CITY OF ASPEN WATER SUPPLY AVAILABILITY STUDY 2016 UPDATE

Prepared for: City of Aspen

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wilsonwater group

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1.0 INTRODUCTION

As a municipal water provider, the City of Aspen (City) is charged with ensuring a reliable and safe water supply to its customers. Accordingly, the City completes periodic evaluations to ensure available water supplies are sufficient to meet existing and foreseeable future water demands. This study builds on, and updates previous studies completed by Sheaffer & Roland, Inc., and ENARTECH Inc. completed in 1984, 1994, and 2000. These studies provide a detailed description of the existing City owned water rights and associated water delivery infrastructure. The most recent raw water availability assessment completed by ENARTECH in 2000 suggest that all potable water demands modeled can be supplied by existing water resources, however in the late summer of drier than average years, raw water shortages may exist on the order of 1.0 cubic foot per second (cfs) or less.

Since 2000, City water demands have changed in response to increased delivery efficiencies, population growth, and water supply agreements to serve additional areas with City water. In addition, climate change and the associated changes in streamflow are beginning to be better understood. As a result, the City wishes to update the 2000 Raw Water Availability study as a part of their Comprehensive Water Management Program. The results of which will help inform the City's future actions regarding water supply, including:

- Creating a monitoring plan to track key variables affecting changes in water availability
- Implementation of water supply projects and programs
- Water conservation efforts
- Planning for future water use restrictions

This study evaluates possible changes to legal and physical water availability to the City over a 50-year planning period. This scenario planning is based on four municipal water demand scenarios and six hydrology scenarios downscaled from Global Climate Models (GCM) to the watersheds of interest, Maroon and Castle Creeks. The six hydrology scenarios were the same used in the 2012 Colorado River Water Availability Study (CRWAS) and intended to represent 80% of the variability of the available 112 models from CMIP3 (Coupled Model Inter-comparison Project). Changes in hydrology and municipal demands were evaluated using a monthly time-step model which simulates the City's raw water system. This model was previously developed by ENARTECH/Grand River Consulting and estimates flow conditions at specific nodes on Castle and Maroon Creeks based on the various hydrology and demand inputs. This streamflow model was used to estimate when water supply deficits may occur and evaluate available tools to mitigate the potential shortages.

2.0 BACKGROUND

The City's potable water supply is primarily sourced from senior water rights which divert from both Castle Creek and Maroon Creek. As shown in Figure 1, water is diverted from Castle Creek and Maroon Creek and conveyed in buried pipeline via gravity to Thomas Reservoir near the Water Treatment Plant. From there, the City provides pressurized raw water from Thomas Reservoir and conveys water for treatment and integration into the potable water system. The City owns and operates additional irrigation diversions downstream of the municipal intake on Castle Creek. These include the Holden, Si Johnson[1], and Marolt Ditches. Pursuant to direction from City Council, all City owned diversion structures are operated to maintain decreed instream flows. In this study, potential future water supply deficits are defined to occur when Castle Creek or Maroon Creek streamflow is inadequate to both allow for needed water diversion and to protect decreed instream flows on Castle Creek and Maroon Creek downstream of the City's diversion facilities.

Junior instream flow (ISF) water rights are held by the Colorado Water Conservation Board (CWCB) on both Castle and Maroon Creeks and are used to inform City operations and ensure a sufficient amount of water remains in the stream for environmental purposes. The decreed ISF on Castle Creek is 12.0 cfs, however for the purposes of this study we have increased the minimum bypass to 13.3 cfs. The City has deemed the higher amount more appropriate for the fishery and stream habitat and is in-line with current City diversion policies. This analysis assumes that 13.3 cfs is maintained below the Marolt Ditch head gate, which is the most downstream City owned diversion structure on Castle Creek. The Maroon Creek ISF is decreed at 14.0 cfs, and is maintained below the Maroon Creek Intake. The City does not currently divert water below this location on Maroon Creek.

The City's potable supply is largely dependent upon streamflow conditions of Maroon Creek and Castle Creek as no significant storage has been developed in the system. Thomas Reservoir is a relatively small retention/stilling pond primarily used to regulate raw water diversions from Castle Creek and Maroon Creek and serves as the first step in the treatment process. Water is conveyed from Thomas Reservoir to the water treatment plants for sedimentation and filtration. Thomas Reservoir has a limited capacity of approximately 10 acre-feet (AF). Therefore, it is important to understand how streamflow conditions may change in relation to anticipated demands. Note, we understand the City is in the process of developing a new well system to help supplement its water supplies.

[1] Si Johnson Ditch is currently managed by a Ditch Company, of which the City holds more than 75% interest. City staff currently operates the ditch on behalf of the company.

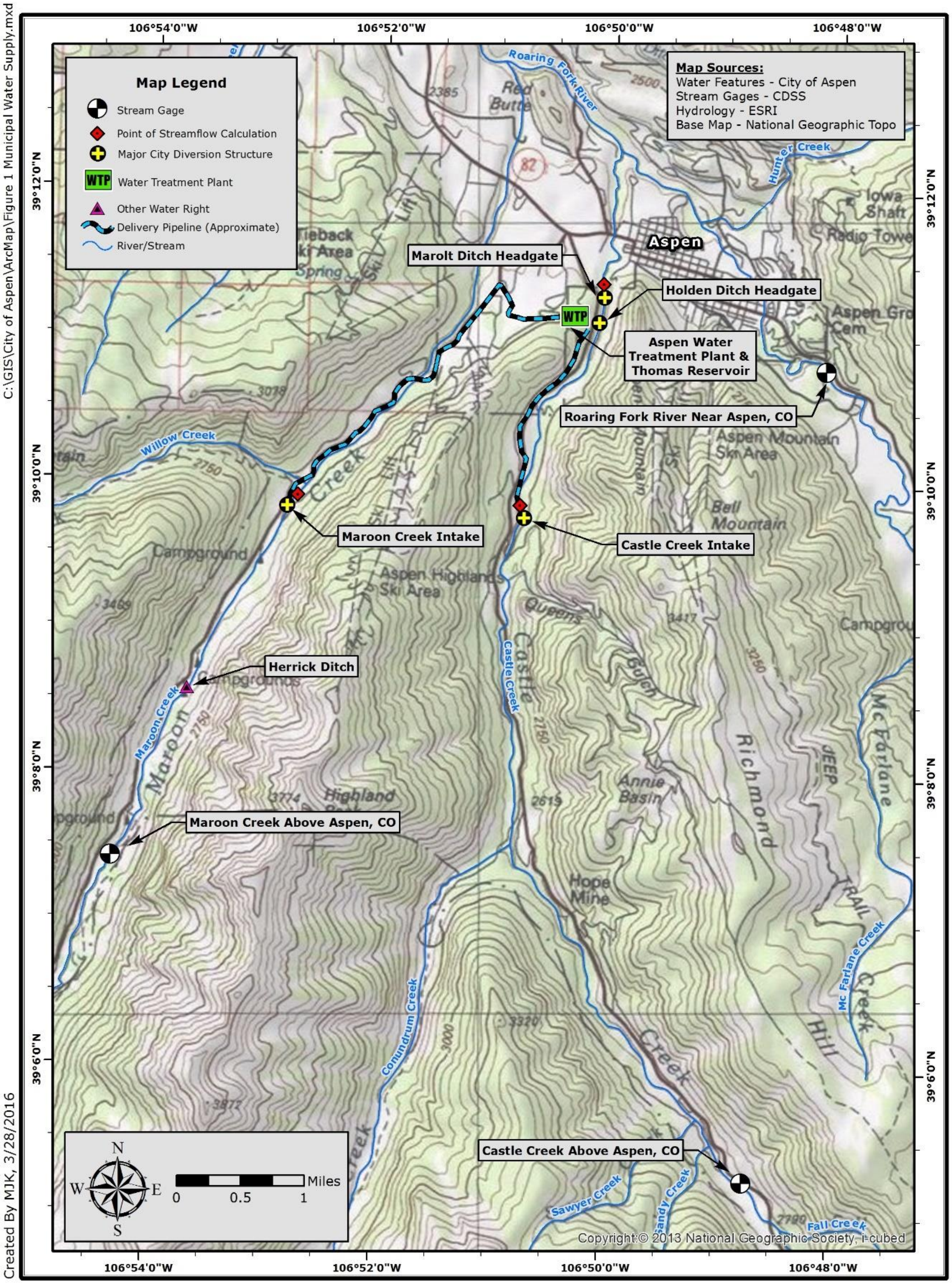


Figure 1: City of Aspen Municipal Water Supply System

3.0 METHODS

Below is a description of how the four demand and six hydrology scenarios were developed as inputs into the monthly streamflow model.

3.1 DEMAND SCENARIOS

Four scenarios were developed to describe municipal water demands for the 50-year planning period. The goal of these demand scenarios is to represent a range of potential municipal water use that may develop within the study period. The scenarios include future demands that range from a no-growth scenario to a maximum annual growth rate of 1.8%.

In each of the scenarios, the non-potable water sourced from Thomas Reservoir and irrigation ditch demands remain constant and were rounded to the nearest tenth of a cfs. This water is used to provide a supply for irrigation and snowmaking uses. Water used for snowmaking and irrigation within these categories is independent of population increases. Based on discussions with City staff it is understood that water used for these specific purposes is expected to remain constant over the next 50-year period, and therefore these uses do not change between demand scenarios. Future operations of non-City owned water rights on Maroon Creek are unknown at this time. All major Castle Creek diversions on are incorporated in the streamflow model.

The City may use existing wells located within City limits to pump groundwater from the Roaring Fork alluvium. This water can be blended with surface water and incorporated into the treated municipal water supply. We have assumed that these well diversions will increase at the same rate as demand for treated water increases. Accordingly, the City well demands shown below increase between scenarios.

3.1.1 Demand Scenario 1A – Existing Baseline Demand

This scenario represents the existing municipal water demands of the City. It is based on historical diversion data collected by the City from water year 2012 which was assessed against other recent year diversion data and determined to be most representative of current demand conditions. 2012 data is assumed to be more representative because drought induced water restrictions were implemented in water year 2013 and resulted in lower than typical water demands. Demand data was not available for the year 2014 to present at the time of this evaluation. Table 1 below shows average monthly water demands of scenario 1A by source and use type.

TABLE 1
City of Aspen Average Monthly Water Demands (cfs)
SCENARIO 1A (Existing Baseline Demand)

	Thomas Reservoir Demands							City Well	Irrigation Ditch Demands	
	Treated Water				Non-	Sub-Total		Demands	Castle Creek[1]	
Month	Indoor	Outdoor	Sub-Total		Potable	**Daily Use**	*Peak 10 Day*			**Total**
January	3.1	0.0	3.09	*2.0 MGD*	0.0	**3.1**	*3.3*	0.2	0.0	**3.3**
February	3.3	0.0	3.25	*2.1 MGD*	0.0	**3.3**	*3.6*	0.2	0.0	**3.5**
March	3.1	0.0	3.14	*2.0 MGD*	0.0	**3.1**	*3.4*	0.2	0.0	**3.4**
April	3.0	0.0	2.96	*1.9 MGD*	0.0	**3.0**	*3.6*	0.2	0.0	**3.2**
May	3.2	3.1	6.32	*4.1 MGD*	0.0	**6.3**	*7.4*	0.2	6.8	**13.4**
June	3.2	6.2	9.40	*6.1 MGD*	0.1	**9.5**	*10.7*	0.2	20.5	**30.2**
July	3.2	5.2	8.41	*5.4 MGD*	0.1	**8.5**	*9.6*	0.3	16.1	**24.8**
August	3.2	3.4	6.60	*4.3 MGD*	0.0	**6.6**	*7.2*	0.3	15.4	**22.4**
September	3.2	2.0	5.23	*3.4 MGD*	0.3	**5.5**	*6.2*	0.3	12.2	**18.1**
October	2.4	0.0	2.38	*1.5 MGD*	0.1	**2.5**	*3.4*	0.3	11.0	**13.8**
November	3.2	0.0	3.20	*2.1 MGD*	0.4	**3.6**	*5.2*	0.3	0.0	**3.9**
December	3.4	0.0	3.38	*2.2 MGD*	0.2	**3.6**	*5.5*	0.3	0.0	**3.9**

[1]Includes Holden Ditch, Marolt Ditch, and Si Johnson Ditch.

3.1.2 Demand Scenario 2A – Historical Growth Rate of 1.2%

This scenario represents municipal water demands for water at the end of the 50-year planning period, year 2064, calculated based on an annual growth rate of 1.2% from current conditions. This rate was estimated based on the historical 20-year average growth rate of new water users in the City. This rate is believed to be reasonable for planning purposes. Note that the 1.2% annual increase was only applied to treated water demands (indoor and outdoor). Non-potable and irrigation ditch demands were assumed to remain constant within the 50-year study period. Table 2 shows average monthly water demands of scenario 2A by use type.

TABLE 2
Estimated City of Aspen Average Monthly Water Demands Year 2064 (cfs)
GROWTH SCENARIO No. 2A (Historical Growth Rate 1.2%)

	Thomas Reservoir Demands							City Well	Irrigation Ditch Demands	
	Treated Water				Non-	Sub-Total		Demands	Castle Creek[1]	
Month	Indoor	Outdoor	Sub-Total		Potable	**Daily Use**	*Peak 10 Day*			**Total**
January	5.6	0.0	5.6	*3.6 MGD*	0.0	**5.6**	*6.0*	0.4	0.0	**6.0**
February	5.9	0.0	5.9	*3.8 MGD*	0.0	**5.9**	*6.6*	0.4	0.0	**6.3**
March	5.7	0.0	5.7	*3.7 MGD*	0.0	**5.7**	*6.1*	0.4	0.0	**6.1**
April	5.4	0.0	5.4	*3.5 MGD*	0.0	**5.4**	*6.5*	0.4	0.0	**5.8**
May	5.8	5.6	11.5	*7.4 MGD*	0.0	**11.5**	*13.5*	0.4	6.8	**18.7**
June	5.8	11.2	17.1	*11.0 MGD*	0.1	**17.1**	*19.4*	0.4	20.5	**38.0**
July	5.8	9.4	15.3	*9.9 MGD*	0.1	**15.3**	*17.3*	0.5	16.1	**31.9**
August	5.8	6.2	12.0	*7.7 MGD*	0.0	**12.0**	*13.1*	0.6	15.4	**28.0**
September	5.8	3.7	9.5	*6.1 MGD*	0.3	**9.8**	*11.0*	0.6	12.2	**22.6**
October	4.3	0.0	4.3	*2.8 MGD*	0.1	**4.4**	*6.1*	0.6	11.0	**16.0**
November	5.8	0.0	5.8	*3.8 MGD*	0.4	**6.2**	*9.0*	0.5	0.0	**6.8**
December	6.1	0.0	6.1	*4.0 MGD*	0.2	**6.4**	*9.7*	0.5	0.0	**6.8**

[1]Includes Holden Ditch, Marolt Ditch, and Si Johnson Ditch.

3.1.3 Demand Scenario 2B – Restricted Development

This scenario represents municipal water demands at the end of the 50-year planning period, year 2064, and was calculated based on an annual growth rate of 1.2% from current conditions. However, this scenario differs from scenario 2A in that treated outdoor water use by new water users located outside the existing City service area is prohibited. Records maintained by the City indicate that of the recent growth in water users, approximately 45% has historically occurred outside of the existing City limits. The goal of this scenario was to reduce the growth of peak annual water demands which has historically occurred during the summertime irrigation season (June – August). Table 3 shows average monthly water demands of scenario 2B by use type.

TABLE 3

Estimated City of Aspen Average Monthly Water Demands Year 2064 (cfs)

GROWTH SCENARIO No. 2B (Restricted Development Scenario)

	Thomas Reservoir Demands								City Well	Irrigation Ditch Demands	
	Treated Water[2]					Non-	Sub-Total		Demands	Castle Creek[1]	
Month	Indoor	Outdoor	Sub-Total			Potable	**Daily Use**	*Peak 10 Day*			**Total**
January	5.6	0.0	5.6	*3.6*	*MGD*	0.0	**5.6**	*6.0*	0.4	0.0	**6.0**
February	5.9	0.0	5.9	*3.8*	*MGD*	0.0	**5.9**	*6.6*	0.4	0.0	**6.3**
March	5.7	0.0	5.7	*3.7*	*MGD*	0.0	**5.7**	*6.1*	0.4	0.0	**6.1**
April	5.4	0.0	5.4	*3.5*	*MGD*	0.0	**5.4**	*6.5*	0.4	0.0	**5.8**
May	5.8	4.5	10.3	*6.7*	*MGD*	0.0	**10.4**	*12.2*	0.4	6.8	**17.6**
June	5.8	9.0	14.8	*9.6*	*MGD*	0.1	**14.9**	*16.8*	0.4	20.5	**35.8**
July	5.8	7.5	13.4	*8.6*	*MGD*	0.1	**13.4**	*15.2*	0.5	16.1	**30.0**
August	5.8	4.9	10.7	*6.9*	*MGD*	0.0	**10.8**	*11.7*	0.6	15.4	**26.8**
September	5.8	2.9	8.8	*5.7*	*MGD*	0.3	**9.1**	*10.2*	0.6	12.2	**21.9**
October	4.3	0.0	4.3	*2.8*	*MGD*	0.1	**4.4**	*6.1*	0.6	11.0	**16.0**
November	5.8	0.0	5.8	*3.8*	*MGD*	0.4	**6.2**	*9.0*	0.5	0.0	**6.8**
December	6.1	0.0	6.1	*4.0*	*MGD*	0.2	**6.4**	*9.7*	0.5	0.0	**6.8**

[1]Includes Holden Ditch, Marolt Ditch, and Si Johnson Ditch.

[2]Treated water demands grow at 1.2%, however 45 % of new growth is estimated to occur beyond existing service area and in these areas will exclude outdoor uses.

3.1.4 Demand Scenario 3A – CO State Demographer Growth Rate of 1.8%

This scenario represents municipal water demands at the end of the 50-year planning period, year 2064, and was calculated based on an annual growth rate of 1.8% from current conditions. This rate is equal to the projected annual growth for Pitkin County as calculated by the Colorado State Demographer. This rate is believed to be the maximum realistic growth rate for the City and appropriate for planning purposes. Please note the 1.8% annual increase was only applied to treated water demands (indoor and outdoor). Non-potable and irrigation ditch demands were assumed to remain constant within the 50-year study period. Table 4 shows average monthly water demands of scenario 3A by use type.

TABLE 4 Estimated City of Aspen Average Monthly Water Demands Year 2064 (cfs) GROWTH SCENARIO No. 3A (CO State Demographer Growth Rate 1.8%)												
	Thomas Reservoir Demands								City Well	Irrigation Ditch Demands	
	Treated Water					Non-	Sub-Total		Demands	Castle Creek[1]	
Month	Indoor	Outdoor	Sub-Total			Potable	Daily Use	Peak 10 Day			Total
January	7.5	0.0	7.5	4.9	MGD	0.0	**7.5**	8.1	0.5	0.0	**8.0**
February	7.9	0.0	7.9	5.1	MGD	0.0	**7.9**	8.8	0.6	0.0	**8.5**
March	7.7	0.0	7.7	4.9	MGD	0.0	**7.7**	8.2	0.6	0.0	**8.2**
April	7.2	0.0	7.2	4.7	MGD	0.0	**7.2**	8.8	0.6	0.0	**7.8**
May	7.8	7.6	15.4	10.0	MGD	0.0	**15.4**	18.1	0.5	6.8	**22.8**
June	7.8	15.1	22.9	14.8	MGD	0.1	**23.0**	26.1	0.5	20.5	**44.0**
July	7.8	12.7	20.5	13.3	MGD	0.1	**20.6**	23.3	0.6	16.1	**37.3**
August	7.8	8.3	16.1	10.4	MGD	0.0	**16.1**	17.6	0.9	15.4	**32.4**
September	7.8	4.9	12.8	8.2	MGD	0.3	**13.1**	14.7	0.8	12.2	**26.1**
October	5.8	0.0	5.8	3.8	MGD	0.1	**5.9**	8.2	0.8	11.0	**17.7**
November	7.8	0.0	7.8	5.1	MGD	0.4	**8.2**	11.9	0.7	0.0	**9.0**
December	8.2	0.0	8.2	5.3	MGD	0.2	**8.5**	12.9	0.6	0.0	**9.1**

[1]Includes Holden Ditch, Marolt Ditch, and Si Johnson Ditch.

We understand City water demands are dynamic and water operators must respond to instantaneous needs including fire protection and peak occupancy rates within the City. However, for the purposes of this study average monthly water demands were used in the model. The primary reason for this was the data limitation of future streamflow regimes. As mentioned above, data from the CRWAS study was utilized for future hydrology regimes. Data from this study was available on a monthly time step. To avoid introducing additional error into this study from downscaling the data to a daily time step, monthly data were used in order to have more confidence in the results.

For this study, future demands were evaluated using the same temporal distribution as they have occurred historically. No effort was made to adjust demands earlier in the season in association with the projected earlier peak in snowmelt runoff because it is beyond the scope of this study to predict how those changes may occur. Historically, peak water use (excluding irrigation purposes) has occurred when occupancy is maximized within the City. One primary factor in occupancy is the time of year when tourists are mostly likely on vacation (summer, holidays, etc.) which is assumed to remain the same and is likely independent of potential changes in the climate.

3.2 HYDROLOGY SCENARIOS

Each of the above mentioned demand scenarios were evaluated against six separate hydrology scenarios. These six scenarios include five Coupled Model Inter-comparison Project 3 (CMIP3) model runs which were utilized in the Colorado Water Conservation Board's *Colorado River Water Availability Study (CRWAS)* published in March of 2012. The sixth scenario was the historic gaged hydrology on Castle and Maroon Creeks (1970-1994). The five CMIP3 scenarios were deliberately chosen out of the available 112 projections in order to represent 80% of the full range of modeled change in streamflow. Table 5 provides information on the change in precipitation, temperature and streamflow for each of the CMIP3 model scenarios. In addition, the percent change in streamflow, as compared to historical hydrology, is also included in the table for: Colorado River at Glenwood Springs, Roaring Fork River near Aspen, and Castle and Maroon Creeks above Aspen.

Table 5: CMIP 3 Model Scenario Statistics relating to: precipitation, temperature and percent change in streamflow.

CMIP3 Run	% Change Precipitation	Change Temperature (°C)	Colorado River at Glenwood Springs % Change in Streamflow	Roaring Fork River near Aspen % Change in Streamflow	Castle Creek above Aspen % Change in Streamflow	Maroon Creek above Aspen % Change in Streamflow	Scenario Identifier
4	-4%	4.5	-24%	-8%	-8%	-9%	Very Hot/Very Dry
53	-1%	3.6	-13%	-12%	-16%	-19%	Warm/Slightly Dry
51	1%	3.7	-8%	-3%	-8%	-13%	Warm/Slightly Wet
13	3%	2.3	1%	2%	0%	-2%	Warm/Wet
12	11%	3.7	13%	16%	9%	2%	Warm/Very Wet

Output from the CMIP3 models needed to be downscaled using the VIC (Variable Infiltration Capacity) model in order to obtain the hydrology at nodes that were not modeled explicitly in the CMIP3 climate models. A dataset was available for the Roaring Fork river near Aspen stream gage site (Figure 1). Note, methods used to downscale the CMIP3 data to the watersheds of interest was beyond the scope of this report, but can be found in the documentation of the CRWAS available through the Colorado Water Conservation Board.

Using the monthly ratio of streamflow of Maroon and Castle Creeks to the Roaring Fork river, the climate scenario time series were developed for both Maroon and Castle Creeks at the location of the inactive USGS gage sites (Figure 1). This was done by using the VIC modeled output for the Roaring Fork and scaled using the relationships of Maroon and Castle creeks for each climate scenario. Figure 2 below shows how the average monthly hydrology of Maroon Creek changes with each climate scenario run and how it compares to the historic hydrology. One point to note is that the "identifier" given to each CMIP3 model run relates to the climate model forcing data: temperature and precipitation. Within this model, the relationship between the climate forcing factors and streamflow is not one to one, but rather varies based on many interrelated variables. In general, warmer climate scenarios tend to have an earlier start to the melt season than historical hydrology, but that is not always the case. As seen in Table 5, the same general trends are maintained between the four watersheds shown under the given climate scenarios, however percent changes in average monthly streamflow do vary. These differences between watersheds illustrate the difficulty of reducing large-scale climate model information to smaller watershed areas with complex topography. Efforts were made to ensure the downscaled hydrology on Maroon and Castle creeks followed the same trends as the nodes further downstream.

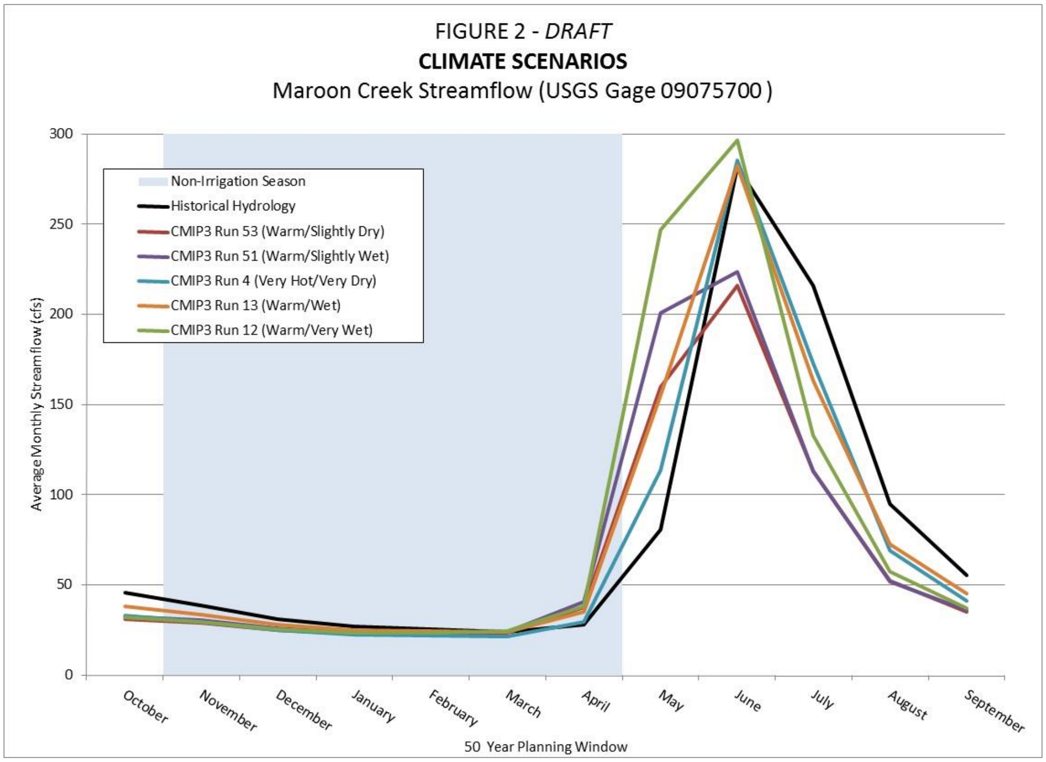


Figure 2: Maroon Creek average monthly streamflow for historical hydrology and the 5 CMIP3 model runs. The non-irrigation season is highlighted in blue. Streamflow is averaged by month and represents variability in hydrology during the 25-year study period.

3.3 Streamflow Model Assumptions

Average monthly streamflow of Castle Creek and Maroon Creek was estimated as described above at the inactive USGS gage sites for each of the six hydrology scenarios. This information was then used in the streamflow tool to estimate flow at specific nodes shown in Figure 1. Streamflow was estimated at the Maroon Creek and Castle Creek intake structures based on a linear regression between flow at the inactive gage sites and the two intake locations. This regression is based on previous assessments carried out by ENARTECH and Grand River Consulting, including paired streamflow measurements. Based upon professional judgement, and knowledge of existing Castle Creek water uses located upstream of the municipal Castle Creek Intake Structure, it was assumed that depletions ranged from 0.5 cfs during the non-irrigation season and up to 2.0 cfs during the irrigation season. These are believed to be conservative assumptions. However, on Maroon Creek the Herrick Ditch can divert significant quantities of water in the reach between the inactive Maroon Creek gage and Maroon Creek Intake structure. Because the City water rights are senior in priority to all but 9.3 cfs of the Herrick Ditch water rights, it was assumed that during low flow periods, the Herrick Ditch would only divert 9.3 cfs of native flow otherwise available at the Maroon Creek Intake structure.

Streamflow at locations downstream of the City intake structures, as shown in Figure 1, were calculated in the model based on specific water demand and inflow criteria to replicate on the ground operations.

4.0 RESULTS

Results for the four potential water demands and six potential hydrology scenarios are shown in Table 6 below. These results show the most severe single year ISF deficits for each scenario during the 25-year study period and are outlined by irrigation (May-Oct) and non-irrigation (Nov-Apr) seasons. Based on this analysis, significant ISF deficits have the potential to develop in only the highest demand under warm and slightly dry conditions. Some of the drier climate scenarios do not result in significant deficits, which is in part due to the change in the timing of runoff realized from changes in temperature and precipitation. Of the 24 modeled combinations, 16 show no or minor and easily mitigated, ISF deficits. However, seven combinations show ISF deficits greater than 200 acre-feet (AF), and one is simulated to develop irrigation season ISF deficits of about 600 AF.

TABLE 6
SCENARIO SUMMARY MATRIX
50-Year Planning Window - Worst Drought Year Conditions (Irrigation Season/Non-Irrigation Season)

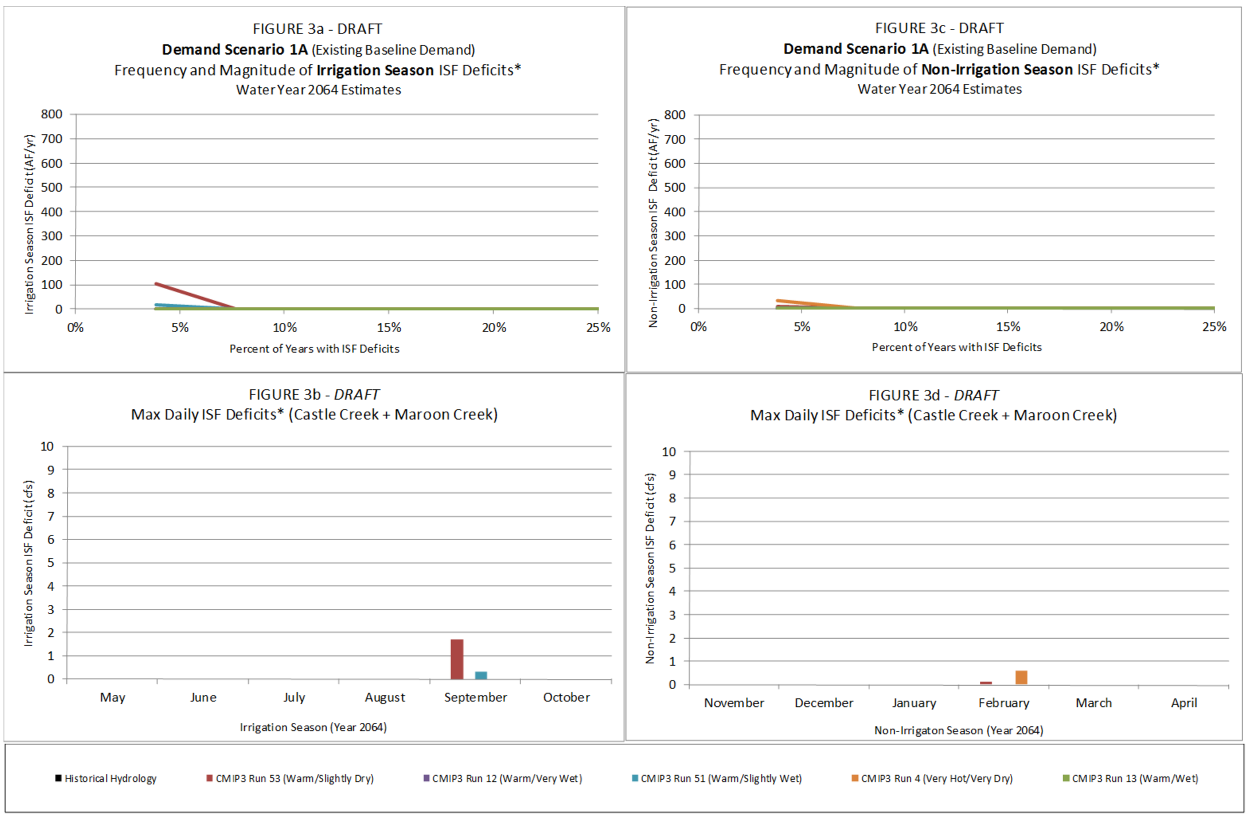
		CLIMATE SCENARIO					
		Historical Hydrology	CMIP3 No. 13 Warm/Wet	CMIP3 No. 12 Warm/Very Wet	CMIP3 No. 51 Warm/Slightly Wet	CMIP3 No. 4 Very Hot/Very Dry	CMIP3 No. 53 Warm/Slightly Dry
DEMAND SCENARIO	1A - Existing Baseline Demand	0 AF / 0 AF	0 AF / 0 AF	0 AF / 0 AF	19 AF / 0 AF	0 AF / 33 AF	102 AF / 7 AF
	2B - Restricted Growth Rate 1.2%	0 AF / 0 AF	0 AF / 35 AF	69 AF / 19 AF	213 AF / 154 AF	0 AF / 307 AF	296 AF / 338 AF
	2A - Historical Growth Rate 1.2%	0 AF / 0 AF	0 AF / 35 AF	113 AF / 19 AF	257 AF / 154 AF	0 AF / 307 AF	340 AF /338 AF
	3A - CO State Demographer Growth Rate 1.8%	0 AF / 0 AF	0 AF / 190 AF	295 AF / 309 AF	439 AF /494 AF	122 AF / 758 AF	595 AF / 678 AF

ISF deficits which have the potential to occur on Castle Creek and Maroon Creek within the 50-year planning window were calculated by demand scenario. The ISF deficits are shown in two ways (1) the percent of years a shortage may occur (frequency) over the gaged hydrology period (1969-1994) and at what seasonal magnitude (AF), and (2) the maximum daily deficit in cubic feet per second (cfs), which were converted to from monthly values.

4.1 Demand Scenario 1A – Existing Baseline Demand

Two of the six hydrology scenarios show an ISF deficit for Demand Scenario 1A during the irrigation season. CMIP3 Run 53 and Run 51 show modest deficits occurring in about 5% of the years. The maximum daily ISF deficits were approximately 1.7 cfs in the late irrigation season. Figure 3a and Figure 3b below show the maximum irrigation season deficits graphically.

Non-irrigation season deficits occurred in two of the six hydrology scenarios, CMIP3 Run 4 and Run 53. These minimal deficits occur at a frequency of about 5% of the years and amounted to approximately 33 acre feet during the month of February in Run 4. This equates to an average maximum daily deficit of about 0.6 cfs. Figure 3c through Figure 3d below depict maximum modeled ISF deficits during the non-irrigation season graphically.



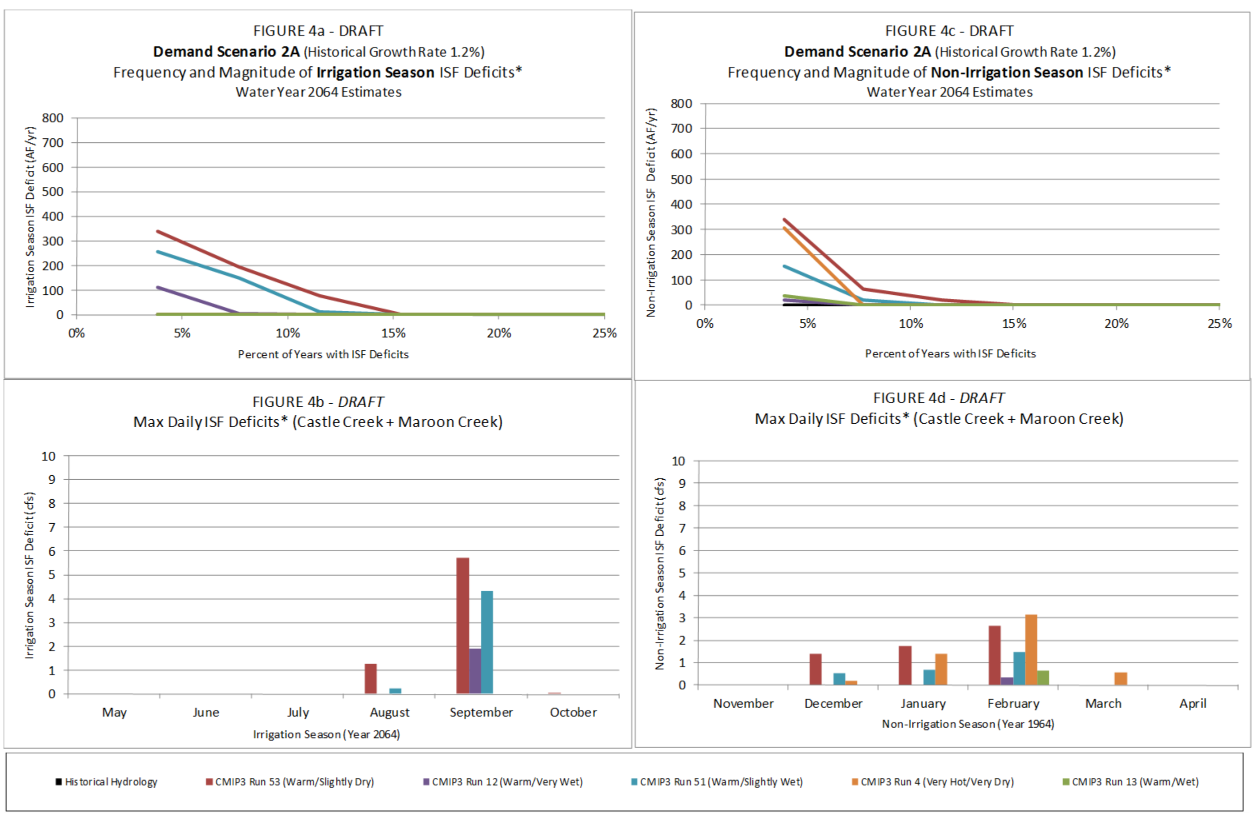
*Modeled ISF Assumptions: Castle Creek 13.3 cfs ISF measured blw Marolt Ditch Hdgt, Maroon Creek 14 cfs ISF measured below City Intake

Figure 3: Demand Scenario 1A Irrigation and Non-irrigation season ISF deficits.

4.2 Demand Scenario 2A – Historical Growth Rate 1.2%

Three of the six hydrology scenarios show an ISF deficit for Demand Scenario 2A during the irrigation season. CMIP3 Run 53 and Run 51 show irrigation season deficits up to about 300 acre feet occurring in ~5% of the years, and lesser deficits occurring about 12% of the years. CMIP3 Run 12 show irrigation season deficits of about 100 acre feet occurring at the 5% frequency. CMIP3 Run 53 and CMIP3 Run 51 show maximum ISF deficits on a daily basis to range from 4.3 cfs to 5.7 cfs during the month of September, while CMIP3 Run 12 has a deficit of about 1.9 cfs. Figure 4a and Figure 4b below show these results for the irrigation season graphically.

Non-irrigation season deficits are present for five of the six hydrology scenarios. Maximum deficits for CMIP3 Run 53 and Run 4 exceed 300 acre feet in approximately 5% of the years studied, while smaller deficits may occur in up to 12% of the years. CMIP3 Run 51 shows a maximum deficit of 150 acre feet occurring 5% of the time. CMIP3 Run 13, and Run 12 show maximum ISF deficits of about 25 acre feet occurring 5% of the time. For each of the three climate scenarios showing ISF deficits, non-irrigation season maximum daily deficits range from about 0.3 cfs to 3.1 cfs. Figure 4c and Figure 4d below show these results graphically.



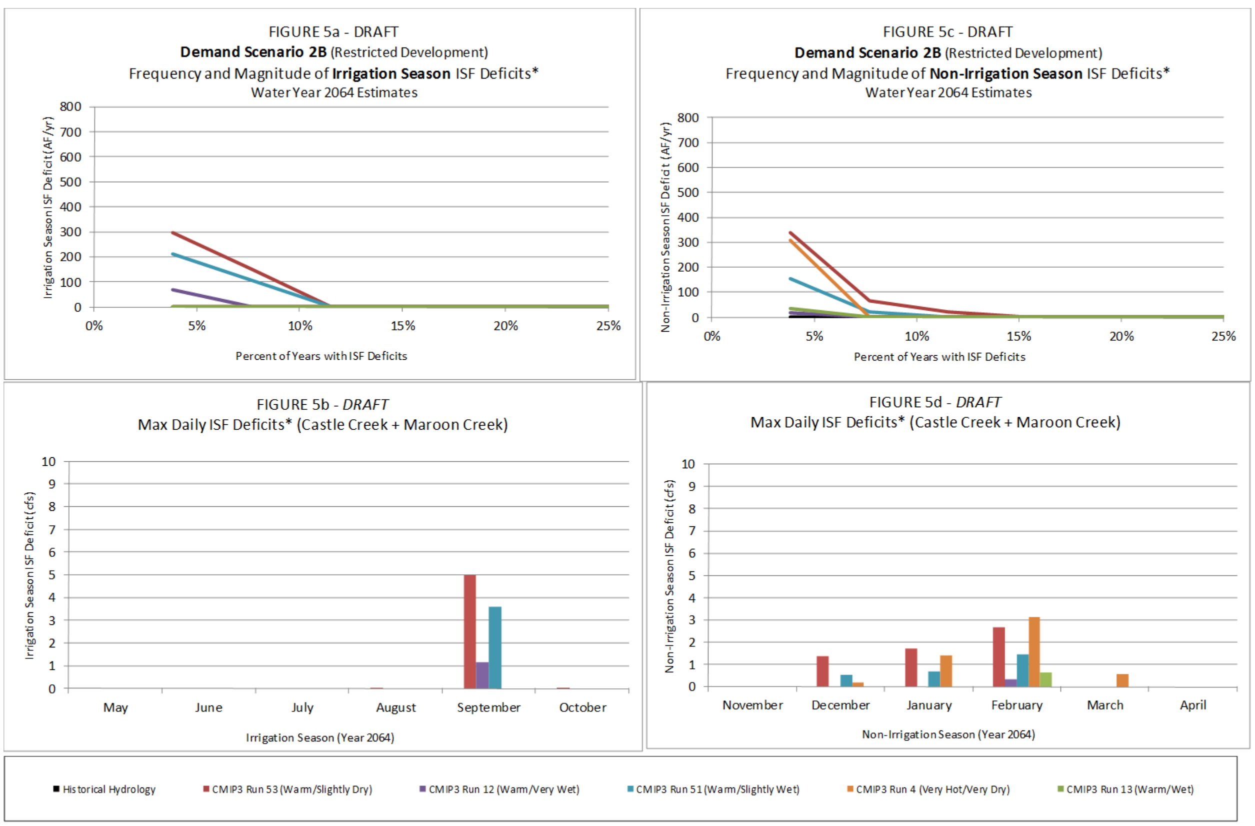
*Modeled ISF Assumptions: Castle Creek 13.3 cfs ISF measured blw Marolt Ditch Hdgt, Maroon Creek 14 cfs ISF measured below City Intake

Figure 4: Demand Scenario 2A Irrigation and Non-Irrigation ISF deficits.

4.3 Demand Scenario 2B – Restricted Development

As with Demand Scenario 2A, Demand Scenario 2B shows three of the six hydrology scenarios with an ISF deficit during the irrigation season. Because growth of outdoor water use was restricted in this demand scenario, we have modeled maximum deficits to equal 44 acre feet less than Demand Scenario 2A during the irrigation season. However, the frequency at which these deficits may occur remains the same at about 5% of the years. Maximum average daily ISF deficits range from about 1.2 cfs to about 5.0 cfs for CMIP3 Run 12 and CMIP Run 53, while CMIP3 Run 51 deficits are about 3.6 cfs. Figure 5a and 5b below show these results graphically.

Outdoor water use was varied only during the irrigation season between Scenario 2A and 2B, therefore non-irrigation season deficits for Demand Scenario 2B are equal to Demand Scenario 2A as shown below in Figures 5c – 5d.



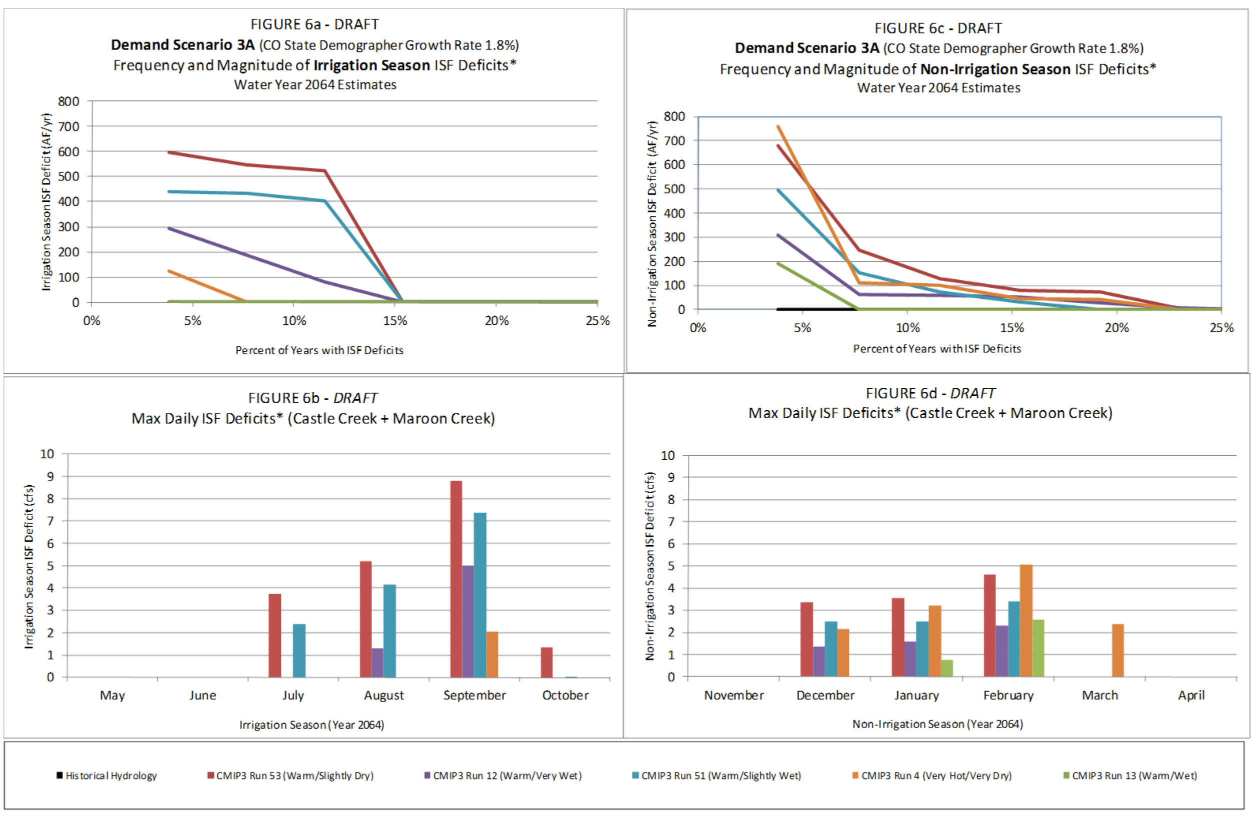
*Modeled ISF Assumptions: Castle Creek 13.3 cfs ISF measured blw Marolt Ditch Hdgt, Maroon Creek 14 cfs ISF measured below City Intake

Figure 5: Demand Scenario 2B Irrigation and Non-Irrigation ISF deficits.

4.4 Demand Scenario 3A – CO State Demographer Growth Rate 1.8%

Four of the six hydrology scenarios show an irrigation season deficit under Demand Scenario 3A. The most severe deficits occur at a frequency of 12% of the years under hydrology's CMIP3 Run 53 and CMIP3 Run 51 and occur at levels of over 400 acre feet during the irrigation season. CMIP3 Run 12 has a maximum deficit of about 300 acre feet and CMIP3 Run 4 is less at 120 acre feet. Maximum average daily deficits are as much as 7.4 cfs and 8.8 cfs for CMIP3 Run 51 and CMIP3 Run 53 during late season. Figure 6a and 6b below show these deficits graphically.

Non-irrigation season ISF deficits for Demand Scenario 3A reach a maximum of about 750 acre feet for CMIP3 Run 4 with smaller deficits recorded in CMIP3 Runs 51, 12, 53 and 13. Two of the hydrology scenarios show minor deficits occurring in up to 23% of the years. Maximum average daily ISF deficits range from about 0.8 cfs to 5.1 cfs during the non-irrigation season for all five CMIP3 hydrology scenarios. Figure 6c and Figure 6d below show these ISF deficits graphically.



*Modeled ISF Assumptions: Castle Creek 13.3 cfs ISF measured blw Marolt Ditch Hdgt, Maroon Creek 14 cfs ISF measured below City Intake

Figure 5: Demand Scenario 3A Irrigation and Non-irrigation season ISF deficits.

4.5 Alternate Herrick Ditch Operation, Demand Scenario 3A

Table 7 below shows the potential water supply deficits by season should the City be unable to place a valid water right call at the Maroon Creek Intake structure. This could potentially result in the Herrick Ditch diverting more than its senior 9.3 cfs water right during critically dry years, as assumed in the analysis described above. As such, this would reduce the amount of Maroon Creek water available for City use. This scenario assumes average monthly diversions by the Herrick Ditch increase from 9.3 cfs to a peak of 16.0 cfs during the month of July. This is based on user supplied diversion data from Herrick Ditch operators in recent years. At this time, it is unknown if this represents the maximum amount of water the Herrick Ditch may divert in the future. Water rights currently decreed to the Herrick Ditch total more than 64.0 cfs, however diversions are limited to the amount of water ditch users can put to legal beneficial use. This analysis represents the most water Herrick Ditch users have used on an average monthly basis in recent history.

TABLE 7
SCENARIO SUMMARY MATRIX - ASSUMING NO CURTAILMENT OF HISTORICAL HERRICK DITCH DIVERSIONS
50-Year Planning Window - Worst Drought Year Conditions (Irrigation Season/Non-Irrigation Season)

		CLIMATE SCENARIO					
		Historical Hydrology	CMIP3 No. 13 Warm/Wet	CMIP3 No. 12 Warm/Very Wet	CMIP3 No. 51 Warm/Slightly Wet	CMIP3 No. 4 Very Hot/Very Dry	CMIP3 No. 53 Warm/Slightly Dry
DEMAND SCENARIO	1A - Existing Baseline Demand	0 AF / 0 AF	0 AF / 0 AF	53 AF / 0 AF	197 AF / 0 AF	0 AF / 33 AF	280 AF / 7 AF
	2B - Restricted Growth Rate 1.2%	0 AF / 0 AF	0 AF / 35 AF	247 AF / 19 AF	432 AF / 154 AF	75 AF / 307 AF	577 AF / 338 AF
	2A - Historical Growth Rate 1.2%	0 AF / 0 AF	0 AF / 35 AF	291 AF / 19 AF	626 AF / 154 AF	118 AF / 307 AF	771 AF /338 AF
	3A - CO State Demographer Growth Rate 1.8%	0 AF / 0 AF	152 AF / 190 AF	698 AF / 309 AF	1,179 AF / 494 AF	396 AF / 758 AF	1,327 AF / 678 AF

Under this assumption, average monthly ISF deficits on Maroon Creek would increase from a maximum scenario (CMIP3 Run 53, Demand Scenario 3A) of 8.8 cfs as described above, to about 11.8 cfs during the irrigation season as shown below in Figure 7a and Figure 7b.

Five of the six hydrology scenarios show an irrigation season deficit under the alternate Herrick Ditch operations and Demand Scenario 3A. The most severe deficits occur at a frequency of 15% of the years under hydrology CMIP3 Run 53 and CMIP3 Run 51 and occur at levels of about 1,300 acre feet during the irrigation season. CMIP3 Run 12 has a maximum deficit of about 700 acre feet and CMIP3 Run 4 is less at 400 acre feet. Maximum average daily deficits are as much as 10.4 cfs and 11.8 cfs for CMIP3 Run 51 and CMIP3 Run 53 during late season. Figure 7a and 7b below show these deficits graphically.

Note, non-irrigation season deficits for this scenario (Figure 7c and Figure 7d) do not change from the deficits described above in Section 4.4 above.

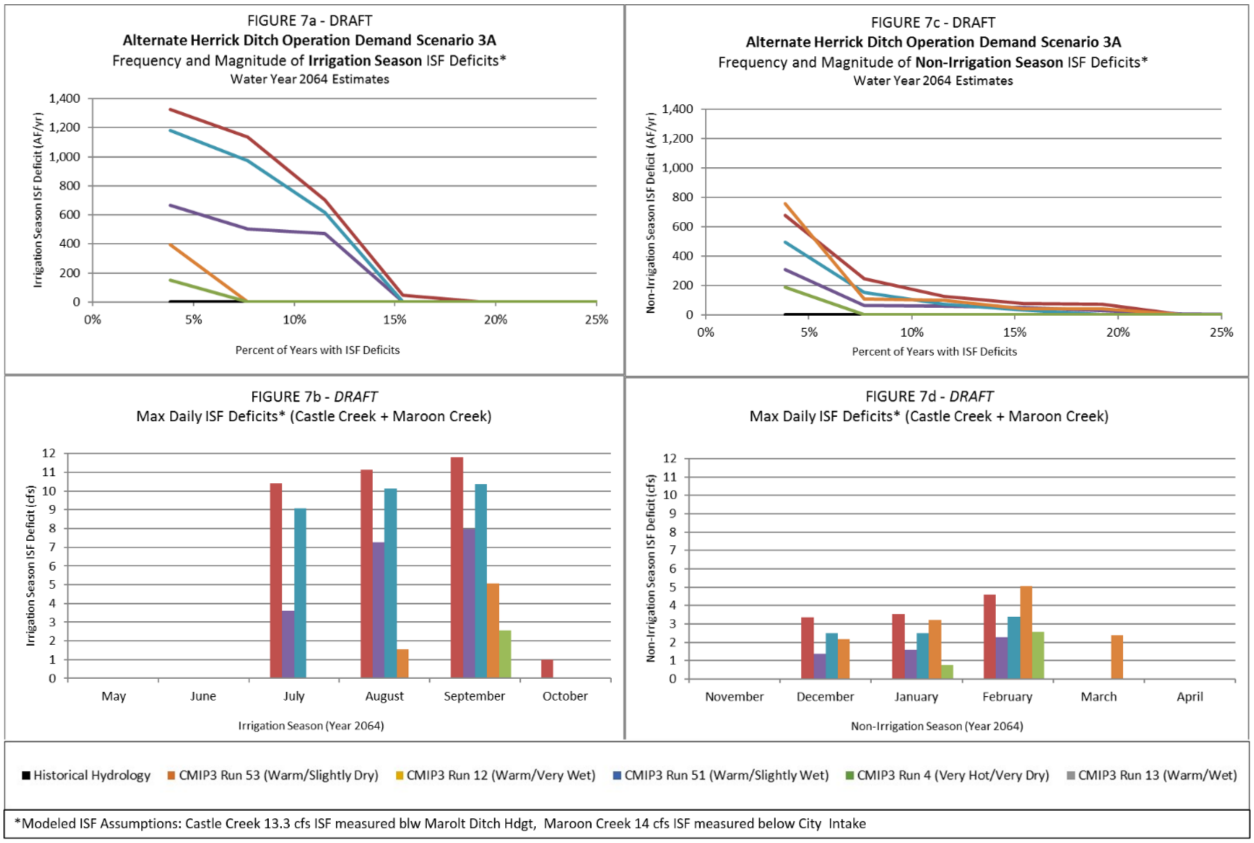


Figure 7: Demand Scenario 3A: Alternate Herrick Ditch Operations with Irrigation and Non-irrigation season ISF deficits

5.0 ALTERNATE WATER SUPPLIES AND THEIR POTENTIAL IMPLEMENTATION

All ISF deficits which may develop in the 50-year planning horizon can likely be mitigated by drought contingency planning that the City already has in place. The section below will describe those mitigation tools currently available to the City (or planned) and how they can be implemented in each of the demand scenarios described above.

5.1 ALTERNATE WATER SUPPLY OPTIONS

5.1.1 Wastewater Reuse Program

The City is diligently working towards bringing this program online. The City plans to pump treated wastewater from the Aspen Water and Sanitation District water treatment plant located near the confluence of Maroon Creek and the Roaring Fork River up to the City golf course. From here this water can be re-used for non-potable irrigation demands and wintertime snowmaking. Under full application, this program can physically supply up to 3.0 cfs of the non-potable irrigation water demands. During the non-irrigation season, this program can supply all non-potable snowmaking demands which average about 0.3 cfs during November and December.

5.1.2 Water Restrictions (potable and non-potable water uses)

The City has adopted revised drought restrictions as of fall of 2015. Restrictions are implemented via action by the City Council and are aimed at all City water users. These restrictions are divided into three stages and vary by water source with specific target reductions. The restriction levels are shown below in Table 8.

Table 8: City of Aspen Water Restriction Stages and Water Savings Target

	Treated Water General	Raw Water (Thomas Line)	Raw Water (Ditches)
Stage 1	10.0%	10.0%	10.0%
Stage 2	15.0%	17.5%	20.0%
Stage 3	20.0%	25.0%	30.0%

In 2012 and 2013, the City implemented Stage 1 and 2 drought restrictions (prior to the 2015 water saving targets revisions). Stage 1 was successful in reducing demands by 10%, however when Stage 2 was implemented, water users did not reach the desired 20% demand reduction target. Table 8 above shows the revised restriction levels with Stage 2 reduced to 15% for treated water, 17.5% for raw pressurized water and 20% for raw water in ditches. In this analysis, it is assumed that under all climate scenarios, water users will reach the targeted reductions put forward by City Council. To the extent this cannot be accomplished, diversions from the City wells may be used to supply additional water to address any remaining deficit to the ISF.

5.1.3 Municipal Wells

The City has in operation several shallow alluvial wells, which can be used to supplement municipal water demands. In addition, the City is in the process of developing a deep bedrock well which can also be used to supplement water demands during drought conditions. For the purposes of this assessment it is assumed that these wells have the potential to produce up to 5.0 cfs in combination. The wells can be operated to provide water supplies and reduce otherwise needed surface water diversions from Castle and Maroon Creeks. In this way, the City can ensure the ISFs on Castle Creek and Maroon Creek are satisfied. Water quality does present an issue in using alluvial well water for potable purposes because of Fluoride and Radionuclides (Uranium) contaminants. Because of these factors, the water must be blended with alternative sources of surface water or treated prior to use. The goal of the City over the 50-year planning period is to identify water supplies suitable for mixing to reduce the contaminant levels (i.e. deep bedrock well) or install a reverse osmosis system to treat the alluvial well water for use as a potable source.

The shallow alluvium wells and deep bedrock well are tributary to the Roaring Fork River at a point upstream of the confluence of Castle Creek. Therefore, all well depletions will occur to the Roaring Fork River. It should be noted, that during times of drought and ISF deficits on Castle and Maroon Creeks, similar conditions may also be present at this location within the Roaring Fork River. The City is planning additional investigations of the deep bedrock well to evaluate specific characteristics of this aquifer. At this time, the City anticipates water produced from this well may be of better quality than the shallower alluvium wells and may also have a significantly longer lag from time of pumping to the time when those depletions occur to the Roaring Fork River. However, regardless of whether the City relies more on the alluvial wells or deep bedrock wells, the net effect on Roaring Fork River streamflow should be considered prior to pumping water from wells during drought conditions.

5.2 IMPLEMENTATION OF ALTERNATE WATER SUPPLY OPTIONS

An evaluation was conducted using the tools described above to mitigate the ISF deficits that were modeled in section 4.0. For simplicity, only the climate scenario that resulted in largest deficit will be addressed.

5.2.1 Demand Scenario 1A – Existing Baseline Demand

Daily irrigation season ISF deficits occur during the month of September at a maximum rate of about 1.7 cfs. This ISF deficit can be addressed by implementing the City wastewater reuse program.

Average daily non-irrigation season ISF deficits may occur at a rate of about 0.1 cfs during February. This deficit can be address with Stage 1 water restrictions (10% reduction of all water demands).

5.2.2 Demand Scenario 2A – Historical Growth Rate 1.2%

Daily irrigation season ISF deficits occur during the months of August and September at a maximum rate of about 5.7 cfs. This ISF deficit can be addressed by implementing the City wastewater reuse program and initiating Stage 2 water restrictions (15% reduction of potable water demands and 20% reduction of ditch diversions).

Non-irrigation season ISF deficits occur from December through March and reach a maximum of about 2.7 cfs in February. During these months, the Stage 2 City water restrictions can help to meet these deficits in combination with pumping well water at a total rate of about 2.2 cfs.

5.2.3 Demand Scenario 2B – Restricted Growth

Daily irrigation season ISF deficits occur during the month of September at a maximum rate of about 5.0 cfs. This ISF deficit can be addressed by implementing City wastewater reuse program and initiating Stage 2 water restrictions. These restrictions would reduce potable water use by 15% and non-potable ditch demands by 20%.

As with Demand Scenario, 2A, non-irrigation season ISF deficits occur from December through March and reach a maximum of about 2.7 cfs in February. During these months, the City can rely on the Stage 2 drought restrictions and municipal wells supplying about 2.2 cfs during February to ensure ISFs are met.

5.2.4 Demand Scenario 3A – CO State Demographer Growth Rate 1.8%

Daily irrigation season ISF deficits occur during the months of July, August, September and October. The maximum deficits occur in September at a rate of about 8.0 cfs. This ISF deficit can be addressed by implementing the City wastewater reuse program and initiating Stage 3 water restrictions. These restrictions would reduce potable demand by 20% and non-potable ditch demands by 30%.

Non-irrigation season ISF deficits occur from December through February and reach a maximum of about 4.6 cfs in February. In combination with Stage 3 water restrictions, municipal wells can supply about 3.5 cfs during the month of February to ensure ISFs are met.

5.2.5 Alternate Herrick Ditch Operation, Demand Scenario 3A

Daily irrigation season ISF deficits occur during the months of July, August, September and October. The maximum deficits occur in September of critically dry years at a rate of 11.8 cfs. All but approximately 1.2 cfs can be mitigated via Stage 3 water restrictions, implementing the City wastewater reuse program and pumping the assumed maximum well diversion of 5.0 cfs. Additional water sources, or other reductions in water demands would be necessary under this scenario.

6.0 DISCUSSION

The City balances available water supplies to provide potable water, raw water, and ensure ISFs are met. The results of this analysis indicate the City can always provide sufficient potable and raw water supplies under these modeled demand and hydrology scenarios. Existing water supply infrastructure and water rights portfolio developed and managed by the City do not appear to be limiting factors in this evaluation. However, during drought periods, physical water supplies may limit the City from satisfying desired ISF bypasses. These modeled ISF deficits are forecasted to occur during drought periods in only the climate scenarios with very low late summer and winter streamflow conditions. Most ISF deficits occur at a frequency of 5% of the time or 1 out of 20 years. The predicted average daily ISF deficits are relatively small and can be managed utilizing the existing water supply tools the City has in place and/or is actively developing. From the climate and hydrology scenarios evaluated, irrigation season deficits may be mitigated by implementing drought related water use restrictions and operating the City wastewater reuse program. Some scenarios in this analysis indicate that well pumping must be relied upon more heavily during the wintertime in order to ensure ISF rates are met. For the 50-year planning window, under the largest growth and driest climate scenario an average monthly ISF deficit of 3.5 cfs is possible, and could be satisfied by increased well pumping. However, as indicated above, these wells are tributary to the Roaring Fork River and may impact streamflow within a reach of the City upstream of the Castle Creek confluence. Depending on how future on-the-ground conditions develop, the City may study how delayed depletions from specific wells - including the deep bedrock aquifer well- affects streamflow of the Roaring Fork River.

The results of this study indicate that under historical hydrology conditions, water demands through the next 50 years can be met. However, under specific dry climate change scenarios, the City would be required to implement several tools to curtail water demands in order to fulfil the objectives of providing a reliable water supply for potable, raw, and ISF purposes. All of the water supply alternatives listed above are either in place currently or the City is actively working towards bringing them online. The 2000 ENARTECH Raw Water Availability report conclusions line up well with the findings of this analysis with respect to historical hydrology conditions, in that no significant deficits are predicted. However, the driest of the climate change hydrology scenarios suggest that water supplies from Castle Creek and Maroon Creek may result in infrequent deficits to the desired ISFs. However, initiating alternative water supply options can reduce projected demand and/or provide enough additional water supply to eliminate these deficits.

This analysis has assumed that in dry years and during times of low streamflow, Herrick Ditch diversions will be curtailed to 9.3 cfs (the Herrick Ditch water right senior in priority to City owned Maroon Creek water rights). Under this assumption, all diversions by the Herrick Ditch junior priorities would be curtailed. As shown in Table 7 and Figure 7, if this were not the case and the Herrick Ditch were able to continue diverting at current rates during critically dry years, the City would experience additional water shortages. Water supply options such as water use restrictions, and wastewater reuse as described in this report may not be sufficient to cover all ISF deficits as modeled.

7.0 RECOMMENDATIONS

The above mentioned strategies can help address ISF deficits simulated under all scenarios evaluated in this study. However, it is recommended that the City establish a long-term program to monitor regional hydrology moving forward. The monitoring program can help City managers recognize trends in both physical water availability and municipal demands. These observations can help inform future planning efforts and identify whether or not actual on the ground conditions are in-line with scenarios evaluated in this study.

The study of climate change and specifically how streamflow responds to potential changes in precipitation and temperature are ever evolving. The hydrology scenarios represented here are intended to represent 80% of the range in potential outcomes over the next 50 years. However, it remains very difficult to accurately assess future conditions in the central Colorado mountains, specifically at the individual watershed level. Therefore, it is recommended that the City initiate a monitoring program to track changes in Castle Creek and Maroon Creek hydrology through time. In this way, specific indicators can be monitored and provide a record of how future water supplies and demands are changing from historical conditions.

It is recommended that the City prepare an annual report to document, summarize and evaluate current trends in water supply from historical data. This document would include the following parameters.

1. **Date of peak snowpack measured at the Independence Pass and Schofield Pass SNOTEL sites.** The federal Natural Resource Conservation Service (NRCS) currently manages several SNOTEL sites in the area where snowpack conditions are monitored. It is recommended that the City identify the date of peak snow pack conditions at both the Independence Pass and Schofield Pass SNOTEL sites, which are in close proximity to Castle Creek and Maroon Creek watershed areas. As such, these two SNOTEL sites should track closely with conditions in the two drainages.

   This information will be used to help inform when peak snowmelt runoff may occur and serve as an indicator to late summer streamflow.

2. **Date of peak snowmelt runoff measured at the Maroon Creek and Castle Creek intake structures.** It is recommended that the City begin monitoring streamflow at both Maroon Creek and Castle Creek intake structures. No streamflow gage currently exists at these locations; however, the City can estimate flow above the diversion structures by adding two measured flow values. The City currently measures the amount of water diverted from the stream at each of these intake structures. Additionally, the City has installed pressure transducers to understand the height of water, or stage, below the diversion dams. This stage data can be related to point flow measurements to develop stage discharge rating curves. The rating curves can be used to estimate streamflow that is bypassed down from the intake

structures on a real time basis. By adding the bypass flow to the diversion, the City can estimate the total amount of flow in each creek at the respective intake structures.

This information can be summarized to provide average daily streamflow, from which the date of peak snowmelt runoff can be recorded each year. Moreover, data from the bypass measurement will be important in critically dry periods when the City is concerned about ensuring water is bypassed at the respective ISF rates.

3. **Monthly rainfall at the City Water Treatment Plant.** Castle Creek and Maroon Creek are snowmelt dominated watersheds. However, rainfall events can have a major effect on streamflow in the late summer and fall time periods. It is recommended that daily rainfall recorded at the City Water Treatment Plant be summarized and documented. This information can be compared to historical information to understand if current trends differ from historical conditions. To date it has been very difficult to predict how climate change may affect summer rainfall patterns, so it is important the City maintains accurate records and understands if any trends appear to deviate from historical data.

   Raw water demands associated with irrigation are also directly linked to summer precipitation. If more rain falls in the area, then irrigation demands would be reduced. Conversely, if less rain falls in the area then irrigation demands may rise above historical levels.

4. **Diversions by other in-basin water users including the Herrick Ditch.** Water users upstream from the City Intake structures in the Castle Creek and Maroon Creek watersheds have a direct effect on the amount of water available to the City. Currently, no significant water diversions exist upstream of the Castle Creek intake, however the Herrick Ditch is a major irrigation diversion located upstream of the Maroon Creek Intake. It's important for the City to understand if future diversions by this structure significantly differ from historical operations.

It is important to understand how these parameters may be changing over time, as well as how they compare with municipal demands. In addition to the water supply, it will also be important to monitor temporal changes in water demands (i.e. peak and duration of irrigation demands) and how they relate to the timing of available water supplies. Though this study did not evaluate this aspect, monitoring of future irrigation demands can help to recognize if changes in the timing/magnitude of such water demands remain in line with the timing of available water supplies.

If at any point within the 50-year planning window City managers find that on-the-ground conditions, or projected forecasts are significantly different than the scenarios evaluated in this study, it may be beneficial for the city to update this analysis. Climate change science is evolving rapidly as is the computing power for running GCM's with more detail.

8.0 REFERENCES

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