Impacts of Climate Change on Water Demand in New Mexico

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New Mexico Interstate Stream Commission

P.O. Box 25102, Santa Fe, New Mexico 87504

Amy C. Lewis, HydroAnalytics LLC

7 Seton Plaza, Santa Fe, New Mexico 87508

Table of Contents

List of Figures

List of Tables

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1. Introduction

Virtually all life's processes require water; from plant growth to wildlife sustenance, to all the various anthropogenic activities we engage in. The amount of water needed is referred to as its water demand. Water demand is the amount of water required for various water-use sectors: (1) irrigated agriculture (AG), (2) public/private water systems (PWS), (3) industrial, commercial, mining and power (ICMP)), (4) watersheds and habitat (WH) (e.g., natural ecological systems for wildlife habitat), or (5) utilized in a non-consumptive way by recreational and quality-of-life activities (RQ).

The first three categories of water use sectors (AG, PWS, and ICMP) are quantified by the NMOSE and are human uses of water. The fourth and fifth water use categories are not generally quantified. The demand estimates for human uses of water do not include the depletion of water that occurs as precipitation falls on our landscape and is absorbed by plants, evaporated from streams, or sublimated from snow.

It is important to distinguish between the words used to describe water "demand" or "use" or "diversion" or "consumption." Some of our water that is "diverted" returns back to the river or aquifer, but a part of that water is "consumed" by plants or evaporated. NMOSE defines water demand with the following terms[1]:

[1] For a more thorough discussion of water demand terminology, see Magnuson et al., 2019

- diversions are water taken from the source of supply (usually an annual amount),
- conveyance losses are losses that occur as water flows from point of diversion to place of use,
- consumptive use is the amount of water consumed from the diversion by crops, landscaping, or other processes through transpiration, evaporation, or sublimation of water into the atmosphere such that it does not return to the local hydrologic system.
- consumptive irrigation requirement (CIR) is the amount of water needed for irrigation considering the temperature, precipitation, growing season, and crop type
- incidental depletions resulting from evaporation from ponded water
- evaporation from cooling towers or forced evaporation cooling

For sectors that rely on surface water storage, a part of the water stored in reservoirs is lost to evaporation, creating another demand. The loss of water to reservoir evaporation can be considered a loss of supply rather than a separate water use sector. Detailed descriptions of water demand and the volume of water diverted by water use sectors for 2015 are available in the New Mexico Water Use by Categories Report (Magnuson et al. 2019).

The amount of rain and snowmelt consumed by the vegetation in forests, rangelands and riparian areas through evapotranspiration or the snow that sublimates (converts from the solid form to vapor form without melting first) is not usually quantified but is an essential water demand to understand and one of the reasons that our prediction of future runoff indicates lower runoff volume, even though total average precipitation is not predicted to change significantly (Dunbar et al., 2021).

This report describes how climate change will likely impact the demands of each water use sector. The most recent estimate of water diversions by water use sectors for 2015 (Magnuson et al., 2019) shows (Figure 1) that irrigated agriculture and PWS account for 76% and 9%, respectively and represents 85% of the total water diversions in the state, a significant portion of which returns to the aquifers and streams. Mining, power, commercial and industrial sectors use about 5% of the state-wide total diversions. NMOSE estimates that domestic and livestock wells each divert about 1% of the water in the state. Reservoir evaporation accounted for 7% of the total water use, and is an amount that is fully consumed through evaporation to the atmosphere, unlike most other uses, and is a loss to the supply.

Reservoir evaporation impacts all water use sectors and for that reason, it is not considered a separate water use sector in this report. Water is primarily stored for public water systems and agriculture, but is also held in storage for industry, commercial, mining and power industries. Stored water is an important part of the watershed habitat and recreational aspects. Reservoir evaporation is going to increase with increasing temperatures. By 2070, evaporation from Elephant Butte reservoir is predicted to be 30% greater than the historic average (Dunbar et. al., 2021). The increase in evaporation will effectively reduce the supply available to the water use sectors holding the water in storage. Each public water system and agricultural system relying on stored water should consider the loss of supply due to the increased evaporation.

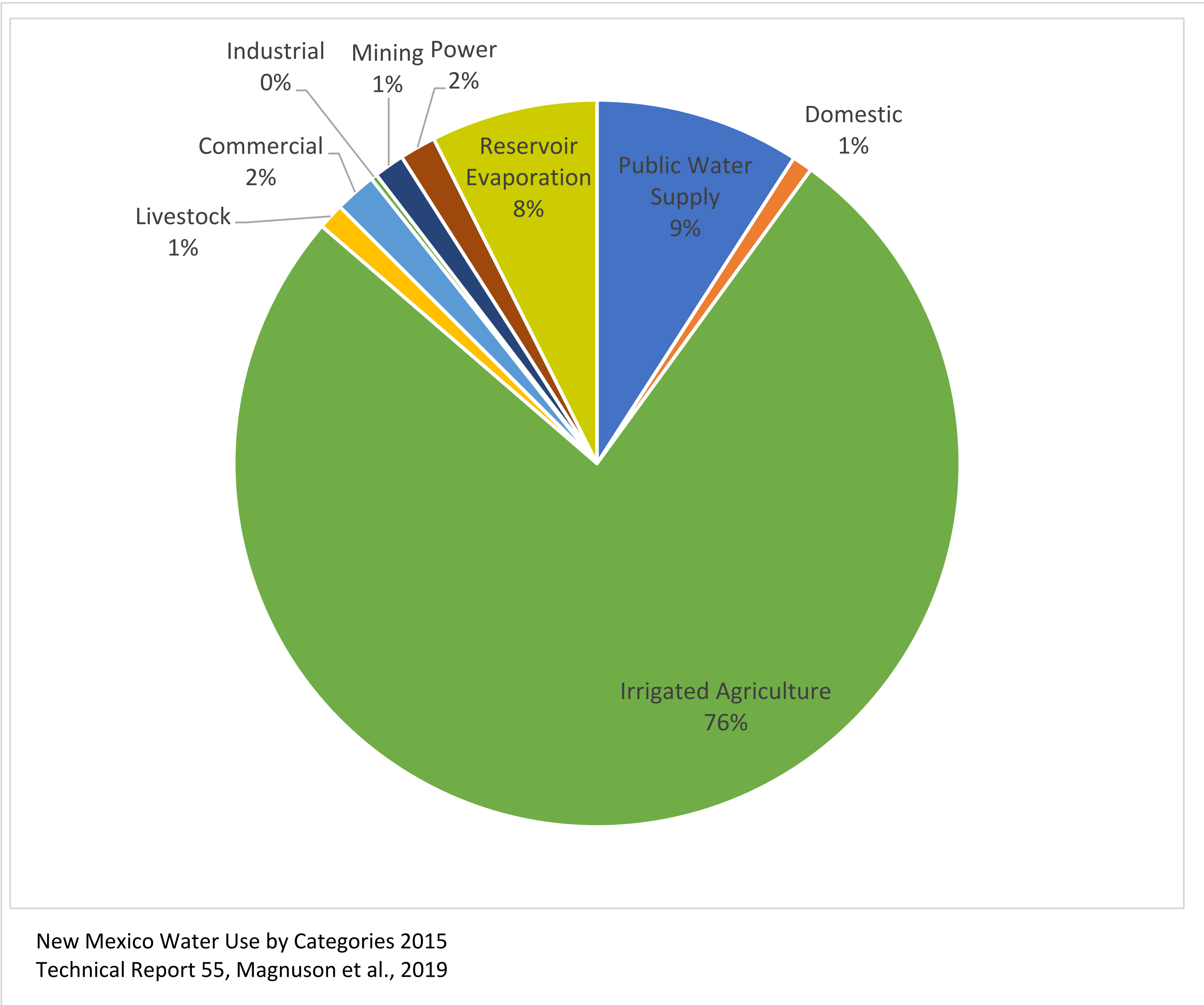

Figure 1. Water Use by Categories in 2015.

2. Changes in Demand of Agriculture

Warmer temperatures and longer growing seasons will increase the water demand of agriculture. The NM Climate Panel report (Dunbar et al., 2021) concluded that temperatures could warm between 5°F and 7°F by 2070 in New Mexico and that the growing season will be longer. Precipitation during the growing season may be impacted by climate change, where some areas in southern New Mexico may receive more monsoonal rainfall, but model predictions are not consistent (Dunbar et al., 2021).

The growing season varies by crop and location because each crop starts and stops growth at different temperatures. The growing season can also be restricted by administrative constraints that prohibit extending the irrigation season. And, of course, insufficient water will limit the amount of water consumed, but this report estimates the amount of water a crop will consume if supplied with sufficient water and no constraints on delivering water.

To examine how a 5°F increase will affect water demand for irrigated agriculture, the change in Consumptive Irrigation Requirement (CIR) was estimated for two different crops: alfalfa and orchards. To calculate the change in water demand for these crops, the original Blaney-Criddle method (Blaney and Criddle, 1950, 1962; Wilson, 1992) was used except for Farmington where the modified Blaney-Criddle method was applied (Wilson, 1992). The NMOSE applied these techniques to estimate water use in 2015 for irrigated crops in the New Mexico Water Use by Categories Reports (Magnuson et al., 2019).

This analysis does not examine changes to demand that may occur before the water reaches the crop. Thus, increased evaporation that may occur in conveyance channels or sprinkler irrigation methods due to warmer temperatures and increased aridity is not considered. Furthermore, the increased infiltration rate in canals and ditches due to warmer temperatures (Constantz, 1998) is not considered. The additional water needed to reach the irrigated crop will vary depending on the irrigation method and the lining and length of off-farm conveyance infrastructure.

The CIR is an estimate of the amount of water a crop will need given the days of sunlight at a specified latitude, the monthly effective rainfall and temperature. The average and minimum monthly precipitation and temperature for 1981-2010 was used to characterize the average past climatic conditions for each location (*Table* 1; NOAA, 2021). The total consumptive use is calculated using the Blaney-Criddle methods and the USBR method for estimating effective rainfall (Wilson, 1992; Magnuson et al., 2019). For each average and minimum monthly temperature, 5° F was added to characterize the climate conditions in 2070, with no changes to the predicted precipitation. Table 2 shows the results for selected areas in the state.

The crop demand for each acre of alfalfa is projected to increase by as much as 28% in Taos, with a statewide average increase of 22% in 2070. Orchard water demand could increase by as much as 30% in Taos, with an average increase of 22% by 2070. Using Blaney-Criddle, NMOSE estimates that the growing season days will increase by about 36 days on average for alfalfa and 34 days for orchards. This is a potentially significant increase in water demand (provided that farmers would be allowed administratively or physically to divert more water over an extended period), which combined with the forecast 25% reduction in runoff and recharge and increase in reservoir evaporation[2] will result in added stress on agricultural systems. The increase in water consumption for off-farm conveyance due to increased temperatures could potentially increase the overall water demand depending on the source of water and the distance and condition of conveyance systems.

Non-irrigated agriculture, or dry-land farming, and rangelands will be under greater stress with increased temperatures and greater aridity. The water use of livestock may increase as evaporation from stock ponds increases.

Table 1. Weather Stations and Average Annual Precipitation and Temperatures.

Location	Weather Station ID		1981-2010 Temperature (°F)		2070 Temperature (+5 °F)	
		Precipitation (inches)	Minimum	Average	Minimum	Average
Farmington	USC00293142	8.6	40	52	45	57
Taos	USC00298668	12.8	32	48	37	53
Albuquerque Valley	USC00290231	10.2	41	56	46	61
Hatch	USC00293855	10.3	43	61	48	66
Conchas Dam	USC00292030	16.1	46	60	51	65
Roswell	USW00023009	12.9	46	61	51	66

(NOAA, 2021)

[2] A 30% greater evaporation rate of water stored in Elephant Butte reservoir for the EBID is predicted to occur by 2070 (Dunbar et al., 2021).

Table 2. Estimated Change in Water Demand for Crops by 2070.

Location	Alfalfa				Orchards [a]			
	CIR (Annual depth of water (feet))		Increase in Growing Season (days)	Increase in Water Use	CIR (Annual depth of water (feet))		Increase in Growing Season (days)	Increase in Water Use
Time Period [b]	Past	Future			Past	Future		
Farmington	2.59	3.27	36	**26%**	1.88	2.32	34	**23%**
Taos	1.55	1.98	33	**28%**	1.04	1.35	31	**30%**
Albuquerque	2.43	2.92	36	**20%**	1.74	2.10	38	**21%**
Hatch	3.02	3.55	42	**18%**	2.77	3.38	37	**22%**
Conchas Dam	2.36	2.86	35	**21%**	1.59	1.96	36	**20%**
Roswell	2.47	2.99	33	**21%**	2.41	2.96	34	**23%**
Average			36	**22%**			34	**22%**

[a] Fruit trees, except pecan trees in Hatch and Roswell
[b] Past is represented by average monthly precipitation and temperatures for 1981-2010, Future is based on 5^{o} F increase in temperature by 2070

3. Changes in Demand of Public Water Systems

Warmer temperatures and longer growing seasons are expected to increase the water demand of the PWS sector. The increase in expected demand is based on a projected 5^{o}F to 7^{o}F increase in temperature for all areas of NM over the period 2007 to 2070 (Dunbar et al., 2021). Warmer temperatures will impact the water demand of PWS in three primary ways: 1) Irrigated landscapes will require more water each day of the growing season, 2) the length of the growing season will increase, and 3) swamp cooler use will increase.

To estimate how much additional water will be required by vegetation due to the warmer temperatures and longer growing seasons, the original Blaney-Criddle simulation method was applied to estimate the total consumptive use, the consumptive irrigation requirement (CIR) and the effective rainfall (Wilson, 1992; Magnuson et al., 2019).[3] The CIR is the amount of water required for irrigating a unit area of landscaping based on the days of sunlight at a specific latitude,

[3] The modified Blaney-Criddle method was applied for estimating CIR in Farmington (Magnuson et al., 2019).

the monthly effective rainfall (USBR method, Wilson, 1992), and monthly temperatures of a nearby weather station. Using the average monthly precipitation and the average and minimum temperatures for the 1981-2010 period (NOAA, 2021, *Table* 1), the water demand for turf and orchards was calculated to provide a baseline. Water use for 2070 was estimated by assuming the precipitation did not change. Table 3 shows the calculated changes in water demand for turf and orchards in selected areas of the state.

Climate change is expected to increase the length of the growing season by a minimum of 19 to 40 days depending on the crop and the geographic location.[4] The projected increase in water consumption for landscaping by 2070 is on average 21% and 22% for turf and fruit trees respectively, with the greatest percentage increase in Taos. This is a significant increase in water demand, and those communities with high per capita demand can expect a significant increase in water demand. Households with water conserving fixtures will generally use about 50 gallons per capita per day (gpcd) (Magnuson et al., 2019) for indoor water use. Thus, a daily per capita use beyond 50 gpcd can be assumed to be used for outdoor watering. The per capita rates for large PWS also includes water use for government, commercial, educational institutions, and other facilities, thus outdoor water use for each PWS cannot be easily calculated. Each PWS will have to consider the current peak summer use on their systems and assume that the outdoor use will likely increase by an average of 15% to 30% based on the values presented in Table 3.

Swamp coolers currently use an estimated 20 gallons per day per person in Las Cruces. With a 5^{o}F temperature rise, swamp cooler use is likely to increase. However, average humidity is forecast to be lower, which will increase the effectiveness of evaporative coolers.

Evaporation from swimming pools will increase with increasing temperatures and more homeowners may want to install pools to seek relief from hot summer days. However, swimming pools can and, in many jurisdictions are required to, be covered to minimize evaporative losses.

[4] Turf grass is Kentucky Bluegrass which will start growing when the mean monthly temperature reaches 45 ^{o}F and stop growing at 45 ^{o}F mean. Fruit trees on average will begin growing when average temperatures reach 50 ^{o}F mean and stop growing at 45 ^{o}F mean.

Water use by domestic wells, while mostly unquantified, could increase for the same reasons as PWS, and perhaps to a greater degree if more landscape watering occurs with domestic wells.

Table 3. Estimated Changes in Water Demand for Landscaping by 2070.

Location	**Turf**				**Fruit Trees**			
	CIR (Annual depth of water (feet))		Percent Increase in Water Use	Increase in Growing Season (days)	CIR (Annual depth of water (feet))		Percent Increase in Water Use	Increase in Growing Season (days)
Time Period [a]	*Past*	*Future*			*Past*	*Future*		
Farmington	2.64	3.33	26%	33	1.88	2.32	23%	34
Taos	2.06	2.61	27%	34	1.04	1.35	30%	31
Albuquerque	3.19	3.81	19 %	40	1.74	2.1	21 %	38
Hatch	3.96	4.55	15%	19	2.16	2.53	17%	28
Conchas Dam	3.26	3.92	20%	48	1.59	1.96	20%	36
Roswell	3.29	3.94	20%	38	1.74	2.12	22%	35
Average			**21%**	**35**			**22%**	**34**

[a] Past is represented by average monthly precipitation and temperatures for 1981-2010, Future is based on 5° F increase in temperature by 2070

4. Changes in Demand of Industry, Commercial, Mining and Power

Water demand for industry, commercial, mining and power is highly variable. Water use within a factory or associated with a particular manufacturing process is unlikely to increase. However, water demand for industrial sectors includes water used for cooling towers, which is sensitive to ambient temperatures and humidity, and will affect the rate of water consumption[5].

Climate change is not expected to significantly impact water demands of mining operations. Process water ponded on mill tailings and in reservoirs may evaporate more quickly, which may incrementally increase demand due to a decrease in the amount of process water that is re-used.

[5] Evaporation ratios for towers are primarily sensitive to ambient vapor pressure and air temperature (wet bulb and dry bulb); ratios for surface-water cooling systems are primarily sensitive to ambient water temperature and wind speed (Diehl et. al, 2013).

Power production in New Mexico is generated from 88 power plants that use coal, natural gas, hydroelectric, solar and wind (FEMA, 2021). The amount of water withdrawn and consumed by a power plant is determined primarily by its cooling-system technology. Of the 88 power plants, 19 consume cooling water by directing water through the plant's condenser to cool the steam used to turn the turbines and generate electricity [6]. Air-cooled power plants use much less water.

The power industry diverted and consumed 50,000 acre-feet of water in 2015, 40,000 acre-feet of which was for the seven then-operating conventional coal-fired power plants. Increasing power demand in turn increases the demand for water for these water-cooled power plants. Heating demand in winter months will go down, but not as significantly as the increase in demand for cooling (EPA, 2017). Thus, warmer temperatures will likely increase the demand for power in summer months for cooling homes[7], which in turn will increase the water demand for power generation. Furthermore, the cooling towers are sensitive to ambient temperatures and warmer air will increase water need, even if power consumption does not increase.

On the other hand, New Mexico is moving away from fossil-fuel powered thermoelectric generation[8]. In particular, the end is nearing for coal-fired power generation in New Mexico. New Mexico's remaining coal-fired power plants in operation[9] are scheduled for decommissioning within the next decade. Due to these planned decommissioning, water demand in this sector is expected to be much less by 2070.

Natural gas fired combustion turbine and steam turbines use much less water than coal-fired generating plants because most are dry-cooled. In 2015, one natural gas steam turbine diverted 286 acre-feet of water and a natural gas fired combustion turbine used only 2.23 acre-feet of water. No solar or wind-powered plants were included in the 2015 Water Use by Categories Report (Magnuson, 2019), as water use by these facilities is negligible (Martinez, 2021).

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[6] 17 recirculating cooling systems, 1 once-through system with forced evaporation, and 1 complex cooling system (Harris and Diehl, 2019)

[7] A 1.8 F increase in temperature increases demand for energy used for cooling by 5-20% (EPA, 2017)

[8] Recently decommissioned coal-fired power plants include the APS's Four Corners Generating Station's Units 1, 2 & 3 in 2013, PNM's San Juan Generating Station's Units 2 & 3 in 2017, and all units at Tri-State's Escalante Station in 2020.

[9] Arizona Public Service (APS)'s Four Corners Generating Station's Units 4 & 5 (planned decommissioning to occur in 2031) and Public Service Company of New Mexico (PNM)'s San Juan Generating Station's Units 1 & 4 (potentially to be decommissioned in 2022)

Four hydroelectric plants at Abiquiu Dam, El Vado Dam, Elephant Butte Dam and Navajo Dam do not consume water, but the power generation relies on water during reservoir releases. Climate change may result in greater frequency of insufficient reservoir water storage for power generation, but no increase in water demand would result.

Fossil-fuel derived generation will likely continue to provide a back-up supply when renewable sources are not sufficient to meet demands. A large-scale method of storing renewable-generated energy, if developed, could mitigate this problem, and reduce the need for fossil-fuel derived power that consumes water.

5. Changes in Demand of Watersheds and Habitat

Watersheds are an area of land that separates waters flowing to different rivers or basins. Within each watershed is habitat for many varied species. Thus, this sector of water use could theoretically cover all uses of water. The intent of this category is to describe in general terms the water used by our natural ecosystems, without consideration for human uses of water. The changing water demand of vegetation in our forests, riparian areas, shrublands, rangelands and deserts due to warming is complicated and poorly understood (Dunbar et al., 2021). Trees, shrubs, and other groundcover below 8,000 feet elevation (outside of riparian areas) cannot increase their use of water, particularly during drought periods, because the water is not available. In most areas of the state the evaporation rate far exceeds the precipitation rates, except during brief thunderstorms, and thus, water in excess of the plants needs is not available below 8,000 ft. Most of our runoff and recharge occurs from the forests at elevations above 8,000 ft.

The vegetation in forests at elevations above 8,000 ft will increase water use as temperatures warm if the water is available. However, during drought periods, the water use will not increase, but instead, many trees and shrubs will rely on stored reserves. By 2070, as temperatures and aridity increase, direct evaporation from soils is likely to dry out soils more rapidly and thoroughly between precipitation events, than historically occurred. During subsequent precipitation events, these drier soils will have more storage capacity, and water-starved plants will uptake more water in the immediate aftermath of the event, resulting in reduced runoff or recharge to the underlying aquifer, even if overall precipitation remain similar. After an extended drought, the trees may die, succumbing to fire or pests and ultimately yield to other vegetation types. These nonlinear, drastic changes in vegetation are expected to occur and we can expect short term changes in water demand as the ecosystem responds.

Riparian[10] vegetation, on the other hand, have their roots in water and as temperatures rise, the demand and use of water will likely increase until available water decreases. With severe extended droughts, vegetation in former riparian areas may die off and thus, water demand and consumption could decline. When a riparian or wetland area dries, the vegetation changes to more upland adapted species that require less water than riparian vegetation. The vegetation change will alter the habitat, such that the animals that previously used that area may move away or die and other animals that can use the new habitat type will move in. Wildlife will also require more water with increasing temperatures, further stressing riparian areas by frequenting them more often and/or spending more time at these locations.

6. Recreation and Quality of Life

Water demand for recreation (i.e., skiing, boating, fishing) and quality of life (i.e., bird watching) will not directly change with climate change because most of the "uses" are non-consumptive. However, the negative impacts to this sector of water use will be significant in response to reduced supply. Less snow in the mountains could impact the ski industry, lower reservoir and lake levels will impact boating, lower stream flows will impact the recreational fishing and white-water rafting activities and the shifts in location and composition of vegetation such as diminished riparian areas will impact wildlife sustainability and attendant hunting and viewing. Quality of life is also likely to be impacted by necessary reductions in outdoor watering and the enjoyment provided by gardening or turf.

Stream flow at the headwaters will be reduced by increased evaporation rates as the water flows downstream through a warmer landscape, further diminishing the supply. Insufficient supply to fill our lakes and reservoirs is a significant problem during drought conditions that has a steady and direct impact on lake and reservoir levels, recreational access to water, safe navigation, and visitor experience. The economic impact on this sector will be significant, but the consumption of water from this sector will not change.

[10] Riparian is a term referring to the bank of a natural watercourse, such as a river or lake

The impacts of climate change on water demand for the downhill ski industry is not expected to be significant for two reasons: 1) the projected winter precipitation (December through February) is expected to be above average for the Sangre de Cristo mountains (Dunbar et al., 2021), and 2) ski areas already use their water rights to make snow, usually in the fall to build up a base and in high traffic areas. Snow making is expensive and many ski areas are already limited by water availability and water rights. While precipitation is projected to be more as rain than snow, New Mexico downhill ski areas are at high elevations (above 10,000 ft) where even a 5 ^{o}F increase in temperature will, on average, not affect the ability to make snow[11]. This industry will more likely be affected by the season starting later due to warming temperatures (Brooks, 2021). One ski area in the Sacramento Mountains could experience less winter precipitation (Dunbar et al., 2021). Cross-country skiing will be affected by climate change, particularly at lower elevations, but the water demand will not be affected because snow making is generally not available for cross-country skiing.

Management of reservoir releases to support recreational activities such as rafting, as is currently conducted, will need to continue if the surface water supply is sufficient. This is not a consumptive use of water.

The rate of reservoir evaporation will increase, but reservoir areas are likely to be smaller, and thus the net depletion from reservoir evaporation may be less. The recreational activities that occur on reservoirs will not affect the evaporative losses or increase demand. However, water demand for non-consumptive recreational uses could increase as demand for water in storage increases. The interest in prioritizing water storage in certain reservoirs to support the recreation-based economy, by establishing and maintaining minimum reservoir pools/lake levels, could cause reservoir evaporation to increase. This issue is front and center for the lake and reservoir-based communities of our state. The controversy arises between the interest in reducing evaporative losses by storing water in higher elevation reservoirs versus storing in lower elevation reservoirs with higher evaporation rates (due to higher temperatures at lower elevations) and the economic costs associated with the management of consumptive uses.

[11] Santa Fe SNOTEL average daily temperature for December, January, and February from 1997-2021 was 22 ^{o}F

Water demand for wildlife refuges could increase with increasing evaporation from ponded water, but the actual use of water is not likely to increase due to water right limitations. Most wildlife refuges have water rights and either divert from surface water or supplemental wells when the stream flow is inadequate (Tashjian, 2021).

Any management decisions that reduce the availability or viability of water-based recreation such as recreational boating and fishing will also reduce revenues of Tribes, Pueblos, Nations, Federal and State Agencies.

7. Conclusions

Water demand will increase significantly for agriculture, livestock watering, public/private water systems, and self-supplied domestic due to warmer temperatures and a longer growing season. The increase is projected to be on average about 22% based on the lowest projected increase in temperature of 5^{o}F. The water demand by industry, commercial, mining and power sectors is not projected to increase significantly, particularly as the state moves away from coal-fired power plants.

Changes in water demand of watersheds and habitat is complicated to summarize. The impact of warmer temperatures and increased aridity on our upland forests is the reason that the supply is projected to decrease (both surface water and groundwater recharge). The demand for water will increase in a forest with warmer temperatures, but unlike in irrigated crops and landscapes, the water will not be available for increased consumption, except for riparian areas. While the water demand and consumption may increase in a riparian area initially, these areas are likely to diminish in size and transition to a non-riparian habitat as the water levels and stream flows decline.

Water demand for recreation and quality of life aspects of water use, while affected by climate change, is not expected to increase significantly.

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