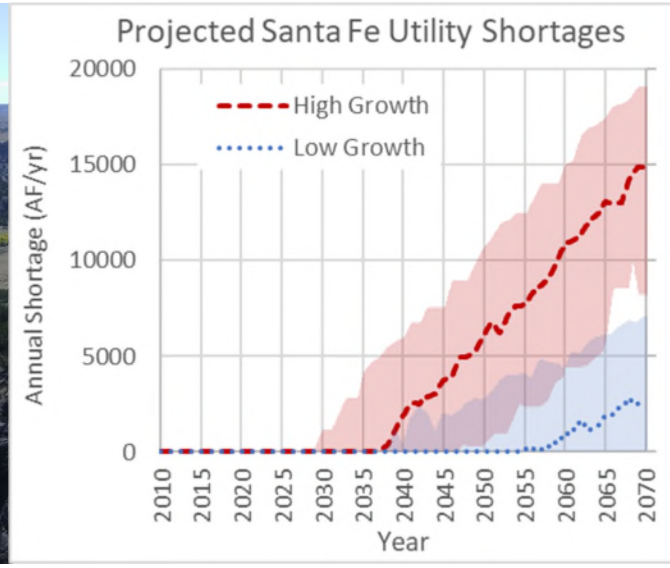
Santa Fe Basin Study Update



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Submitted to:

U.S. Bureau of Reclamation
Albuquerque Area Office
555 Broadway NE Suite 100
Albuquerque, New Mexico 87102-2352

Prepared by:

Tetra Tech, Inc.
502 West Cordova Road, Suite C
Santa Fe, New Mexico 87505

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EXECUTIVE SUMMARY

The 2015 Santa Fe Basin Study (Basin Study) (Llewellyn *et al.*, 2015) used a sequence of quantitative models and analysis techniques to estimate that, without changes to current water management operations, the Santa Fe Basin could expect shortages of between 5000 and 9000 acre-feet per year (AF/yr) by 2055 due to demand growth and climate change impacts on supply and demand. The nature and timing of these shortages prior to 2055 was not addressed in the Basin Study. In this Santa Fe Basin Study Update, the Basin Study analysis was extended. Results suggest that, without changes to current water supplies or operations, shortages greater than 1000 AF/yr may be expected in 10% or more of years in the Santa Fe Basin by 2030 under high growth and hotter-drier climate change scenarios. By 2055, shortages of between zero and 12,000 AF/yr may be expected in 10% of years, depending on population growth and climate-change scenarios. This large range of uncertainty more than 35 years out is difficult to avoid, due to the large role of future human behavior in the actual shortages. The following are key conclusions and recommendations from the Santa Fe Basin Study Update:

- Without changes to current water supplies or operations, shortages greater than 1000 AF/yr may be expected in 10% or more of years in the Santa Fe Basin by 2030 under high growth and hotter-drier climate change scenarios.
- The range of demand projections considered result in larger ranges of shortage uncertainties than do the range of (climate change driven) supply projections.
- Use of resources to improve understanding of drivers of local demographic and per-capita water-use trends are strongly recommended.
- It is recommended that the projections of future water supply and demand developed in the Santa Fe Basin Study and Basin Study Update be updated every 5 years, and more regularly if markedly different supply and demand projections become available.

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ABBREVIATIONS AND ACRONYMS USED

AF	acre-feet
AF/yr	acre-feet per year
Basin Study	Santa Fe Basin Study
Basin Study Update	Santa Fe Basin Study Update
BDD	Buckman Direct Diversion
City	City of Santa Fe
CMIP3	Coupled Model Intercomparison Project, Phase 3
CMIP5	Coupled Model Intercomparison Project, Phase 5
County	Santa Fe County
GCM	General Circulation Model
GPCD	gallons per capita per day
HDe	Hybrid Delta Ensemble
MGD	million gallons per day
SDA-1	Sustainable Development Area 1
SFCU	Santa Fe County Public Utilities
SFCU Master Plan	DRAFT Water and Wastewater Utility Master Plan
SJC	San Juan – Chama
SURFS	Stream Unit Response Function Solvers
URGSiM	Upper Rio Grande Simulation Model
VIC	Variable Infiltration Capacity
WaterMAPS	Water Management and Planning Simulation Model
yr	year

1. INTRODUCTION

The Santa Fe Basin Study Update (Basin Study Update), like the original Santa Fe Basin Study (Llewellyn *et al.*, 2015), focuses on the Santa Fe River watershed, a 285 square mile sub-basin of the Rio Grande (Figure 1), but also includes the Rio Grande watershed upstream of the Buckman Direct Diversion (BDD), and three tributaries to the San Juan River, which are connected to the Rio Grande basin by the San Juan-Chama (SJC) Project. The City of Santa Fe (City) and Santa Fe County (County) divert native and SJC water from the Rio Grande for municipal use at the BDD. In addition to these three surface-water supplies, the City and County also use groundwater from the aquifers of the Santa Fe Group inside and outside of the Santa Fe Watershed (Figure 1). For more information on the water supply portfolio of the City and County, refer to the original Santa Fe Basin Study.

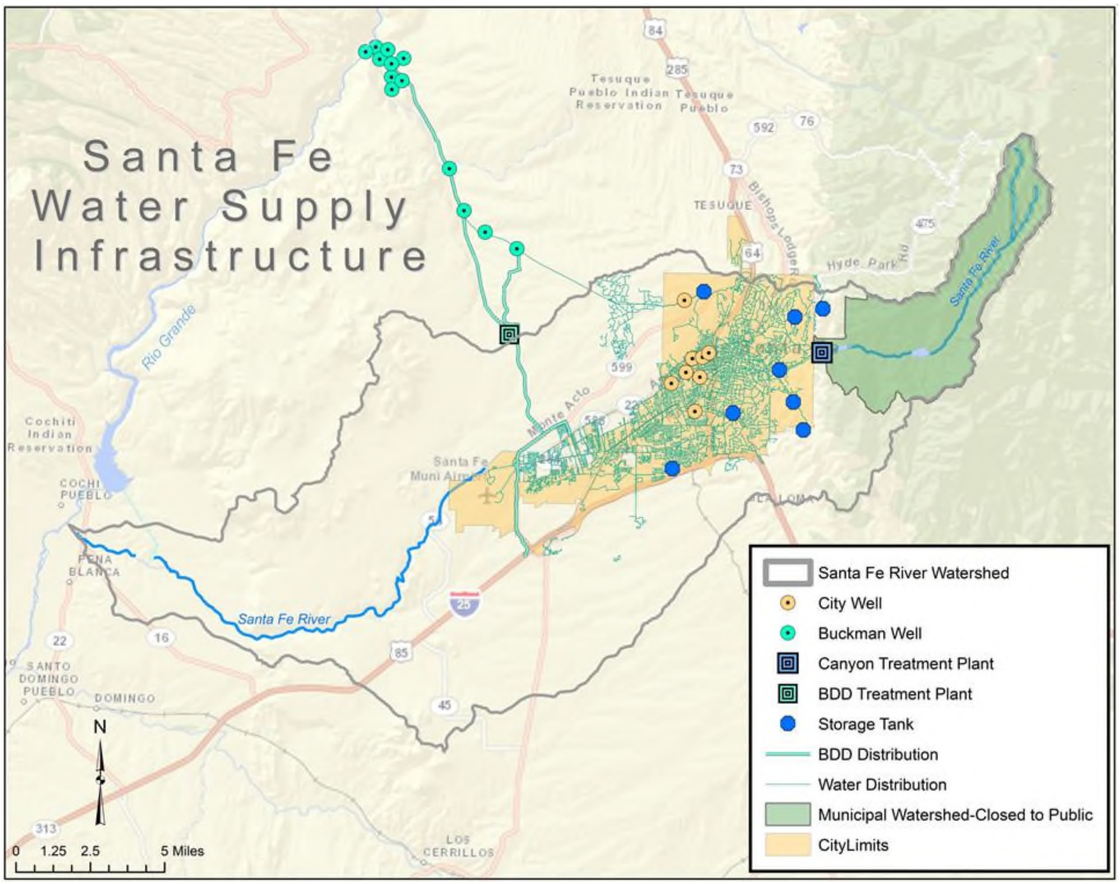

Figure 1: Santa Fe Water Supply Sources and Infrastructure

The Basin Study projected a water supply shortage to the City and County under projected 2055 conditions ranging between 5,155 and 9,323 AF/yr. The Basin Study did not evaluate the timing of the onset of these shortages leading up to 2055. The projected rate of onset is an important factor in decisions on implementation of adaptation strategies to offset these shortages. This update fills in the missing temporal-onset component, and also updates demand projections based on newly available population projections. The updated information on timing of impacts will help the City determine timing for implementation of planned water adaptation strategies.

2. METHODS

As described in the Basin Study (Llewellyn *et al.*, 2015), potential climate change impacts on the Santa Fe Basin are estimated through a series of models starting with the Coupled Model Intercomparison Project, Phase 3[1] (CMIP3) General Circulation Model (GCM) simulations. Temperature and precipitation output from all 112 CMIP3 GCM simulations was statistically downscaled and used as input to the Variable Infiltration Capacity (VIC) landsurface model in order to generate basin flows. These flows, along with select downscaled temperature and precipitation output from the CMIP3 GCM simulations was used as input to the Upper Rio Grande Simulation Model (URGSiM) to calculate operations within the basin and resulting river flows and reservoir storage levels. Certain outputs from the CMIP3 GCM simulations, the VIC simulations, and the URGSiM simulations, were then used as input to the City's Water Management and Planning Simulation Model (WaterMAPS) to determine specific supply and demand imbalances possible under climate-change-impacted future conditions. The Hybrid Delta Ensemble (HDe) methodology utilized in the Basin Study uses changes in precipitation and temperature between historical and future periods in all CMIP3 GCM runs to derive representative changes to each of these parameters for similar groupings of GCMs. These changes are then imposed on historical hydrology and fed through the VIC and URGSiM models to generate WaterMAPS inputs representative of historical variability perturbed by a climate change signal. For additional details on manipulation of data from GCMs to generate inputs to WaterMAPS, and use of the HDe method to produce a small number of climate change scenarios from a large number of CMIP3 GCM simulations, see Appendix B of the Basin Study (Llewellyn *et al.*, 2015).

The Basin Study Update estimates the onset of demand growth and climate-change-driven imbalances between supply and (updated) demand in two different ways. The first method uses the HDe method as was done in the Basin Study, but with demands and supplies representative of 2025 conditions rather than 2055 conditions. This method provides another snapshot of estimated shortages, but at a less-distant future period. The second method used in the Basin Study Update uses outputs from each of 70 GCM runs. In this so called "transient" approach, GCM, VIC, and URGSiM data based on a given GCM from 2010 through 2069 (60 years) was used to drive WaterMAPS.

The strength of the HDe method is in capturing historical variability and climate change impacts with a small number of model runs, and a direct comparison to conditions expected without climate change. The weakness of this period analysis is that it does not capture changes through time. The strength of the transient runs is a direct representation of how changes manifest through time in the GCMs. The weaknesses include a need for a larger number of model runs, and a weakness in the ability of GCMs to capture local-scale climate variability and extremes (such as very dry years or very wet years) (e.g. Costa-Cabral et al., 2016).

[1] A more recent set of GCM runs known as CMIP5 is now available and was considered for use in the Basin Study Update. The CMIP5 runs have not yet been processed by a basin scale operations model and as a result, certain inputs to WaterMAPS available for CMIP3 runs are not available for CMIP5 runs. Due to this lack of input data, and for consistency with the Basin Study, CMIP3 GCM runs were used in the Basin Study Update.

2.1. Basin Study Update Demand Projections

WaterMAPS calculates total demand by multiplying population served by an annual average use rate expressed in gallons per capita per day (GPCD). Total demand is distributed through the year with monthly factors to reflect the seasonality of water demand. Data used to develop estimated population served by the City and County water utilities from 2010 through 2069, and the average GPCD of those populations is described in the following sections.

2.1.1. City Population Scenarios

The HDe runs use static population levels to start 2025 and 2055, while the transient runs use population values that evolve through time from 2010 through 2069. In the Basin Study Update, high and low population growth rate scenarios were developed to provide a range of potential demands. Census-based City growth projections are relatively low (0.4%/yr into the future) due to historically slow growth between the 2000 and 2010 census surveys. Population projections based on this recent growth rate were chosen as representative of a lower growth scenario for the City. A higher population growth rate was chosen for 2020 forward to provide a higher potential City demand. The City high-growth scenario uses a historically reasonable 1.5% growth rate from 2020-2040 that slows by 0.1% every 5 years after 2040 to avoid runaway population growth in the distant future. In the Basin Study Update, the City population to start 2025 is 87,988 or 92,810 for the lower and higher City growth scenarios respectively. In the Basin Study, the City population to start 2055 was 125,019, while in the Basin Study Update, the City population to start 2055 is 99,000 or 145,070 for the lower and higher City growth scenarios respectively. Figure 2 shows the City population scenarios used in the Basin Study Update.

2.1.2. County Population Scenarios

The Santa Fe County Public Utilities (SFCU) DRAFT Water and Wastewater Utility Master Plan (SFCU Master Plan) includes water demand projections for 2030 and 2040 for a portion of the SFCU service area called the Sustainable Development Area 1 (SDA-1) (HDR Engineering Inc., 2019). SDA-1 is expected to see the most growth in the SFCU service area, and the SFCU Master Plan does not include water demand projections outside of SDA-1. Assuming constant demand from 2016 forward in SFCU service areas outside of SDA-1, the SFCU Master-Plan-based projected SFCU total demand in 2030 and 2040 is greater than SFCU demands associated with Basin Study SFCU population. Thus, the Basin Study SFCU population is used as the lower-growth SFCU population scenario, while the SFCU Master Plan is used to derive population served for the higher growth SFCU scenario. A 90 GPCD total average SFCU use rate (see Section 2.1.3) was used to derive SFCU population served from total water demand projections.

SFCU population served in 2010 was estimated as 4921 persons based on a value of 7968 persons in 2015 contained in the WaterMAPS Basin Study model, and SFCU growth rates implicit in that model. For the lower growth scenario, SFCU population from 2015 through 2055 was the same as in the Basin Study. From 2055 through 2069, SFCU population growth was extrapolated at 2.4% per year based on 2054 SFCU growth rates implicit in the Basin Study model. For the higher growth scenario, the SFCU 2010 starting population of 4921 was increased linearly to a 2015 SFCU population served estimate of 10,395 in 2015 based on 2015 SFCU total water demand and a 90 GPCD total average SFCU use rate (see Section 2.1.3). The SFCU population served was then increased linearly from 10,395 in 2015 to 31,289 in 2030 and 48,837 in 2040, populations that are implied by the SFCU Master Plan projected total demand assuming an average use rate of 90 GPCD. After 2040, the higher growth scenario SFCU population was projected forward starting with a 3.5% annual average growth rate that was decreased by 0.5% every 5 years through 2069.

The SFCU population to start 2025 is 18,048 or 23,803 for the lower and higher SFCU growth scenarios respectively. In the Basin Study, SFCU population to start 2055 was 44,673, while in the Basin Study Update, the SFCU population to start 2055 ranges from the same 44,673 to 76,074 for the lower and higher SFCU growth scenarios respectively. Figure 2 shows the SFCU population scenarios used in the Basin Study Update.

2.1.3. City and County GPCD Use

In the Basin Study, the annual average base water use rate across the City and County population in 2055 was 114 GPCD. Recent analysis suggests an average use rate of 90 GPCD for the City (Schneider, 2018). County data for 2015 suggests the utility provided 341 million gallons of water (HDR Engineering Inc., 2019) to approximately 10,000 people (Borchert, Aaboe and Duran, 2016) for a total annual average GPCD of approximately 94. For consistency and simplicity, 90 GPCD is used in the Basin Study Update to calculate total water demand for both the City and the County for all simulated years. As discussed above, the Basin Study Update includes a range of demands based on a range of population projections for both the City and County populations served by water utilities. A range of GPCD values was not used because GPCD has historically decreased through time in both the City and County but a good understanding of where it might go in the future is lacking. Do to this uncertainty, and the use of population scenarios that will provide a range of potential demands without any variation to GPCD, the conservative assumption of no change to base GPCD was employed.

WaterMAPS uses monthly factors to distribute the base GPCD demand through the year to capture the seasonality of demand. As described in Section 2.6.3 of the Basin Study (Llewellyn *et al.*, 2015), the annual average base GPCD demand rises with increases to max temperature and decreases to precipitation, thus the climate change scenarios also impact demand.

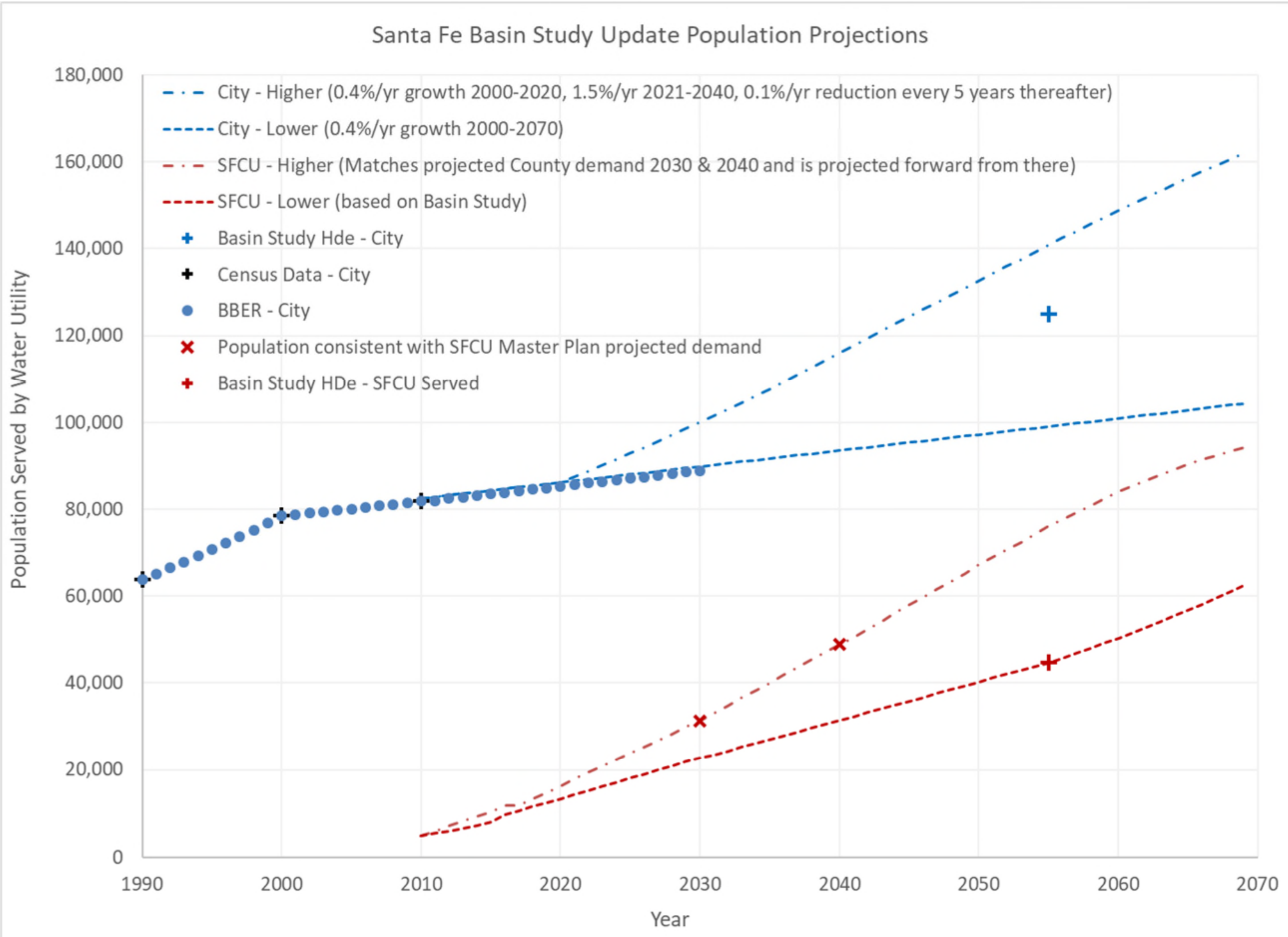

Figure 2: Range of projected populations for the City and County used in the Basin Study Update.

2.2. Updated HDe Runs

2.2.1. HDe Input Data

Timeseries projections required by WaterMAPS were developed at a monthly timestep for 48 years of hydrology, which were used as input to drive the HDe runs. The eight different time series along with their source and use in WaterMAPS are listed in Table 1. The projections for the 2055 future period was developed previously for the Basin Study as documented in Appendix B and Appendix C1 of that report (Llewellyn *et al.*, 2015). The projections were extracted for the 2025 future period from an archive of all data developed but not utilized in the Basin Study. For the 2025 and 2055 time series, four scenarios were utilized in each period. The first scenario is a Simulated Historical period in which all model outputs were generated based on estimated historical temperature and precipitation data for the 48-year period from 1951 through 1998. The next three are HDe-based scenarios representing the 48-year simulated historical period perturbed by changes to temperature and precipitation averaged across groups of GCMs representing a range of hydro-climatic conditions; less temperature rise and less precipitation decrease (Warm Wet) in a given future period (2025 or 2055), GCM-average climate changes (Central Tendency), and more temperature rise and more precipitation decrease (Hot Dry) in the same future period.

Table 1: Monthly time series data developed for 48-year inputs to WaterMAPS for 2025 and 2055 HDe analysis.

Parameter	Source	Use in WaterMAPS	Scenarios
Average Daily Maximum & Minimum Temperatures	Downscaled GCM data*	Reservoir Evaporation	Simulated Historic 2025 Hot Dry 2025 Warm Wet 2055 Hot Dry 2055 Warm Wet
Cumulative Precipitation	Downscaled GCM data*	Reservoir Precipitation	
Santa Fe River flow above McClure	VIC model**	Reservoir inflows	
Rio Grande flow at Otowi	URGSiM***	BDD operations	
San Juan Chama Allocation	URGSiM***	BDD operations	
Abiquiu Reservoir Evaporation	URGSiM***	BDD operations	
Article VII Status	URGSiM***	Reservoir operations	

* Extraction of downscaled GCM data for two, 1/8th degree cells approximately overlying McClure Reservoir and the City of Santa Fe for HDe 2025 and 2055 scenarios as described (for the 2055 scenarios) in Appendix C1 of the Basin Study (Llewellyn *et al.*, 2015).

** Flow data from the VIC landsurface model driven by downscaled GCM data processed with the HDe method as described in Appendix B of the Basin Study (Llewellyn *et al.*, 2015).

*** Output data from URGSiM for 2025 and 2055 HDe runs driven by downscaled GCM data and flow data from the VIC landsurface model as described in Appendix B of the Basin Study (Llewellyn *et al.*, 2015) and the Upper Rio Grande Impacts Assessment main report and Appendix E (Llewellyn *et al.*, 2013).

2.2.2. WaterMAPS HDe Runs

In the HDe simulations, a 48-year hydrologic sequence representative of probabilistic conditions in 2025 or 2055 defines water supply, while City and County demand remains constant at 2025 or

2055 levels. WaterMAPS is coupled with a separate spreadsheet model, the Stream Unit Response Function Solvers (SURFS), which defines the state of the groundwater system associated with a given WaterMAPS run. In the HDe runs, WaterMAPS is run once to estimate groundwater pumping through time, and that pumping is used as input to SURFS. The SURFS model calculates the impact of the groundwater pumping on well drawdown and stream leakage during the year of interest (either 2025 or 2055). The pumping-induced leakage and well drawdown information is fed into WaterMAPS for the HDe runs. WaterMAPS27.stmx and SURFS_V12.xlsm, which were the most updated version of each model, were provided to Tetra Tech Inc. by Enrique Lopezcalva of Woodard Curran (Lopezcalva, 2018).

The WaterMAPS27.stmx model included two invalid data variables that prevented the model from running. The logic used to update those variables is included in Appendix A. No documentation was obtained detailing model updates since the original Basin Study, and the WaterMAPS model instance used in that study was not available. As a result, the first modeling task undertaken in the Basin Study Update was to recreate the Basin Study results with WaterMAPS27.stmx and SURFS_V12.xlsm. All user-interface switches and toggles were left in their default positions, and the 2055 climate scenario based hydrologic data, 2055 population projections, and 2055 GPCD demand used in the Basin Study were used as model inputs.

The updated WaterMAPS model replicating the Basin Study (referred to here as the 2018-2055 Basin Study model) generates results very similar, but not identical to those reported in the Basin Study. Table 2 lists the modeled supply and demand reported in the Basin Study as compared to output from the 2018-2055 Basin Study model. In all four climate scenarios, differences in modeled supply and demand values between the Basin Study and the 2018-2055 Basin Study model outputs were less than 1%. These differences were considered acceptable for the purposes of the Basin Study Update.

Table 2: WaterMAPS27 changes for 2018 Replications of 2015 Basin Study

	2015 Basin Study	2018-2055 Model	2015 Basin Study	2018-2055 Model
	Simulated Historical		Central Tendency	
Average Demand (AF/yr)	21,643	21,608	22,925	22,888
Average Supply (AF/yr)	16,488	16,473	15,550	15,532
Average Deficit (AF/yr)	5,155	5,135	7,375	7,356
	Wet & Warm		Hot & Dry	
Average Demand (AF/yr)	22,646	22,609	23,299	23,261
Average Supply (AF/yr)	16,304	16,286	13,976	13,960
Average Deficit (AF/yr)	6,342	6,323	9,323	9,301

The 2018-2055 Basin Study model along with SURFS_V12.xlsm was the basis for Basin Study Update HDe runs for the 2025 and 2055 periods with updated population and GPCD demand data (See Section 2.1). For the 2025 HDe runs, climate data inputs for the four planning year climate change scenarios (Simulated Historical, Central Tendency, Wet & Warm, and Hot & Dry, detailed in Section 2.2.1) were used to drive the model.

2.3. Transient Runs

2.3.1. Transient Input Data

The same inputs listed in Table 1 for the HDe runs were developed for the transient runs. However, whereas the HDe inputs were four 48-year sequences based on historical hydrology perturbed by different degrees of climate change simulated by groups of CMIP3 GCM runs, the transient runs directly utilize outputs from the 70 different CMIP3 GCM runs that made up the Warm Wet and Hot Dry HDe groupings in the 2055 HDe analysis, for the simulated years 2010 through 2069. In other words, CMIP3 GCM run 109 (arbitrary) was one of 35 CMIP3 GCM runs used to define temperature and precipitation data in 2055 for the Warm Wet HDe scenario by informing the degree of change to historical temperature and precipitation data used as inputs to the VIC, URGSiM, and WaterMAPS models. Output from an additional 35 different GCM runs were utilized to represent the Hot Dry grouping. In the transient runs on the other hand, the timeseries of simulated temperature and precipitation outputs from GCM 109 (and 69 other GCM runs) in each month from January 2010 through December 2069 were used to drive VIC, URGSiM, and WaterMAPS, resulting in a timeseries of model output specific to the climactic conditions and autocorrelation structure represented by GCM run 109 (and the other 69 GCM runs). The specific time period utilized for this transient analysis represents 60 years from 2010 through 2069.

2.3.1. WaterMAPS Transient Runs

The HDe runs represent a range of possible surface water supply years associated with a fixed future period. As a result, demand does not change during the runs, nor do groundwater conditions in the basin. The transient runs on the other hand each represent an alternate potential future with supply, demand, and groundwater conditions changing together from year to year. This conceptual difference is important from the perspective of the groundwater system. Whereas in the HDe runs, a single SURFS run based on historical pumping defines the state of the groundwater system for all scenario runs associated with a given future year, in the transient runs, the groundwater system is changing as a function of time based on groundwater pumping, which depends on available surface supply. Because of this interdependence between WaterMAPS and SURFS, the models must be run iteratively until the solutions converge. Test runs determined that to achieve convergence in the transient run application, WaterMAPS had to be run four times, and SURFS three times (between each WaterMAPS run).

The 2018-2055 Basin Study model was used as the starting model to create the transient model runs. WaterMAPS was updated to run for 60-years, from 2010 through 2069. All sequential time series data inputs were updated to allow data to be imported for 60 years. The climate data inputs developed were unique for each of the 70 GCM climate models. To facilitate iterative model runs for 70 different scenarios, WaterMAPS was automated through a command line batch process file to automatically import data from each of the 70 GCM runs and generate unique output files. Some of these output files were used as input for a batch run of SURFS, while others included model outputs related to Supply and Demand. The transient model results reported in the next section are from output from the fourth WaterMAPS run (i.e. the runs that converged).

3. SCENARIO RUN RESULTS

3.1. Shortage Results

As seen in Figure 3, HDe results for 2055 probability of shortages (without any adaptation) in the high growth scenario are only slightly higher than the probability of shortages that were projected in the Basin Study. This is because the Basin Study Update high -growth scenario has higher population levels (221,100 population served) but lower GPCD (90 GPCD) than the Basin Study (169,700 and 112 respectively). The base daily demand associated with multiplying these numbers together is 19.9 million gallons per day (MGD) in 2055 for the Basin Study Update high-growth scenario compared to 19 MGD for the Basin Study. The colored areas in Figure 3 represent the distribution of results associated with all climate change scenarios, with the bottom of the colored bands defined by the Warm Wet scenario (less climate change), and the top of the colored bands defined by the Hot Dry scenario (more climate change). The 2025 HDe results suggest that, with the combination of high growth and more climate change, shortages may occur in approximately one in four years as early as 2025. Figure 4 repeats the information in Figure 3, but for the 2055 Basin Study Update runs only, and specifically includes the Central Tendency climate scenario.

As seen in Figure 4, under the low growth scenario, shortages would be expected in 4 of 5 years (80% probability) around 2055 with more climate change, and only 1 in 10 (10%) with less. With Central Tendency climate change, shortages would be expected in the low growth scenario about every other year (50% probability) around 2055. Under high growth conditions, shortages would range from 4700 to 7200 AF/yr in even the wettest years, and 9000 to 14,000 AF/yr in the driest years, with the range of values resulting from the variation in climate change scenarios. The potential shortages occurring with 10% probability in 2055 range from zero to 12,000 AF/yr depending on population growth and climate change severity. This range is large enough that it is not easily used for immediate planning purposes. This suggests that additional planning studies should be made on a regular basis as additional and improved supply and demand projections become available.

The two arrows in Figure 4 show the relative contribution of population growth and climate change uncertainty in this range of shortages. For shortages occurring with 10% probability, population growth uncertainty is responsible for approximately 2/3rds of the total scenario uncertainty, and climate change uncertainty for the balance. The sensitivity of future shortages to demand growth is also shown in Figure 5. Without climate change (Simulated Historic HDe scenario), projected shortages in 2055 under the high growth scenario range from 3400 AF/yr in the wettest years to 7600 AF/yr in the driest, whereas without climate change, projected shortages in the low growth scenario are negligible. In other words, demand growth alone poses challenges to existing water supply and management strategies in the long term, and potential climate change related impacts to supply and demand add further stress to the system.

Results from the transient runs are shown in Figure 6, along with representations of the total range of projected HDe shortages in 2025 and 2055. According to the transient runs, the possibility of annual shortages will begin between the late 2020s and mid 2030s depending on population growth rates. Shortages are seen in the median transient results starting in 2037 with high population growth and 2055 with low growth.

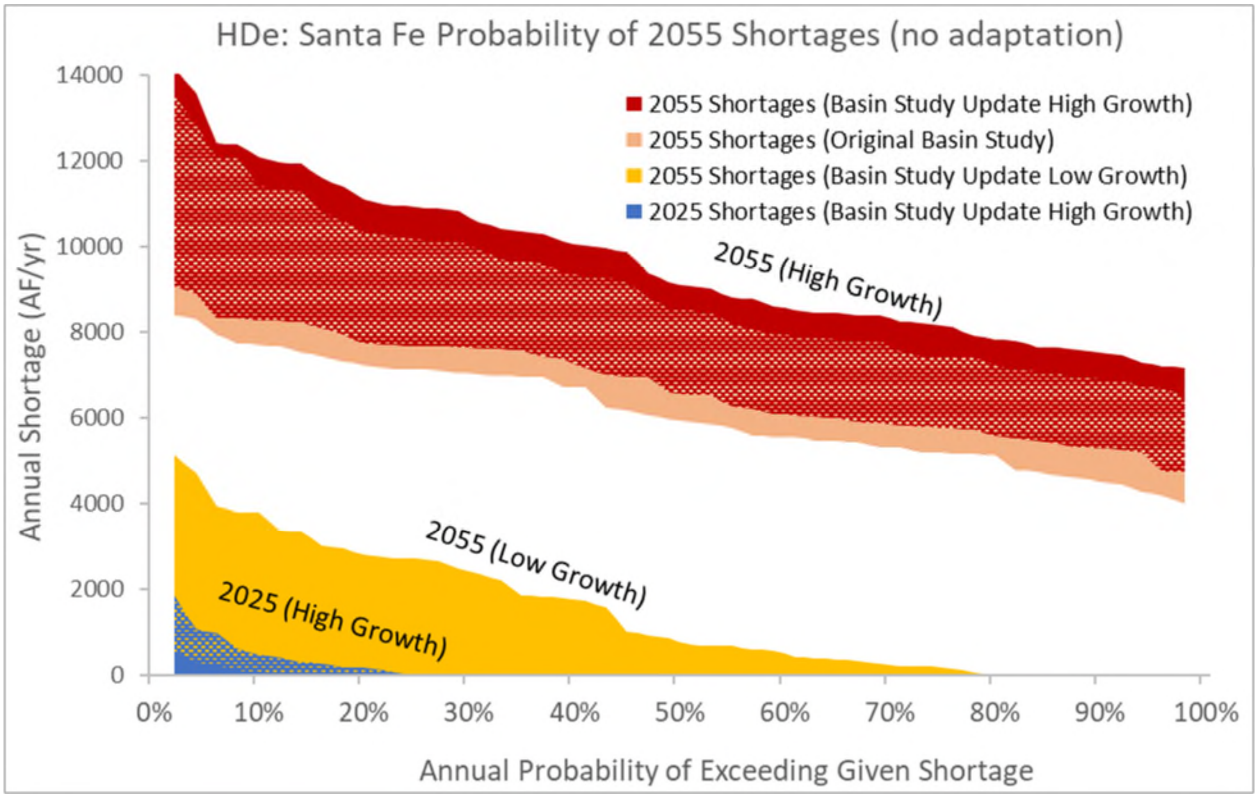

Figure 3: Range of projected shortages in 2025 and 2055 using the HDe Method.

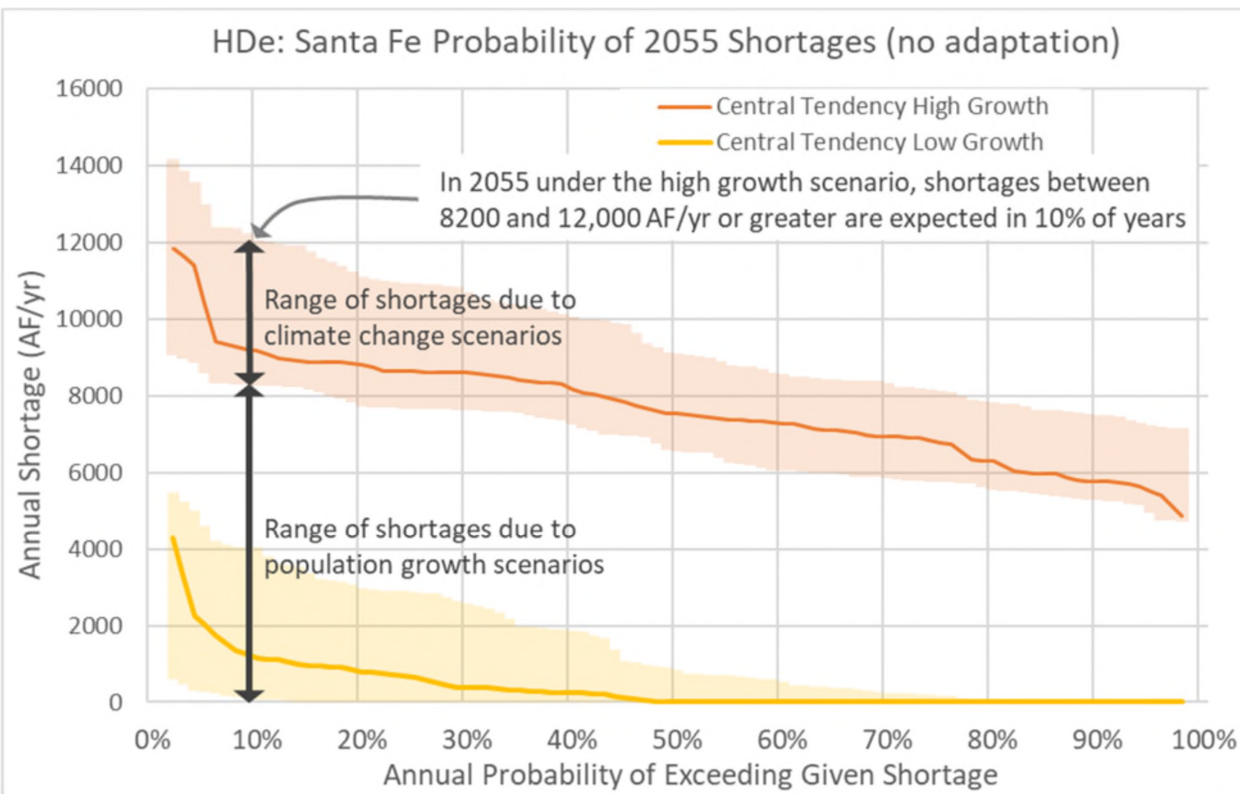

Figure 4: Basin Study Update projected shortages in 2055. Shading represents range of climate scenarios.

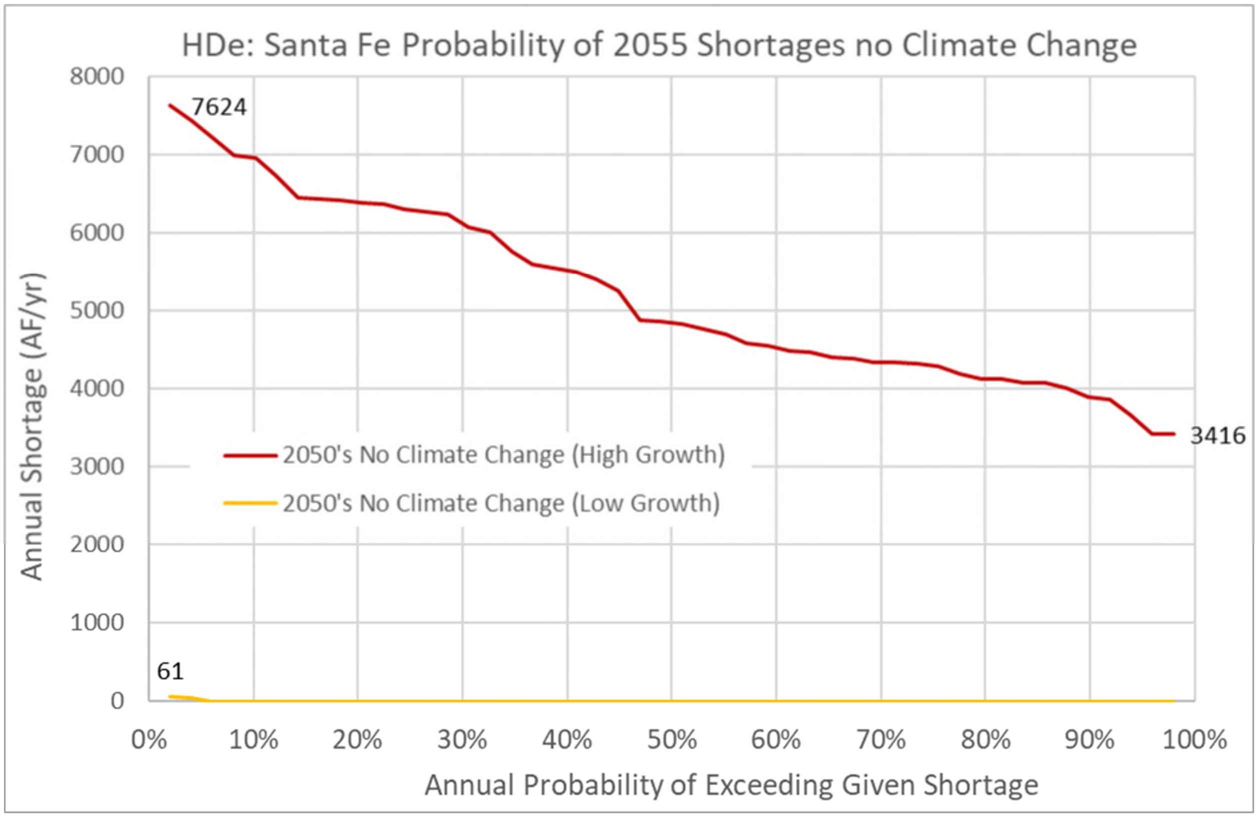

Figure 5: Basin Study Update projected shortages in 2055 without climate change.

The ranges of potential shortages suggested in 2025 and 2055 by the transient runs do not line up with the range of potential shortages suggested by the HDe methodology for the same years. This is not entirely surprising, however, because while WaterMAPS utilizes *demand* from either 2025 or 2055 in the HDe based methodology, the associated *supply* is based on changes to GCM behavior averaged across 30-year future periods centered on 2025 and 2055. In addition, in the HDe method the year to year variability and magnitude of historical extremes compared to average are based on the historical record. Transient hydrologic inflows to WaterMAPS were "bias corrected" to historical observations to capture overall mass balance, but likely do not capture historical statistics of the wettest or driest years. The largest shortages seen in the HDe runs are greater than the largest shortages in the transient runs for the same growth scenario in the HDe analysis year, but the range of shortages seen in the transient runs is generally larger when the 15 years before and after the HDe demand year are included in the comparison.

While the range of shortages is not easily comparable between the transient and HDe analysis, the median shortages from the transient runs in 2025 and 2055 are similar to the associated Central Tendency 50% shortages as seen in Table 3. In 2025 this comparison is trivial because there are no 2025 shortages in the transient runs or the 50% probability of exceedance Central Tendency HDe climate scenarios for either growth scenario. In 2055, the median transient shortage is 210 AF/yr for low growth and 8300 AF/yr for high growth which are similar to the HDe Central Tendency 50% probabilities of 0 AF/yr and 7520 AF/yr respectively.

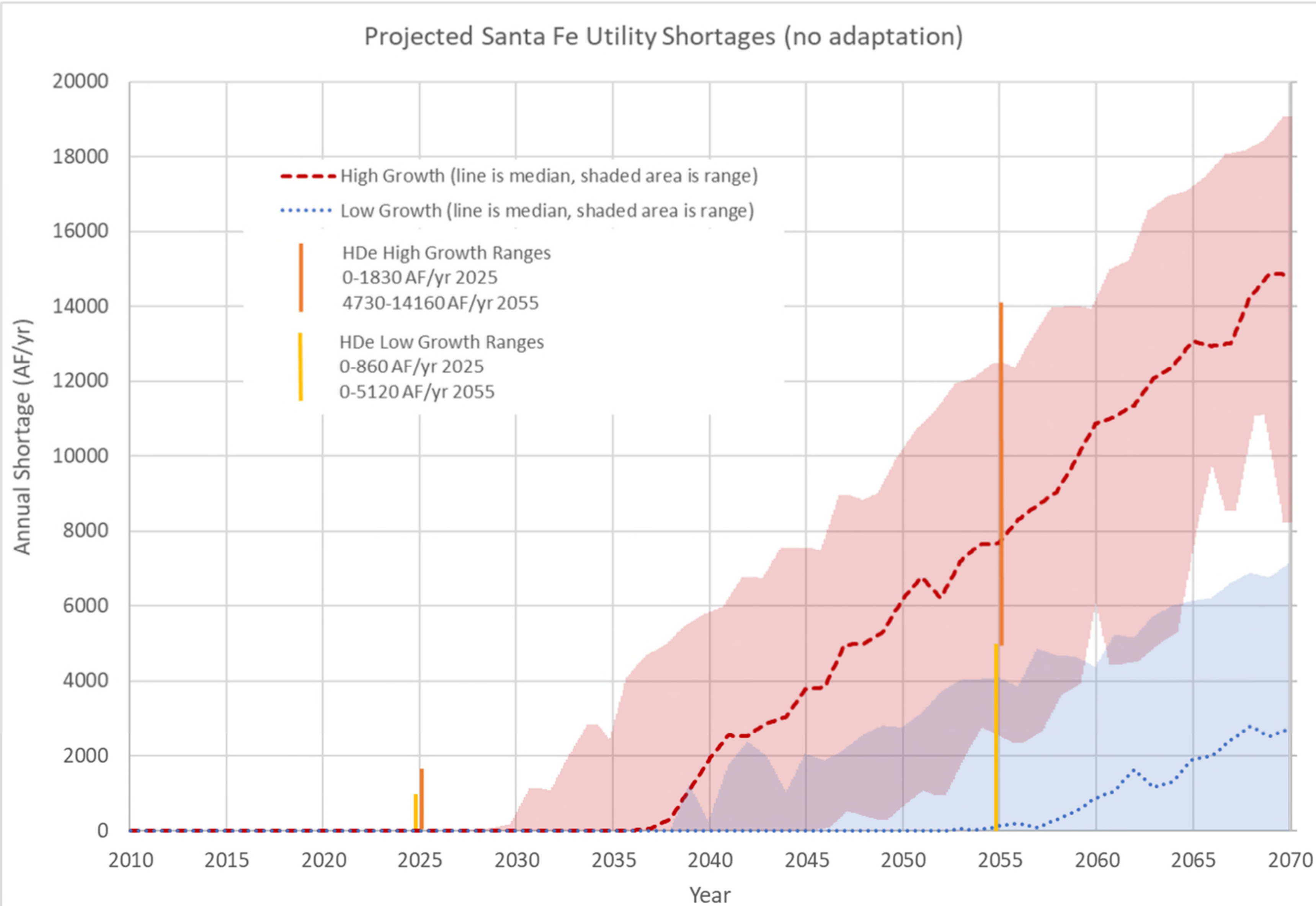

Figure 6: Basin Study Update projected shortages through time for transient and HDe methods.

Table 3: Comparison of HDe and Transient Shortages

Scenario \ Method	HDe Central Tendency 50% Probability	Median Transient
2025 Low Growth	0 AF/yr	0 AF/yr
2025 High Growth	0 AF/yr	0 AF/yr
2055 Low Growth	0 AF/yr	210 AF/yr
2055 High Growth	7520 AF/yr	8300 AF/yr

While the HDe and transient approach do not provide an apples-to-apples analysis of how impacts associated with climate change and demand growth will set in in Santa Fe, comparison of results from both methods provides information that, taken together, can help inform this question. The next section uses results from both methods to estimate the year of onset of water shortages in the Study Area.

3.2. Onset of Shortages

The question addressed by this Basin Study Update is as follows: “In the absence of adaptation, when will demand growth and climate change impacts result in water shortages in the area served by the City and County Water Utilities?”. To answer this question quantitatively with the model runs presented here, “shortage” needs to be defined both in terms of magnitude and frequency of the event. A quantitatively more specific question then might be: “In the absence of adaptation, when will demand growth and climate change impacts result in water shortages greater than 1000 AF/yr in more than 10% of years in the area served by the City and County Water Utilities?” Table 4 includes the answers to that question provided where possible by the HDe and transient methods for a variety of shortage sizes and frequencies.

An answer to the question can be offered with the transient methodology by recording the first year when the specified shortage value is exceeded in a greater percentage of runs than specified as the frequency. For example, 2033 is the first year more than 7 of 70 transient high growth runs have a shortage of 1000 AF/yr or more. That year is placed in the appropriate cell in Table 4. This method uses the variability between GCM runs in a given future year as a proxy for hydrologic variability. A “NA” value in Table 4 indicates that the level of shortage did not occur at the specified frequency in the transient run before 2070.

Table 4: Estimated year of onset of shortages as a function of shortage size and frequency

Method	Growth	*frequency*	≥100 AF/yr	≥1000 AF/yr	≥4000 AF/yr	≥7000 AF/yr
Transient Runs	Low	10%	2046	2048	2060	NA
	High		2031	2033	2038	2057
	Low	30%	2050	2055	2066	NA
	High		2034	2038	2043	2049
	Low	50%	2054	2060	NA	NA
	High		2037	2038	2046	2052

The onset information available from the snapshot-in-time HDe analysis is slightly different. The HDe analysis can answer the question "How often will a given shortage be expected to occur in 2025 or 2055?". In this case, the historical hydrological variability is the underlying proxy for future hydrological variability. The range of frequencies shown in Table 5 is defined by the low (Warm Wet), middle (Central Tendency), and high (Hot Dry) climate change scenarios.

Table 5: HDe method based estimates of frequency of shortages in 2025 and 2055

Future Year	Growth	≥100 AF/yr	≥1000 AF/yr	≥4000 AF/yr	≥7000 AF/yr
2025	Low	0% - **4%** - 5%	0% - **0%** - 0%	0% - **0%** - 0%	0% - **0%** - 0%
	High	0% - **7%*** - 22%	0% - **0%** - 5%	0% - **0%** - 0%	0% - **0%** - 0%
2055	Low	8% - **45%** - 76%	0% - **12%**** - 45%	0% - **2%** - 5%	0% - **0%** - 0%
	High	100% - **100%** - 100%	100% - **100%** - 100%	100% - **100%** - 100%	42% - **67%** - 100%

* 2031 onset of 10% frequency shortages in transient methodology for same scenario (see Table 4).
** 2048 onset of 10% frequency shortages in transient methodology for same scenario (see Table 4).

The HDe frequency results shown in Table 5 are close enough to 10% for two of the shortages to compare with the estimated year of shortage onset from the transient method for those particular scenarios and shortages. Shortages greater than or equal to 1000 AF/yr occur 12% of the time in 2055 in the HDe Central Tendency low-growth scenario, meaning they would begin to occur at 10% frequency sometime before 2055 for this scenario. This agrees reasonably with the transient method-based estimate of a 2048 onset for these shortages. Shortages greater than or equal to 100 AF/yr occur 7% of the time in 2025 in the HDe Central Tendency high growth scenario, meaning they would begin to occur at 10% frequency sometime after 2025 for this scenario. This agrees reasonably with the transient-method-based estimate of a 2031 onset for these shortages. These results lend additional support to the idea that, while not directly comparable, the transient and HDe methodologies project a similar picture of future shortages in the basin, and the temporal resolution provided by the transient methodology is a valuable addition to analysis of projected shortages in the Santa Fe Basin.

4. CONCLUSIONS

It has been said that it is dangerous to make predictions, especially about the future. This proverb applies directly to projections of future water supply and demand in the Santa Fe Basin. On the other hand, predictions about the future are exactly what is needed to make decisions about water management policy and infrastructure that are time consuming to put in place. The combination of uncertainty about future water demand in the face of population growth and water use trends, and the uncertainty about future water supply in the face of a changing climatic system leaves a wide range of possibilities in long range forecasts. To account for both uncertainties, the Basin Study Update results have been provided for a range of demands and a range of supplies. This approach helps maintain a sense of the inherent uncertainty associated with the projections but is not necessarily useful for specific decisions on project implementation. Here then is an attempt to distill these results into more actionable information.

Without changes to current water supplies or operations, shortages greater than 1000 AF/yr may be expected in 10% or more of years in the Santa Fe Basin by 2030 under high growth and large climate change conditions.

The water utility(s) providing water in the basin need to decide what magnitude of shortage can be managed with short term emergency actions, and what magnitude of shortage will require greater lead time to address. This information, in conjunction with the information in Table 4 and Table 5 can be used to develop a plan for implementation of projects; a long-range capital improvement plan for water resources. It is recommended that the Santa Fe Basin Study be updated every 5 years or so, and more regularly if population or climate trends change significantly or in ways that were not predicted in previous updates. Such additional updates to the Santa Fe Basin Study can be used to refine the most appropriate timing for implementation of capital projects in the plan.

For Santa Fe, demand projections (mostly driven by population growth) are associated with larger ranges of shortage uncertainties in the current analysis than are supply projections (mostly driven by climate and hydrology changes). These demand projections have also been developed using very simple methodologies and assumptions, compared to the supply projections, which have been based on complex climate, hydrology, and water operations modeling. This suggests that future planning studies would be benefited most by more attention to demand projections. Use of resources to improve understanding of drivers of local demographic and per-capita water-use trends are strongly recommended.

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APPENDIX A:

In the WaterMAPS27.stmx model provided by the City, two data variables, “Stage Reg” and “Efficient Capacity Available After BDD Base Want”, were invalid. The logic in those codes was updated accordingly.

“Stage Reg”

- **Original (Invalid Code):**
  ```
  IF(0<DM_Required<=0.15)THEN(1)ELSE(IF(0.15<DM_Required<=0.35)THEN(2)ELSE(IF(0.35<DM_Required<=0.50)THEN(3)ELSE(IF(0.50<DM_Required)THEN(4)ELSE(0))))
  ```

- **Updated:**
  ```
  IF(DM_Required<0)THEN(0)
  ELSE(IF(DM_Required<=0.15)THEN(1)
  ELSE(IF(DM_Required<=0.35)THEN(2)
  ELSE(IF(DM_Required<=0.50)THEN(3)
  ELSE(4))))
  ```

“Efficient Capacity Available After BDD Base Want”

- **Original (Invalid Code):**
- Planning_Year_All_Hydrology+Forty_Year_Sequential_Time_Series)*MAX(Max_Diversion_Possible*Total_Peak_BDD_Capacity_AFY/12-BDD_Base_Supply_Want)

- **Updated:**
  (Planning_Year_All_Hydrology+Forty_Year_Sequential_Time_Series)
  *(Max_Diversion_Possible*Total_Peak_BDD_Capacity_AFY/12-
  BDD_Base_Supply_Want)