assumed these are built within one year.

13.1.2 Pipeline

To pump 51,648 AFY, or 71.34 cubic feet per second (cfs) at an ideal mean velocity of 1.83 meters per second, a 54-inch concrete cylinder pipeline would be preferable (McAllister, 2002). A U.S. Bureau of Reclamation report claims large-diameter water pipeline installation costs are typically about $10 per inch-diameter per foot (USBR, 2006) ($11.38 for subsequent inflation). The distance to Santa Fe along Augustin Plains Ranch’s projected path (Figure 13) is about 192 miles, or 1,013,760 feet. Therefore the estimated cost of infrastructure needed to transport 51,648 AFY would be $622,975,795 as of 2012. This increases to $722,651,922 after factoring in typical 16% consultant fees (Cynoyia, 2008). However, to greatly reduce costs, lower-diameter conveyances are possible. A 44-inch pipeline is not ideal but would cost an estimated $588,827,492 after fees and inflation (USBR, 2006). An ABCWUA representative estimates the approximate cost of a 44-inch pipeline would be $250 per linear foot

(Cynova, 2008), or $313,229,132 after fees and inflation. The average of the two estimates is $451,028,312.

In addition, there are costs incidental to pipeline installation (Byrd et al., 2004) (Parkinson, 1999) (SCTRWPG, 2010). Total pipeline costs are summarized in Table 16. The construction timeline is estimated at two years.

Item	**Description**	**Estimated Cost**
Pipeline	192 miles	($451,028,312)
Direct assessment cost	192 miles @ $10,000 per mile: Physical inspection, pipeline mapping, direct voltage gradient surveys, corrosion technologies	($1,192,000)
Inspection	192 miles @ $2,000 per mile	($384,000)
Program development	Administrative, legal	($150,000)
Hydrostatic test		($80,000)
Specialized software		($40,000)
Pump stations (4)	4 @ 60 mil. gallons per day	($43,696,066)
Permanent Easement	40-ft width, $8712 per acre	($8,110,080)
Total		**($504,680,458)**

Table 16. Pipeline and associated costs.

13.1.3 Operation and Maintenance

There are operation and maintenance costs associated with the project (Byrd et al., 2004). These are summarized in Table 17:

Operation and Maintenance	**Annual Cost**	**Total Cost**
Equipment	($50,000)	($2,000,000)
Electricity	($8,262,000)	($330,480,000)
Data Analysis and Software Licenses	($5,000)	($200,000)
Pipeline Engineer	($80,000)	($3,200,000)
Program Manager	($80,000)	($3,200,000)
Laborers/Technicians (3)	($105,000)	($4,200,000)
Field Inspections Coordinator	($50,000)	($2,000,000)

Corrosion Engineer	($60,000)	($2,400,000)
Total	**($8,692,000)**	**($347,680,000)**

Table 17. Annual operation and maintenance costs.

Electricity costs are calculated at $0.17 per acre-foot per foot of lift (adjusted from $0.13656 for inflation), based on a pump requiring 1.707 kwh of energy per acre-foot per foot of lift, 900 foot average lift, and a 60% efficiency (Al-Sabbry et al., 2002).

13.1.4 Irrigated Agriculture

Despite crop revenues, the ranch would not ultimately benefit economically as a result of irrigated agriculture. The application for permit states plans to irrigate 4440 acres (Appendix A) with water that could otherwise be leased for an estimated $500 per acre-foot of consumptive use (Turner, 2011). Irrigation would be minimized (2353 AFY) if the land is planted with winter wheat (USDA, 2005). Yields have averaged about $5.50 per bushel since 2001. Catron County has relatively low yields of 26.5 bushels per acre on average (USDA, 2007). Applying the estimated need of 6.36 inches or 2353 acre-feet each year (USDA, 2005) would be equivalent to paying $265 per acre in water for a $146 annual return. With 4440 acres, this sums to $1,176,600 for a $647,130 return. Taxes are not accounted for here. Revenues could be increased, but only by planting crops with much greater irrigation requirements (USDA, 2005), with consequent increased costs. In addition, production costs for U.S. wheat, minus water, are at about $257 per planted acre (USDA, 2010), or $1,140,991 for 4440 acres. Altogether, ranch irrigation costs may total over $2.3 billion (Table 18).

Irrigated Agriculture—Winter Wheat			$100 per afcu
Crop Revenue	26.5 bushels/acre @ $5.50/bushel * 4440 acres * 40 years	$25,885,200	$25,885,200
Farm Costs	$-256.98/acre * 4440 acres * 40 yrs	($45,639,648)	($45,639,648)
Water Costs	0.53 ft/ac * 4440 ac * -$500/afcu * 40 yr @ 1.02 appreciation	($91,595,597)	($18,319,119)
Total:		($111,350,045)	($38,073,567)

Table 18. Irrigated agriculture costs and benefits.

13.1.5 Water Marketing

Assuming a minimal 147 AFY are lost in conveyance, and in accordance with the application for permit, which states in part "any impairment of existing rights, in the Gila-San Francisco basin, the Rio Grande basin, or any other basin, that would be caused by the pumping applied for, will be offset or replaced" (Appendix A), decreases in discharge are offset or replaced at the same cost, decreasing marketable water from 51,500 AFY to 38,653 AFY as of 2058 (28,302 AFY to 45,140 AFY in sensitivity analysis). Pumping effects on discharge are not entirely immediate and as a result the State Engineer may grant time to acquire offsets (Jones, 2002).

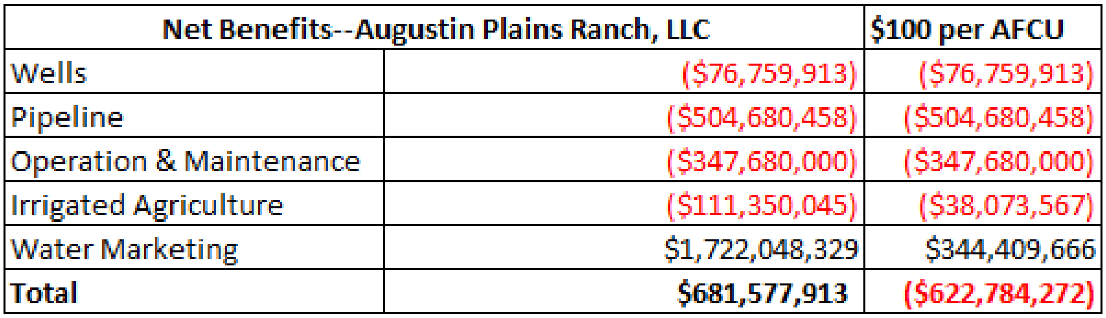
The value of New Mexico water has greatly increased in recent years. In the Middle Rio Grande region, where water is fully appropriated and most growth occurs (OSE, 2000), the value of a water right is currently about $15,000 per acre-foot of consumptive use (afcu) per year (Brown, 2007) (Turner, 2011), up from about $1000 in 1994 (Brown, 2008). Rates are currently about $18,000 at Santa Fe and $6000 near Las Cruces (Turner, 2011). Agreeable with the application for permit, it is assumed that some, or one-fifth in this analysis, of transported water would go to Santa Fe and one-fifth to areas below the Middle Rio Grande such as Truth or Consequences, for a mean value of $13,800 afcu per year. Appreciation is accounted for. Using a conservative 2% annual growth rate, water right value reaches $35,002 afcu per year through 2057, or $1.81 billion for 54,000 afcu.

However, these are water right values; prices paid for water are typically much lower. This is often termed raw, bulk, leased, or rented water. Using data compiled from the trade journal *Water Strategist*, Brown (2007) lists quantities and prices of several water transactions throughout western states. Santa Fe is currently leasing up to 3000 acre-feet per year of San Juan-Chama diversion project water for up to 50 years from the Jicarilla Apache Nation at a price of $500 afcu per year. San Juan-Chama project water leases at up to $100 afcu per year under various short-term leases. Prices generally increase the longer the lease (Brown, 2007) (Brown, 2008).

Due to price variability, water modeling conservatively lists $500 afcu per year as the rate at which Augustin Plains Ranch leases water, in addition to an alternative $100 rate. Value appreciates at 2% annually. Leases from 2018-2057 total $1.72 billion ($1.43-$1.88 billion in sensitivity analysis), or $344 million at a $100 rate ($287-$376 million in sensitivity analysis). Taxes are not considered.

13.1.6 Synthesis

In conclusion, then, Augustin Plains Ranch would over 40 years realize an estimated economic benefit of $682 million (Table 19) ($393 million to $841 million in sensitivity analysis, -$623 million at a $100 afcu rate). Results depend most on the value of water. To realize a net gain, water would need to be leased at a minimum $290.99 afcu appreciating at 2% annually.



Net Benefits--Augustin Plains Ranch, LLC		$100 per AFCU
Wells	($76,759,913)	($76,759,913)
Pipeline	($504,680,458)	($504,680,458)
Operation & Maintenance	($347,680,000)	($347,680,000)
Irrigated Agriculture	($111,350,045)	($38,073,567)
Water Marketing	$1,722,048,329	$344,409,666
Total	**$681,577,913**	**($622,784,272)**

Table 19. Augustin Plains Ranch estimated costs and benefits.

13.2 Basin Residents

Economically, San Agustin basin residents would benefit little from pumping, except for indirect activity resulting from construction, operations and possible easement compensation. In contrast, costs include drilling new or deeper wells with a possible loss of water altogether.

Construction-related economic benefits to basin residents would be minimal. These are difficult to determine in detail, but may still be estimated. Due to its rural nature, little if any construction material would be procured here. Approximately 10.1% of the pipeline is within the San Agustin basin. If construction-related employment averages 100 over two years, then an average 10 employees may be working and spending within the basin. If each employee spends an average $1500 per month on goods and services sold within or near the basin (e.g. housing, groceries, entertainment), then $363,600 are spent here. Also, assuming long-term project employment is 10, 10.1% of activity may occur within the basin. Over 40 years, $1500 per month sums to $727,200.

Income multipliers estimate the total impact of funds invested in an economy. A portion of the original investment "leaks" out of the area but a portion remains to fuel additional economic activity. This in turn supports even further activity until the effect is negligible. An income multiplier of 1.29, representing $1.29 in economic output for every dollar of input, is used by Lillywhite and Starbuck (2008) in an analysis of the New Mexico oil and gas industry. Applied to water pipeline construction, total economic benefits to the San Agustin basin are $1,407,132.

Costs to basin residents include deeper wells and associated electricity costs. Mean depth to water is 165 feet basin-wide, 265 feet for the East Bolson block (OSE, 2011b). Over 40 years, water levels in each of the six blocks drop as shown in Table 20. For the standard 101,993 AFY analysis water levels drop an average 11 feet and as much as 46 feet for the East Bolson block (100 feet using the Combination analysis). Twenty-eight of 1027 total wells are projected to become dry using the 101,993 AFY recharge/discharge analysis, 27 in the East Bolson block. All wells are active. It should be noted that water table decreases are averaged for each block; cone of depression effects would result in wells closer to the pumping center being impacted more than distant wells, despite unconfined aquifer conditions.

For drilling costs, Caraway Drilling of nearby Pie Town gives a typical quote of $22 per foot for residential wells. This includes costs for gravel-packed wells with 8-inch diameter casings and 5-inch PVC lining to a depth up to 500 feet, including labor. In addition, costs are $2.44 per foot for submersible pump cable and $2.50 per foot for 1.25-inch Schedule 80 PVC drop pipe. Costs are approximately $1800 for each pump capable of pumping from a 350-foot well at 5 gallons per minute, plus $500 for labor to install each well cap. Parts not mentioned here are assumed to be reused from previous wells (Caraway, 2012).

Wells that go dry by 2058 are drilled to a depth 100 feet below the projected 2058 block water table. Altogether, 10,731 feet would need to be drilled for a cost of $353,493. Electricity costs are calculated in the same manner as the Augustin Plains Ranch wells (Al-Sabbry et al., 2002). Total costs are listed in Table 20:

Ground-water Block	**No. of Wells**	**Water Table Drop (ft)**	**Wells to Redrill**	**Feet to Drill (2058)**	**Cost to Drill (2058)**	**Acre-feet (2058)**	**Annual Addtnl Elctrcty**	**Total Cost**
NW	683	1.5	0	0	$0	1899	($484)	($19,370)
NE	39	11.8	0	0	$0	587	($1178)	($47,101)
West Blsn	130	1.4	0	0	$0	910	($217)	($8664)
East Blsn	92	46.1	27	10,625	($348,338)	4463	($34,977)	($1,747,399)
SW	58	4.2	0	0	$0	110	($79)	($3142)
SE	25	17	1	106	($5156)	1414	($4086)	($168,614)
Total	**1027**		**28**	**11,391**	**($375,874)**	**9383**	**($41,020)**	**($1,994,288)**

Table 20. Well costs associated with water table decreases.

In sum, benefits to basin residents over 40 years are estimated to be $1,407,132 while costs are $1,994,288, for a loss of $587,156.

However, it should be noted that compensation by Augustin Plains Ranch, LLC is a possibility. They have stated that “any impairment of existing rights, in the Gila-San Francisco Basin, the Rio Grande Basin, or any other basin, that would be caused by the pumping applied for, will be offset or replaced” (Appendix A) as well as that it “has committed to developing the resource without imposing a negative impact on existing water users—there will be no impairment of existing rights and no shift of water away from a current beneficial use” (Augustin Plains Ranch, 2011).

13.3 General Public

After accounting for irrigation, offsets for effects on discharge, and leaks, 38,653 AFY (differs in sensitivity analysis) would be available for export from the basin. Economic benefit to the state of New Mexico would principally consist of enhanced development of urban areas along the middle Rio Grande. The negative economic impacts beyond the San Agustin basin would consist of reduced flows to Alamosa Creek and Gila River, as well as reduced flow to the lower Rio Grande. However, reduced flow in the lower Rio Grande may be offset by increased return flows in the middle reaches of the river. Reduced flow in the Gila River and Alamosa Creek may impact endangered species. However, these numbers have little to do with the focus of this project on impact to those of especial concern, namely the ranch, application protestants (who are largely basin residents), and endangered species. They are also highly speculative and are therefore not addressed here.

13.4 Endangered Species

There is a loss of welfare to society when threatened or endangered species decline or become extinct. This project therefore includes society's value of such species as an indirect cost of pumping. Augustin Plains Ranch states that it will offset or replace impacted water rights in the Gila and other basins (Appendix A) (Augustin Plains Ranch, 2011). However, due to the perceived difficulty of the ranch being able to obtain all offsets upstream of species habitat, particularly in the Alamosa Creek basin, as well as mitigating discharge effects on Alamosa Warm Springs near basin headwaters, endangered species impacts are likely. Economic analysis estimates the maximum possible economic impact to these species.

The Alamosa springsnail (*Tryonia alamosae)* is an endangered species that survives at five individual thermal springheads within one-half mile of each other near Monticello Box (Burton and Metzinger, 1994). The Chiricahua leopard frog (*Lithobates chiricahuensis*) is a threatened species with limited territory in both the Alamosa Creek and Gila River basins (Endangered and Threatened Wildlife and Plants, 2012b). The Gila River basin within New Mexico serves as habitat for one other threatened riverine vertebrate species, the Gila trout (*Oncorhynchus gilae*), as well as three endangered species, *viz.* Gila chub (*Gila intermedia*), loach minnow (*Tiaroga cobitis*), spikedace (*Meda fulgida*),. As suggested by hydraulic gradients, groundwater seeps under the Continental Divide may provide flow to the Gila River watershed (Blodgett and Titus, 1973) (Myers et al., 1994) (OSE, 2008).

There are significant non-market values for the protection of New Mexico instream flow. If a species becomes extinct then society loses its value forever. An economic value is assigned to each species. Analysis of willingness to pay (WTP) helps to do so.

Berrens et al. (2000) sampled 500,000 households in New Mexico in 1995 and 1996 to estimate their annual WTP over five years to acquire the instream flows needed to preserve 11 New Mexico native threatened or endangered riverine fish species. Means amounted to $26 per year to preserve Rio Grande silvery minnow and $72 per year to preserve all species (including the silvery minnow) on the Gila, Pecos, Rio Grande, and San Juan rivers. Adjusted to 2012 dollars, these numbers are $38 and $105, respectively. Willingness to pay averages $9.55 per species per year for five years. This is in rough agreement with estimates by Loomis and White (1996) that households are willing to pay

$6 ($8.77 in 2012) to preserve rare or endangered fish. Census results state New Mexico has 791,395 households. Assuming its 2000-2010 growth rate of 13.2% (U.S. Census, 2010) has remained valid, 2012 households total 812,289. Relating this to the species in question, it can be assumed that the value of each to New Mexico is:

*$9.545 per year * 5 years * 812,289 households = $38,768,330.*

However, most of the 11 species are also found in Arizona or outside the Gila River and Alamosa Creek basins. U.S. Fish and Wildlife Service habitat studies are used to find the Local Value for each species by finding the share of overall habitat (including Arizona), that is local (Local Habitat), or affected by San Agustin basin discharge (assumed to be via the Gila River and Alamosa Creek basins), and multiplying it by the overall species value:

*Local Value = Local Habitat * $38,768,330.*

The Alamosa springsnail (*Tryonia alamosae)* is an endangered species that survives solely at five thermal springheads within one-half mile of each other near the headwaters of Alamosa Creek. Due to this proximity, it is highly possible that any significant decrease in discharge could dry the springs (Burton and Metzinger, 1994). Replacement water via pipeline may not be a viable alternative, and there are likely insufficient water rights upstream from which sufficient offsets could be obtained to stave off effects.

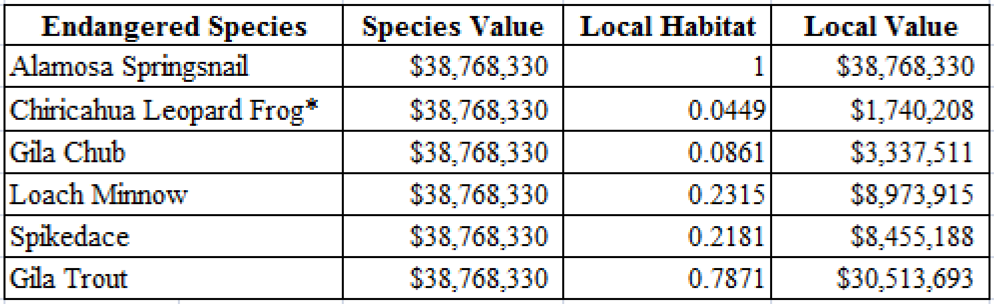
The threatened Chiricahua leopard frog (*Lithobates chiricahuensis*) occurs near the springsnail in the Alamosa Creek basin, having 79 acres of designated critical habitat here, but it is found more frequently in the Gila River basin, where 387 of 10,346 acres of designated critical habitat would be affected by subsurface discharge, assuming a hydrologic connection (Endangered and Threatened Wildlife and Plants, 2012b).

The other species of concern are only affected by Gila block discharge. The Gila chub (*Gila intermedia*) is an endangered species found in Arizona and near Gila River headwaters. There are 13.8 of 160.3 miles of critical habitat (Endangered and Threatened Wildlife and Plants, 2005), which may be affected by seepage to the Gila River basin.

The endangered loach minnow (*Tiaroga cobitis*) and spikedace (*Meda fulgida*) have critical habitats of 610 miles and 630 miles, respectively, including much of the Gila River within New Mexico (Endangered and Threatened Wildlife and Plants, 2012a). Respectively, 141.2 and 137.4 of these miles are within New Mexico and considered affected by subsurface flow from the San Agustin basin.

The Gila trout (*Oncorhynchus gilae*) is a threatened species found largely near Gila River headwaters. There are 53.6 of 68.1 miles of known habitat (Endangered and Threatened Wildlife and Plants, 2006) which would be affected by seepage to the Gila River basin, assuming a hydrologic connection.

Local Value for each species is listed in Table 21:



Endangered Species	Species Value	Local Habitat	Local Value
Alamosa Springsnail	$38,768,330	1	$38,768,330
Chiricahua Leopard Frog*	$38,768,330	0.0449	$1,740,208
Gila Chub	$38,768,330	0.0861	$3,337,511
Loach Minnow	$38,768,330	0.2315	$8,973,915
Spikedace	$38,768,330	0.2181	$8,455,188
Gila Trout	$38,768,330	0.7871	$30,513,693

*Alamosa Creek Local Habitat = 0.00763, Gila/S.F. Local Habitat = 0.373

Table 21. Overall economic values of species and local values.

Augustin Plains Ranch pumping impacts the Local Value of each species (absent sufficient acquisition of offsets or replacement water). This exacts an Endangered Species Cost. Any decrease in discharge to either the Gila or Alamosa block does not affect streamflow to the same amount.

For the Alamosa block, subsurface discharge to the Alamosa block amounts up to 77,025 AFY for the 203,986 AFY no-development scenario (Appendix D). In comparison, Alamosa Creek streamflow near Alamosa Warm Springs averaged 5985 AFY from 1932-1941 and 1959-1971 (USGS, 2011). Therefore, for modeling purposes, Alamosa Creek Endangered Species Cost is based on proportional changes in discharge. In the model, a complete cessation of discharge would extirpate the Alamosa springsnail and local Chiricahua leopard frog populations:

*Alamosa Creek Endangered Species Cost = Local Value - (2058 appropriation discharge to Alamosa block / 2018 appropriation discharge to Alamosa block * Local Value).*

Due to the proximity of Alamosa Warm Springs to the San Agustin basin, it is highly possible that any significant decrease in discharge could dry the springs (Burton and Metzinger, 1994).

In contrast, the species of the Gila block only partially depend on San Agustin discharge. The model subtracts 2058 appropriation scenario discharge from initial discharge. This difference is divided by streamflow of the Gila River, as measured by a USGS gage near the Arizona border. Streamflow has averaged 151,844 AFY since 1932 (excepting 1978-1980) at the Gila River Below Blue Creek Near Virden, NM gage (USGS, 2011). Lastly, the quotient is multiplied by the Local Value of each species:

*Gila Basin Endangered Species Cost = (2058 no-development discharge to Gila block - 2058 appropriation discharge to Gila block) / 151,844 AFY * Local Value.*

Final economic costs are included in Table 22:

Species	**Local Value (2018)**	**Endangered Species Cost**
Alamosa Springsnail	$38,768,330	($11,706,327)
Chiricahua Lprd Frog	$1,740,208	($182,160)
Gila Chub	$3,337,511	($36,646)
Loach Minnow	$8,973,915	($79,317)
Spikedace	$8,455,188	($79,317)
Gila Trout	$30,513,693	($346,870)
Total	**$91,788,845**	**($12,430,637)**

Table 22. Endangered species costs.

Pumping would likely not harm the Rio Grande silvery minnow (*Hybognathus amarus*) because its critical habitat in New Mexico is the river upstream of Elephant Butte Reservoir to Cochiti Dam (Endangered and Threatened Wildlife and Plants, 2010), and Alamosa Creek drains southeast to the Rio Grande at Elephant Butte Reservoir. Pumping of water upstream as far as Santa Fe may even help. The minnow would benefit to the extent water is added to the river system and not consumed for other purposes.

This may be limited, however, due to the value of water and large relative volume of Rio Grande flow, averaging 936,330 AFY since 1974 as measured at the USGS Rio Grande At Albuquerque, NM gage (USGS, 2011). Based on Berrens et al. (2000) and U.S. Census data, a species valuation of silvery minnow can be estimated at $154,334,877. In accordance with the application for permit, which states environmental purposes of use, if 1000 AFY are inserted to river flow, and assuming silvery minnow populations are proportional with river flow, a net benefit of $164,830 would result. However, at a cost $500,000 (if $500 per afcu), this would not be economical for the ranch, and so is not considered further here.

Indirect harm is possible due to increased stress on the overall Rio Grande system, which could be exacerbated if Augustin Plains Ranch water transport ever declines or ceases and related water consumption does not decline at the same rate.

13.5 Synthesis

Table 23 summarizes the net present value of the economic impact of 54,000 AFY of pumping to stakeholders and endangered species. Value to the ranch would be higher if water impacts on others are not assumed to be offset or replaced.

Net Present Value of Economic Impact to 2058		$100 per afcu
Augustin Plains Ranch	$681,577,913	($622,784,272)
Basin Residents	($587,156)	($587,156)
Endangered Species	(12,430,636)	(12,430,636)

Table 23. Net present value of economic impact to 2058.

14.0 Legal and Policy Considerations

Proposed projects such as OSE Application No. RG-88943 must comply not only with state water laws and policies, but federal legislation, case law, and more.

Water in New Mexico, as in much of the American west, is a scarce resource. Rights to use it are therefore administered on a priority basis. As provided in the New Mexico Constitution, those who first legally appropriate and continue to beneficially use water have first priority to it, and so normally have the most protection in times of shortage. Such water rights may be sold or leased (D.B. Stephens, 2003), but being a usufructory right, may be revoked by the state through continued non-use.

Concerning groundwater, a permit to drill a well and appropriate water is required in areas designated by the State Engineer as underground water basins. The San Agustin basin is part of the Rio Grande Underground Water Basin (Figure 16), declared May 14, 1976. It includes areas within the Middle Rio Grande (San Acacia Dam upstream to Cochiti Dam) basin where groundwater is interconnected with the Rio Grande (OSE, 2000).

Figure 16. Underground Water Basins of New Mexico. Image source: www.ose.state.nm.us/PDF/Maps/underground_water.pdf.

Various laws and guidelines govern an application for a permit to appropriate groundwater. Of primary importance are the requirements of New Mexico Statutes Annotated (NMSA) 1978 § 72-12-3 (Appendix B), which require an applicant to state the source of the water sought, amount applied for, place of use, beneficial use(s), location of wells, landowner name(s), and description of any irrigated lands (NMSA 72-12-3(A)). Application No. RG-88943 (Appendix A) lists all of these, stating "domestic, livestock, irrigation, municipal, industrial, commercial, environmental, recreational, subdivision and related, replacement and augmentation purposes of use" in seven New Mexico counties. These are not elaborated upon.

Vagueness is claimed by several protestants as a reason to deny the application (OSE, 2008), which in fact occurred on April 2, 2012. State Engineer Scott Verhines stated:

> *The application was denied because it was vague, over broad, lacked specificity, and the effects of granting it cannot be reasonably evaluated; problems which are contrary to public policy….Reasonable applications are those that identify a clear purpose for the use of the water, include reasonable design plans, and include specifics as to the end user of the water….Along with the proof of clear demand for the water in one area, and an absence of harm to those in the basin from which the water is taken, a commitment to proper backing and contractual arrangements must also be in place (OSE, 2012).*

On April 5 the ranch appealed this decision to the New Mexico Seventh Judicial District Court (Draper, 2012), where the application resides as of October 2012. Water right cases upon appeal proceed *de novo*, as provided for in the state constitution.

The State Engineer's ruling is not without precedent. Former State Engineer John D'Antonio cited vagueness as a reason in denying an application by Berrendo LLC, which sought to pump 6600 AFY of groundwater from the Fort Sumner area to near Santa Fe. He said, "this application lacked specificity in a number of key areas….Because the application was vague and overbroad, I was compelled to deny the application" (OSE, 2011a).

Surface and ground waters in the Rio Grande basin have been considered fully allocated since the Rio Grande Compact, ratified in 1939, quantified water deliveries to Texas (RGC, 1939). New surface diversions within the Rio Grande basin are not allowed (OSE, 2000).

However, groundwater withdrawals from the Rio Grande Underground Water Basin are possible. Permits may be granted only if applicants acquire the full amount of water needed to offset all effects on Rio Grande surface flow (OSE, 2000). Water right transfers statewide are approved only if they "can be made without detriment to existing water rights and are not contrary to conservation of water within the state and not detrimental to the public welfare of the state" (NMSA 72-5-23, 72-12-3(D)).

State law mandates that an application for permit be approved only if the proposed diversion does "not impair existing water rights from the source" (NMSA 72-12-3(E)). Many ranchers and other senior groundwater users in the San Agustin basin believe they would be harmed (OSE, 2011b).

For the standard 101,993 AFY analysis, model results predict an 11-foot regional decline in the water table in the basin after 40 years, 46 feet in the East Bolson block (99.97 feet using the Combination analysis). Twenty-eight of 1027 wells are projected to become dry, 27 in the East Bolson block.

Although the application states that any diversion would "not be allowed to jeopardize existing water rights or natural springs" (Augustin Plains Ranch, 2011), its OSE application (Appendix A) admits impairment may occur. Instead of avoiding it, it calls for offsets and replacement. "Any impairment of existing rights, in the Gila-San Francisco basin, the Rio Grande basin, or any other basin, that would be caused by the pumping applied for, will be offset or replaced" (Appendix A). This reduces modeled marketable water from 51,500 AFY to 38,653 AFY as of 2058.

One possible method to replace all San Agustin basin domestic and livestock water would be for Augustin Plains Ranch to transport water from its 37 wells to each existing well impacted by the project. Another possibility is to drill replacement wells. Each well is projected to be affected by pumping, but replacement, at Augustin Plains

Ranch expense, is possible for the 30 wells projected to become dry. Additional legal support may be needed to force an alternative water supply by a private entity upon other, more senior water right holders.

However, an 11-foot drop (46.1 feet in the East Bolson block, and up to 99.97 feet under the Combination analysis) in the water table may not constitute impairment at all. New Mexico law does not quantify impairment, traditionally deferring instead to the judgment of the State Engineer. In his denial, State Engineer Verhines stated that it is imperative that there be "an absence of harm to those in the basin area from which the water is taken" (OSE, 2012). What constitutes harm?

Case law provides guidance. In *Mathers v. Texaco, Inc.* (77 N.M. 239, 421 P.2d 771 (1966)), the New Mexico State Supreme Court held that state law preventing impairment does not necessarily mean additional permits for withdrawals from nonrechargeable aquifers are not allowed. New Mexico is unlike some other states which limit withdrawals to safe sustaining yield or anticipated annual rate of recharge (Grant, 1981). *Mathers* upheld a State Engineer plan to withdraw up to two-thirds of a local aquifer over 40 years, assuming water could still be economically withdrawn for at least some domestic uses after that time.

The model states that 1.76% of San Agustin basin water would be withdrawn over 40 years (1.56%-3.87% in sensitivity analysis), with up to 10.4% of the East Bolson block under the Combination analysis. With an 11-foot average decline in head, it should remain possible to withdraw water for domestic use. However, this assumes uniform levels throughout each block. Despite unconfined conditions of the basin, particularly of the bolson-fill (Basabilvazo, 1997), cone of depression effects are possible in the vicinity of wells. In addition, although *Mathers* concerns the non-rechargeable Ogallala aquifer, it states that beneficial use "of the waters in a *closed* or non-rechargeable basin requires giving to the use of such waters a time limitation" (77 N.M. 239, 421 P.2d 771, 1966) (emphasis added). The San Agustin basin, although rechargeable, is a closed basin.

Other numbers can be used to estimate impairment. A Critical Management Area (CMA) is a designated area in New Mexico where currently observed and/or predicted decreases in the water table exceed 2.5 feet per year. "Critical" areas must be evaluated to ensure that drawdowns do not exceed 250 feet over 40 years. These standards have been applied to the Middle Rio Grande Administrative Area (OSE, 2000), Tularosa Underground Water Basin (OSE, 1997), and elsewhere in the state. If applied to the San Agustin basin, no block would qualify as a CMA, having instead a predicted maximum 2.499 foot per year average drawdown (East Bolson block under the Combination analysis; the second-greatest drop is 1.97 feet per year for the same block in the 49.9 million acre-foot volume analysis). If any basin block becomes critical, then no subsequent groundwater appropriations would be granted. Appropriations may be granted in adjoining blocks, but only if drawdowns do not exceed 2 feet per year (D.B. Stephens, 2005).

Pumping must not be "detrimental to the public welfare of the state" (NMSA 72-12-3(D)). This is a subjective phrase. Does it refer to each area within the state including the San Agustin Plains, or the state generally? What exactly is welfare? Is any harm allowed?

According to MRGAA Administrative Guidelines (OSE, 2000), "the public welfare of the state is promoted only if there is certainty that a permittee will be able to obtain and transfer all necessary valid surface water rights to prevent adverse effects upon the flow of the Rio Grande." It may therefore be legally imperative that Augustin Plains Ranch offset or replace impaired water rights in the Rio Grande basin, as well as the Gila River and San Agustin basins. The ranch states it would do so (Appendix A).

Rather than harmful, pumping could be construed as providing a net benefit to state welfare. New Mexico currently imports an average of 94,200 AFY of San Juan-Chama Project water over the Continental Divide. This is unreliable due to Colorado River Compact delivery requirements to lower basin states (CRC, 1922) (Kelly, 2007). Rio Grande water passing through Albuquerque (at Central Avenue) averages 936,330 AFY (OSE, 2011b). In comparison, 38,653 AFY (as of 2058) would be a helpful addition, available to relieve pressure on the river from its various demands.

The State Engineer must deny the application if it is "contrary to conservation of water within the state" (NMSA 72-12-3(D)). The State Engineer has in at least one instance defined water conservation "as any action or technology that reduces the amount of water withdrawn from water supply sources, reduces consumptive use, reduces the loss or waste of water, improves the efficiency of water use, increases recycling and reuse of water, or prevents the pollution of water" (D.B. Stephens, 2003). In the Tularosa Underground Water Basin, conservation requirements are met if applications "ensure the highest and best technology practically available will be utilized to ensure conservation of water to the maximum extent possible" (OSE, 1997). The Socorro-Sierra Regional Water Plan (D.B. Stephens, 2003) echoes that sentiment. It and the Southwest New Mexico Regional Water Plan (D.B. Stephens, 2005) were developed in large part to promote water conservation in these regions (Figure 17).

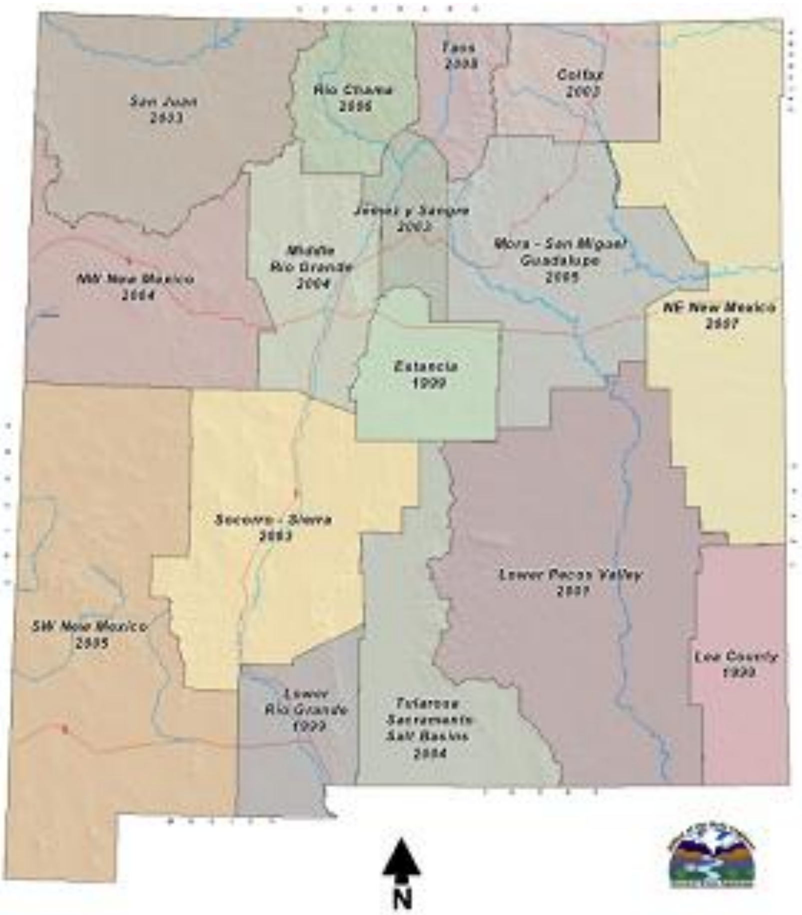


Figure 17. New Mexico Interstate Stream Commission water planning regions. Image source: www.ose.state.nm.us/isc_regional_plans.html.

Water rights within New Mexico can be condemned to an extent. Counties are empowered to condemn water rights if for the purpose of developing a "county water supply system" (NMSA 72-4-2). Municipalities also have condemnation powers (NMSA 3-27-2(A)(1)). However, there is no extant law allowing the state to condemn valid water rights.

Considering that Catron and Socorro Counties, as well as several local and state organizations are protestants to the application (OSE, 2010), it is unlikely they would condemn valid local water rights. In contrast, counties and municipalities are allowed to acquire available water rights and retain them unused for up to 40 years. This is due to

New Mexico state law, which states that certain public entities, including counties and municipalities, are allowed to acquire water rights to accommodate their reasonable development needs for a period of 40 years, starting from the date of application for an appropriation or change of place or purpose of use that is pursuant to a water development plan (NMSA 72-1-9). Although regional water plans have been developed (D.B. Stephens, 2003) (D.B. Stephens, 2005), there appear to be no other water plans in these regions approved by the Interstate Stream Commission.

There would be easement concerns. Any pipeline would likely cross the lands of several public, private, and Pueblo entities (Figure 18), including those of application protestants. Along the stated pipeline route (Figure 13), such protestants include the U.S. Department of Agriculture, Middle Rio Grande Conservancy District, New Mexico Commissioner of Public Lands, New Mexico Interstate Stream Commission, several Pueblos, Socorro County, and private landowners (OSE, 2010). The ranch would need to overcome landowner opposition through judicial means. If this occurs, the state may authorize a ranch representative as a condemnor to acquire needed easements, if property is sought to be appropriated for public use (NMSA 19-7-57, 42A-1-1 to 42A-1-33).

Securing easements over Pueblo and other federally-titled land may be more problematic. The ruling of *Plains Electric Generation & Transmission Cooperative v. Pueblo of Laguna*, 542 F.2d 1375 (10th Cir. 1976), affirms 25 U.S.C. § 323 as to the authority of the Secretary of the Interior over granting of rights-of-way over Pueblo lands.

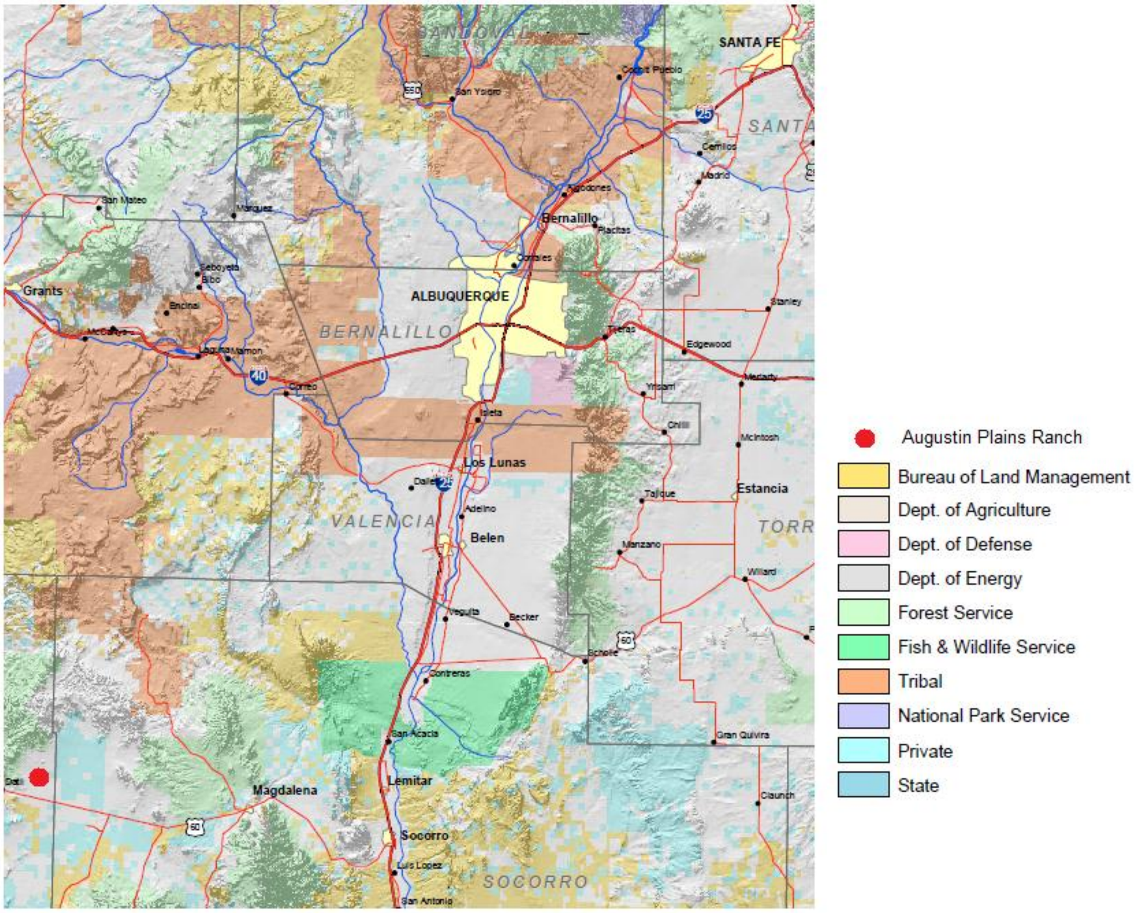


Figure 18. Land ownership of central New Mexico.
Image source: Bureau of Land Management, 2007.

14.1 Environmental Considerations

There is opposition to the application due to concerns over possible pumping effects on Rio Grande silvery minnow, Alamosa springsnail, Chiricahua leopard frog, other species, as well as other environmental issues. As a result, the New Mexico State Department of Game and Fish, Gila Conservation Coalition, and others have joined in protesting the application (OSE, 2010).

One of the State Engineer's mandates is to ensure that allocated water is put to beneficial use. Environmental purposes are proposed in the application (Appendix A). Not elaborated upon, this would likely be achieved through the addition of water to the

Rio Grande, which presumably would benefit endemic species such as the minnow. In 1998, former New Mexico Attorney General Tom Udall opined that instream flow is a beneficial use, at least for Endangered Species Act purposes (New Mex. Attorney Gen. Op. No. 98-01).

Endangered silvery minnow (Figure 19) designated critical habitat is the Middle Rio Grande between Cochiti Dam and Elephant Butte Reservoir (Endangered and Threatened Wildlife and Plants, Rio Grande, 2010). If a pipeline is to be built terminating near Socorro (Appendix C) or anywhere else south of any habitat, and consumptive use upstream is allowed, then minnow habitat would likely be subjected to less water. Section 7(a)(2) of the Endangered Species Act of 1973 requires the federal government to not take any action which might jeopardize the continued existence of a threatened or endangered species or adversely impact any designated critical habitat for such species.

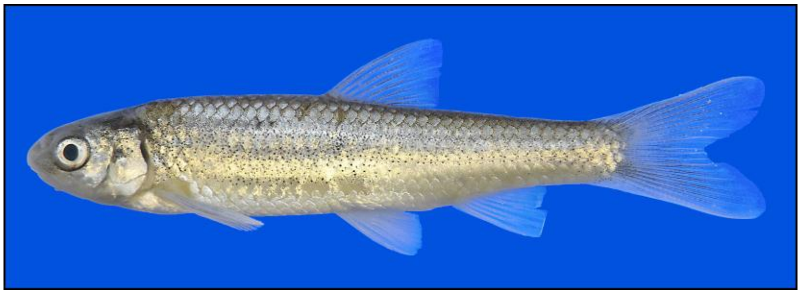


Figure 19. Rio Grande Silvery Minnow (*Hybognathus amarus*) (adult maximum size to scale). Image source:http://www.bio.txstate.edu/~tbonner/txfishes/hybognathus%20 amarus.htm.

On the other hand, a pipeline to Santa Fe (Figure 13), as Augustin Plains Ranch has previously expressed interest in (Augustin Plains Ranch, 2011), may help the minnow, but only to the extent this water is not consumed for other uses. It should be kept in mind, however, that the minnow could be hurt long-term if Augustin Plains Ranch ever decreases pumping yet upstream consumptive use does not decline at the same rate.

Projected decreases in Alamosa Creek flow may affect critical habitat for the endangered Alamosa springsnail. It is found only at Alamosa Warm Springs, a Socorro County thermal complex of five individual springheads that flow together. Its recovery plan states that "any activity that would interrupt the flow of water from these springs, lessen the quantity of both the aquatic and terrestrial habitat, or degrade the water quality of the habitats inhabited by [this] species could threaten [its] existence" (Burton and Metzinger, 1994). Critical habitat for the threatened Chiricahua leopard frog also includes the springs, as well as a nearby one-mile stretch of Alamosa Creek (Endangered and Threatened Wildlife and Plants, 2012b).

Concern exists over potential reduced discharge to the Gila River basin, predicted to be 1620 AFY as of 2058. This would affect endangered and threatened fish. However, the ranch states impaired water rights here, as elsewhere, would be offset or replaced (Appendix A), likely through acquisition of existing rights. In addition, it is possible that little hydrologic connection exists with this basin.

Like the Rio Grande basin, the Gila River basin in New Mexico is considered fully appropriated. Apportionment between Arizona and New Mexico is governed by *Arizona v. California*, 376 U.S. 340 (1964), which incorporated the earlier Globe Equity Decree No. 59 (1935). Total consumptive use is limited to 136,620 acre-feet during a 10-year period in the Gila River (above the Virden Valley) basin. Consumptive water rights cannot be transferred between it and the San Francisco River subbasin (D.B. Stephens, 2005).

The Colorado River Basin Project Act, 43 U.S.C. 1524 (1968), authorized the Central Arizona Project (CAP). Section 304 authorizes the Secretary of the Interior to contract with New Mexico water users in the Gila basin (including the San Francisco subbasin) to amounts up to 180,000 acre-feet of consumptive use over any 10-year period. This is over and above consumptive use previously authorized. In addition, it approves river development in the form of a dam or suitable alternative (D.B. Stephens, 2005).

This act was amended by the 2004 Arizona Water Settlements Act, a result in part due to litigation from the United States and Arizona plaintiffs seeking judicial relief from upper Gila River basin water users. It provides that in exchange for reduced water usage and lowering New Mexico CAP water to 140,000 acre-feet of consumptive use over 10 years (14,000 acre-feet in any one year), $66-$128 million (available beginning in 2012) will be dispersed from the Lower Colorado Basin Development Fund to build New Mexico's CAP unit, or up to $66 million to fund water projects and activities (D.B. Stephens, 2005).

Regarding OSE Application No. RG-89943, it may be possible, with state support, to debit discharge decreases to the 14,000 acre-foot annual allowance. New Mexico has currently made little progress in developing its entitlement.

The 1972 amendments to the Federal Water Pollution Control Act, commonly known as the Clean Water Act, are relevant. Its objective is to "restore and maintain the chemical, physical and biological integrity" of the waters of the United States (33 U.S.C. § 1251(a) (2002)) through regulating the discharge of pollutants. Section 402 provides the statutory basis for the National Pollutant Discharge Elimination System (NPDES) permit program. Construction activities with over an acre of disturbance and which affect waters of the United States require a permit. Considering that Augustin Plains Ranch's proposed pipeline route (Figure 13) crosses and parallels the Rio Grande and other streams, a permit appears necessary. Common mandates include submission of an NPDES Application or Notice of Intent, as well as development, implementation, and maintenance of a Stormwater Pollution Prevention Plan. The Environmental Protection Agency develops and administers the program in New Mexico (EPA, 2012).

In addition, a Section 404 Dredge and Fill Permit and Section 10 Rivers and Harbors Act Permit may be required from the U.S. Army Corps of Engineers. Issuance of either of these permits is a "major" Federal Action that may trigger a NEPA review. A Section 404 permit is required if construction is planned in navigable waters of the United States, or if discharge, dredged, or fill material is anticipated into waters of the United States. A Section 10 permit, authorized by the Rivers and Harbors Appropriation Act of 1899, covers construction, excavation, or deposition of materials in, over, or under waters of the United States, as well as any work which would affect the condition of these waters, including wetlands.

15.0 Summary and Suggestions for Future Work

Augustin Plains Ranch pumping would likely be sustainable over 40 years. According to model results, basin-wide water levels drop an average of 11 feet (1.76% volume), 46 feet (4.78% volume) in the East Bolson (east plains) block where the ranch is located. Twenty-eight of 1027 wells are projected to become dry, 27 in the East Bolson block. Results show a significant impact on groundwater discharge to the Alamosa Creek watershed, decreasing from 37,179 AFY to 25,953 AFY. Discharge to the Gila watershed is impacted to a lesser degree, decreasing from 55,296 AFY to 53,676 AFY.

Sensitivity analyses utilize numbers considered possible by other studies, *viz.* recharge, hydraulic conductivity, volume, climate change, and water price figures. Basin-wide groundwater volume decreases 1.56-3.87%. Water levels decrease 10.6-24.7 feet. East Bolson block water volume decreases 4.02-10.35%, or 38.8-99.97 feet. Subsurface discharge to the Alamosa Creek and Gila River watersheds decreases 21.7-73.7% and 1.67-7.86%, respectively.

Most if not all groundwater right holders in the San Agustin basin would thus be affected. New Mexico utilizes the prior appropriation doctrine which protects existing water rights. However, any decision as to whether prohibited ‘harm’ would occur is left to the discretion of the State Engineer. All blocks in all analyses would not exceed Critical Management Area thresholds, which have been applied by the OSE to other areas in the state to help evaluate possible impairment (OSE, 1997) (OSE, 2000).

Pumping also must not be contrary state public welfare. This may be promoted only if all necessary valid water rights are acquired to prevent adverse streamflow effects

(OSE, 2000). Uncertainty remains about the ability of the ranch to replace water or to obtain sufficient offsets upstream of several endangered or threatened species, particularly the Alamosa springsnail which resides solely at Alamosa Warm Springs.

Pumping would exact costs. Endangered and threatened species such as the springsnail and Chiricahua leopard frog may be harmed by decreases in groundwater discharge. Assuming no offsets or replacement water, endangered species costs are $12.4 million. Costs to basin residents result from a need to drill some wells to a greater depth. However, they indirectly benefit from ranch-related economic activity. Net costs to basin residents are $587,156. Costs to the ranch include well, pipeline, and infrastructure construction, operations, maintenance, irrigation, and more. Benefits to the ranch come primarily through marketing water elsewhere, such as for municipal or irrigation use. Excluding taxes, its net present value of net income is projected at $1.72 billion ($1.43-$1.88 billion in sensitivity analysis).

Model limitations occur due to limited data. Inferences must be made due to little to no hydraulic conductivity, saturated thickness, storativity, and transmissivity empirical data concerning the Datil aquifer. There is limited data for the bolson-fill aquifer. Here, volume, six specific yield, saturated thickness data (Myers et al., 1994), and seven transmissivity measurements (Basabilvazo, 1997) are available, from which hydraulic conductivity and Datil characteristics can be estimated.

Due to these uncertainties, model sensitivity analyses exist. Some compensate for uncertainty regarding the amount of groundwater recharge and discharge (Blodgett and Titus, 1973), while another factors for possible climate change. One sensitivity analysis accounts for differing volume readings. Myers et al. (1994) estimate the total volume of water in the bolson-fill aquifer to be 62.4 million acre-feet (1994), but the Southwest New Mexico Regional Water Plan (D.B. Stephens, 2005) estimates the volume of groundwater in the *entire* basin to be 49,908,000 acre-feet. This is another basin characteristic that should be further investigated.

Relatively few geologic core samples in the San Agustin Plains are available. These indicate a wide variability regarding the placement and thickness of bolson-fill layers, from 200-4600 feet thick. Having moderate to large well yields, but interspersed with volcanic rocks ranging from rhyolite to andesite having significantly lower yields (Myers et al. 1994) (Basabilvazo, 1997), it is important to know geologic profiles (Myers et al. 1994) (Basabilvazo, 1997) if planning large-scale water development.

The basin's relationship with the Alamosa Creek watershed is little understood. Blodgett and Titus (1973) and others present evidence suggesting southward leakage, but this has not been investigated in detail until the presently ongoing San Agustin and Alamosa Creek Study being performed by the state Bureau of Geology and Mineral Resources Aquifer Mapping Program.

A similar lack of understanding exists concerning the basin's hydrogeologic relationship with the Gila River watershed (Basabilvazo, 1997), particularly concerning hydraulic conductivity. An aquifer study here would be beneficial. Also, a complete and available adjudication of water rights for the basin and Alamosa Creek basin would be helpful.

In addition, basin-specific evapotranspiration and infiltration measurements within plant communities, ranging from grasslands to alpine forests, would be of use. Finally, regarding the endangered Alamosa springsnail, investigations could be conducted into the possibility of creating artificial habitat or sources of water, in case of pumping, drought, or other effects on the sensitive Alamosa Warm Springs (Burton and Metzinger, 1994).

Bibliography

Allen, Bruce D., 2005. Ice age lakes in New Mexico. New Mexico's ice ages. New Mexico Museum of Natural History and Science Bulletin 28, p. 107-113.

Al-Sabbry, Mohammed, M., Harris, DeVerle, and Fox, Roger, 2002. An economic assessment of ground water recharge in the Tucson Basin. Journal of the American Water Resources Association, 38, p. 119-131.

Anderson, Orin J., Jones, Glen E., and Green, Greg N., 1997. Geologic Map of New Mexico. New Mexico Bureau of Mines and Mineral Resources Open-File Report 97-52, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Augustin Plains Ranch, LLC, 2011. Water Resource Development Project: Supporting the Economic Development, Agricultural, and Environmental Needs of New Mexico.

Basabilvazo, George T., 1997. Water-Resources Investigations Report 96-4258, U.S. Geological Survey. Prepared in Cooperation with New Mexico Office of the State Engineer.

Berrens Robert P., Bohara, Alok K., Silva, Carol L., Brookshire, David S., and Mckee, Michael, 2000. Contingent valuation for New Mexico instream flows: with tests of scope group-size reminder and temporal reliability. Journal of Environmental Management 58, p. 73-90.

Blodgett, Daniel D., and Titus, Frank B., 1973. Hydrogeology of the San Agustin Plains, New Mexico. New Mexico Bureau of Mines and Mineral Resources Open-File Report 51, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Brooks, Kenneth N., Ffolliott, Peter F., Gregersen, Hans M., and DeBano, Leonard F. Hydrology and the Management of Watersheds (3rd ed.): Ames, IA, Iowa State University Press.

Brown, F. Lee, 2007. Market Prices as Measures of Water Scarcity in New Mexico and the West, in: C.O. Klett (Ed.) Beyond the Year of Water: Living within our Water Limitations (Albuquerque, NM: New Mexico Water Resources Research Institute).

Brown, F. Lee, 2008. Evolution of Markets for Water Rights and Bulk Water. 53rd Annual Water Conference Proceedings, New Mexico Water Resources Research Institute, Albuquerque, New Mexico.

Burton, Gerald L., and Metzinger, Bernadine, 1994. Socorro and Alamosa Springsnail Recovery Plan. U.S. Fish and Wildlife Service and New Mexico Ecological State Office, Albuquerque, New Mexico.

Byrd, William R., McCoy, Ron G., and Wint, David D., 2004. A success guide for pipeline integrity management. Pipeline and Gas Journal November 2004, p. 24-26.

Caraway Drilling (Caraway), Pie Town, New Mexico, 2012. Personal communication on 8/7/2012.

Cartron, Jean-Luc E., Cook, Rosamonde R., Garber, Gail L., and Madden, Kristin K., 2002. Nesting and productivity of ferruginous hawks in two areas of central and western New Mexico, 1999-2000. The Southwestern Naturalist 47(3), p. 482-485.

Clapp, R., and Hornberger, G. Empirical equations for some hydraulic properties. Water Resources Research 14(4), p. 601-604.

Colorado River Compact (CRC), 1922. States of Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming.

Cynoyia, T. 2008. Personal communication with Albuquerque Bernalillo County Water Utility Authority staff member on May 10, 2008.

Daniel B. Stephens and Associates, Inc. (D.B. Stephens), 2003. Socorro-Sierra Regional Water Plan. Prepared for Socorro Soil and Water Conservation District.

Daniel B. Stephens and Associates, Inc. (D.B. Stephens), 2005. Southwest New Mexico Regional Water Plan. Prepared for Southwest New Mexico Regional Water Plan Steering Committee.

Dortignac, Edward J., 1960. Water yield from pinyon-juniper woodland. In: Warnock, Barton H. and Gardner J.L., eds. Water yield in relation to environment in the southwestern United States. Alpine, TX: American Association for the Advancement of Science, Rocky Mountain Division, Committee on Desert and Arid Zone Research: 16-27.

Draper, John B. 2012, April 9. State of New Mexico Catron County Seventh Judicial District Court in the Matter of the Application to the New Mexico State Engineer by Augustin Plains Ranch, LLC for Permit to Appropriate Groundwater in the Rio Grande Underground Water Basin of New Mexico. Albuquerque Journal. URL http://legals.abqjournal.com/legals/show/279214. Accessed 4/20/2012.

Endangered and Threatened Wildlife and Plants; Designation of Revised Critical Habitat for Southwestern Willow Flycatcher; Proposed Rule, 76 Fed Reg. 50542 (2011) (to be codified at 50 CFR pt. 17).

Endangered and Threatened Wildlife and Plants; Endangered Status and Designations of Critical Habitat for Spikedace and Loach Minnow; Final Rule, 77 Fed. Reg. 10810

(2012a) (to be codified at 50 CFR pt. 17).

Endangered and Threatened Wildlife and Plants; Listing and Designation of Critical Habitat for the Chiricahua Leopard Frog; Final Rule, 77 Fed. Reg. 16324 (2012b) (to be codified at 50 CFR pt. 17).

Endangered and Threatened Wildlife and Plants; Listing Gila Chub as Endangered with Critical Habitat; Final Rule, 70 Fed. Reg. 66664 (2005) (to be codified at 50 CFR pt. 17).

Endangered and Threatened Wildlife and Plants; Reclassification of the Gila Trout (Oncorhynchus gilae) from Endangered to Threatened; Special Rule for Gila Trout in New Mexico and Arizona, 71 Fed. Reg. 40657 (2006) (to be codified at 50 CFR pt. 17).

Endangered and Threatened Wildlife and Plants; Rio Grande Silvery Minnow (Hybognathus amarus) Recovery Plan, First Revision, 75 Fed. Reg. 7625 (2010) (to be codified at 50 CFR pt. 17).

Freeze, Alan R., and Cherry, John A., 1979. Groundwater: New Jersey, Prentice Hall.

Griffith, Glen E., Omermik, James M., McGraw, Maryann M., Jacobi, Gerald Z., Canavan, Christopher M., Schrader, T. Scott, Mercer, David, Hill, Robert, and Moran, Brian C., 2006. Ecoregions of New Mexico (color poster with map, descriptive text, summary tables, and photographs). Reston, Virginia: U.S. Geological Survey (map scale 1:1,400,000).

Hawley, John W., 1993. Geomorphic Setting and Late Quarternary History of Pluvial-Lake Basins in the Southern New Mexico Region. New Mexico Bureau of Mines and Mineral Resources Open-File Report 391, New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Hendricks, David M., 1985. Arizona Soils. University of Arizona College of Agriculture, Tucson, AZ.

Intergovernmental Panel on Climate Change, 2007. Fourth Assessment Report: Climate Change 2007.

Johnson, Peggy, 1990. A Paleohydrologic and Paleoclimatic Reconstruction for the San Agustin Basin, New Mexico, Based on Oxygen—l8 Variation in Ostracode Shells. New Mexico Institute of Mining and Technology, Socorro, New Mexico.

Jones, Celina A., 2002. The administration of the Middle Rio Grande Basin, 1956-2002. University of New Mexico Natural Resources Journal 42, p. 939-968.

Kelly, Susan, 2007. Modeling reservoir storage scenarios by consensus. University of New Mexico School of Law Natural Resources Journal 47, p. 653-674.

Lillywhite, Jay and Starbuck, C. Meghan, 2008. The Economic Impact of New Mexico's Oil and Gas Industry. Prepared for Brothers and Co.

Loomis, John B. and White, Douglas S., 1996. Economic benefit of rare and endangered species: summary and meta-analysis. Ecological Economics 18, p. 197-206.

McAllister, E.W., 2002. Pipeline Rules of Thumb Handbook. First Edition. Butterworth-Heinemann. Woburn, MA.

Middle Rio Grande Water Assembly (Water Assembly), 2004. Middle Rio Grande Regional Water Plan.

Myers, Robert G., Everheart, J.T., and Wilson, C.A., 1994. Geohydrology of the San Agustin Basin, Alamosa Creek Basin upstream from Monticello Box, and Upper Gila Basin in parts of Catron, Socorro, and Sierra Counties, New Mexico. Water-Resources Investigations Report 94-4125, U.S. Geological Survey. Prepared in cooperation with New Mexico Office of the State Engineer.

New Mex. Att'y Gen. Op. No. 98-01 (March 27, 1998). URL lawschool.unm.edu/instream/powerpoints/Opinion98-01.pdf. Accessed 12/4/11.

New Mexico Office of the State Engineer (OSE), 1997. Tularosa Underground Water Basin Administrative Criteria for the Alamogordo-Tularosa Area.

New Mexico Office of the State Engineer (OSE), 2000. Middle Rio Grande Administrative Area Guidelines for Review of Water Right Applications.

New Mexico Office of the State Engineer (OSE), 2008. New Mexico Water Rights Reporting System. URL http://www.ose.state.nm.us/waters_db_index.html. Accessed 2/15/2008.

New Mexico Office of the State Engineer (OSE), 2010. Hearing No. 09-096, OSE File No. RG-89943. Before the New Mexico State Engineer: In the Matter of the Application by Augustin Plains Ranch, LLC for Permit to Appropriate Groundwater in the Rio Grande Underground Water Basin of New Mexico.

New Mexico Office of the State Engineer (OSE), 2011a. New Mexico State Engineer Denies Proposed Berrendo Pipeline. Press release dated 2/9/2011.

New Mexico Office of the State Engineer (OSE), 2011b. New Mexico Water Rights Reporting System. URL http://www.ose.state.nm.us/waters_db_index.html. Received upon request 9/20/2011.

New Mexico Office of the State Engineer (OSE), 2012. New Mexico State Engineer Denies Augustin Plains Ranch LLC Application. Press release dated 4/2/2012.

Osborn, H.B., and Laursen, E.M., 1973. Thunderstorm runoff in southeastern Arizona. J. Hydraulics Div., ASCE, 99(7), 1129-1145.

Parkinson, 1999. Updated Project Cost Estimates for CIP. Memo dated 10/4/1999.

Passell, Howard D., Tidwell, Vincent C., Conrad, Stephen H., Thomas, Richard P., and Roach, Jesse, 2003. Cooperative Water Resources Modeling in the Middle Rio Grande Basin.

Rio Grande Compact (RGC), Public Law No. 76-96, 53 Stat. 785 (1939) (signed by Colorado, New Mexico, and Texas 18 Mar. 1938).

Roybal, F. Eileen, 1991. Ground-Water Resources of Socorro County, New Mexico. Water-Resources Investigations Report 89-4083, U.S. Geological Survey. Prepared in cooperation with New Mexico State Engineer Office and New Mexico Bureau of Mines and Mineral Resources. .

Seager, Richard, Ting, Mingfang F., Held, Isaac M., Kushnir, Yochanan, Lu, Jian, Vecchi, Gabriel, Huang, Huei-Ping, Harnik, Nili, Leetmaa, Ants, Lau, Ngar-Cheung, Li, Cuihua, Velez, Jennifer, and Naik, Naomi, 2007. Model projections of an imminent transition to a more arid climate in southwestern North America. Science 316, p. 1181-1184.

Shomaker, John W., Galemore, Sherry B., and Hagan, Laura B., 2002. Assessment of the New Mexico Office of the State Engineer U.S. Geological Survey Cooperative Groundwater Level Monitoring Program.

South Central Texas Regional Water Planning Group (SCTRWPG), 2010. South Central Texas Regional Water Planning Area: 2011 Regional Water Plan. Volume II: Technical Evaluations of Water Management Strategies.

Stearns, Charles E., 1962. Geology of the northern half of the Pelona Quadrangle, Catron County, New Mexico. New Mexico Bureau of Mines and Mineral Resouruces 78.

Stephens, D.B., and Knowlton, Robert, Jr., 1986. Soil water movement and recharge through sand at a semiarid site in New Mexico: Water Resources Research 22(6), 881-889.

Svoboda, Mark D., 2012. U.S. Drought Monitor: September 25, 2012. URL http://droughtmonitor.unl.edu. Accessed 10/3/2012.

Tidwell, Vincent C., Sandia National Laboratories, 2008. Personal communications

February-April, 2008.

Turner, Willam M., 2011. Personal communication on 12/15/2011.

U.S. Bureau of Labor Statistics (BLS), 2012. CPI Inflation Calculator. URL http://www.bls.gov/data/inflation_calculator.htm. Accessed 4/6/2012.

U.S. Bureau of Land Management (BLM), 2007. Socorro Field Office Resource Management Plan Revision and Record of Decision. URL http://www.blm.gov/nm/st/en/fo/Socorro_Field_Office/socorro_prmp.html. Accessed 11/15/2010.

U.S. Bureau of Reclamation (USBR), 2006. Final Boise/Payette Water Storage Assessment Report.

U.S. Bureau of the Census (U.S. Census), 2010. American FactFinder. URL http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml. Accessed 9/5/2011.

U.S. Department of Agriculture (USDA) Natural Resource Conservation Service, 2005. Irrigation Water Requirements: Crop Summary Data—Datil, NM. URL http://www.nm.nrcs.usda.gov/technical/fotg/section-1/consumptive-use/datil-cu.pdf. Accessed 12/9/2011.

U.S. Department of Agriculture (USDA), 2007. Census of Agriculture—County Data—New Mexico. URL http://www.agcensus.usda.gov/Publications/2007/index.asp. Accessed 12/11/2011.

U.S. Department of Agriculture (USDA) Economic Research Service, 2010. U.S. Wheat Production Costs and Returns per Planted Acre, Excluding Government Payments, 2009-2010. URL http://cta.ornl.gov/bedb/feedstocks/Grains/Wheat_Production_Costs_and_Returns_by_Region.xls. Accessed 12/11/2011.

U.S. Environmental Protection Agency (EPA), 2001. Public Health and Environmental Protection Standards for Yucca Mountain, NV. Final Background Information Document for 40 CFR 197. Appendix 4: Well Drilling and Pumping Costs.

U.S. Environmental Protection Agency (EPA), 2011. National Pollutant Discharge Elimination System: EPA Construction General Permit. URL http://cfpub.epa.gov/npdes/stormwater/cgp.cfm. Accessed 1/3/2012.

U.S. Fish and Wildlife Service New Mexico Ecological Services Field Office (USFWS), 1996. Reintroduction of the Mexican Wolf within its Historic Range in the Southwestern United States: Final Environmental Impact Statement.

U.S. Geological Survey (USGS), 2011. USGS Surface-Water Annual Statistics for New Mexico. URL http://waterdata.usgs.gov/nm/nwis/annual/?referred_module=sw.

Accessed 12/22/2011.

U.S. Global Change Research Program (USGCRP), 2009. Global climate change impacts in the United States. Cambridge, MA: Cambridge University Press.

U.S. Office of Management and Budget (OMB), 1992. Circular No. A-94 Revised. Transmittal Memo No. 64. October 29, 1992.

U.S. National Oceanic and Atmospheric Administration (NOAA), 2012. IPS – Record of Climatological Observations. URL http://www.wrcc.dri.edu/summary/Climsmnm.html. Accessed 1/9/2012.

Weiss, Jeremy L., 2007. Climate Change Projections for the United States. URL http://www.geo.arizona.edu/dgesl/research/regional/projected_US_climate_change/projected_US_climate_change.htm. Accessed 10/27/2012.

Woodhouse, Betsy, 2008. Approaches to ET measurement. Southwest Hydrology 7, p. 20-21.

Appendix A

Application No. RG-89943 – Amended

NOTICE is hereby given that on October 12, 2007, and on May 5, 2008, Augustin Plains Ranch, LLC, c/o Montgomery & Andrews, P.A., P. O. Box 2307, Santa Fe, New Mexico 87504, filed Application No. RG-89943 with the STATE ENGINEER for Permit to Appropriate Underground Water in the Rio Grande Basin.

The applicant proposes to drill 37 wells, all with 20-inch casing, and all to a depth not to exceed 3,000 feet in order to divert and consumptively use 54,000 acre-feet of ground water per annum for domestic, livestock, irrigation, municipal, industrial, commercial, environmental, recreational, subdivision and related, replacement and augmentation purposes of use. The applicant further proposes to provide water by pipeline to supplement or offset the effects of existing uses and for new uses at the proposed places of use described below in order to reduce the current stress on the water supply of the Rio Grande Basin. Any impairment of existing rights, in the Gila-San Francisco Basin, the Rio Grande Basin, or any other basin, that would be caused by the pumping applied for, will be offset or replaced.

The applicant proposes to irrigate 120 acres of land within a 1,290-foot radius of each of the 37 proposed wells listed below for a total of 4,440 acres of irrigated land within the boundaries of Augustin Plains Ranch, also described below.

The proposed well locations are on land owned by the applicant in Catron County:

RG-89943-POD1: 34 deg., 13 min, 29.779 sec. N lat., 107 deg., 43 min, 13.037 sec. W long.;
RG-89943-POD2: 34 deg., 12 min, 58.958 sec. N lat., 107 deg., 43 min, 12.778 sec. W long.;
RG-89943-POD3: 34 deg., 12 min, 58.177 sec. N lat., 107 deg., 43 min, 47.907 sec. W long.;
RG-8994- POD4: 34 deg., 12 min, 35.848 sec. N lat., 107 deg., 43 min, 13.644 sec. W long.;
RG-89943-POD5: 34 deg., 12 min, 36.275 sec. N lat., 107 deg., 43 min, 47.142 sec. W long.;
RG-89943-POD6: 34 deg., 12 min, 6.665 sec. N lat., 107 deg., 43 min, 48.654 sec. W long.;
RG-89943-POD7: 34 deg., 12 min, 5.993 sec. N lat., 107 deg., 43 min, 13.036 sec. W long.;
RG-89943-POD8: 34 deg., 10 min, 1.772 sec. N lat., 107 deg., 44 min, 16.442 sec. W long.;
RG-89943-POD9: 34 deg., 10 min, 0.982 sec. N lat., 107 deg., 44 min, 51.761 sec. W long.;
RG-89943-POD10: 34 deg., 9 min, 31.664 sec. N lat., 107 deg., 44 min, 48.998 sec. W long.;
RG-89943-POD11: 34 deg., 9 min, 32.342 sec. N lat., 107 deg., 44 min, 18.662 sec. W long.;
RG-89943-POD12: 34 deg., 9 min, 7.181 sec. N lat., 107 deg., 45 min, 18.499 sec. W long.;
RG-89943-POD13: 34 deg., 9 min, 7.200 sec. N lat., 107 deg., 45 min, 51.100 sec. W long.;
RG-89943-POD14: 34 deg., 8 min, 40.493 sec. N lat., 107 deg., 45 min, 50.229 sec. W long.;
RG-89943-POD15: 34 deg., 8 min, 40.850 sec. N lat., 107 deg., 45 min, 17.644 sec. W long.;
RG-89943-POD16: 34 deg., 8 min, 17.728 sec. N lat., 107 deg., 44 min, 15.850 sec. W long.;
RG-89943-POD17: 34 deg., 8 min, 17.186 sec. N lat., 107 deg., 44 min, 49.916 sec. W long.;
RG-89943-POD18: 34 deg., 7 min, 43.544 sec. N lat., 107 deg., 44 min, 51.204 sec. W long.;
RG-89943-POD19: 34 deg., 7 min, 43.653 sec. N lat., 107 deg., 44 min, 16.864 sec. W long.;
RG-89943-POD20: 34 deg., 8 min, 15.697 sec. N lat., 107 deg., 45 min, 17.752 sec. W long.;
RG-89943-POD21: 34 deg., 8 min, 15.832 sec. N lat., 107 deg., 45 min, 50.787 sec. W long.;
RG-89943-POD22: 34 deg., 7 min, 44.814 sec. N lat., 107 deg., 45 min, 52.419 sec. W long.;
RG-89943-POD23: 34 deg., 7 min, 44.043 sec. N lat., 107 deg., 45 min, 18.309 sec. W long.;
RG-89943-POD24: 34 deg., 7 min, 21.076 sec. N lat., 107 deg., 45 min, 18.892 sec. W long.;
RG-89943-POD25: 34 deg., 7 min, 20.532 sec. N lat., 107 deg., 45 min, 53.118 sec. W long.;
RG-89943-POD26: 34 deg., 7min, 21.630 sec. N lat., 107 deg., 46 min, 19.041 sec. W long.;
RG-89943-POD27: 34 deg., 6 min, 52.325 sec. N lat., 107 deg., 45 min, 20.948 sec. W long.;
RG-89943-POD28: 34 deg., 7 min, 22.957 sec. N lat., 107 deg., 44 min, 15.086 sec. W long.;
RG-89943-POD29: 34 deg., 7 min, 21.062 sec. N lat., 107 deg., 44 min, 49.269 sec. W long.;
RG-89943-POD30: 34 deg., 6 min, 53.305 sec. N lat., 107 deg., 44 min, 47.283 sec. W long.;

RG-89943-POD31: 34 deg., 6 min, 53.777 sec. N lat., 107 deg., 44 min, 16.047 sec. W long.;
RG-89943-POD32: 34 deg., 6 min, 32.564 sec. N lat., 107 deg., 44 min, 14.548 sec. W long.;
RG-89943-POD33: 34 deg., 6 min, 32.477 sec. N lat., 107 deg., 44 min, 48.784 sec. W long.;
RG-89943-POD34: 34 deg., 7 min, 45.577 sec. N lat., 107 deg., 46 min, 20.103 sec. W long.;
RG-89943-POD35: 34 deg., 8 min, 14.721 sec. N lat., 107 deg., 46 min, 17.697 sec. W long.;
RG-89943-POD36: 34 deg., 10 min, 1.553 sec. N lat., 107 deg., 45 min, 15.118 sec. W long.; and
RG-89943-POD37: 34 deg., 9 min, 30.586 sec. N lat., 107 deg., 45 min, 15.791 sec. W long.

The proposed wells are generally located north and south of U.S. Highway 60 between the Catron-Socorro County Line and Datil, New Mexico. All of the wells are located within the exterior boundaries of the Augustin Plains Ranch, described below.

The proposed places of use are: (1) Within the exterior boundaries of Augustin Plains Ranch ("Ranch"), which is located in Catron County, New Mexico; and (2) any areas within Catron, Sierra, Socorro, Valencia, Bernalillo, Sandoval, and Santa Fe Counties that are situated within the geographic boundaries of the Rio Grande Basin in New Mexico. The location of the Ranch is described as follows:

Township 1 South, Range 9 West, NMPM:
S1/2 Section 1; Section 12; Section 13; Section 14; Section 15; Section 16; Section 20; Section 21; Section 22; Section 23; Section 24; Section 27; Section 28; Section 29; Section 32; Section 33; and Section 34; all in Catron County.

Township 2 South, Range 9 West, NMPM:
NW1/4 SW1/4 Section 1; Lots 1, 2, 3, 4, S1/2 N1/2, and S1/2 Section 2; Section 3; Section 4; S1/2 SE1/4 Section 7; E1/2, S1/2 SW1/4 Section 8; Section 10; Section 14; Section 15; Section 16; Section 17; Lot 1, NE1/4 NW1/4, N1/2 NE1/4, SE1/4 NE1/4, S1/2 S1/2, and NE1/4 SE1/4 Section 18; all that portion of Section 21 which lies north of old U.S. Highway 60 except the NE1/4 NE1/4 NE1/4 and the N1/2 NW1/4; N1/2, N1/2 S1/2, and SE1/4 SE1/4 Section 22; Section 23; and NE1/4 NE1/4 Section 26; all in Catron County.

Any person or other entity shall have standing to file an objection or protest if the person or entity objects that the granting of the application will: (1) Impair the objector's water right; or (2) Be contrary to the conservation of water within the state or detrimental to the public welfare of the state, provided that the objector shows how he will be substantially and specifically affected by the granting of the application.

A valid objection or protest shall set forth the grounds for asserting standing and shall be legible, signed, and include the complete mailing address of the objector. An objection or protest must be filed with the State Engineer not later than 10 calendar days after the date of the last publication of this notice. An objection or protest may be mailed to the Office of the State Engineer, 121 Tijeras NE, Suite 2000, Albuquerque, NM 87102, or faxed to 505-764-3892 provided the original is hand-delivered or postmarked within 24 hours after transmission of the fax.

In the event that a party filed a timely written protest or objection to the original Application to Appropriate RG-89943-POD1 through RG-89943-POD37, filed with the State Engineer on October 12, 2007, it is not necessary to file an additional written protest. A party's timely protest to the original application constitutes a valid protest to the amended application set forth in this notice. To confirm that a written protest was received by the Office of the State Engineer within the required time limits, visit http://www.ose.state.nm.us to view the list of timely protestants to the original application. If duplicate protests are received from any group or individual, the second protest will not be acknowledged by letter from the Office of the State Engineer.

The State Engineer will take the application up for consideration in the most appropriate and timely manner practical.

Appendix B

NMSA 72-12-3. Application for use of underground water; publication of notice; permit

A. Any person, firm or corporation or any other entity desiring to appropriate for beneficial use any of the waters described in Chapter 72, Article 12 NMSA 1978 shall apply to the state engineer in a form prescribed by him. In the application, the applicant shall designate:

(1) the particular underground stream, channel, artesian basin, reservoir or lake from which water will be appropriated;
(2) the beneficial use to which the water will be applied;
(3) the location of the proposed well;
(4) the name of the owner of the land on which the well will be located;
(5) the amount of water applied for;
(6) the place of the use for which the water is desired; and
(7) if the use is for irrigation, the description of the land to be irrigated and the name of the owner of the land.

B. If the well will be located on privately owned land and the applicant is not the owner of the land or the owner or the lessee of the mineral or oil and gas rights under the land, the application shall be accompanied by an acknowledged statement executed by the owner of the land that the applicant is granted access across the owner's land to the drilling site and has permission to occupy such portion of the owner's land as is necessary to drill and operate the well. This subsection does not apply to the state or any of its political subdivisions. If the application is approved, the applicant shall have the permit and statement, executed by the owner of the land, recorded in the office of the county clerk of the county in which the land is located.

C. No application shall be accepted by the state engineer unless it is accompanied by all the information required by Subsections A and B of this section.

D. Upon the filing of an application, the state engineer shall cause to be published in a newspaper that is published and distributed in the county where the well will be located and in each county where the water will be or has been put to beneficial use or where other water rights may be affected…a notice that the application has been filed and that objections to the granting of the application may be filed within ten days after the last publication of the notice. Any person, firm or corporation or other entity objecting that the granting of the application will impair the objector's water right shall have standing to file objections or protests. Any person, firm or corporation or other entity objecting that the granting of the application will be contrary to the conservation of water within the state or detrimental to the public welfare of the state and showing that the objector will be substantially and specifically affected by the granting of the application shall have standing to file objections or protests. Any person, firm or corporation or other entity objecting that the granting of the application will be contrary to the conservation of water within the state or detrimental to the public welfare of the state and showing that the objector will be substantially and specifically affected by the granting of the application shall have standing to file objections or protests; provided, however, that the state of New Mexico or any of its branches, agencies, departments, boards, instrumentalities or institutions, and all political subdivisions of the state and their agencies, instrumentalities and institutions shall have standing to file objections or protests.

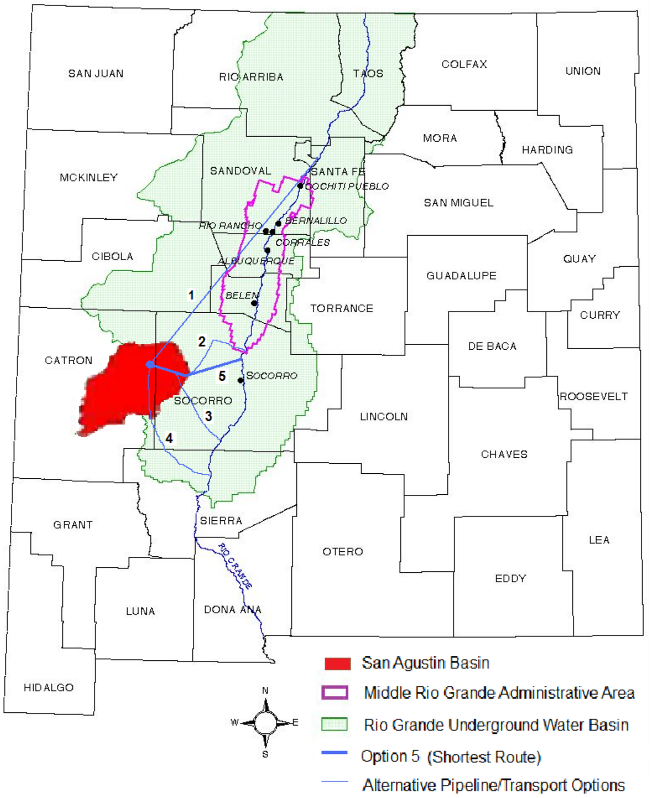
E. After the expiration of the time for filing objections, if no objections have been filed, the state engineer shall, if he finds that there are in the underground stream, channel, artesian basin, reservoir or lake unappropriated waters or that the proposed appropriation would not impair existing water rights from the source, is not contrary to conservation of water within the state and is not detrimental to the public welfare of the state, grant the application and issue a permit to the applicant to appropriate all or a part of the waters applied for, subject to the rights of all prior appropriators from the source.

F. If objections or protests have been filed within the time prescribed in the notice or if the state engineer is of the opinion that the permit should not be issued, the state engineer may deny the application without a hearing or, before he acts on the application, may order that a hearing be held. He shall notify the applicant of his action by certified mail sent to the address shown in the application.

Appendix C

Alternative Pipeline Routes

There appear to be five other general pipeline routes, or alternatives. These are not considered in the Powersim Studio® 9 model due to perceived significant legal, physical, economic, legal, and/or environmental challenges.



Alternative Pipeline Routes/Middle Rio Grande Administrative Area

Based on http://www.ose.state.nm.us/doing-business/mrgbasin/fig1mrgbasin.jpg

Alternative 1 travels to Santa Fe and is a direct route to the Buckman Diversion Dam site 145 miles away. It would have numerous terrain and right-of-way issues.

Alternative 2 considers a 29-mile pipeline to the Rio Salado system, where the pipeline ends and diverted water begins to flow 33 miles to the Rio Grande. Similar to Alternative 5, pipeline length is minimized, but evaporation, seepage, and environmental change would be extant, considering that the Rio Salado is an ephemeral stream. Adding 38,653 AFY would be significant. Water would enter the river at a point 2.8 miles upstream of San Acacia Dam (within the Middle Rio Grande Administrative Area) and 17 miles upstream of Socorro, thus benefiting the city and some silvery minnow habitat.

The third alternative is a pipeline of 56 miles coursing through Milligan Gulch to Elephant Butte Reservoir. This is a direct path to the Rio Grande, adjoining the bed of an ephemeral stream and State Route 107. Erosion and evaporation are minimized. It has relatively few environmental hurdles. It could decrease Alamosa Creek flows, but the most significant disadvantage may be that it does not add to flows in the Socorro region, thus potentially harming irrigators, silvery minnow, and others north of the pipeline terminus if resulting use is allowed further upstream.

Alternative 4 travels approximately 72 miles to Elephant Butte Reservoir via Alamosa Creek. It could be shortened to 29 miles, with the final 43 miles being emptied into the creek. Advantages are a cheaper pipeline and the ability to alleviate concerns of drying the creek and Alamosa Warm Springs. A disadvantage includes flooding the creek with much more water than naturally present, which averaged 5985 AFY from 1932-1941 and 1959-1971 (USGS, 2011). This would likely introduce downcutting concerns as well as threats to the endangered Alamosa springsnail and threatened Chiricahua leopard frog. Evaporation, seepage, and upstream use are other concerns.

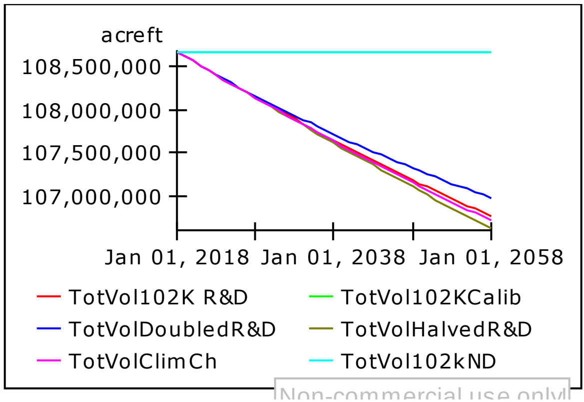
Alternative 5 appears to be cheapest of all routes. Solely pipeline, it follows a near-direct path 55.8 miles east to the Rio Grande, the shortest of all options. Erosion and evaporation are minimal. It could also decrease Alamosa Creek flows, but nonetheless likely has the fewest environmental issues. Much of it parallels U.S. 60, allowing easy access. At first its route is the same as Alternative 2 but instead of angling into the Rio Salado basin, a pipeline continues east over a low range (whose peak elevation is lower than the pump site by about 500 feet) directly to the Rio Grande, with a terminus about 9 miles south of that of Alternative 2.

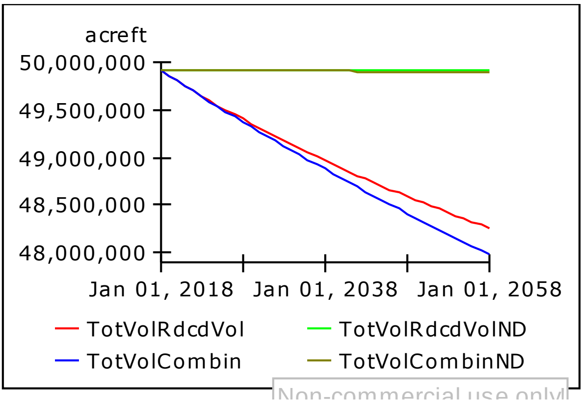
Appendix D

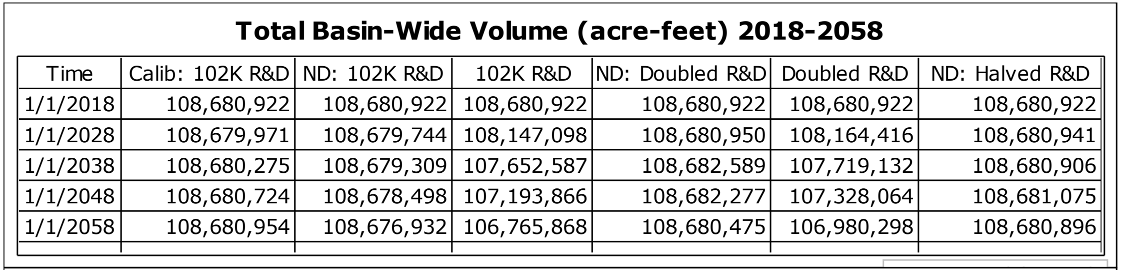
Basin-wide 2018-2058 Volume, Head, and Discharge

Abbreviation Key			
Calib.: Calibration	ND: No-Development	102K: 101,993 AFY	R&D: Recharge and Discharge
TotVol: Total Volume	Combin.: Combination	Clim.Ch.: Climate Change	RdcdVol: Reduced (49,908,000 Acre-Foot) Initial Volume

Volume:

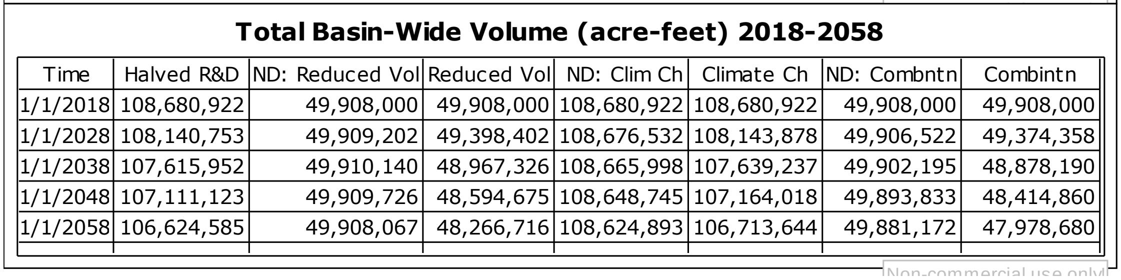






Total Basin-Wide Volume (acre-feet) 2018-2058

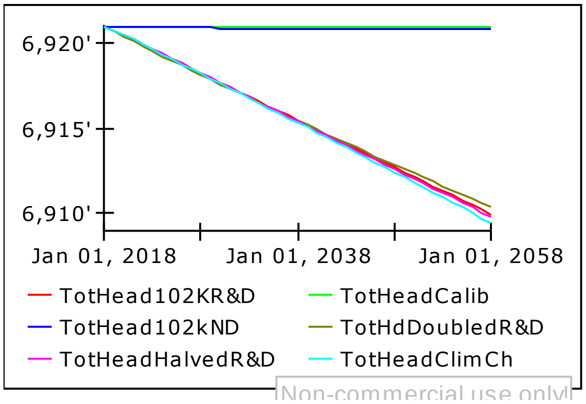
Time	Calib: 102K R&D	ND: 102K R&D	102K R&D	ND: Doubled R&D	Doubled R&D	ND: Halved R&D
1/1/2018	108,680,922	108,680,922	108,680,922	108,680,922	108,680,922	108,680,922
1/1/2028	108,679,971	108,679,744	108,147,098	108,680,950	108,164,416	108,680,941
1/1/2038	108,680,275	108,679,309	107,652,587	108,682,589	107,719,132	108,680,906
1/1/2048	108,680,724	108,678,498	107,193,866	108,682,277	107,328,064	108,681,075
1/1/2058	108,680,954	108,676,932	106,765,868	108,680,475	106,980,298	108,680,896

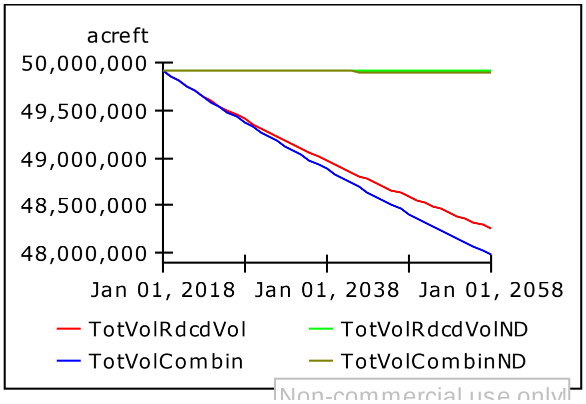


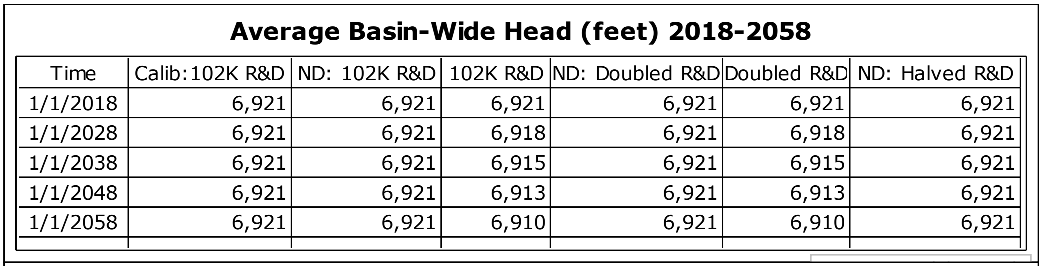
Total Basin-Wide Volume (acre-feet) 2018-2058

Time	Halved R&D	ND: Reduced Vol	Reduced Vol	ND: Clim Ch	Climate Ch	ND: Combntn	Combintn
1/1/2018	108,680,922	49,908,000	49,908,000	108,680,922	108,680,922	49,908,000	49,908,000
1/1/2028	108,140,753	49,909,202	49,398,402	108,676,532	108,143,878	49,906,522	49,374,358
1/1/2038	107,615,952	49,910,140	48,967,326	108,665,998	107,639,237	49,902,195	48,878,190
1/1/2048	107,111,123	49,909,726	48,594,675	108,648,745	107,164,018	49,893,833	48,414,860
1/1/2058	106,624,585	49,908,067	48,266,716	108,624,893	106,713,644	49,881,172	47,978,680

Head:

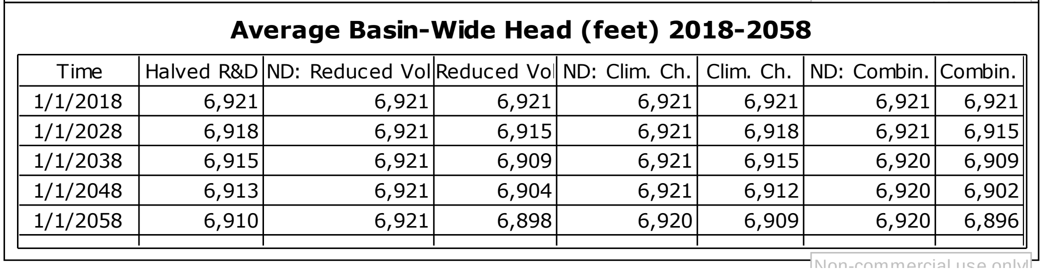






Average Basin-Wide Head (feet) 2018-2058

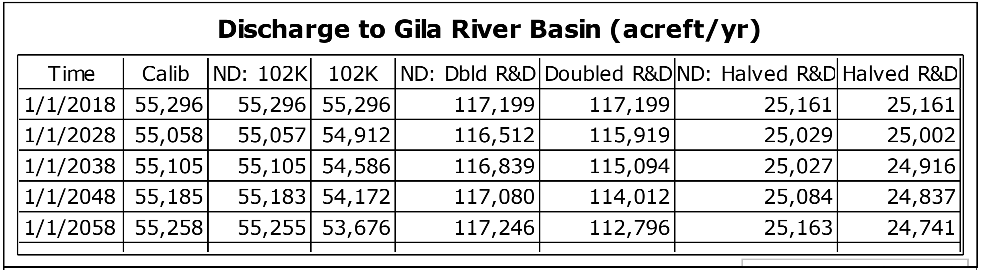
Time	Calib:102K R&D	ND: 102K R&D	102K R&D	ND: Doubled R&D	Doubled R&D	ND: Halved R&D
1/1/2018	6,921	6,921	6,921	6,921	6,921	6,921
1/1/2028	6,921	6,921	6,918	6,921	6,918	6,921
1/1/2038	6,921	6,921	6,915	6,921	6,915	6,921
1/1/2048	6,921	6,921	6,913	6,921	6,913	6,921
1/1/2058	6,921	6,921	6,910	6,921	6,910	6,921



Average Basin-Wide Head (feet) 2018-2058

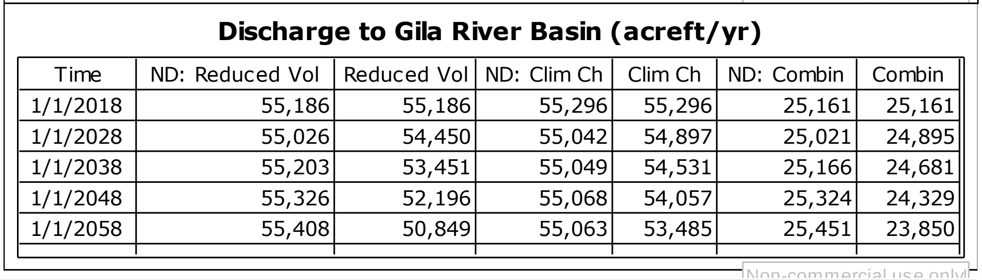
Time	Halved R&D	ND: Reduced Vol	Reduced Vol	ND: Clim. Ch.	Clim. Ch.	ND: Combin.	Combin.
1/1/2018	6,921	6,921	6,921	6,921	6,921	6,921	6,921
1/1/2028	6,918	6,921	6,915	6,921	6,918	6,921	6,915
1/1/2038	6,915	6,921	6,909	6,921	6,915	6,920	6,909
1/1/2048	6,913	6,921	6,904	6,921	6,912	6,920	6,902
1/1/2058	6,910	6,921	6,898	6,920	6,909	6,920	6,896

Discharge:



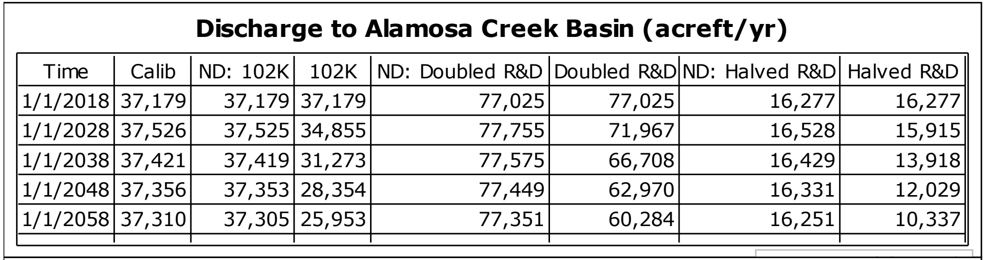
Discharge to Gila River Basin (acreft/yr)

Time	Calib	ND: 102K	102K	ND: Dbld R&D	Doubled R&D	ND: Halved R&D	Halved R&D
1/1/2018	55,296	55,296	55,296	117,199	117,199	25,161	25,161
1/1/2028	55,058	55,057	54,912	116,512	115,919	25,029	25,002
1/1/2038	55,105	55,105	54,586	116,839	115,094	25,027	24,916
1/1/2048	55,185	55,183	54,172	117,080	114,012	25,084	24,837
1/1/2058	55,258	55,255	53,676	117,246	112,796	25,163	24,741



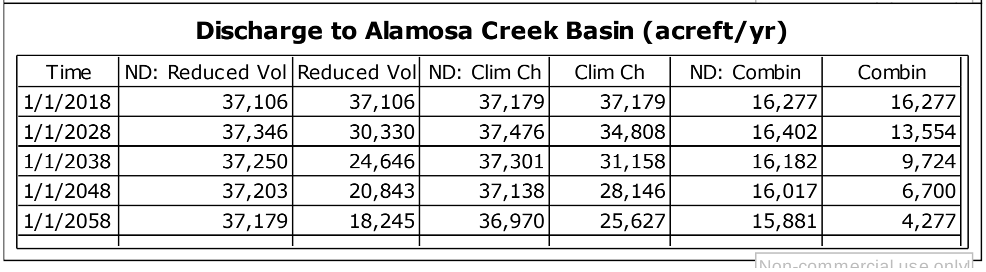
Discharge to Gila River Basin (acreft/yr)

Time	ND: Reduced Vol	Reduced Vol	ND: Clim Ch	Clim Ch	ND: Combin	Combin
1/1/2018	55,186	55,186	55,296	55,296	25,161	25,161
1/1/2028	55,026	54,450	55,042	54,897	25,021	24,895
1/1/2038	55,203	53,451	55,049	54,531	25,166	24,681
1/1/2048	55,326	52,196	55,068	54,057	25,324	24,329
1/1/2058	55,408	50,849	55,063	53,485	25,451	23,850



Discharge to Alamosa Creek Basin (acreft/yr)

Time	Calib	ND: 102K	102K	ND: Doubled R&D	Doubled R&D	ND: Halved R&D	Halved R&D
1/1/2018	37,179	37,179	37,179	77,025	77,025	16,277	16,277
1/1/2028	37,526	37,525	34,855	77,755	71,967	16,528	15,915
1/1/2038	37,421	37,419	31,273	77,575	66,708	16,429	13,918
1/1/2048	37,356	37,353	28,354	77,449	62,970	16,331	12,029
1/1/2058	37,310	37,305	25,953	77,351	60,284	16,251	10,337



Discharge to Alamosa Creek Basin (acreft/yr)

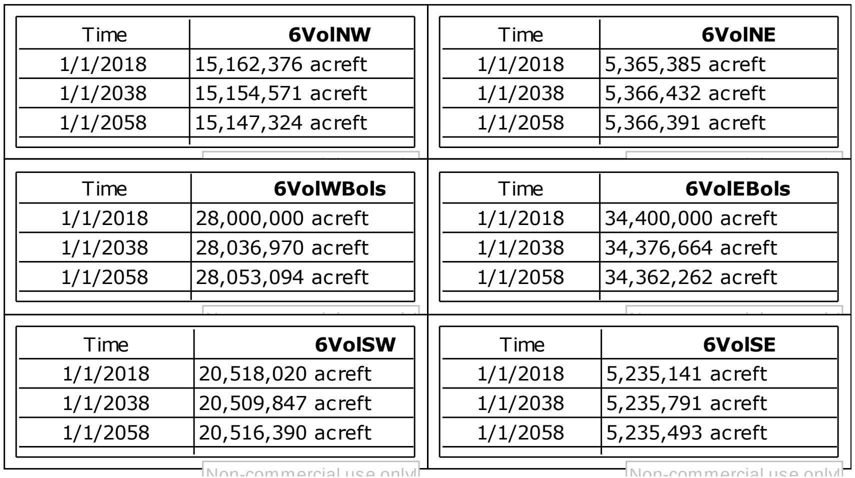
Time	ND: Reduced Vol	Reduced Vol	ND: Clim Ch	Clim Ch	ND: Combin	Combin
1/1/2018	37,106	37,106	37,179	37,179	16,277	16,277
1/1/2028	37,346	30,330	37,476	34,808	16,402	13,554
1/1/2038	37,250	24,646	37,301	31,158	16,182	9,724
1/1/2048	37,203	20,843	37,138	28,146	16,017	6,700
1/1/2058	37,179	18,245	36,970	25,627	15,881	4,277

Appendix E

Block-Specific 2018-2058 Volume and Head

101,993 AFY: Volume and Head

Calibration (No appropriation or population growth):



Time	**6VolNW**
1/1/2018	15,162,376 acreft
1/1/2038	15,154,571 acreft
1/1/2058	15,147,324 acreft

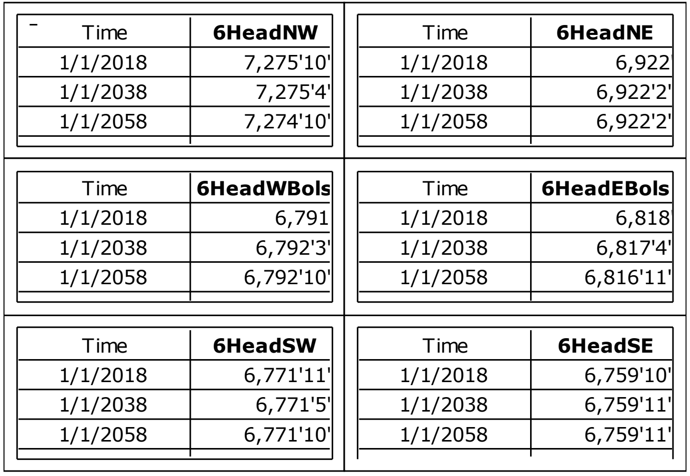
Time	**6VolNE**
1/1/2018	5,365,385 acreft
1/1/2038	5,366,432 acreft
1/1/2058	5,366,391 acreft

Time	**6VolWBols**
1/1/2018	28,000,000 acreft
1/1/2038	28,036,970 acreft
1/1/2058	28,053,094 acreft

Time	**6VolEBols**
1/1/2018	34,400,000 acreft
1/1/2038	34,376,664 acreft
1/1/2058	34,362,262 acreft

Time	**6VolSW**
1/1/2018	20,518,020 acreft
1/1/2038	20,509,847 acreft
1/1/2058	20,516,390 acreft

Time	**6VolSE**
1/1/2018	5,235,141 acreft
1/1/2038	5,235,791 acreft
1/1/2058	5,235,493 acreft



Time	**6HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,275'4'
1/1/2058	7,274'10'

Time	**6HeadNE**
1/1/2018	6,922
1/1/2038	6,922'2'
1/1/2058	6,922'2'

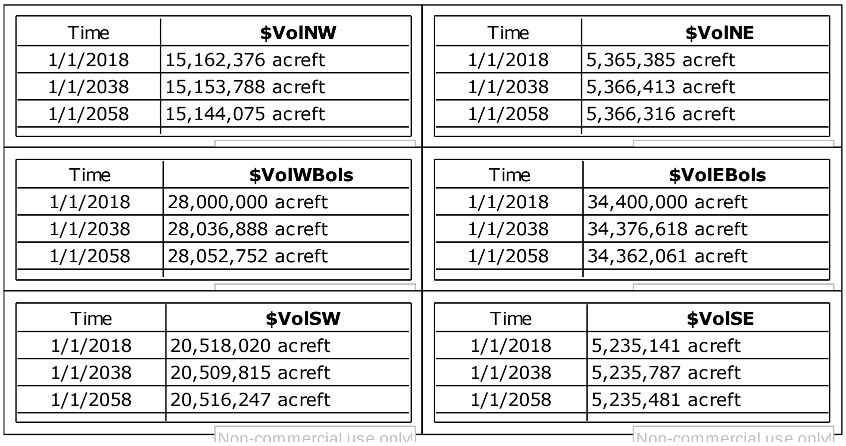
Time	**6HeadWBols**
1/1/2018	6,791
1/1/2038	6,792'3'
1/1/2058	6,792'10'

Time	**6HeadEBols**
1/1/2018	6,818
1/1/2038	6,817'4'
1/1/2058	6,816'11'

Time	**6HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,771'5'
1/1/2058	6,771'10'

Time	**6HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,759'11'
1/1/2058	6,759'11'

No-Development (No appropriation):



Time	**$VolNW**
1/1/2018	15,162,376 acreft
1/1/2038	15,153,788 acreft
1/1/2058	15,144,075 acreft

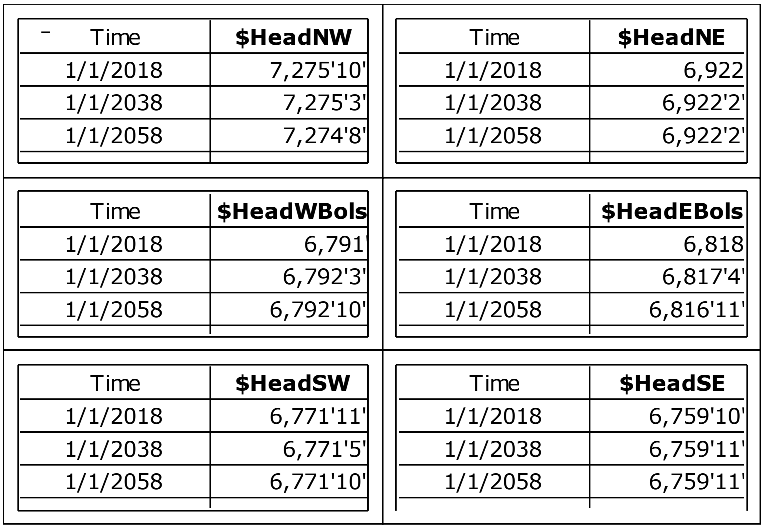
Time	**$VolNE**
1/1/2018	5,365,385 acreft
1/1/2038	5,366,413 acreft
1/1/2058	5,366,316 acreft

Time	**$VolWBols**
1/1/2018	28,000,000 acreft
1/1/2038	28,036,888 acreft
1/1/2058	28,052,752 acreft

Time	**$VolEBols**
1/1/2018	34,400,000 acreft
1/1/2038	34,376,618 acreft
1/1/2058	34,362,061 acreft

Time	**$VolSW**
1/1/2018	20,518,020 acreft
1/1/2038	20,509,815 acreft
1/1/2058	20,516,247 acreft

Time	**$VolSE**
1/1/2018	5,235,141 acreft
1/1/2038	5,235,787 acreft
1/1/2058	5,235,481 acreft



Time	**$HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,275'3'
1/1/2058	7,274'8'

Time	**$HeadNE**
1/1/2018	6,922
1/1/2038	6,922'2'
1/1/2058	6,922'2'

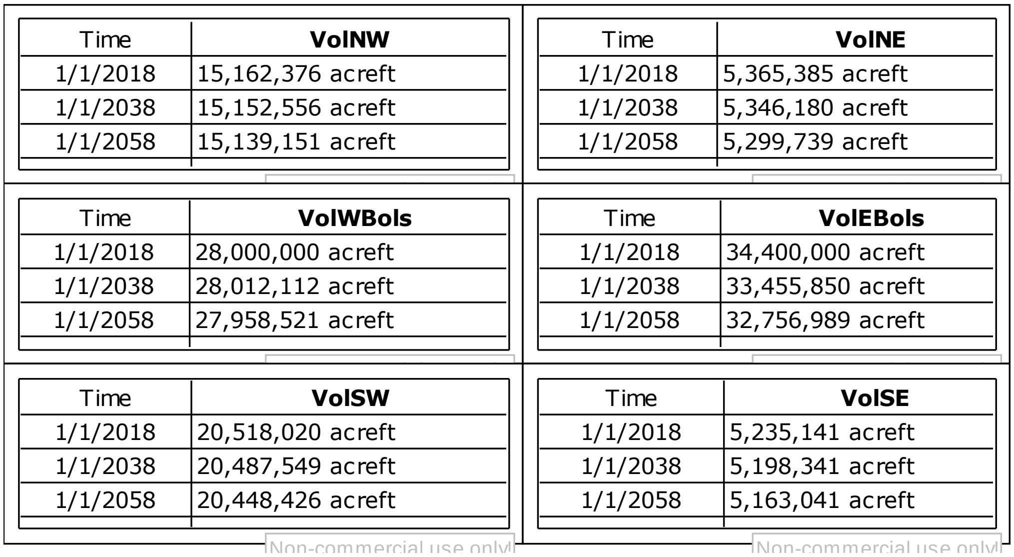
Time	**$HeadWBols**
1/1/2018	6,791
1/1/2038	6,792'3'
1/1/2058	6,792'10'

Time	**$HeadEBols**
1/1/2018	6,818
1/1/2038	6,817'4'
1/1/2058	6,816'11'

Time	**$HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,771'5'
1/1/2058	6,771'10'

Time	**$HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,759'11'
1/1/2058	6,759'11'

Appropriation:



Time	**VolNW**
1/1/2018	15,162,376 acreft
1/1/2038	15,152,556 acreft
1/1/2058	15,139,151 acreft

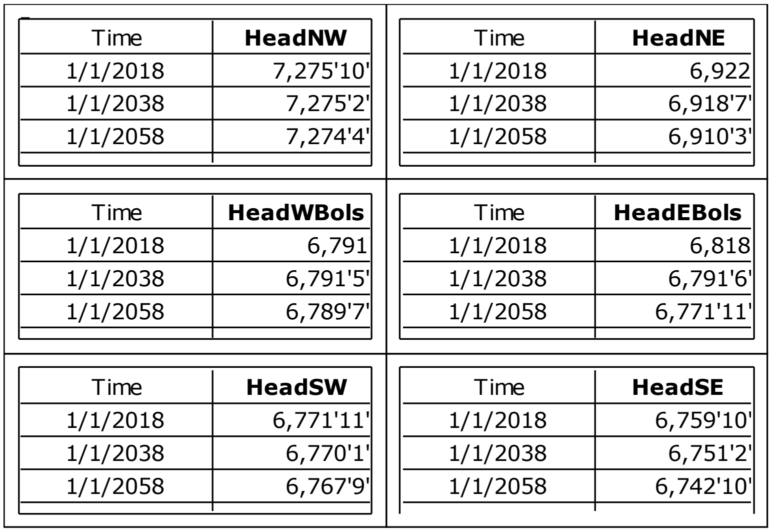
Time	**VolNE**
1/1/2018	5,365,385 acreft
1/1/2038	5,346,180 acreft
1/1/2058	5,299,739 acreft

Time	**VolWBols**
1/1/2018	28,000,000 acreft
1/1/2038	28,012,112 acreft
1/1/2058	27,958,521 acreft

Time	**VolEBols**
1/1/2018	34,400,000 acreft
1/1/2038	33,455,850 acreft
1/1/2058	32,756,989 acreft

Time	**VolSW**
1/1/2018	20,518,020 acreft
1/1/2038	20,487,549 acreft
1/1/2058	20,448,426 acreft

Time	**VolSE**
1/1/2018	5,235,141 acreft
1/1/2038	5,198,341 acreft
1/1/2058	5,163,041 acreft



Time	**HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,275'2'
1/1/2058	7,274'4'

Time	**HeadNE**
1/1/2018	6,922
1/1/2038	6,918'7'
1/1/2058	6,910'3'

Time	**HeadWBols**
1/1/2018	6,791
1/1/2038	6,791'5'
1/1/2058	6,789'7'

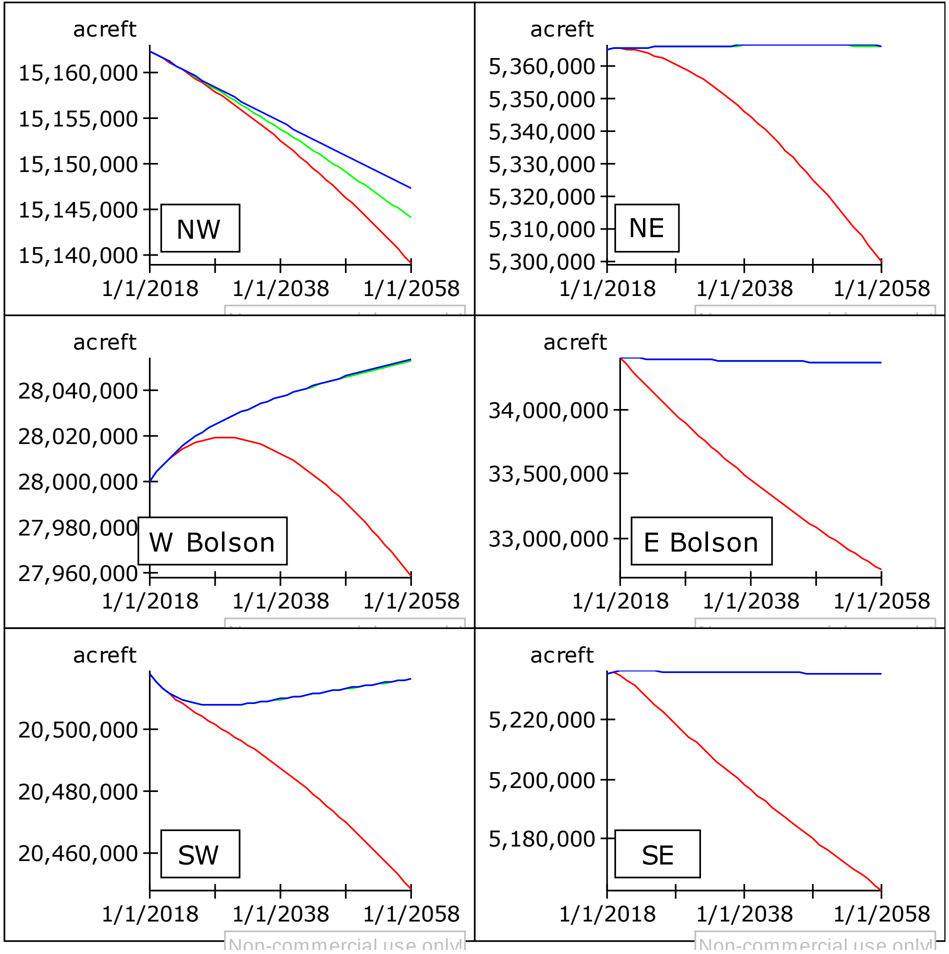
Time	**HeadEBols**
1/1/2018	6,818
1/1/2038	6,791'6'
1/1/2058	6,771'11'

Time	**HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,770'1'
1/1/2058	6,767'9'

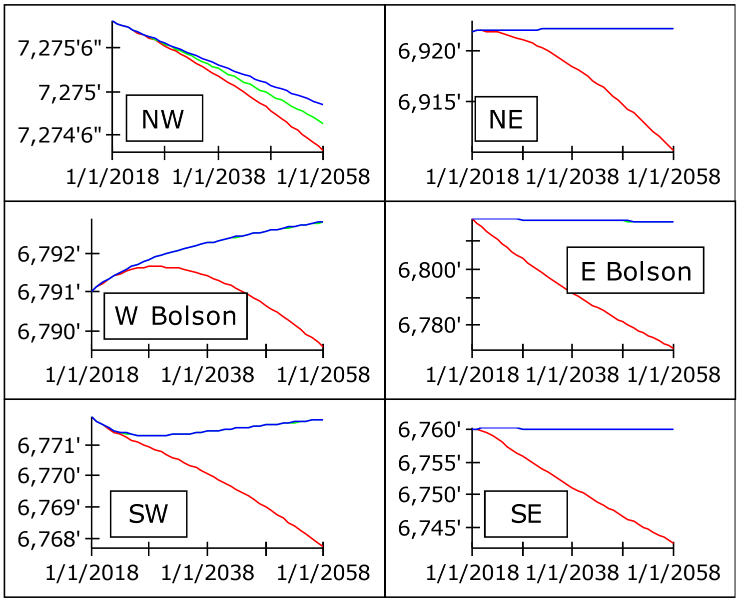
Time	**HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,751'2'
1/1/2058	6,742'10'

Volume

Blue = Calibration, Green = No-Development, Red = Appropriation

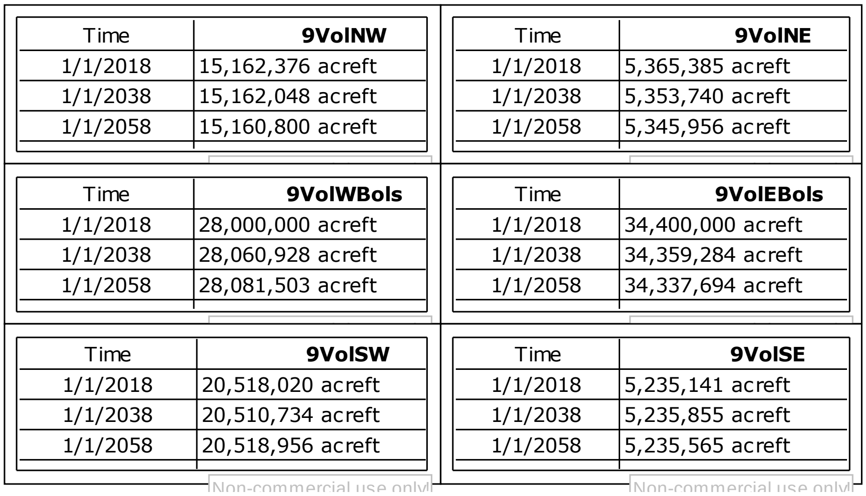


Head



Doubled Recharge/Discharge: Volume and Head

No-Development:



Time	9VolNW
1/1/2018	15,162,376 acreft
1/1/2038	15,162,048 acreft
1/1/2058	15,160,800 acreft

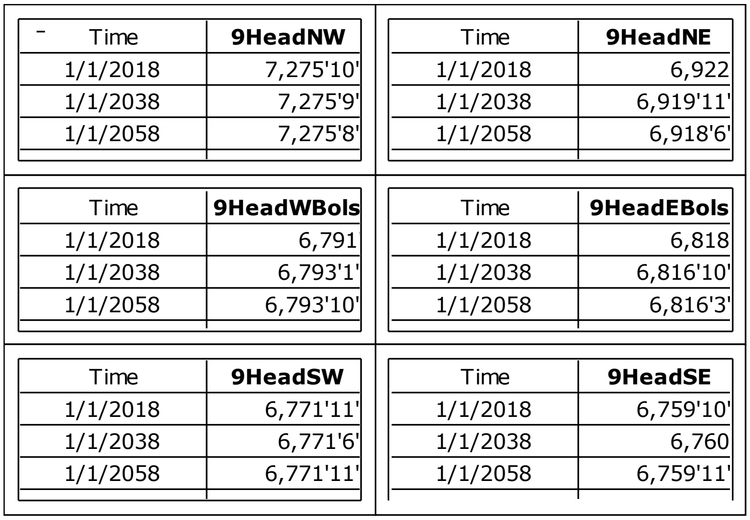
Time	9VolNE
1/1/2018	5,365,385 acreft
1/1/2038	5,353,740 acreft
1/1/2058	5,345,956 acreft

Time	9VolWBols
1/1/2018	28,000,000 acreft
1/1/2038	28,060,928 acreft
1/1/2058	28,081,503 acreft

Time	9VolEBols
1/1/2018	34,400,000 acreft
1/1/2038	34,359,284 acreft
1/1/2058	34,337,694 acreft

Time	9VolSW
1/1/2018	20,518,020 acreft
1/1/2038	20,510,734 acreft
1/1/2058	20,518,956 acreft

Time	9VolSE
1/1/2018	5,235,141 acreft
1/1/2038	5,235,855 acreft
1/1/2058	5,235,565 acreft



Time	9HeadNW
1/1/2018	7,275'10'
1/1/2038	7,275'9'
1/1/2058	7,275'8'

Time	9HeadNE
1/1/2018	6,922
1/1/2038	6,919'11'
1/1/2058	6,918'6'

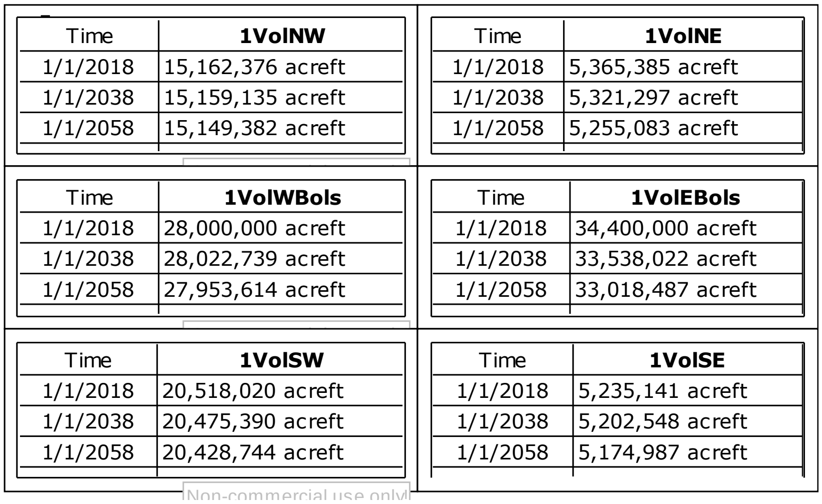
Time	9HeadWBols
1/1/2018	6,791
1/1/2038	6,793'1'
1/1/2058	6,793'10'

Time	9HeadEBols
1/1/2018	6,818
1/1/2038	6,816'10'
1/1/2058	6,816'3'

Time	9HeadSW
1/1/2018	6,771'11'
1/1/2038	6,771'6'
1/1/2058	6,771'11'

Time	9HeadSE
1/1/2018	6,759'10'
1/1/2038	6,760
1/1/2058	6,759'11'

Appropriation:



Time	1VolNW
1/1/2018	15,162,376 acreft
1/1/2038	15,159,135 acreft
1/1/2058	15,149,382 acreft

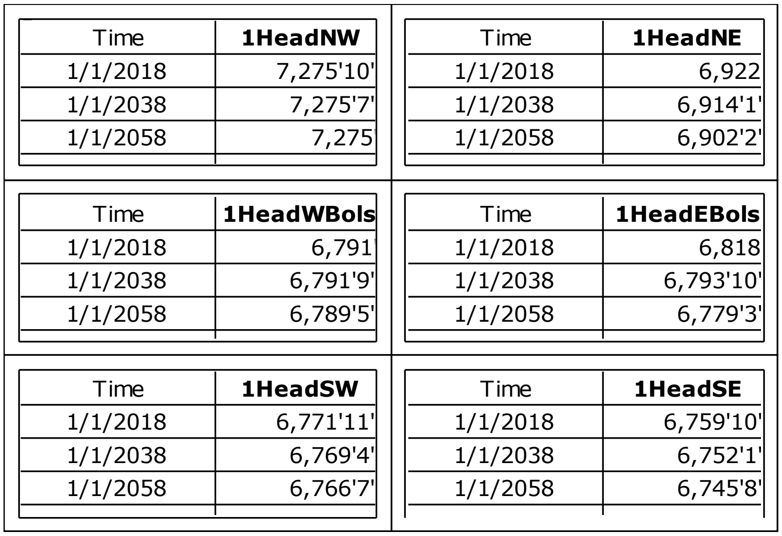
Time	1VolNE
1/1/2018	5,365,385 acreft
1/1/2038	5,321,297 acreft
1/1/2058	5,255,083 acreft

Time	1VolWBols
1/1/2018	28,000,000 acreft
1/1/2038	28,022,739 acreft
1/1/2058	27,953,614 acreft

Time	1VolEBols
1/1/2018	34,400,000 acreft
1/1/2038	33,538,022 acreft
1/1/2058	33,018,487 acreft

Time	1VolSW
1/1/2018	20,518,020 acreft
1/1/2038	20,475,390 acreft
1/1/2058	20,428,744 acreft

Time	1VolSE
1/1/2018	5,235,141 acreft
1/1/2038	5,202,548 acreft
1/1/2058	5,174,987 acreft



Time	**1HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,275'7'
1/1/2058	7,275

Time	**1HeadNE**
1/1/2018	6,922
1/1/2038	6,914'1'
1/1/2058	6,902'2'

Time	**1HeadWBols**
1/1/2018	6,791
1/1/2038	6,791'9'
1/1/2058	6,789'5'

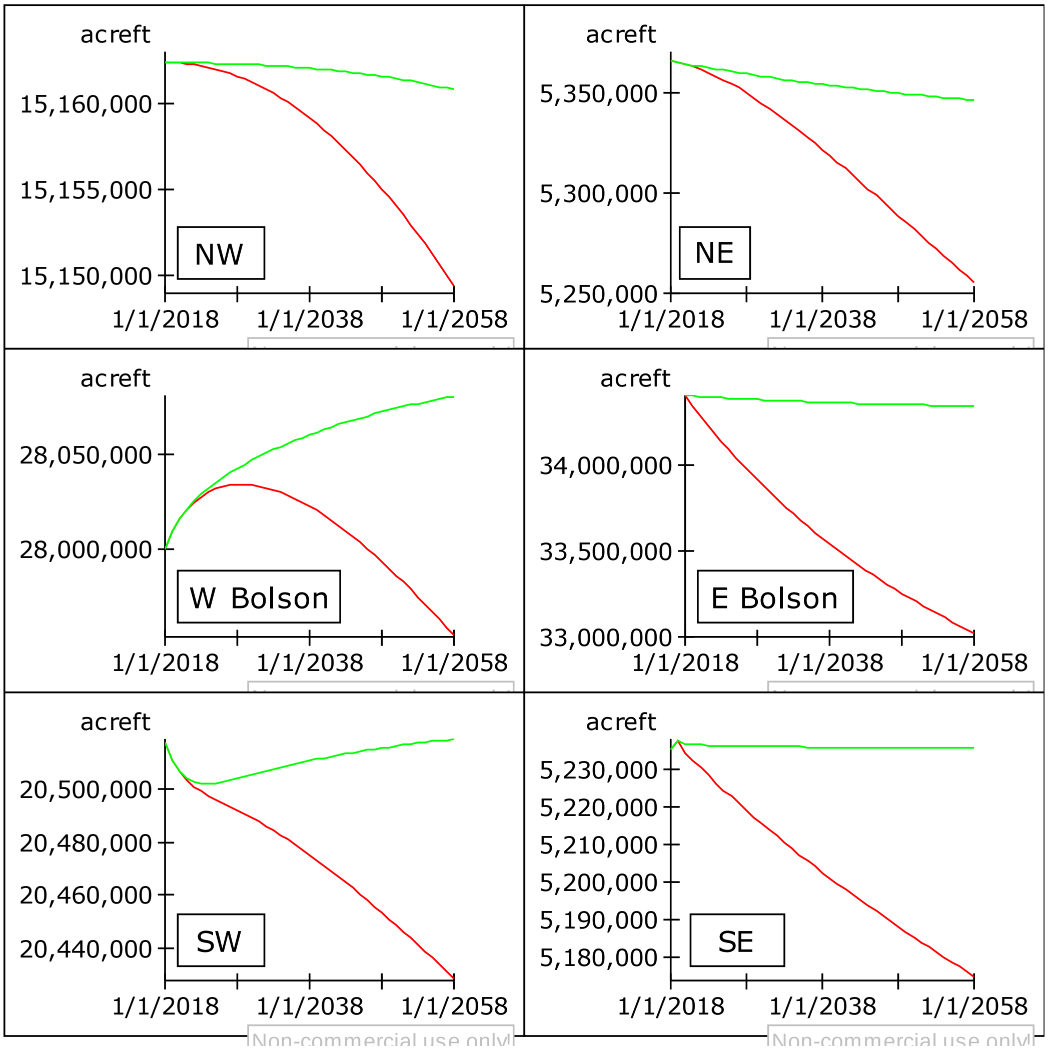
Time	**1HeadEBols**
1/1/2018	6,818
1/1/2038	6,793'10'
1/1/2058	6,779'3'

Time	**1HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,769'4'
1/1/2058	6,766'7'

Time	**1HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,752'1'
1/1/2058	6,745'8'

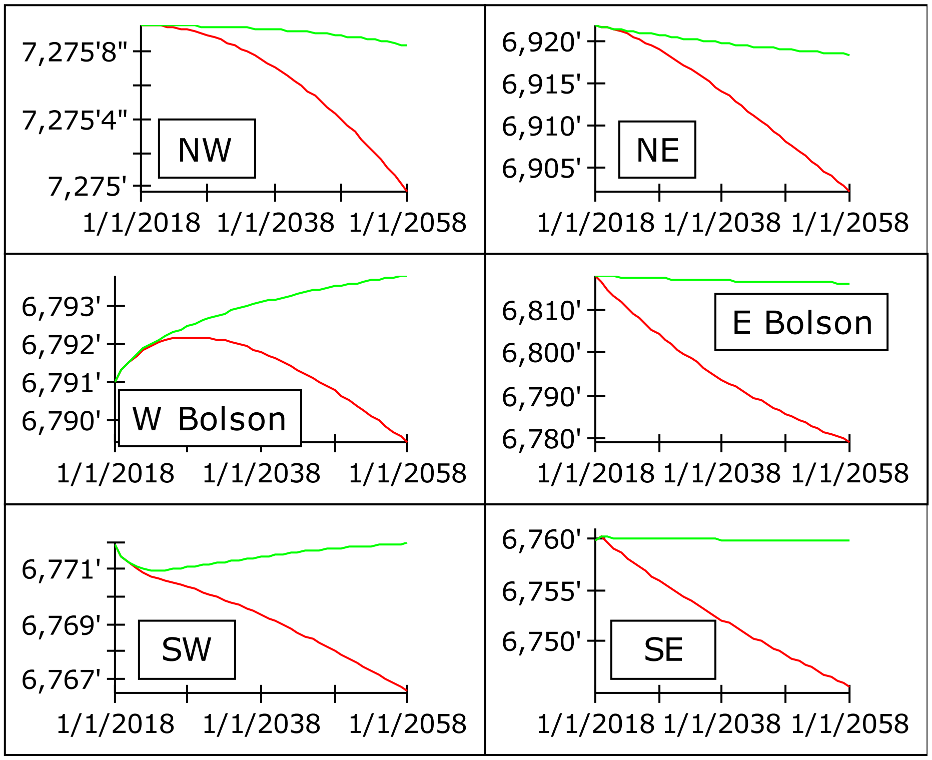
Volume

Green = No-Development, Red = Appropriation



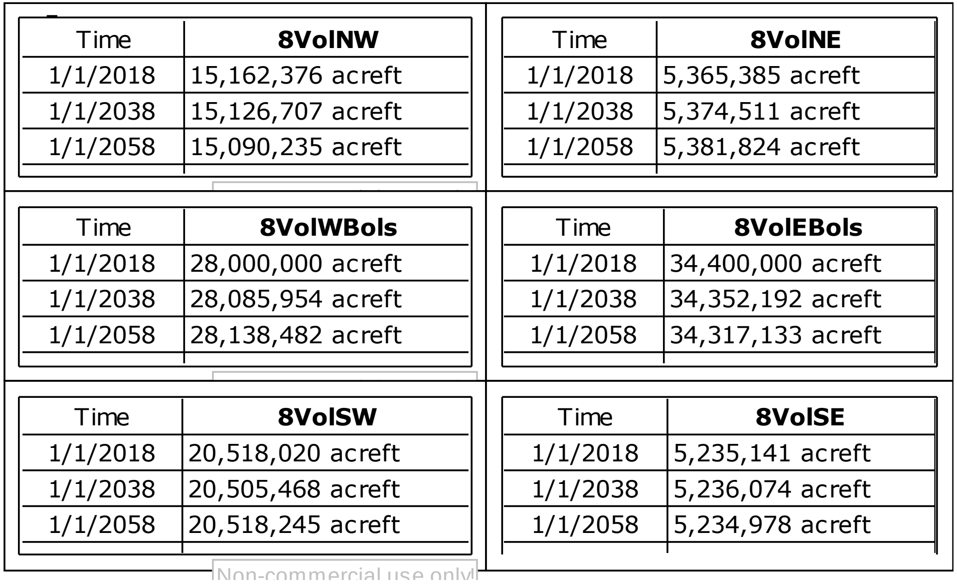
Head

Green = No-Development, Red = Appropriation



Halved Recharge/Discharge: Volume and Head

No-Development:



Time	**8VolNW**
1/1/2018	15,162,376 acreft
1/1/2038	15,126,707 acreft
1/1/2058	15,090,235 acreft

Time	**8VolNE**
1/1/2018	5,365,385 acreft
1/1/2038	5,374,511 acreft
1/1/2058	5,381,824 acreft

Time	**8VolWBols**
1/1/2018	28,000,000 acreft
1/1/2038	28,085,954 acreft
1/1/2058	28,138,482 acreft

Time	**8VolEBols**
1/1/2018	34,400,000 acreft
1/1/2038	34,352,192 acreft
1/1/2058	34,317,133 acreft

Time	**8VolSW**
1/1/2018	20,518,020 acreft
1/1/2038	20,505,468 acreft
1/1/2058	20,518,245 acreft

Time	**8VolSE**
1/1/2018	5,235,141 acreft
1/1/2038	5,236,074 acreft
1/1/2058	5,234,978 acreft

Time	**8HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,273'6'
1/1/2058	7,271'3'

Time	**8HeadNE**
1/1/2018	6,922
1/1/2038	6,923'8'
1/1/2058	6,924'11'

Time	**8HeadWBols**
1/1/2018	6,791
1/1/2038	6,793'11'
1/1/2058	6,795'9'

Time	**8HeadEBols**
1/1/2018	6,818
1/1/2038	6,816'8'
1/1/2058	6,815'8'

Time	**8HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,771'2'
1/1/2058	6,771'11'

Time	**8HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,760
1/1/2058	6,759'9'

Appropriation:

Time	**2VolNW**
1/1/2018	15,162,376 acreft
1/1/2038	15,126,146 acreft
1/1/2058	15,087,966 acreft

Time	**2VolNE**
1/1/2018	5,365,385 acreft
1/1/2038	5,366,413 acreft
1/1/2058	5,351,938 acreft

Time	**2VolWBols**
1/1/2018	28,000,000 acreft
1/1/2038	28,065,803 acreft
1/1/2058	28,063,149 acreft

Time	**2VolEBols**
1/1/2018	34,400,000 acreft
1/1/2038	33,363,456 acreft
1/1/2058	32,487,591 acreft

Time	**2VolSW**
1/1/2018	20,518,020 acreft
1/1/2038	20,494,958 acreft
1/1/2058	20,478,404 acreft

Time	**2VolSE**
1/1/2018	5,235,141 acreft
1/1/2038	5,199,176 acreft
1/1/2058	5,155,537 acreft

Time	**2HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,273'6'
1/1/2058	7,271'1'

Time	**2HeadNE**
1/1/2018	6,922
1/1/2038	6,922'2'
1/1/2058	6,919'7'

Time	**2HeadWBols**
1/1/2018	6,791
1/1/2038	6,793'3'
1/1/2058	6,793'2'

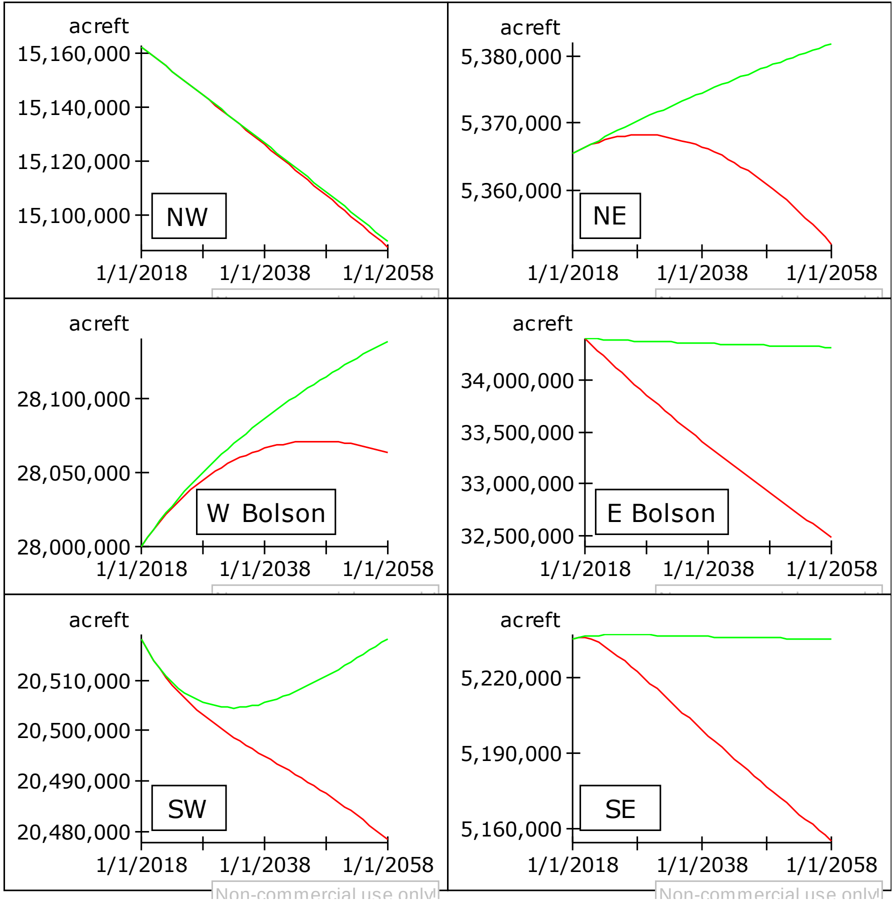
Time	**2HeadEBols**
1/1/2018	6,818
1/1/2038	6,788'11'
1/1/2058	6,764'4'

Time	**2HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,770'6'
1/1/2058	6,769'6'

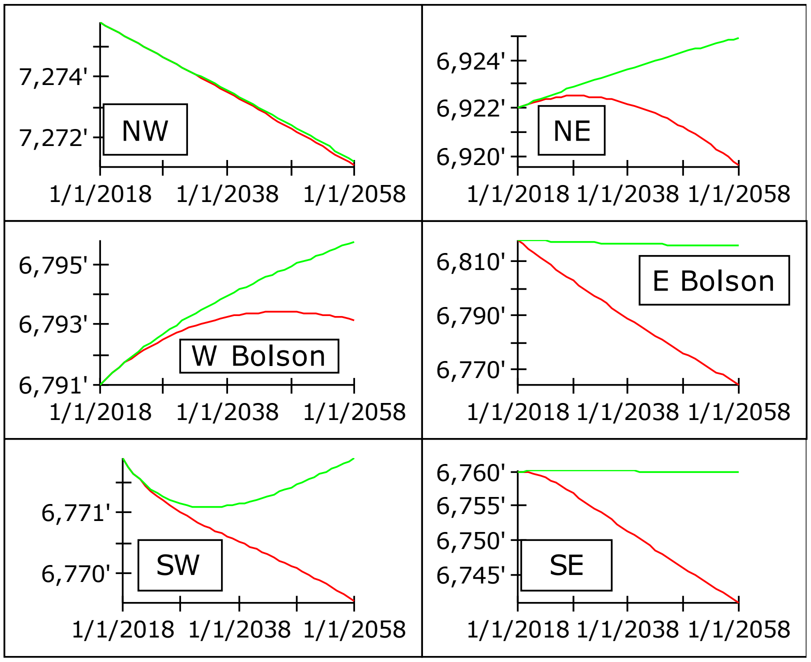
Time	**2HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,751'4'
1/1/2058	6,741'1'

Volume

Green = No-Development, Red = Appropriation

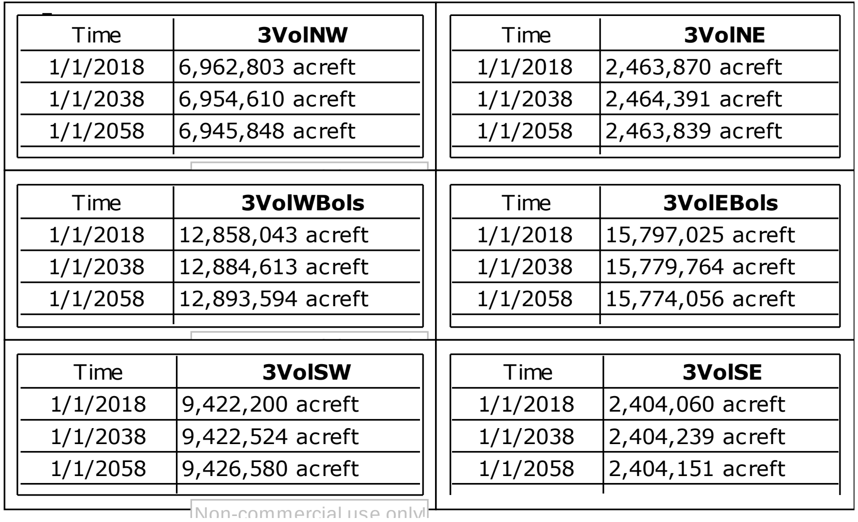


Head



Reduced Basin-Wide Volume: Volume and Head

No-Development:



Time	**3VolNW**
1/1/2018	6,962,803 acreft
1/1/2038	6,954,610 acreft
1/1/2058	6,945,848 acreft

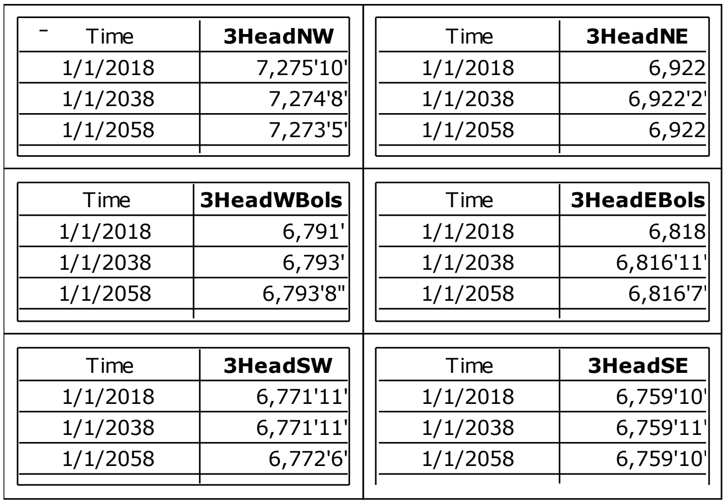
Time	**3VolNE**
1/1/2018	2,463,870 acreft
1/1/2038	2,464,391 acreft
1/1/2058	2,463,839 acreft

Time	**3VolWBols**
1/1/2018	12,858,043 acreft
1/1/2038	12,884,613 acreft
1/1/2058	12,893,594 acreft

Time	**3VolEBols**
1/1/2018	15,797,025 acreft
1/1/2038	15,779,764 acreft
1/1/2058	15,774,056 acreft

Time	**3VolSW**
1/1/2018	9,422,200 acreft
1/1/2038	9,422,524 acreft
1/1/2058	9,426,580 acreft

Time	**3VolSE**
1/1/2018	2,404,060 acreft
1/1/2038	2,404,239 acreft
1/1/2058	2,404,151 acreft



Time	**3HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,274'8'
1/1/2058	7,273'5'

Time	**3HeadNE**
1/1/2018	6,922
1/1/2038	6,922'2'
1/1/2058	6,922

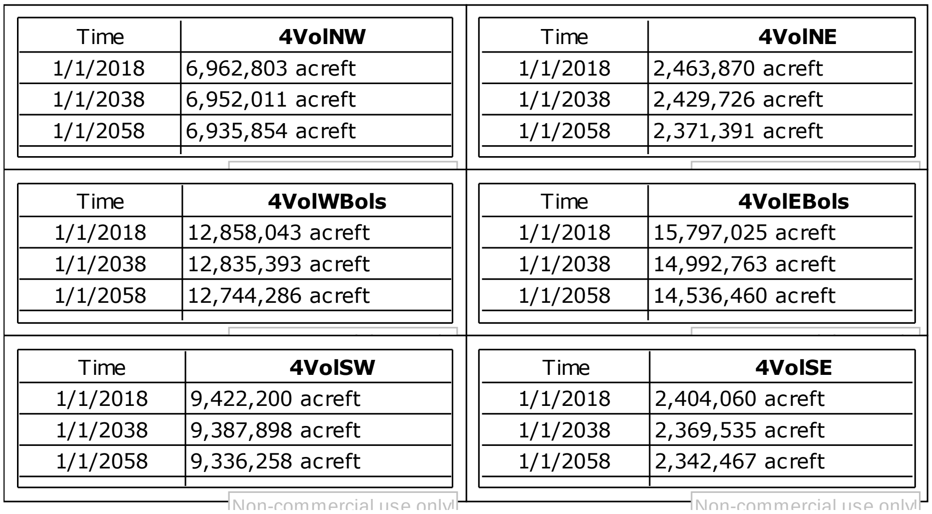
Time	**3HeadWBols**
1/1/2018	6,791'
1/1/2038	6,793'
1/1/2058	6,793'8"

Time	**3HeadEBols**
1/1/2018	6,818
1/1/2038	6,816'11'
1/1/2058	6,816'7'

Time	**3HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,771'11'
1/1/2058	6,772'6'

Time	**3HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,759'11'
1/1/2058	6,759'10'

Appropriation:



Time	**4VolNW**
1/1/2018	6,962,803 acreft
1/1/2038	6,952,011 acreft
1/1/2058	6,935,854 acreft

Time	**4VolNE**
1/1/2018	2,463,870 acreft
1/1/2038	2,429,726 acreft
1/1/2058	2,371,391 acreft

Time	**4VolWBols**
1/1/2018	12,858,043 acreft
1/1/2038	12,835,393 acreft
1/1/2058	12,744,286 acreft

Time	**4VolEBols**
1/1/2018	15,797,025 acreft
1/1/2038	14,992,763 acreft
1/1/2058	14,536,460 acreft

Time	**4VolSW**
1/1/2018	9,422,200 acreft
1/1/2038	9,387,898 acreft
1/1/2058	9,336,258 acreft

Time	**4VolSE**
1/1/2018	2,404,060 acreft
1/1/2038	2,369,535 acreft
1/1/2058	2,342,467 acreft

Time	**4HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,274'4'
1/1/2058	7,272'1'

Time	**4HeadNE**
1/1/2018	6,922
1/1/2038	6,908'8'
1/1/2058	6,885'10'

Time	**4HeadWBols**
1/1/2018	6,791
1/1/2038	6,789'4'
1/1/2058	6,782'6'

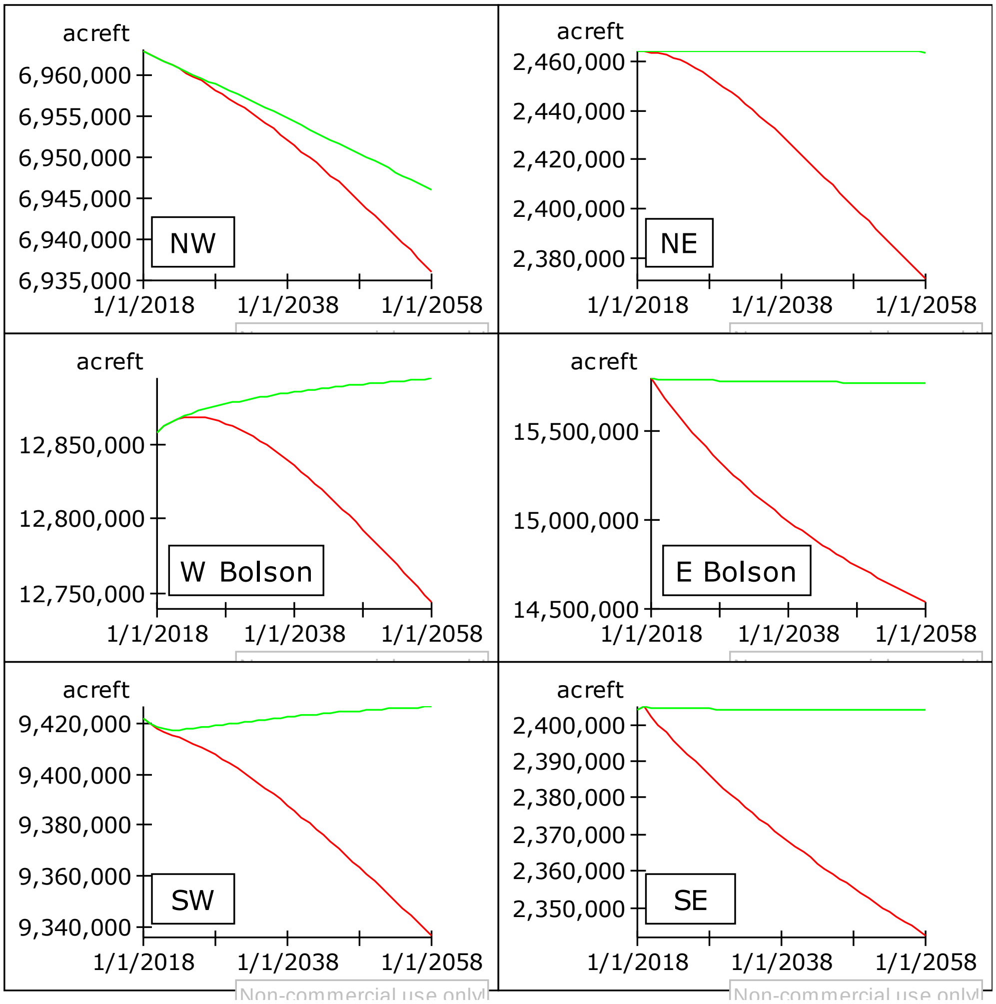
Time	**4HeadEBols**
1/1/2018	6,818
1/1/2038	6,768'10'
1/1/2058	6,740'11'

Time	**4HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,767'5'
1/1/2058	6,760'8'

Time	**4HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,742'1'
1/1/2058	6,728'3'

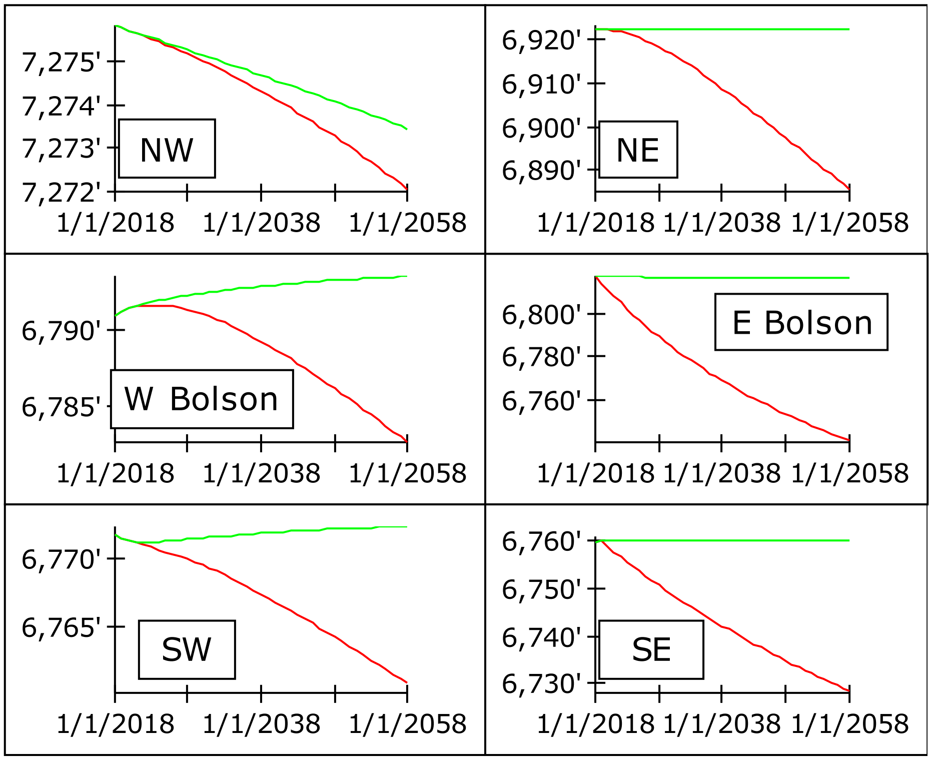
Volume

Green = No-Development, Red = Appropriation



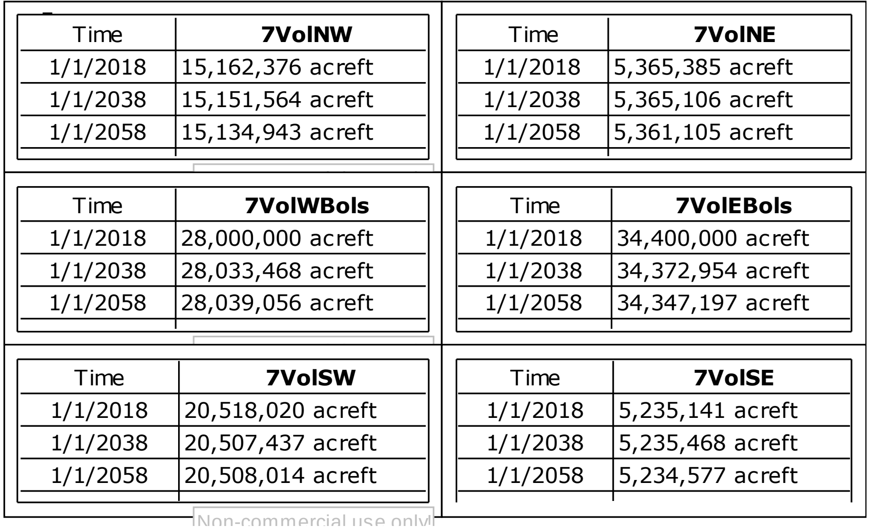
Head

Green = No-Development, Red = Appropriation



Climate Change: Volume and Head

No-Development:



Time	7VolNW
1/1/2018	15,162,376 acreft
1/1/2038	15,151,564 acreft
1/1/2058	15,134,943 acreft

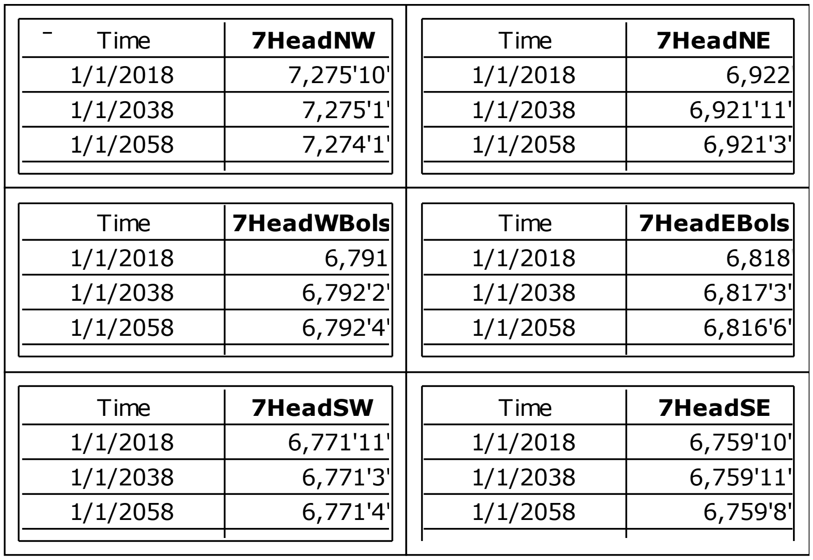
Time	7VolNE
1/1/2018	5,365,385 acreft
1/1/2038	5,365,106 acreft
1/1/2058	5,361,105 acreft

Time	7VolWBols
1/1/2018	28,000,000 acreft
1/1/2038	28,033,468 acreft
1/1/2058	28,039,056 acreft

Time	7VolEBols
1/1/2018	34,400,000 acreft
1/1/2038	34,372,954 acreft
1/1/2058	34,347,197 acreft

Time	7VolSW
1/1/2018	20,518,020 acreft
1/1/2038	20,507,437 acreft
1/1/2058	20,508,014 acreft

Time	7VolSE
1/1/2018	5,235,141 acreft
1/1/2038	5,235,468 acreft
1/1/2058	5,234,577 acreft



Time	7HeadNW
1/1/2018	7,275'10'
1/1/2038	7,275'1'
1/1/2058	7,274'1'

Time	7HeadNE
1/1/2018	6,922
1/1/2038	6,921'11'
1/1/2058	6,921'3'

Time	7HeadWBols
1/1/2018	6,791
1/1/2038	6,792'2'
1/1/2058	6,792'4'

Time	7HeadEBols
1/1/2018	6,818
1/1/2038	6,817'3'
1/1/2058	6,816'6'

Time	7HeadSW
1/1/2018	6,771'11'
1/1/2038	6,771'3'
1/1/2058	6,771'4'

Time	7HeadSE
1/1/2018	6,759'10'
1/1/2038	6,759'11'
1/1/2058	6,759'8'

Appropriation:

Time	5VolNW
1/1/2018	15,162,376 acreft
1/1/2038	15,150,334 acreft
1/1/2058	15,130,023 acreft

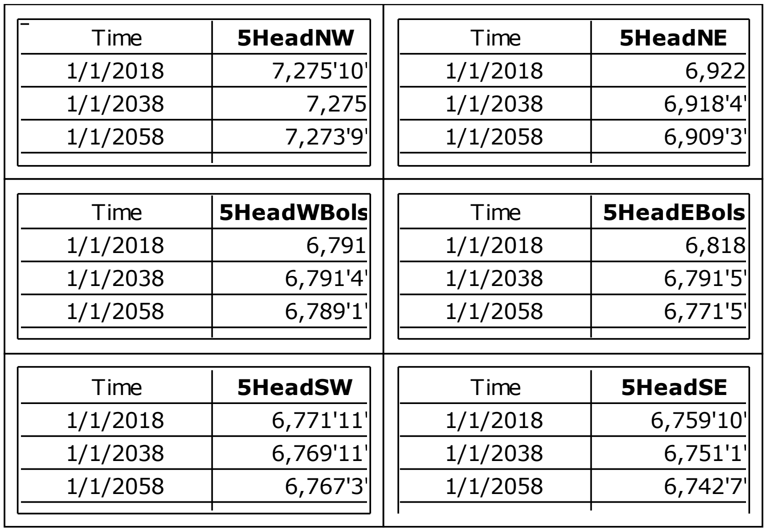
Time	5VolNE
1/1/2018	5,365,385 acreft
1/1/2038	5,344,885 acreft
1/1/2058	5,294,562 acreft

Time	5VolWBols
1/1/2018	28,000,000 acreft
1/1/2038	28,008,710 acreft
1/1/2058	27,944,893 acreft

Time	5VolEBols
1/1/2018	34,400,000 acreft
1/1/2038	33,452,096 acreft
1/1/2058	32,741,786 acreft

Time	5VolSW
1/1/2018	20,518,020 acreft
1/1/2038	20,485,182 acreft
1/1/2058	20,440,226 acreft

Time	5VolSE
1/1/2018	5,235,141 acreft
1/1/2038	5,198,031 acreft
1/1/2058	5,162,155 acreft



Time	5HeadNW
1/1/2018	7,275'10'
1/1/2038	7,275
1/1/2058	7,273'9'

Time	5HeadNE
1/1/2018	6,922
1/1/2038	6,918'4'
1/1/2058	6,909'3'

Time	5HeadWBols
1/1/2018	6,791
1/1/2038	6,791'4'
1/1/2058	6,789'1'

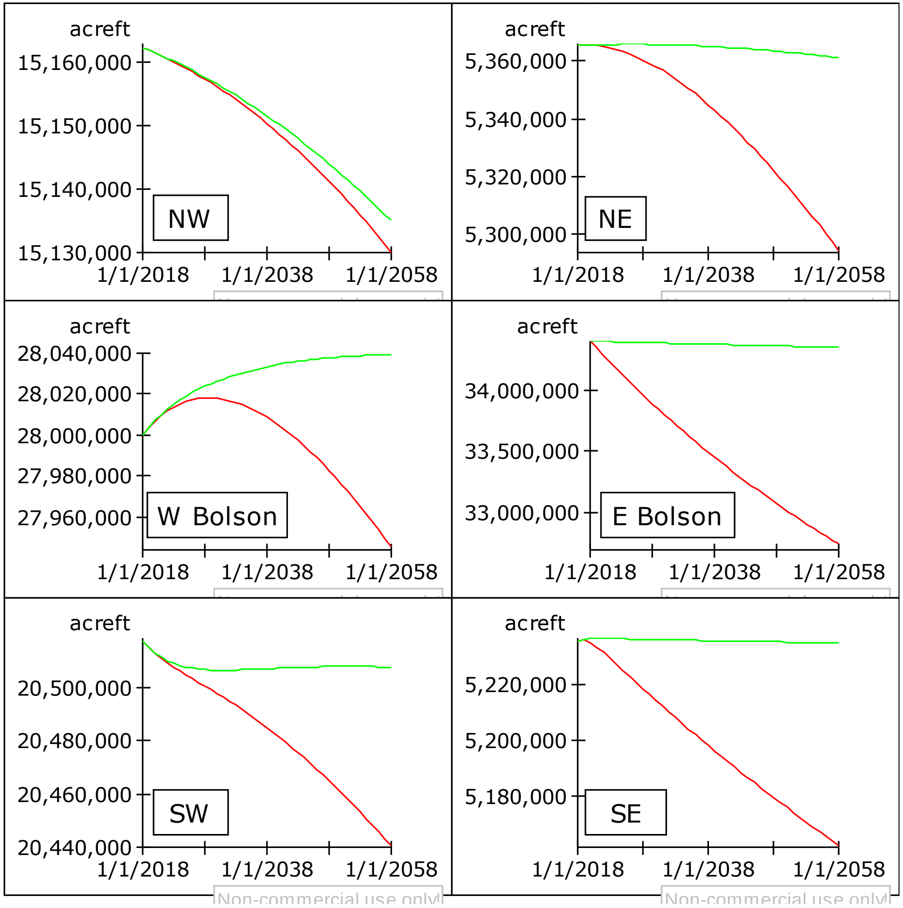
Time	5HeadEBols
1/1/2018	6,818
1/1/2038	6,791'5'
1/1/2058	6,771'5'

Time	5HeadSW
1/1/2018	6,771'11'
1/1/2038	6,769'11'
1/1/2058	6,767'3'

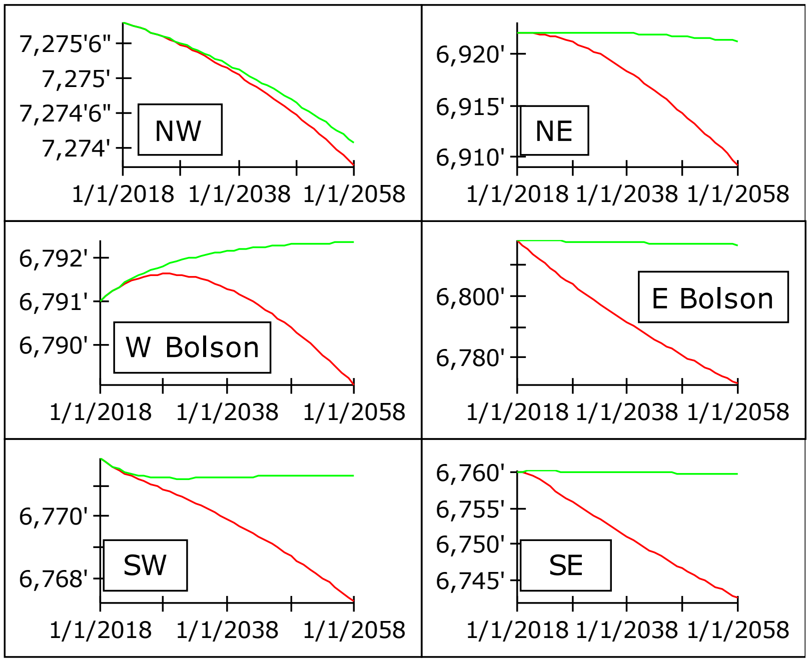
Time	5HeadSE
1/1/2018	6,759'10'
1/1/2038	6,751'1'
1/1/2058	6,742'7'

Volume

Green = No-Development, Red = Appropriation

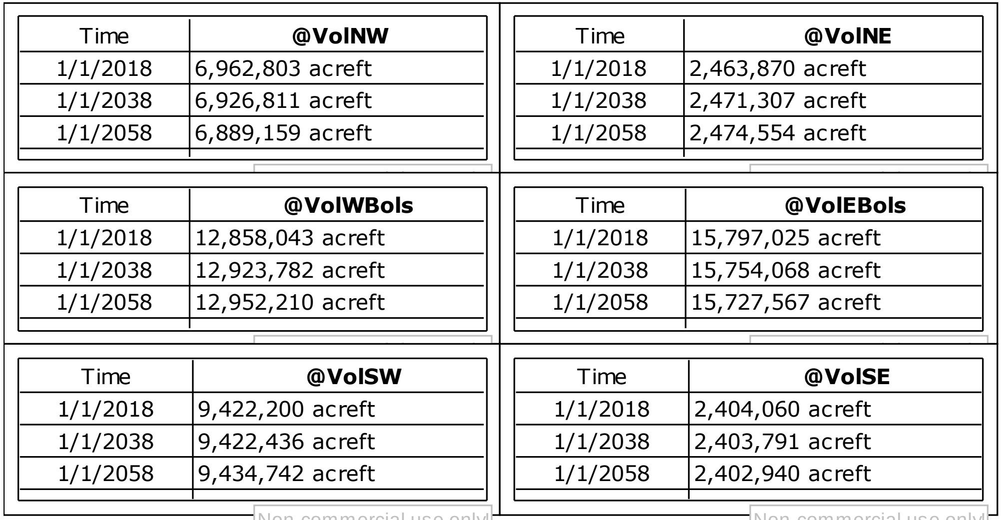


Head



Combination: Volume and Head

No-Development:



Time	@VolNW
1/1/2018	6,962,803 acreft
1/1/2038	6,926,811 acreft
1/1/2058	6,889,159 acreft

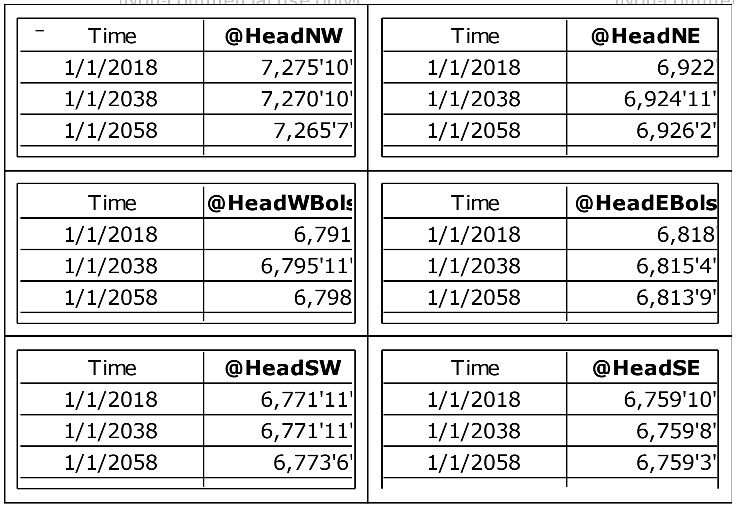
Time	@VolNE
1/1/2018	2,463,870 acreft
1/1/2038	2,471,307 acreft
1/1/2058	2,474,554 acreft

Time	@VolWBols
1/1/2018	12,858,043 acreft
1/1/2038	12,923,782 acreft
1/1/2058	12,952,210 acreft

Time	@VolEBols
1/1/2018	15,797,025 acreft
1/1/2038	15,754,068 acreft
1/1/2058	15,727,567 acreft

Time	@VolSW
1/1/2018	9,422,200 acreft
1/1/2038	9,422,436 acreft
1/1/2058	9,434,742 acreft

Time	@VolSE
1/1/2018	2,404,060 acreft
1/1/2038	2,403,791 acreft
1/1/2058	2,402,940 acreft



Time	@HeadNW
1/1/2018	7,275'10'
1/1/2038	7,270'10'
1/1/2058	7,265'7'

Time	@HeadNE
1/1/2018	6,922
1/1/2038	6,924'11'
1/1/2058	6,926'2'

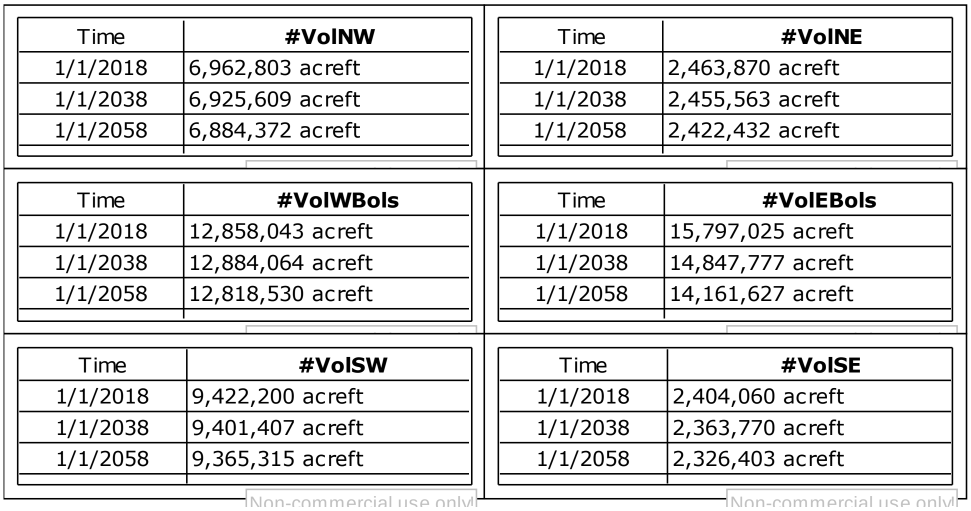
Time	@HeadWBols
1/1/2018	6,791
1/1/2038	6,795'11'
1/1/2058	6,798

Time	@HeadEBols
1/1/2018	6,818
1/1/2038	6,815'4'
1/1/2058	6,813'9'

Time	@HeadSW
1/1/2018	6,771'11'
1/1/2038	6,771'11'
1/1/2058	6,773'6'

Time	@HeadSE
1/1/2018	6,759'10'
1/1/2038	6,759'8'
1/1/2058	6,759'3'

Appropriation:



Time	#VolNW
1/1/2018	6,962,803 acreft
1/1/2038	6,925,609 acreft
1/1/2058	6,884,372 acreft

Time	#VolNE
1/1/2018	2,463,870 acreft
1/1/2038	2,455,563 acreft
1/1/2058	2,422,432 acreft

Time	#VolWBols
1/1/2018	12,858,043 acreft
1/1/2038	12,884,064 acreft
1/1/2058	12,818,530 acreft

Time	#VolEBols
1/1/2018	15,797,025 acreft
1/1/2038	14,847,777 acreft
1/1/2058	14,161,627 acreft

Time	#VolSW
1/1/2018	9,422,200 acreft
1/1/2038	9,401,407 acreft
1/1/2058	9,365,315 acreft

Time	#VolSE
1/1/2018	2,404,060 acreft
1/1/2038	2,363,770 acreft
1/1/2058	2,326,403 acreft

Time	**#HeadNW**
1/1/2018	7,275'10'
1/1/2038	7,270'8'
1/1/2058	7,264'11'

Time	**#HeadNE**
1/1/2018	6,922
1/1/2038	6,918'9'
1/1/2058	6,905'10'

Time	**#HeadWBols**
1/1/2018	6,791
1/1/2038	6,792'11'
1/1/2058	6,788'1'

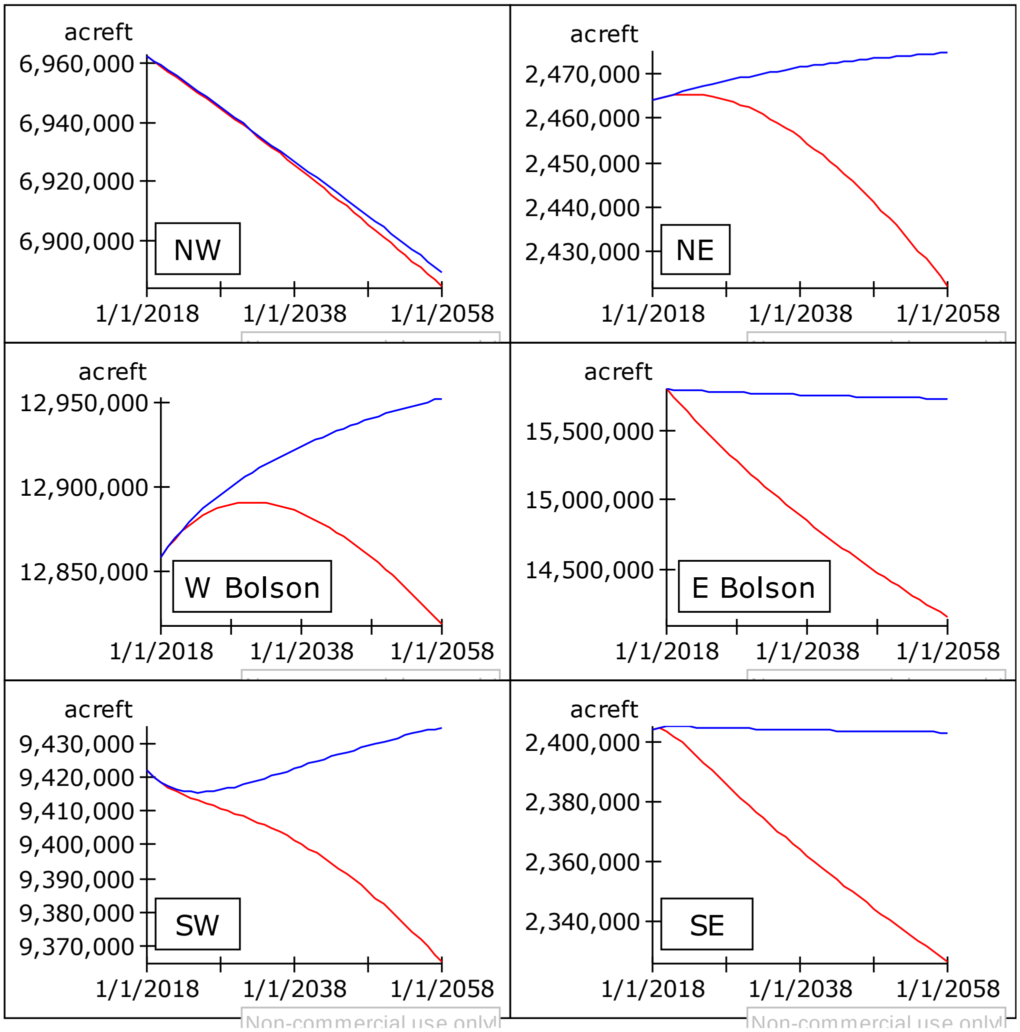
Time	**#HeadEBols**
1/1/2018	6,818
1/1/2038	6,760
1/1/2058	6,718

Time	**#HeadSW**
1/1/2018	6,771'11'
1/1/2038	6,769'2'
1/1/2058	6,764'6'

Time	**#HeadSE**
1/1/2018	6,759'10'
1/1/2038	6,739'2'
1/1/2058	6,720

Volume

Blue = No-Development, Red = Appropriation



Head

Blue = No-Development, Red = Appropriation