Chapter 6

Sensitivity to Climate Change and Drought

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6.1 Background

As we have seen in the other chapters of this study, weather can have a large impact on water withdrawals. The scenarios of future water withdrawals presented assume normal weather conditions. Specifically, the values of air temperature and precipitation, which are used as explanatory variables in the water-demand models, represent long-term averages based on the 30-year record from 1971 to 2000. Using normal weather conditions to estimate future water withdrawals assumes that the weather patterns of the past will be the same in the future. Recent studies on global climate change have shown that this assumption may not be realistic at some point in the future. For this reason, the weather variables within the water withdrawal models were adjusted to analyze the potential effects of climate change on the future water withdrawals. The effects of these changes will vary by water sector depending on the sensitivity of water demand to air temperature and precipitation. The specific assumptions about the changes in weather variables are discussed separately for each of the major water sectors.

6.1.1 Climate change and global warming

Climate change refers to significant changes in climate parameters, like precipitation, temperature, and wind, that would last for long periods of time, like a decade or longer. Climate change may result from any individual or a combination of natural factors (i.e., change in sun intensity or changes in Earth's orbit around the sun), natural processes (i.e., changes in ocean circulation, and volcanic eruptions), or human activities that impact atmosphere composition (i.e., burning of fossil fuels) or land surface (i.e., urbanization, deforestation, and desertification). Global warming and climate change are terms often used interchangeably although climate change has been gaining preference because it refers to other climatic changes than just temperature increase. Global warming refers to increase of average atmospheric temperatures that can impact global climate patterns. Causes of global warming can be natural or human, like the increased emissions of greenhouse gases. Because the period of analysis for water demand scenarios extends until the year 2050 the average weather conditions are expected to change in response to climate change and global warming.

6.1.2 Climate change models in Illinois

With the increase of greenhouse gases and the rising of global average temperatures and changes in precipitation, many climate models have been developed by researchers throughout the world to model future changes in climate. Climate models indicate by 2050, a possible average annual temperature departure from the 1971-2000 long-term normal of up to $+6^{\circ}F$ in Illinois. Climate models also indicate a possible Illinois departure from 1971-2000 normal annual precipitation in a range from -5 inches to +5 inches per year. The future estimates of the climate models are shown in Figures 6.1 and 6.2. The future scenarios shown in Figures 6.1 and 6.2 were derived from 21 models on the latest set of global climate model simulations produced for the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). Simulations were produced for three different scenarios about how emissions may change in the future, moderately high scenario (denoted as "A2"), an intermediate scenario (denoted as "A1B"), and a low scenario (denoted as "B1") [ISWS, 2007]. Some models simulate the emissions sdenarios with different starting conditions in the atmosphere and oceans. In total there were more than 120 model simulations. The model simulations are smoothed to show trends and reduce year-to-year variability.

Because there are so many models with large ranges of simulated climate conditions, scientists treat results for each model as being equal, after eliminating the extremes by selecting the 5th and 95th percentile limits of all model runs. This accounts for 90 percent of all model scenarios. Within the 5th and 95th percentile limits, the model results cover all scenarios in between.

Future water withdrawals will be affected by the anticipated changes in temperature and precipitation. In order to analyze the impacts these potential weather changes could have on water withdrawals in East-Central Illinois, we applied the temperature increase predicted from the global climate models to our water withdrawal models. We also simulated the possible increase and decrease in precipitation to our water withdrawal models.

Figure 6.1 shows an approximate linear increase in temperature departure between 2005 and 2050. Therefore, for this sensitivity analysis, the normal temperature in the model is increased linearly to an additional $6^{\circ}F$ in 2050. The annual temperature increase of $6^{\circ}F$ was applied to the summer growing season.

The annual range in potential changes in precipitation is ±5 inches. The winter, fall, and spring precipitation ranges are within -1.5 to +2.5 inches and the growing season range is +2.5 to -3.5 inches. Figure 6.2 indicates that the precipitation change takes place early during the 2005-2050 period. Therefore, for the sensitivity analysis it is assumed that changes in precipitation will reach the +2.5 inches and -3.5 inches by 2015.

So, for each sector we analyzed the impacts of five different weather scenarios.

- an increase of $6^{\circ}F$ applied to the summer growing season (applied as a linear increase, reaching $6^{\circ}F$ by 2050)
- a decrease of 3.5 inches during the growing season (assumed to decrease by 3.5 inches by 2015)

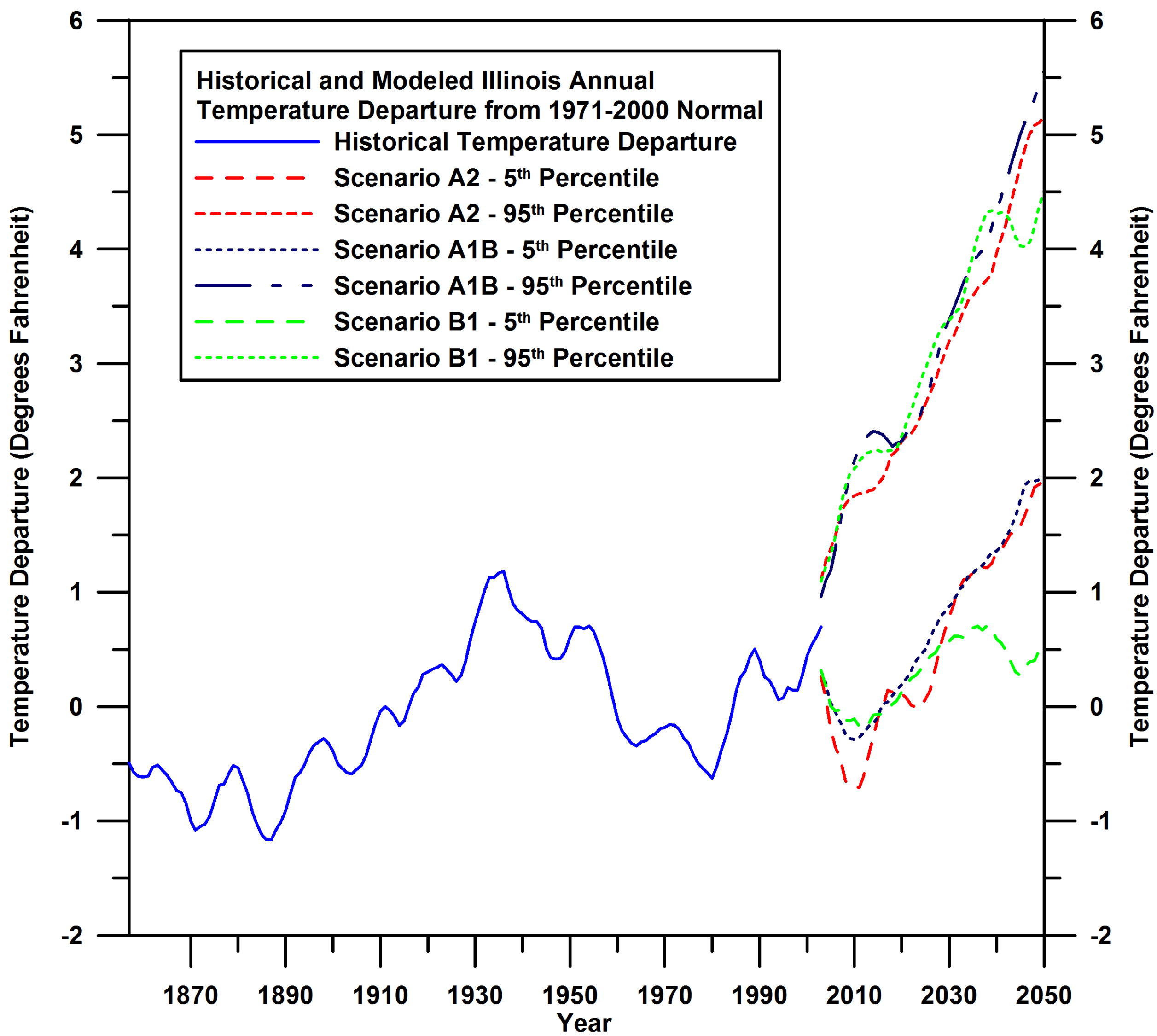

Figure 6.1: Global climate model scenarios on potential departures from normal annual temperature: 2005-2050 (ISWS, 2007).

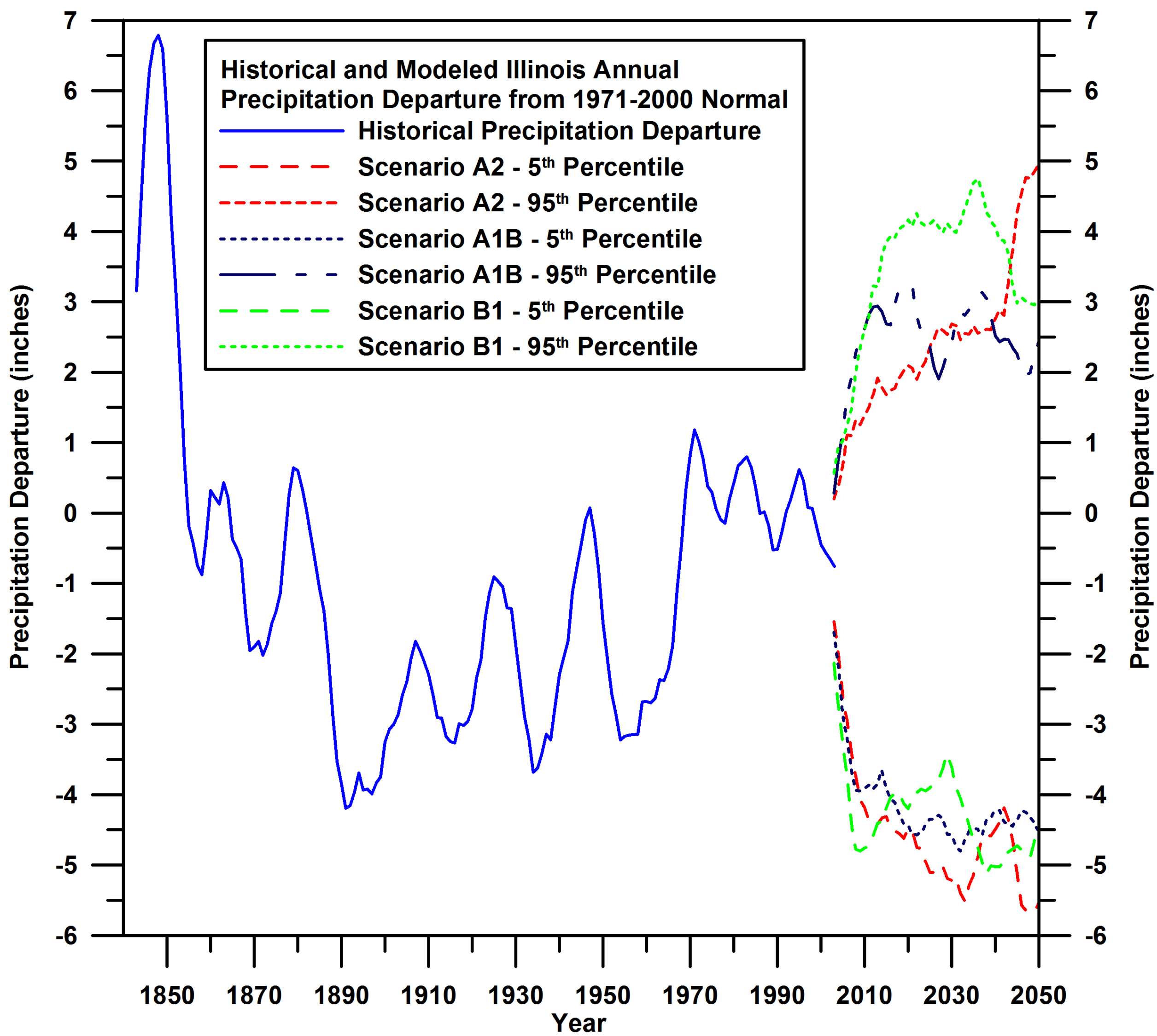

Figure 6.2: Global climate model scenarios on potential departures from normal annual precipitation: 2005-2050 (ISWS, 2007).

- an increase of 2.5 inches during the growing season (assumed to increase by 2.5 inches by 2015)
- an increase of $6^\circ F$ and a decrease of 3.5 inches during the growing season
- an increase of $6^\circ F$ and an increase of 2.5 inches during the growing season

These changes were applied to the baseline scenario in each sector. The normal weather (1971-2000) was used as the base values for the temperature and precipitation departures. The results for the climate change and drought sensitivity analysis are provided in the following sections.

6.1.3 Drought

Another type of climate impact on water demand is the effect of periodic droughts. In the future, in addition to possible changes in mean annual temperature and precipitation, it can be expected that periodic droughts will occur. While the severity and duration of future droughts is not known, their impact on water demand can be determined by examining historical droughts. The most severe historical drought in Illinois took place in the 1930s and 1950s. These were multi-year droughts which were associated with growing season precipitation deficits during the driest year of approximately 40 percent below normal. For purposes of the drought analysis, it was assumed that during future droughts, the 1971-2000 precipitation for the growing season would be reduced by 40 percent to represent a historical drought. For each sector, except power generation, the precipitation was decreased by 40 percent in the baseline scenario in order to anticipate the possible effects of future droughts. The results of this analysis is provided in the following sections.

6.2 Public water supply sector

The sensitivity of public water supply (PWS) withdrawals to weather conditions are captured by two variables: average maximum daily temperatures and total precipitation during the 5-month growing season from May 1 to September 30. The estimated constant elasticity of the temperature variable is +1.42 indicating that per capita water demand would be expected to increase by 1.42 percent in response to a 1.0 percent increase in temperature. The estimated constant elasticity of growing season precipitation is -0.11 indicating that average annual per capita water demand would be expected to decrease by 0.11 percent in response to a 1.0 percent increase in precipitation.

Table 6.1: Impact of a $6°F$ temperature increase on public water supply withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6°F$, $+0''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	138.9	-	-	-
2005 (Normal)	127.2	-	-	-
2010	131.9	133.4	1.5	1.2
2015	137.6	140.8	3.2	2.3
2020	144.2	149.2	5.0	3.5
2025	149.9	156.9	7.0	4.7
2030	154.3	163.2	9.0	5.8
2035	159.7	170.9	11.2	7.0
2040	165.2	178.8	13.6	8.2
2045	171.0	187.0	16.1	9.4
2050	176.9	195.6	18.8	10.6

BL = baseline scenario; MGD = million gallons per day.

($+6°F$, $+0''$) means $6°F$ increase in temperature and no changes in precipitation.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

6.2.1 Impacts of climate change

The five different climate change scenarios were applied to the baseline scenario of the public water supply model. The water withdrawal impacts of the combinations of temperature and precipitation changes during the growing season are shown in Tables 6.1 to 6.5.

Table 6.1 shows the effects of a gradual temperature increase on total water withdrawals in the PWS sector. By 2050, the $6°F$ increase in air temperature would increase total PWS withdrawals by 18.8 MGD or 10.6 percent relative to normal weather demand in the baseline scenario.

Tables 6.2 and 6.3 show the impact of changes in growing season precipitation without the temperature increase. The 2.5 inches increase in precipitation by 2050 would decrease withdrawals by 2.4 MGD or 1.4 percent decrease relative to the baseline scenario. The 3.5 inches decrease in precipitation would increase withdrawals by 4.1 MGD or 2.3 percent.

Table 6.2: Impact of 2.5 *inches* increase in growing season precipitation on public water supply withdrawals.

Year	BL scenario withdrawals (MGD)*	$+0^oF$, $+2.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	138.9	-	-	-
2005 (Normal)	127.2	-	-	-
2010	131.9	130.9	-0.9	-0.7
2015	137.6	135.7	-1.9	-1.4
2020	144.2	142.2	-2.0	-1.4
2025	149.9	147.8	-2.1	-1.4
2030	154.3	152.1	-2.1	-1.4
2035	159.7	157.5	-2.2	-1.4
2040	165.2	163.0	-2.3	-1.4
2045	171.0	168.6	-2.4	-1.4
2050	176.9	174.4	-2.4	-1.4

BL = baseline scenario; MGD = million gallons per day.

($+0°F$, $+2.5''$) means no increase in temperature and 2.5 inches increase in precipitation.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.3: Impact of 3.5 *inches* decrease in growing season precipitation on public water supply withdrawals.

Year	BL scenario withdrawals (MGD)*	$+0^oF$, $-3.5''$ Withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	138.9	-	-	-
2005 (Normal)	127.2	-	-	-
2010	131.9	133.3	1.4	1.1
2015	137.6	140.8	3.2	2.3
2020	144.2	147.5	3.3	2.3
2025	149.9	153.3	3.5	2.3
2030	154.3	157.8	3.6	2.3
2035	159.7	163.4	3.7	2.3
2040	165.2	169.1	3.8	2.3
2045	171.0	174.9	3.9	2.3
2050	176.9	181.0	4.1	2.3

BL = baseline scenario; MGD = million gallons per day.

($+0°F$, $-3.5''$) means no temperature increase and 3.5 *inches* decrease in precipitation.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.4: Impact of combined $6^\circ F$ temperature increase and $2.5\,inches$ precipitation increase on public water supply withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6^\circ F$, $+2.5''$ withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	138.9	-	-	-
2005 (Normal)	127.2	-	-	-
2010	131.9	132.5	0.6	0.4
2015	137.6	138.9	1.3	0.9
2020	144.2	147.2	3.0	2.1
2025	149.9	154.8	4.9	3.3
2030	154.3	161.1	6.8	4.4
2035	159.7	168.7	8.9	5.6
2040	165.2	176.4	11.2	6.8
2045	171.0	184.6	13.6	8.0
2050	176.9	193.0	16.2	9.1

BL = baseline scenario; MGD = million gallons per day.

($+6^\circ F$, $+2.5''$) means $6^\circ F$ increase in temperature and $2.5 inches$ increase in precipitation.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more detail information about 2005 (Normal) and 2005 (Weather).

Table 6.5: Impact of combined $6\,^{\circ}F$ temperature increase and $3.5\,inches$ precipitation decrease on public water supply withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6\,^{\circ}F$, $-3.5''$ withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	138.9	-	-	-
2005 (Normal)	127.2	-	-	-
2010	131.9	134.9	3.0	2.3
2015	137.6	144.1	6.5	4.7
2020	144.2	152.7	8.5	5.9
2025	149.9	160.6	10.7	7.1
2030	154.3	167.1	12.8	8.3
2035	159.7	175.0	15.3	9.5
2040	165.2	183.0	17.8	10.8
2045	171.0	191.5	20.5	12.0
2050	176.9	200.3	23.4	13.2

BL = baseline scenario; MGD = million gallons per day.

($+6\,^{\circ}F$, $-3.5''$) means $6\,^{\circ}F$ increase in temperature and 3.5 inches decrease in precipitation.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more detail information about 2005 (Normal) and 2005 (Weather).

Tables 6.4 and 6.5 show the combined impact of changes in growing season temperature and precipitation. The temperature change combined with the 2.5 inches increase in precipitation would increase withdrawals by 16.2 MGD, or 9.1 percent by 2050. The 3.5 inches decrease in precipitation combined with the temperature change results on 23.4 MGD increase in withdrawals, or 13.2 percent.

Figure 6.3 shows the results of the potential effects of climate change on the public water supply sector. The figure shows that all scenarios of climate change, except the increase in precipitation, will increase the water withdrawals in the region. The scenario with the largest impact is the combination of the increase in temperature and the decrease in precipitation, resulting in 13.2 percent increase in withdrawals.

6.2.2 Impacts of drought

For purposes of this analysis, it was assumed that during future droughts the 1971-2000 precipitation for the growing season would be reduced by 40 percent. Table 6.6 shows the result for average day water demand in the public supply sector under the conditions of a drought.

The results in Table 6.6 indicate that during a drought year total public supply withdrawals would increase by 6 percent. This percentage increase would be equivalent to an additional 7.9 MGD by 2010, and 10.6 MGD by 2050.

6.3 Power generation sector

Higher air temperatures will have an impact on the quantity of water withdrawn for thermoelectric cooling. In once-through cooling systems, warmer intake water may lead to increased rates of withdrawals in order meet thermal effluent limits. Also, the performance of cooling towers will be affected by higher air temperatures. However, the actual impacts on water withdrawals cannot be easily quantified and are not included in the sensitivity analysis conducted here.

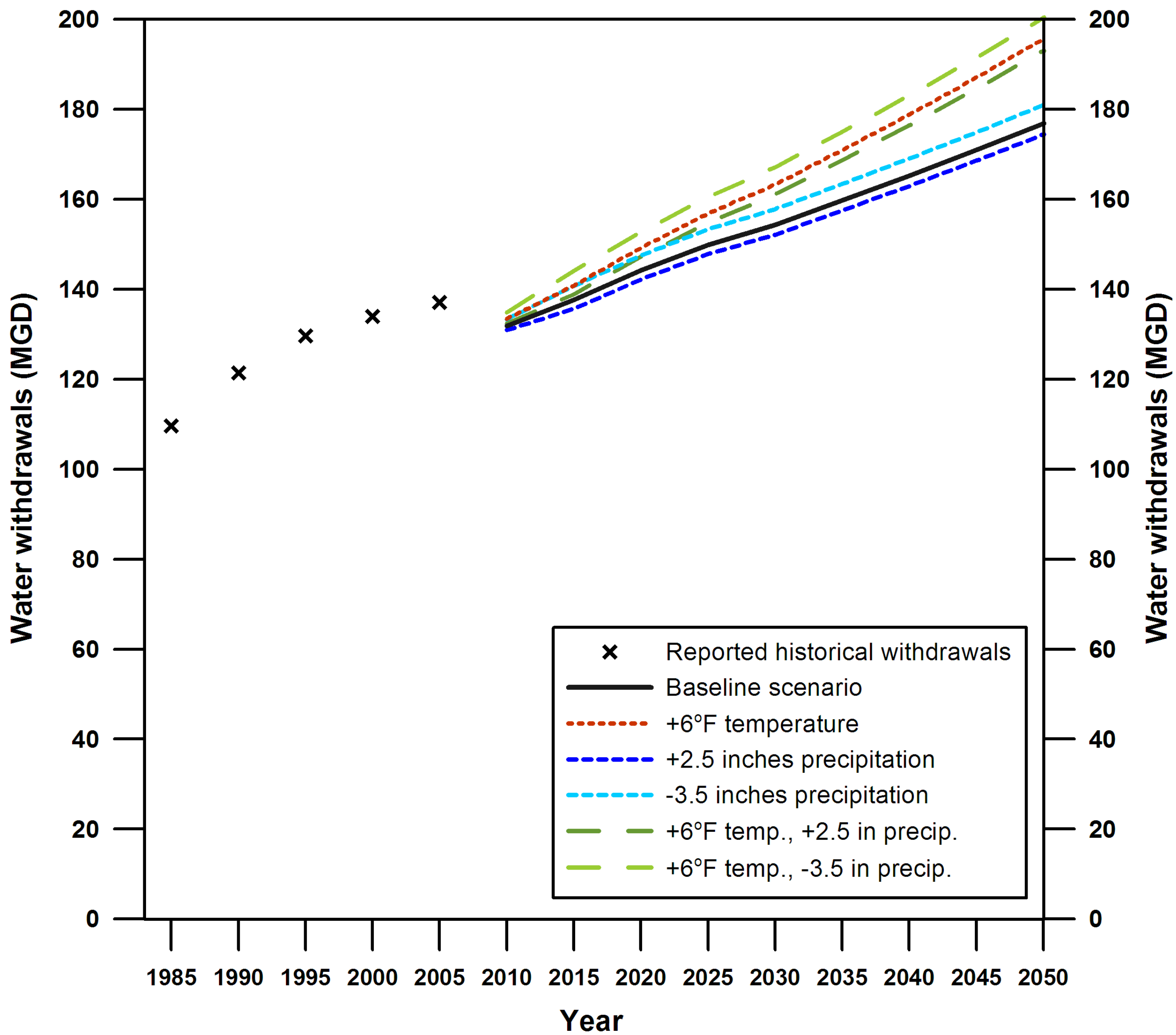

Figure 6.3: Sensitivity analysis results for public water supply sector.

Table 6.6: Impact of drought-induced precipitation deficit on total public supply withdrawals (compared to baseline scenario).

Year	BL scenario withdrawals (MGD)*	Drought scenario withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Normal)	127.2	134.9	7.6	6.0
2010	131.9	139.8	7.9	6.0
2015	137.6	145.8	8.2	6.0
2020	144.2	152.8	8.6	6.0
2025	149.9	158.9	9.0	6.0
2030	154.3	163.5	9.2	6.0
2035	159.7	169.3	9.6	6.0
2040	165.2	175.2	9.9	6.0
2045	171.0	181.2	10.2	6.0
2050	176.9	187.5	10.6	6.0

BL = baseline scenario; MGD = million gallons per day.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal).

6.4 Commercial and industrial sector

The sensitivity of commercial and industrial (C&I) water withdrawals to weather conditions are captured by two variables: total cooling degree days and total precipitation during the 5-month growing season from May 1 to September 30. The estimated constant elasticity of the cooling degree days variable is 0.529 indicating that per employee water demand would be expected to increase by 0.53 percent in response to a 1.0 percent increase in cooling degree days. The estimated constant elasticity of growing season precipitation is -0.2766 indicating that average annual per employee water demand would be expected to decrease by 0.28 percent in response to a 1.0 percent increase in precipitation. The same size but opposite effect would result from a 1.0 percent increase in precipitation.

6.4.1 Impacts of climate change

A $6\,^{\circ}F$ increase in annual average temperature by 2050 will translate into higher values for cooling degree days. Using the historical daily temperatures from 1985-2000 for each of the 29 weather stations, the temperature was increased linearly to $6\,^{\circ}F$ and the new number of cooling degree days was calculated for each year. The average number of cooling degree days from 1985-2005 was calculated and used in the sensitivity analysis. The average cooling degree days value was used to estimate the impact of temperature increase on C&I water withdrawals.

Table 6.7 shows the effects of cooling degree days increase on total water withdrawals in the C&I sector. By 2050, the impact of the increase in cooling degree days would increase total C&I withdrawals by 49.6 MGD, or 36.1 percent relatively to normal weather demand. Tables 6.8 and 6.9 show the effects on the increase and decrease of precipitation without an increase in cooling degree days on C&I withdrawals. An increase of 2.5 *inches* in precipitation by 2050 would decrease withdrawals by 4.2 MGD or 3.1 percent. A decrease of 3.5 *inches* in precipitation would increase withdrawal by 7.3 MGD or 5.3 percent by 2050.

Tables 6.10 and 6.11 give a summary of impacts of changes of combined cooling degree days and precipitation on self-supplied C&I water demand as compared to the baseline scenario under normal weather conditions. The results show that by 2050 the self-supplied C&I withdrawals would increase by 47.3 MGD or 31.8 percent if the increase in temperature is associated with a 2.5 *inches* increase in precipitation. If the temperature increase is associated with a 3.5 *inches* decrease in precipitation, total withdrawals would increase by 59.7 MGD or 43.4 percent.

Figure 6.4 shows the results of the potential effects of climate change on the C&I sector. The figure illustrates the increase in cooling degree days with the precipitation decrease is the most

Table 6.7: Estimated effects of $6^{\circ}F$ temperature increase, represented by an increase in annual cooling degree days, on commercial and industrial (C&I) water withdrawals.

Year	BL scenario withdrawals (MGD)*	$+CDD$, $+0''$ withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	85.3	–	–	–
2005 (Normal)	63.7	–	–	–
2010	76.5	81.3	4.8	6.3
2015	87.9	96.2	8.3	9.4
2020	94.7	107.1	12.5	13.2
2025	101.4	118.6	17.2	17.0
2030	108.4	130.9	22.5	20.7
2035	115.7	144.1	28.4	24.5
2040	123.0	158.0	34.9	28.4
2045	130.4	172.3	42.0	32.2
2050	137.5	187.1	49.6	36.1

BL = baseline scenario; MGD = million gallons per day.

(+CDD, 0”) means cooling degree days increase and no precipitation change.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more information about 2005 (Normal) and 2005 (Weather).

influential factor in the increase of C&I withdrawals. With exception of precipitation increase, all other climate change scenarios increase withdrawals. The change in slope for all scenarios is due to the effects of the assumed increase of $2.5\,inches$ and decrease of $3.5\,inches$ in precipitation by 2015.

6.4.2 Impacts of drought

Water withdrawals in the self-supplied commercial and industrial sector will also be affected by periodic droughts in the future. For the purpose of this analysis, it was assumed that during future droughts, the 1971-2000 precipitation for the growing season would be reduced by 40 percent.

Table 6.12 shows the results for the average-day water demand in the commercial and industrial

Table 6.8: Estimated effects of 2.5 *inches* precipitation increase on commercial and industrial (C&I) water withdrawals.

Year	BL scenario withdrawals (MGD)*	$0\,CDD, +2.5''$ withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	85.3	–	–	–
2005 (Normal)	63.7	–	–	–
2010	76.5	75.3	-1.2	-1.5
2015	87.9	85.4	-2.5	-2.8
2020	94.7	91.9	-2.7	-2.9
2025	101.4	98.4	-3.0	-2.9
2030	108.4	105.2	-3.2	-2.9
2035	115.7	112.2	-3.4	-3.0
2040	123.0	119.3	-3.7	-3.0
2045	130.4	126.4	-4.0	-3.0
2050	137.5	133.3	-4.2	-3.1

BL = baseline scenario; MGD = million gallons per day.

(0 CDD, +2.5”) means no cooling degree days change and 2.5 *inches* precipitation increase.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more information about 2005 (Normal) and 2005 (Weather).

Table 6.9: Estimated effects of 3.5 *inches* precipitation decrease on commercial and industrial (C&I) water withdrawals.

Year	BL scenario withdrawals (MGD)*	$0\,CDD, -3.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	85.3	–	–	–
2005 (Normal)	63.7	–	–	–
2010	76.5	78.4	1.9	2.5
2015	87.9	92.3	4.4	5.0
2020	94.7	99.5	4.8	5.1
2025	101.4	106.6	5.2	5.1
2030	108.4	114.0	5.6	5.2
2035	115.7	121.7	6.0	5.2
2040	123.0	129.5	6.4	5.2
2045	130.4	137.2	6.9	5.3
2050	137.5	144.8	7.3	5.3

BL = baseline scenario; MGD = million gallons per day.

(0 CDD, -3.5”) means no cooling degree days change and 3.5 *inches* precipitation decrease.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more information about 2005 (Normal) and 2005 (Weather).

Table 6.10: Impact of combined increase in temperature and 2.5 *inches* increase in precipitation on self-supplied commercial and industrial withdrawals.

Year	BL scenario withdrawals (MGD)*	$+CDD, +2.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	85.3	–	–	–
2005 (Normal)	63.7	–	–	–
2010	76.5	80.0	3.5	4.6
2015	87.9	93.3	5.5	6.2
2020	94.7	103.9	9.3	9.8
2025	101.4	115.0	13.6	13.4
2030	108.4	126.9	18.5	17.0
2035	115.7	139.6	24.0	20.7
2040	123.0	153.1	30.1	24.4
2045	130.4	167.0	36.6	28.1
2050	137.5	181.3	43.7	31.8

Baseline withdrawals represent normal weather (1971-2000).

(+CDD, +2.5”) means cooling degree days increase and 2.5 *inches* precipitation increase.

MGD = million gallons per day.

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more information about 2005 (Normal) and 2005 (Weather).

Table 6.11: Impact of combined increase in temperature and 3.5 *inches* decrease in precipitation on self-supplied commercial and industrial withdrawals.

Year	BL scenario withdrawals (MGD)*	$+CDD, -3.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	85.3	–	–	–
2005 (Normal)	63.7	–	–	–
2010	76.5	83.3	6.8	8.9
2015	87.9	101.0	13.2	15.0
2020	94.7	112.6	17.9	19.0
2025	101.4	124.7	23.3	23.0
2030	108.4	137.7	29.3	27.0
2035	115.7	151.7	36.0	31.1
2040	123.0	166.4	43.3	35.2
2045	130.4	181.6	51.2	39.3
2050	137.5	197.2	59.7	43.4

BL = baseline scenario; MGD = million gallons per day.

(+CDD, -3.5”) means cooling degree days increase and 3.5 *inches*of precipitation decrease.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See instructions for more information about 2005 (Normal) and 2005 (Weather).

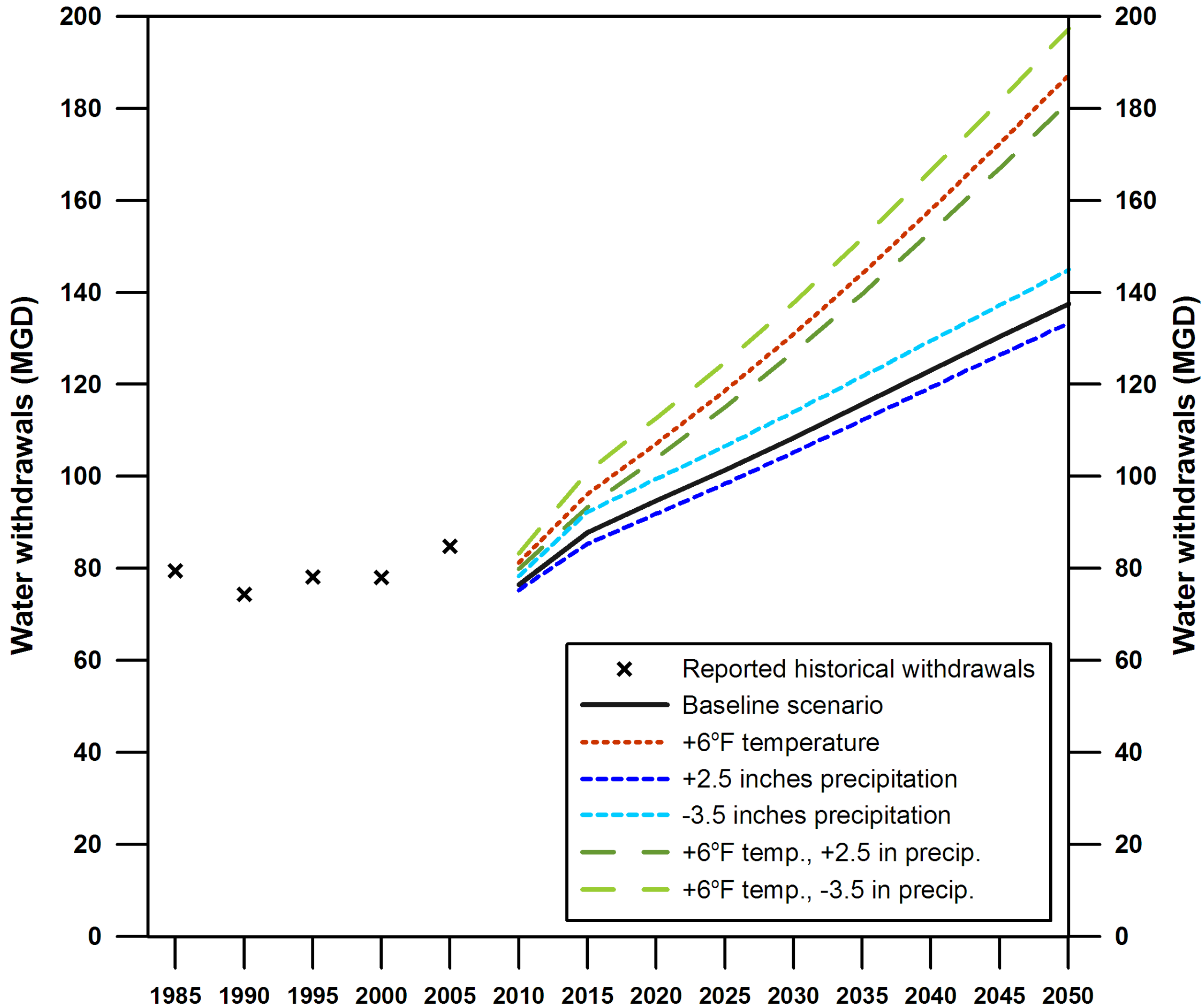

Figure 6.4: Sensitivity analysis results for commercial and industrial sector.

Table 6.12: Impact of drought-induced precipitation on commercial and industrial (C&I) water withdrawals.

Year	BL scenario withdrawals (MGD)*	Total withdrawals during drought (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Normal)	63.7	73.4	9.7	15.2
2010	76.5	87.2	10.7	14.0
2015	87.9	99.5	11.6	13.2
2020	94.7	107.3	12.6	13.3
2025	101.4	115.0	13.7	13.5
2030	108.4	123.2	14.7	13.6
2035	115.7	131.5	15.8	13.7
2040	123.0	140.0	16.9	13.8
2045	130.4	148.4	18.1	13.8
2050	137.5	156.7	19.1	13.9

BL = baseline scenario, MGD = million gallons per day.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal).

during the drought. The results in Table 6.12 indicate that during a drought year, self-supplied C&I withdrawals would increase by 13.9 percent. This percentage increase would be equivalent to additional 10.7 MGD by 2010, and 19.1 MGD by 2050.

6.5 Irrigation and agriculture sector

For the purpose of the sensitivity analysis with respect to climate change, future estimates of water demand for irrigation and agriculture (IR&AG) were further analyzed for the effects of decreased or increased precipitation and the effect of increased temperature on evapotranspiration. The effect of the change in normal precipitation was translated into change in the precipitation deficit. The change was calculated using the equation:

$$d_t = 20.760 - 0.585.P_n$$

Where:

d_t = precipitation deficit during irrigation season (May 1 - August 31),

P_n = normal precipitation during the irrigation season increased by $2.5\,inches$ or decreased by $3.5\,inches$.

The correction for the departure of average irrigation season temperature is based on the analysis of potential evapotranspiration and monthly temperature by Dr. Ken Kunkel and his staff at ISWS. It is approximated using the adjustment of $0.1\,inches/degree\,Fahrenheit$:

$$d_t^c = d_t + 0.1.(T_a - T_n)$$

Where:

d_t^c= the corrected total application depth during the irrigation season,

T_a= is average monthly air temperature for May 1 – August 31,

T_n= average of normal monthly temperatures during the 4-month irrigation season.

In arriving at this relationship, Dr. Kunkel analyzed the soil moisture model data in order to examine the year-to-year variability in the ratio ET/PET (actual to potential evapotranspiration) for each month of the irrigation season. In July and August, there are years when the model-estimated ratio is 1.0 thus indicating that the use of PET as actual ET is appropriate. In June, the highest ET/PET values were in the range of 0.90 to 0.95. In May, the highest ET/PET values were near or slightly above 0.70. The average value for May was 0.50. Assuming that a stretch of 1-2 weeks of dry weather in May would concern a farmer enough to irrigate, the higher value of 0.70 would be appropriate for May. Because development of a weighted coefficient for ET/PET ratio would require monthly data (while seasonally aggregated data are used in this study), no downward adjustment for actual ET was introduced (thus assuming a value of 1.0 for all months of the irrigation season). This assumption contributes to slightly overestimated effects of temperature on irrigation water demand.

6.5.1 Impacts of climate change

The water withdrawal impacts of the combinations of temperature and precipitation changes for the IR&AG are shown in Tables 6.13 to 6.17.

Table 6.13 shows the effects of gradual temperature increase on total water withdrawals. By 2050, a $6^{\circ}F$ increase in air temperature would increase total IR&AG withdrawals by 10.5 MGD or 5.6 percent relative to normal weather demand.

Tables 6.14 and 6.15 show the impact of changes in precipitation deficit without the temperature increase. The 2.5 inches increase in precipitation translates into a decrease of 29.4 MGD or 15.8 percent on water withdrawals by 2050. The 3.5 inches decrease in precipitation would increase withdrawals by 34.3 MGD or 18.4 percent.

By 2050, a $6^{\circ}F$ increase in air temperature combined with $2.5\,inches$ increase in precipitation would decrease total agricultural withdrawals by 18.6 MGD or 10.0 percent relative to normal weather (Tables 6.16). When a $6^{\circ}F$ increase in air temperature is combined with $3.5\,inches$ decrease in precipitation, the 2050 withdrawals increase by 44.9 MGD or by 24.1 percent relative to normal weather baseline withdrawals (Table 6.17).

Figure 6.5 shows the results of potential effects of climate change on the IR&AG sector. The figure shows that temperature increase, without a change in precipitation, increases withdrawals slightly but decrease in precipitation has a large effect on total water withdrawals for this sector. Both the increase in precipitation and the combined increase in precipitation and temperature decrease the water withdrawals. The changes in slopes of the climate change scenarios, as well as the baseline scenario are due to the dependence of results on the precipitation deficit factor and the irrigated acreage increase.

6.5.2 Impacts of drought

Water withdrawals by the IR&AG sector will also be affected by periodic droughts in the future. Irrigation demands are very sensitive to the decreasing precipitation during the summer growing season. The assumption that during future droughts, the normal precipitation for the growing season would be reduced by 40 percent would substantially increase the amount of water applied

Table 6.13: Impact of a $6^{\circ}F$ temperature increase of on irrigation and agriculture (IR&AG) withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6^{o}F$, $+0''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	233.1	–	–	–
2005 (Normal)	139.4	–	–	–
2010	162.4	163.1	0.8	0.5
2015	171.9	173.7	1.8	1.1
2020	181.3	184.4	3.1	1.7
2025	182.5	186.8	4.3	2.4
2030	183.6	189.1	5.5	3.0
2035	184.5	191.3	6.8	3.7
2040	185.3	193.3	8.0	4.3
2045	186.0	195.2	9.2	5.0
2050	186.5	196.9	10.5	5.6

BL = baseline scenario; MGD = million gallons per day.

(+6^{o}F, +0”) means 6^{o}F temperature increase and no precipitation change.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.14: Impact of 2.5 *inches* precipitation increase on irrigation and agriculture (IR&AG) withdrawals.

Year	BL scenario withdrawals (MGD)*	$+0^oF$, $+2.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	233.1	–	–	–
2005 (Normal)	139.4	–	–	–
2010	162.4	148.4	-14.0	-8.6
2015	171.9	144.8	-27.1	-15.8
2020	181.3	152.7	-28.6	-15.8
2025	182.5	153.7	-28.8	-15.8
2030	183.6	154.6	-29.0	-15.8
2035	184.5	155.4	-29.1	-15.8
2040	185.3	156.1	-29.2	-15.8
2045	186.0	156.6	-29.3	-15.8
2050	186.5	157.0	-29.4	-15.8

BL = baseline scenario; MGD = million gallons per day.

(+0^{o}F, +2.5”) means no temperature increase and 2.5 inches precipitation increase.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.15: Impact of 3.5 *inches* precipitation decrease on irrigation and agriculture (IR&AG) withdrawals.

Year	BL scenario withdrawals (MGD)*	$+0^oF$, $-3.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	233.1	–	–	–
2005 (Normal)	139.4	–	–	–
2010	162.4	176.2	13.8	8.5
2015	171.9	203.6	31.8	18.5
2020	181.3	214.8	33.5	18.5
2025	182.5	216.2	33.7	18.5
2030	183.6	217.4	33.8	18.4
2035	184.5	218.5	34.0	18.4
2040	185.3	219.4	34.1	18.4
2045	186.0	220.2	34.2	18.4
2050	186.5	220.8	34.3	18.4

BL = baseline scenario; MGD = million gallons per day.

($+0^o$F, -3.5”) means no temperature increase and 3.5 inches precipitation decrease.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.16: Effects of $6^{\circ}F$ temperature increase and 2.5 *inches* precipitation increase on irrigation and agriculture withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6^{o}F$, $+2.5''$ withdrawals (MGD)	Change from baseline (MGD)	Change from baseline (%)
2005 (Weather)	233.1	–	–	–
2005 (Normal)	139.4	–	–	–
2010	162.4	149.4	-13.0	-8.0
2015	171.9	146.9	-24.9	-14.5
2020	181.3	156.2	-25.1	-13.9
2025	182.5	158.4	-24.1	-13.2
2030	183.6	160.5	-23.1	-12.6
2035	184.5	162.5	-22.0	-11.9
2040	185.3	164.4	-20.9	-11.3
2045	186.0	166.2	-19.8	-10.6
2050	186.5	167.9	-18.6	-10.0

BL = baseline scenario; MGD = million gallons per day.

(+6^{o}F, +2.5”) means 6^{o}F temperature increase and 2.5 inches precipitation increase.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

Table 6.17: Effects of $6^{\circ}F$ temperature increase and 3.5 *inches* precipitation decrease on irrigation and agriculture withdrawals.

Year	BL scenario withdrawals (MGD)*	$+6^{o}F$, $-3.5''$ withdrawals (MGD)	Change from baseline	
			(MGD)	(%)
2005 (Weather)	233.1	–	–	–
2005 (Normal)	139.4	–	–	–
2010	162.4	177.1	14.7	9.1
2015	171.9	205.6	33.8	19.6
2020	181.3	218.1	36.8	20.3
2025	182.5	220.6	38.2	20.9
2030	183.6	223.1	39.5	21.5
2035	184.5	225.4	40.9	22.2
2040	185.3	227.6	42.2	22.8
2045	186.0	229.5	43.6	23.4
2050	186.5	231.4	44.9	24.1

BL = baseline scenario; MGD = million gallons per day.

(+6^{o}F, -3.5”) means 6^{o}F temperature increase and 3.5 inches precipitation decrease.

*Baseline withdrawals represent normal weather (1971-2000).

2005 (Weather) = modeled 2005 withdrawals using actual weather data.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

see introduction for more detailed information about 2005 (Normal) and 2005 (Weather).

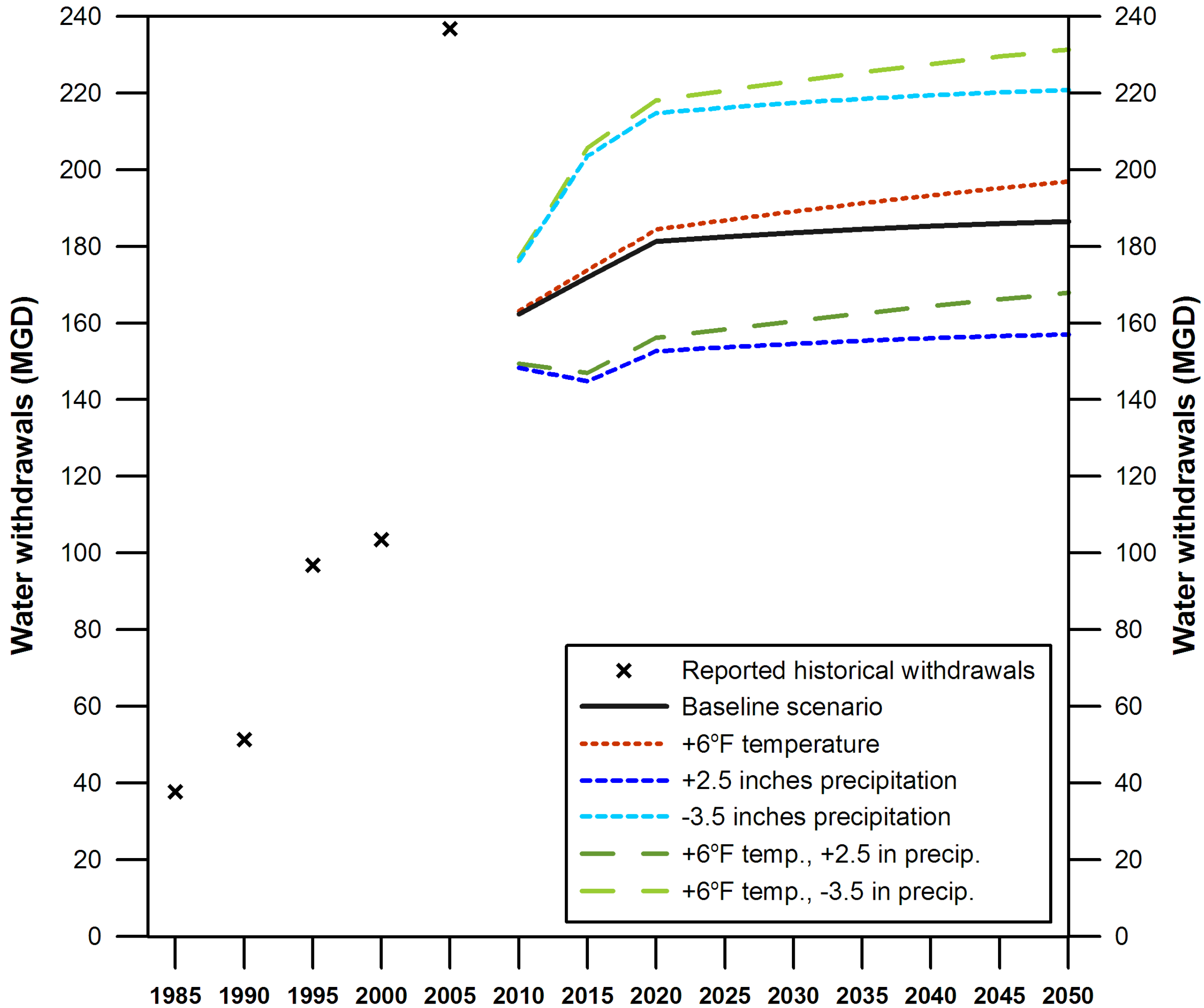

Figure 6.5: Sensitivity analysis results for irrigation and agriculture sector.

Table 6.18: Impact of drought-induced precipitation deficit on irrigation and agriculture withdrawals (compared to baseline scenario).

Year	Total normal weather withdrawals (MGD)	Total withdrawals during drought (MGD)	Change from normal weather (MGD)	Change from normal weather (%)
2005 (Normal)	139.4	233.5	94.1	67.5
2010	162.4	229.2	66.9	41.2
2015	171.9	242.6	70.8	41.2
2020	181.3	255.9	74.6	41.2
2025	182.5	257.6	75.1	41.1
2030	183.6	259.0	75.4	41.1
2035	184.5	260.3	75.8	41.1
2040	185.3	261.4	76.1	41.1
2045	186.0	262.3	76.3	41.1
2050	186.5	263.0	76.6	41.1

Total normal weather withdrawals represent baseline scenario.

MGD = million gallons per day.

2005 (Normal) = modeled 2005 withdrawals using normal weather data.

See introduction for more detailed information about 2005 (Normal).

for crop and turf irrigation.

Table 6.18 shows the results for average-day water demand in the IR&AG sector during a drought. The results in Table 6.18 indicate that during a drought year, self-supplied IR&AG withdrawals would increase approximately 41 percent. This percentage increase would be equivalent to additional 66.9 MGD by 2010 and 76.6 MGD by 2050.

6.6 Summary of climate change and drought impacts

To test the model sensitivity to climate change and drought, precipitation and temperature changes were analyzed for three sectors; PWS, C&I, and IR&AG. The five scenario analyzed were: 1) linear increase of temperature up to $6\,^{\circ}F$ by 2050, 2) increase of $2.5\,inches$ in total annual precipitation (+1.25 inches in 2010 and +2.5 inches by 2015), 3) 3.5 inches decrease in precipitation (-1.75 inches in 2010 and -3.5 inches by 2015), 4) combination of increase in temperature and precipitation, and 5) increase in temperature and decrease in precipitation by the respective values described above.

Table 6.19 shows the summary of climate change scenarios per sector. The change from the baseline scenario (normal conditions) is shown in the last column. For all three analyzed sectors, the combination of temperature increase and precipitation decrease has the largest impact on total water withdrawals, increasing withdrawals by 128 MGD by 2050. This makes sense given the established relationship to temperature and precipitation for each of the sectors; as temperature increases withdrawals will increase, as precipitation decreases water withdrawals will increase. This scenario had the largest impact on the C&I sector (+59.7 MGD), followed by IR&AG (44.9 MGD), and PWS (23.4 MGD).

The scenarios with just the change in precipitation affected the IR&AG sector the most. The precipitation decrease scenario increased withdrawals in IR&AG by 34.3 MGD. The precipitation increase scenario decreased withdrawals in IR&AG by 29.5 MGD.

The temperature increase scenario has the largest impact on C&I (+49.6 MGD), followed by PWS (+18.7 MGD) and IR&AG (+10.4 MGD) for a total increase of 78.7 MGD for all sectors (excluding power generation) by 2050.

Table 6.20 shows the effects of drought on withdrawals for all sectors. Drought conditions could increase the total withdrawals for the region 106.3 MGD, from 500.9 MGD to 607.2 MGD in 2050. IR&AG would be the most affected sector with water withdrawals increasing 76.5 MGD from baseline conditions. This makes sense from what we learned in the climate change scenarios; IR&AG is more effected by precipitation that the other sectors. Overall, this drought scenario shows that, without a change in temperature, a precipitation drought can cause an increase of approximately 100 MGD on any given year. This is important to remember when looking at the graphs and tables of future water withdrawal estimates.

Table 6.19: Effects of possible climate change on water withdrawals (in MGD) in East-Central Illinois.

Weather scenario/ Sector	2005 (Normal) withdrawals (MGD)	2030 withdrawals (MGD)	2050 withdrawals (MGD)	Change from BL in 2050
Baseline (BL) scenario				
Public-supply	127.2	154.3	176.9	–
Self-supplied C&I	63.7	108.4	137.5	–
Irrigation and agriculture	139.4	183.6	186.5	–
All sectors (w/o power)	330.3	446.0	500.9	–
$+6^\circ F$ temperature only				
Public-supply	127.2	163.2	195.6	18.7
Self-supplied C&I	63.7	130.9	187.1	49.6
Irrigation and agriculture	139.4	189.1	196.9	10.4
All sectors (w/o power)	330.3	483.2	579.6	78.7
+2.5” precipitation only				
Public-supply	127.2	152.1	174.4	-2.5
Self-supplied C&I	63.7	105.2	133.3	-4.2
Irrigation and agriculture	139.4	154.6	157.0	-29.5
All sectors (w/o power)	330.3	411.9	464.7	-36.2
−3.5” precipitation only				
Public-supply	127.2	157.8	181.0	4.1
Self-supplied C&I	63.7	114.0	144.8	7.3
Irrigation and agriculture	139.4	217.4	220.8	34.3
All sectors (w/o power)	330.3	489.2	546.6	45.7
$+6^\circ F$ temperature, +2.5” precipitation				
Public-supply	127.2	161.1	193.0	16.1
Self-supplied C&I	63.7	126.9	181.3	43.8
Irrigation and agriculture	139.4	160.5	167.9	-18.6
All sectors (w/o power)	330.3	448.5	542.2	41.3
$+6^\circ F$ temperature, −3.5” precipitation				
Public-supply	127.2	167.1	200.3	23.4
Self-supplied C&I	63.7	137.7	197.2	59.7
Irrigation and agriculture	139.4	223.1	231.4	44.9
All sectors (w/o power)	330.3	527.9	628.9	128.0

Table 6.20: Effects of drought on water withdrawals (in MGD) in East-Central Illinois.

Weather scenario/ Sector	2005 (Normal) withdrawals (MGD)	2030 withdrawals (MGD)	2050 withdrawals (MGD)	Change from BL (MGD)
Baseline (BL) scenario				
Public-supply	127.2	154.3	176.9	–
Self-supplied C&I	63.7	108.1	137.5	–
Irrigation and agriculture	139.4	183.6	186.5	–
All sectors (w/o power)	330.3	446.0	500.9	–
Drought year (40 percent precipitation deficit)				
Public-supply	127.2	163.5	187.5	10.6
Self-supplied C&I	63.7	123.2	156.7	19.2
Irrigation and agriculture	139.4	259.0	263.0	76.5
All sectors (w/o power)	330.3	545.7	607.2	106.3

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