Appendix A: Changing Conditions in Southeastern Colorado

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1 - Guidance

Analysis of changing conditions impacts to all USACE undertakings is governed by the following policy and guidance: USACE ECB 2018-14.

2 - Relevant Climatological Factors

Spring Creek is a small watershed that carries surface runoff, potentially supplemented by near-surface groundwater, to Fountain Creek (El Paso Public Works basin FOFO4200, https://assets-publicworks.elpasoco.com/wp-content/uploads/Stormwater/Current_Website/Drainage-Basins.pdf). With the exception of a small wetland area immediately upstream of the project, the watershed above the project area consists almost entirely of developed areas (including The Citadel (which has almost no greenspace around it), as well as housing and industrial land uses). The creek is down cutting through surface sediment, and in places this downcutting appeared to be limited by exposed bedrock. This suggests that the wetland exists in this location in part because this aquitard prevents further infiltration of surface runoff (A. Flammang, pers. Comm., 2022).

Given the small, entirely low-elevation watershed, the relevant climatological factors to consider are:

1. **Direct precipitation** in the vicinity of the project (USGS HUC 11020003 - Fountain), including storm water (1-day precipitation maxima as proxies for intensity) to account for surface flows as well as annual and/or monthly precipitation as a proxy for shallow water aquifer recharge / soil moisture. Summer precipitation, associated with North American Monsoon flows, is the dominant water source in the project area.
2. **Increases in temperature**, because these are likely to 1) drive up evapotranspiration (eT), since eT scales with temperature and 2) increase overall water demand because warmer temperatures are likely to extend the growing season. In addition to vegetation stress, these changes will reduce soil moisture, which may impact runoff and infiltration rates, particularly during summer convective precipitation.
3. As the climate warms, **regional water stress** may be manifest as tighter controls on and higher prices for municipal and industrial water use, resulting in reductions in the amount of water wasted to the stormwater system on a chronic (daily) basis. This would have the effect of reducing base flows in the project area. Colorado Springs does not have a native water source but receives water from the Colorado and Arkansas River Basins via pipeline (~100+ miles away). Supplemental water to support ecosystem restoration in the project area, especially during drought, would probably be unlikely and/or costly.

Changes to regional snowpack and wildfire effects, which are critical concerns for regional water supplies, are not concerns for streamflow in this small, low elevation, urbanized watershed.

3 - Existing Conditions and Observed Trends

3.1 Existing Climate in the Project Area

Colorado's climate is influenced by its location in the middle of the continent (far from the ameliorating effects of the ocean), its overall high elevation, and its complex topography. Thus, the state experiences frequent sunshine, low humidity and rapid and large variations in temperatures. Moisture enters the state primarily along the westerlies from late fall to early spring, with increasing intrusion of moist, tropical air from the south and east during the remainder of the year (Lukas et al., 2014). The Rocky Mountains are tall enough to create rainshadows on their downwind sides, predominantly on the eastern side of mountain ranges in the winter half of the year, and predominantly on the western side of mountain ranges in the summer half of the year (Lukas et al., 2014).

The project is located in the city of Colorado Springs, which has a semi-arid climate characterized by cool dry, winters and warm, dry summers, with large diurnal temperature ranges in all months. Winter (December, January February) temperatures average at or below freezing, with daytime highs averaging in the lower 40s°F, and overnight lows averaging below 20°F. Located at the base of, and in the rainshadow of the Rockies, winters tend to be dry, averaging less than an inch of precipitation during the winter months (Figure 1). In the mountains above Colorado Springs, Ruxton Park, Colorado (station number 057309, at 9050 ft asl), precipitation is similarly low at under an inch for each of the winter months.

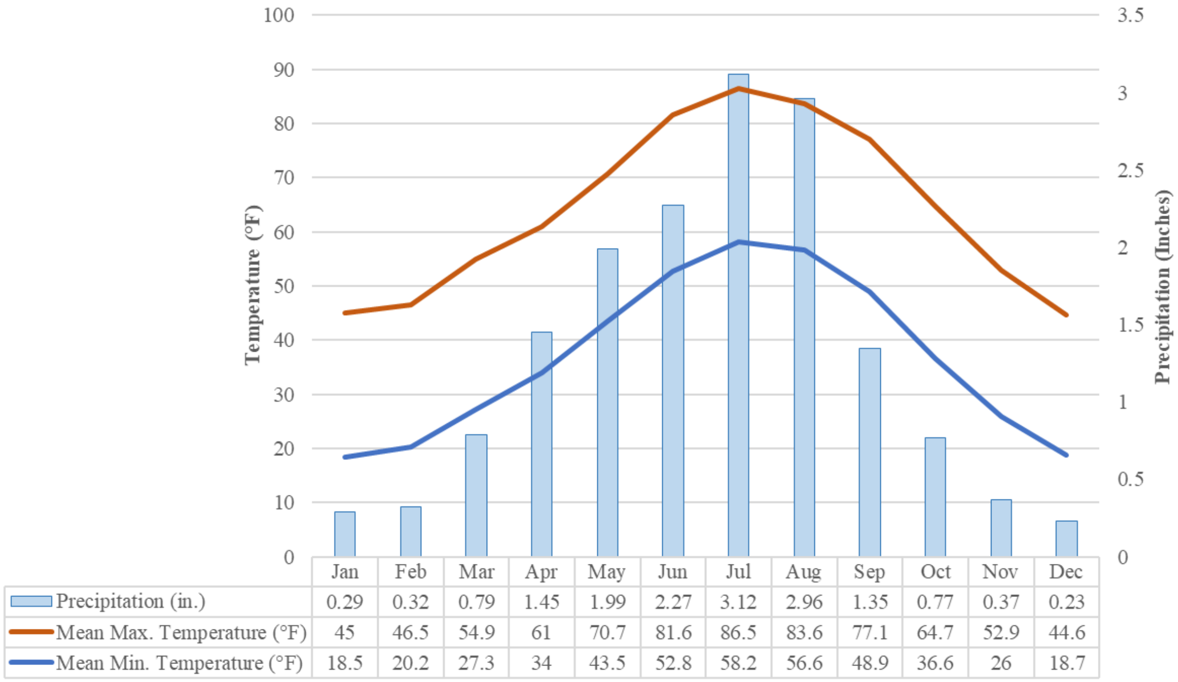
Spring (March, April and May) and summer (June, July, August) are the wettest seasons. Precipitation increases across spring and summer, from an average of 1 inch in March to a peak average of 3.34 inches in August. In the mountains at Ruxton Park, precipitation hovers close to 2.5 inches for each month March through June, and then increases in July and August, peaking at an average of 4.37 inches. Higher up and further west in the highest portion of the Rockies, precipitation is greater in winter than in summer (Lukas et al. 2014). Frontal systems play an important role in precipitation year-round. Summer high temperatures exceed 80°F.

Annually, snowmelt results in high spring flows along Fountain Creek, with high river stages but not necessarily general flooding. Extensive flooding may occur in years of exceptional snowpack, or when there is widespread lower elevation snow accumulation accompanied by sudden warming (Doesken et al. 2003). Because of the small, low elevation watershed above the project area, snowmelt runoff makes a negligible contribution to surface runoff in the project area and the location is outside the reach of spring runoff flooding along Fountain Creek.

Summer precipitation makes the largest contribution to surface runoff in the project area. Locally-intense summer thunderstorms occur as a result of strong orographic or frontal uplift, often in combination with an influx of low-level moist air masses originating over the Gulf of Mexico or Gulf of California (Doesken et al. 2003) via the North American Monsoon (NAM). Interannual variability in the NAM is poorly understood. Antecedent soil moisture is thought to be an important driver of NAM precipitation in early summer.

The name “Spring Creek” implies the presence of springs in the project area, but no historical records of springs were found. If shallow aquifer contributions to base flows occur in the project area, no information was found to quantify these flows nor to assess impacts due to climate change and urbanization.

Annual pan evaporation rates of 45-50 inches/year greatly exceed the average annual precipitation of 16 inches.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (in.)	0.29	0.32	0.79	1.45	1.99	2.27	3.12	2.96	1.35	0.77	0.37	0.23
Mean Max. Temperature (°F)	45	46.5	54.9	61	70.7	81.6	86.5	83.6	77.1	64.7	52.9	44.6
Mean Min. Temperature (°F)	18.5	20.2	27.3	34	43.5	52.8	58.2	56.6	48.9	36.6	26	18.7

Source: Western Regional Climate Center, http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?co1778, accessed 12 December 2022.

Figure 1 1991-2020 monthly climate normals, Colorado Springs Municipal Airport, Colorado, Cooperative Observer Station (051778).

3.2 Observed Trends

A recent report for the Colorado Water Conservation Board (Lukas et al., 2014) summarizes the observed trends in climate variables over the historic period. Statewide, Colorado's annual average temperature has increased by 2.5°F since 1980, and 3.0°F since 1900. Increases have occurred in all seasons, with daily minimums increasing faster than daily maximums. No long-term trends have been observed in the precipitation record, and no long-term trends detected in April 1 snowpack snow-water equivalent (SWE) (Mahoney, et al. 2018, Figure 2). Since 2000, however, Colorado has experienced both reduced precipitation and below-average April 1 SWE in the headwaters of all of the major river basins. The last 30 years, the timing of snowmelt and peak runoff has shifted to earlier in spring by 1 to 4 weeks. This advance in runoff timing is due to warming spring temperatures, reductions in SWE since 2000, and increased dust on snow, which enhances solar absorption leading to increased melt rates. Below average precipitation and warming temperatures have also contributed to reductions in soil moisture and increases in the severity of soil-moisture drought conditions. No changes have been detected in heavy precipitation patterns, and no statewide trend in the magnitude of flood events has been detected.

For the project area, the most important of these recent changes has been the reduction in precipitation in conjunction with overall higher temperatures. These changes have likely reduced soil moisture in the project area available to support desired vegetation types. The city of Colorado Springs has not, however, adopted comprehensive outdoor water use restrictions that might impact urban excess water runoff into the project area.

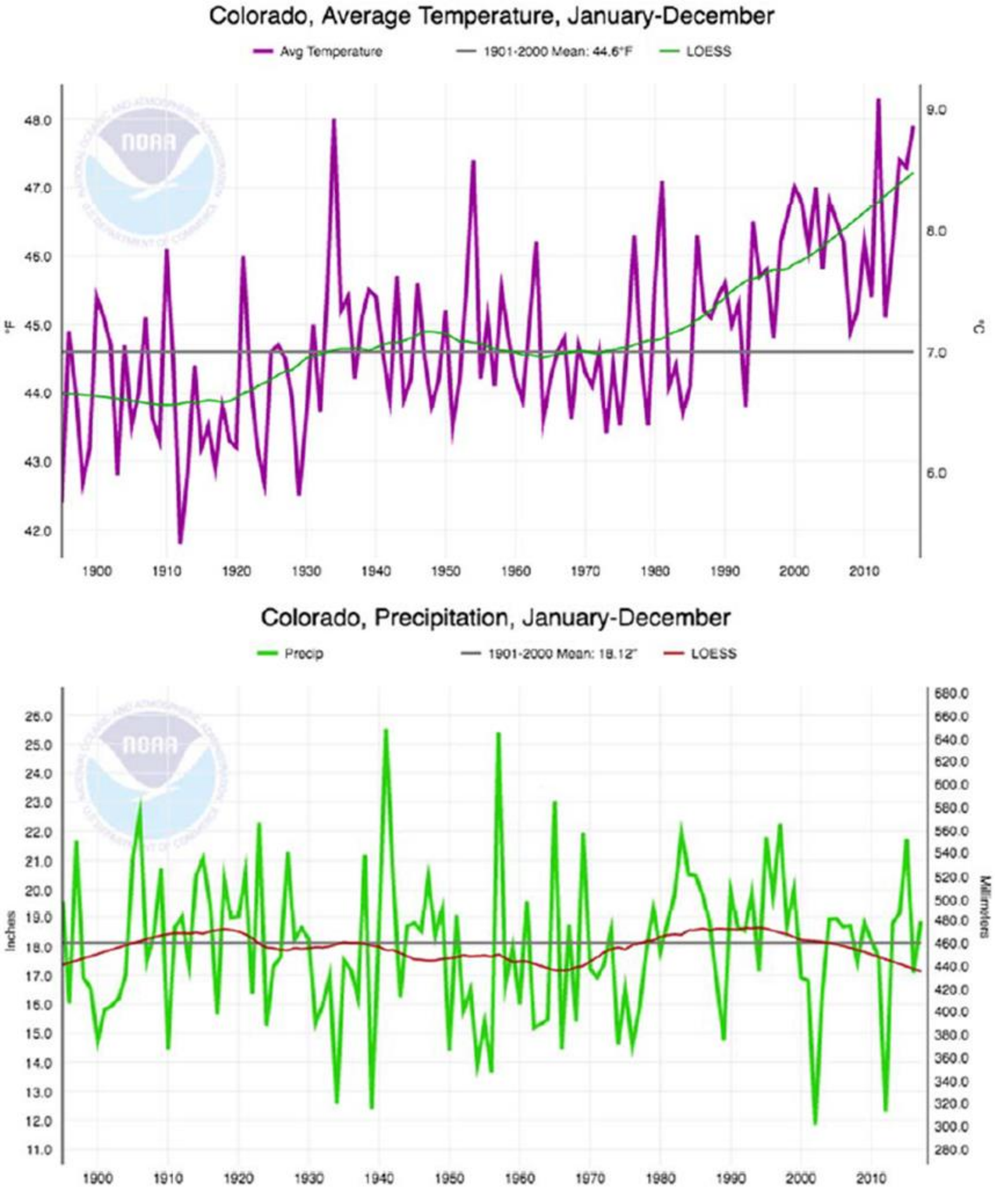
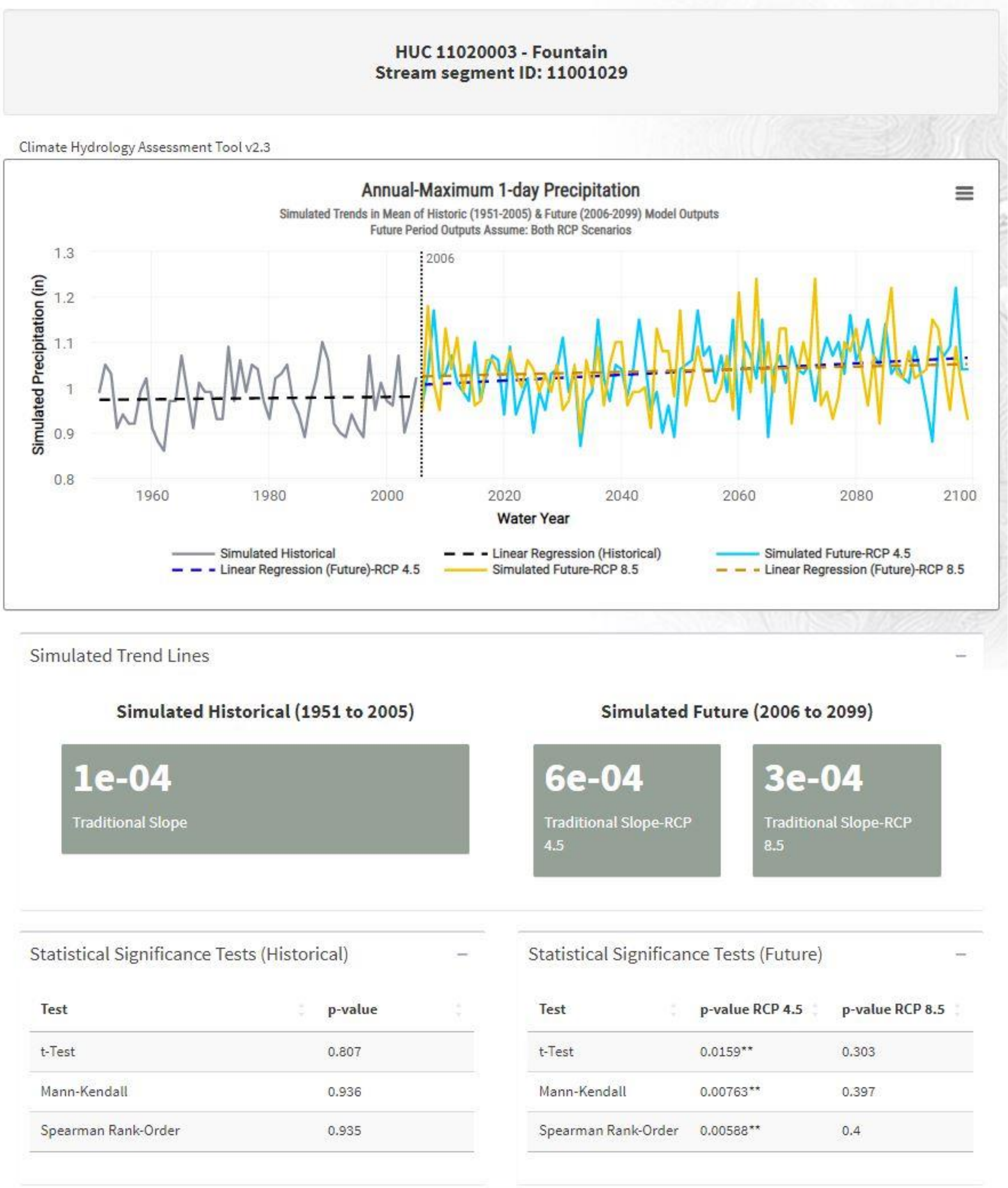


Figure 2 Observed changes in temperature and precipitation, State of Colorado as a whole (Mahoney et al. 2018).

The USACE Comprehensive Hydrology Assessment Tool (CHAT) was used to further explore historical and projected future changes in maximum 1-day precipitation (Figure 3) and annual 1-day streamflow in the Fountain Creek watershed (HUC 1102003) (Figure 4). Since Spring Creek is not included in the dataset, the CHAT assessment uses data for the Templeton Gap Floodway (Stream Segment ID 11001029), which is the only stream segment in the CHAT that originates east of Monument Creek in the vicinity of the Spring Creek headwaters. Changes in flows along the floodway should be similar in direction but different in magnitude from those along Spring Creek. For the modeled historical period, there is no detectable statistical trend in either variable. This finding is consistent with the findings of researchers cited above.



HUC 11020003 - Fountain
Stream segment ID: 11001029

Climate Hydrology Assessment Tool v2.3

Simulated Trend Lines

Simulated Historical (1951 to 2005)

1e-04
Traditional Slope

Simulated Future (2006 to 2099)

6e-04
Traditional Slope-RCP 4.5

3e-04
Traditional Slope-RCP 8.5

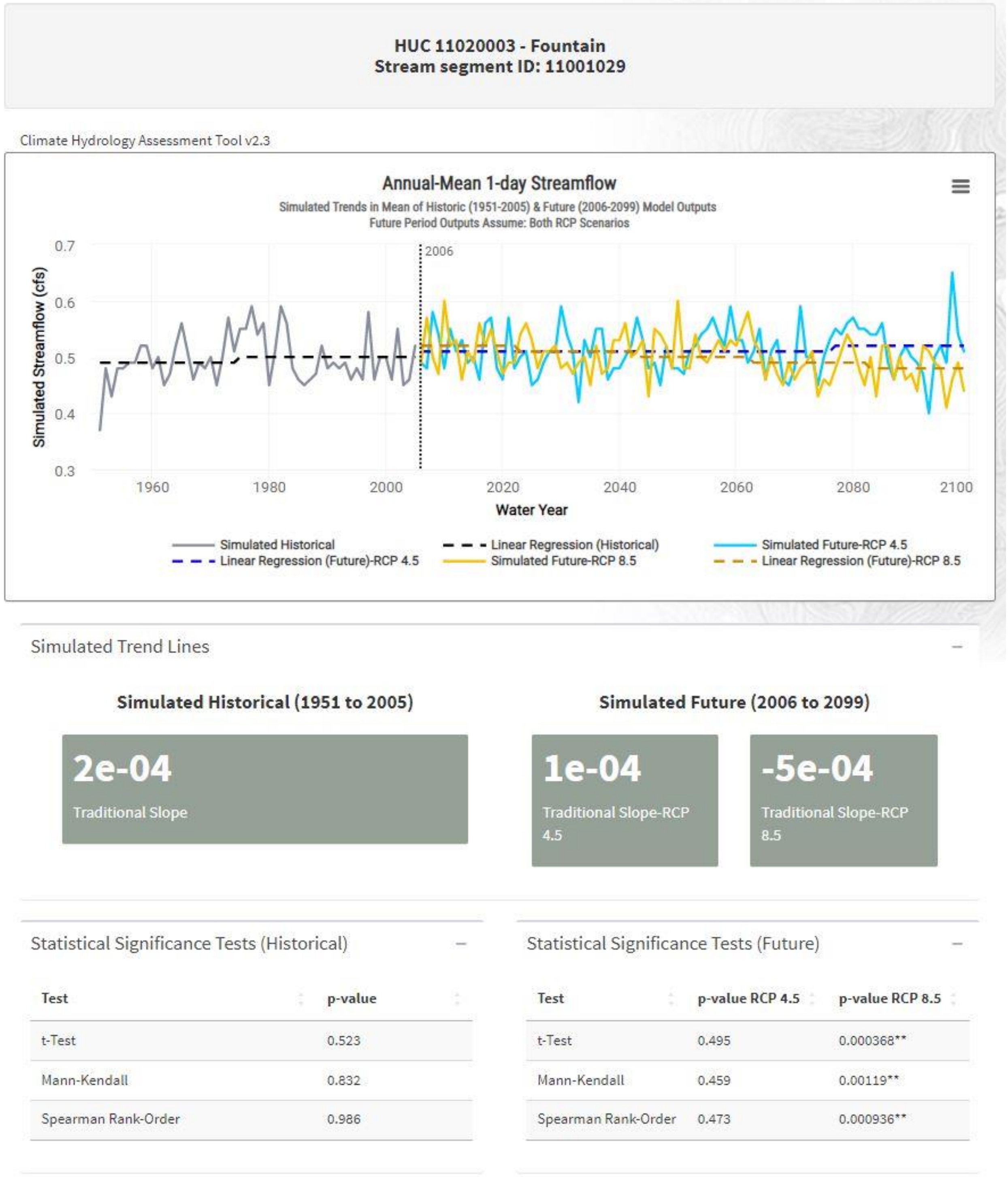
Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.807
Mann-Kendall	0.936
Spearman Rank-Order	0.935

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.0159**	0.303
Mann-Kendall	0.00763**	0.397
Spearman Rank-Order	0.00588**	0.4

Figure 3 USACE Comprehensive Hydrology Assessment Tool (CHAT) output for HUC 11020003 Fountain, Stream Segment Id. 11001029: Annual maximum 1-day precipitation.



HUC 11020003 - Fountain
Stream segment ID: 11001029

Climate Hydrology Assessment Tool v2.3

Simulated Trend Lines

Simulated Historical (1951 to 2005)

2e-04
Traditional Slope

Simulated Future (2006 to 2099)

1e-04
Traditional Slope-RCP 4.5

-5e-04
Traditional Slope-RCP 8.5

Statistical Significance Tests (Historical)

Test	p-value
t-Test	0.523
Mann-Kendall	0.832
Spearman Rank-Order	0.986

Statistical Significance Tests (Future)

Test	p-value RCP 4.5	p-value RCP 8.5
t-Test	0.495	0.000368**
Mann-Kendall	0.459	0.00119**
Spearman Rank-Order	0.473	0.000936**

Figure 4 USACE Comprehensive Hydrology Assessment Tool (CHAT) output for HUC 11020003 Fountain, Stream Segment Id. 11001029: Annual-mean 1-day streamflow.

Data for evaluating recent peak flow trends more closely is not available for the Templeton Gap Floodway (USGS 07104500-Templeton Gap Floodway at Colorado Springs, CO, period of record 1952-1981), but is available for Cottonwood Creek several miles to the north. Cottonwood Creek heads in slightly higher terrain around the Black Forest on the north side of Colorado Springs. For the USGS gage site Cottonwood Creek at Mouth at Pikeview, CO (USGS 07103990), over the period of record (1986-2021), the USACE Time Series Toolbox detected a nonstationarity in instantaneous peak flows in the period 1998-2000. A shift into a higher mean and more extreme instantaneous peak flows was detected by multiple statistical tests. The breakpoint analysis puts the break at the year 2000. Prior to 2000, the Cottonwood Creek instantaneous peak flow data show an increasing, but not statistically significant trend. After the breakpoint, the data show a decreasing and not statistically-significant trend. The breakpoint corresponds to the shift in regime of the Pacific Decadal Oscillation from a phase favoring wetter climate in the project area to one favoring drier climate in the region (Newman et al. 2016: Figure 6). There is not a detectable non-stationarity in the Cottonwood Creek instantaneous peak flow record associated with the 2013 Black Forest Fire, which burned the majority of the forest (14,280 acres), destroyed 509 homes and killed two people (Wikipedia, Black Forest Fire, accessed 1/30/2023, https://en.wikipedia.org/wiki/Black_Forest_Fire).

Analyses of the outputs of the CHAT and Time Series Toolbox align with the results of regional analyses: in recent decades, there has not been a detectable change in direction precipitation maximum or resulting runoff in the project area. The nonstationarity observed circa 2000 aligns with the shift in the Pacific Decadal Oscillation that results in slightly wetter conditions to slightly drier conditions in the project area. This resulted in slightly higher (0.01 in.) and more variable peak flows since 2000.

3.3 Summary of Existing Conditions

The project area has a cool, semi-arid climate. Winters are cool and dry, with occasional snow that rapidly melts and/or sublimates, amounting to an average of less than an inch of precipitation per month. The warm half year encompasses the wettest months, in which convective precipitation averages <3.25 inches in the wettest month (August). Precipitation occurs as spatially-discrete heavy downpours when warm, humid air pulled north by the North American Monsoon is lifted by a weather front or by orographic means (Doesken et al. 2003). While base flows in Spring Creek are the result of municipal and industrial water wastage, summer convective storms constitute the majority of the high flows through the project area. Because of where the project is located, it does not receive snowmelt runoff from the Front Range, and is topographically above the reach of spring runoff floods along Fountain and Monument Creeks.

There is a detectable historical trend in increasing temperatures (2.5°F since 1980, Lukas et al., 2014), and this likely has led to increasing potential evapotranspiration in the region. This change in water balance may be contributing to vegetation stress in the parts of the project area adjacent to the aquatic and riparian zones. The USACE CHAT and Timeseries Toolbox show no statistically-significant, detectable trend in 1-day maximum precipitation in the project area, nor is there any practically-significant change in mean 1-day streamflow, or in instantaneous peak flows in hydrologically-similar streams in Colorado Springs. Surface runoff contribution to the project area has not likely been significantly affected by climate changes observed to date.

4 - Future With and Without Project Conditions: Changing Conditions Impacts

Models are unanimous in projecting a warmer climate future statewide under all future emissions scenarios (Lukas et al. 2014). Statewide, under the RCP[1] 4.5 average annual temperatures are projected to warm by ~2.3°F to ~7°F by 2050 relative to the average temperature for the period 1901-1960, and by ~2.5 to ~9.0°F by 2100 (mean = ~5°F); under the RCP 8.5 temperatures are projected to increase 2.5°F to 8.0°F by 2050, and approximately 7 to 15°F by 2100 (mean = ~11°F; Frankson et al. 2022:Figure 1). Monthly temperature changes were projected for selected subregions of the state (Lukas et al. 2014). For the Arkansas Valley, among the projections based on the RCP 4.5 scenario, by 2050 warming in January-April is projected to be 3.0 to 3.5°F; in May-October warming is projected to be 4.0 to 4.5°F, with September averaging half a degree warmer than this; and in November-December, projected warming is 3.5 to 4.0°F.

Warmer temperatures are projected to (Frankson et al. 2022):

- Raise the snow line, resulting in less overwinter storage and more winter runoff as a percent of the total.
- Lead to an earlier melting of the snowpack, increased evaporation rates, and decreased soil moisture, further decreasing water availability during the already-dry summer months.
- Increase the ability of the atmosphere to hold moisture.
    - When moisture is available, this will increase atmospheric water vapor (due to rising sea surface temperatures in the oceanic regions that are the moisture sources for Colorado precipitation) and may increase the frequency and intensity of heavy precipitation events.
    - When moisture is not available, eT will increase significantly leading to drier soils and greater vegetation water demand.

In general, models agree that annual precipitation will not change very much. As a group, the model projections of average annual precipitation for Colorado in the mid-21st century (2035-2064) are evenly split between increases up to +5 to 10%, decreases up to -5 to 10%, or no change, compared to a 1971-2000 baseline. Models do not agree on future changes in ENSO (El Niño/La Niña) events, which can strongly influence whether a year is wet, dry, or in between.

Precipitation will not be distributed the same across the year: there is a pronounced tendency towards future increases in winter precipitation (esp. Mar, Apr) and decreases in summer precipitation. The most recent analysis of projected climate change in Colorado (Lukas et al. 2014) uses an ensemble of Coupled Model Intercomparison Project 5 (CMIP5) models projecting temperature and precipitation change for the period 2035-2064, the thirty-year period centered on 2050 (hereafter referred to just as 2050). These models were downscaled using the Bias-Correction Spatial Disaggregation (BCSD) method to provide data more directly related to Colorado, accounting at least in part for its complex topography. Hydrology projections were also derived from this downscaled data.

For the Arkansas Valley in particular, modeled precipitation increases for November to March of 10-20% are offset by precipitation decrease in the wettest months of July and August by 5 to 10% among the projections based on the RCP 4.5 scenario. Similar findings were found with CMIP6 model data: increase

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[1] RCP is "relative concentration pathway", a scenario for capturing projected increases in atmospheric greenhouse gases over time. RCP 4.5 is an emissions scenario that increases radiative forcing by 4.5 W/m^2; RCP 8.5 increases it by 8.5 W/m^2 by 2100.

in winter precipitation of 10 to 15%, with a possible decrease in summer precipitation (Frankson et al. 2022).

As a group, the models consistently indicate that extreme precipitation events (>99th percentile) will become more frequent/intense in the future in Colorado, whether the output is downscaled or not, and regardless of downscaling methodology (Kharin et al. 2013, Janssen et al. 2014, Janssen et al. 2016). For example, an analysis of non-downscaled global model data for the Southwest US (including Colorado and New Mexico) showed that the 1-in-5-year (0.2 AEP) 2-day event will become, by the 2070s, the 1-in-3-year event (0.33 AEP) under the RCP4.5 and the 1-in-2.5-year (0.4 AEP) event under the higher emission scenario RCP8.5 (Janssen et al. 2014).

These modeled changes in extreme precipitation are driven largely by the projected widespread increases in precipitable water (PW, the amount of atmospheric moisture, which increases with temperature). Compared to the baseline period 1976 to 2005, the Colorado-New Mexico Regional Extreme Precipitation Study (Mahoney et al. 2018) found an increase of about 14 to 19% in precipitable water by the decade centered on 2060 (Figure 5). The takeaway from this and other studies is that individual storms will become more moist, consistent with the Clausius-Clapeyron relation of a 7% increase in moisture content for each increase in degree C.

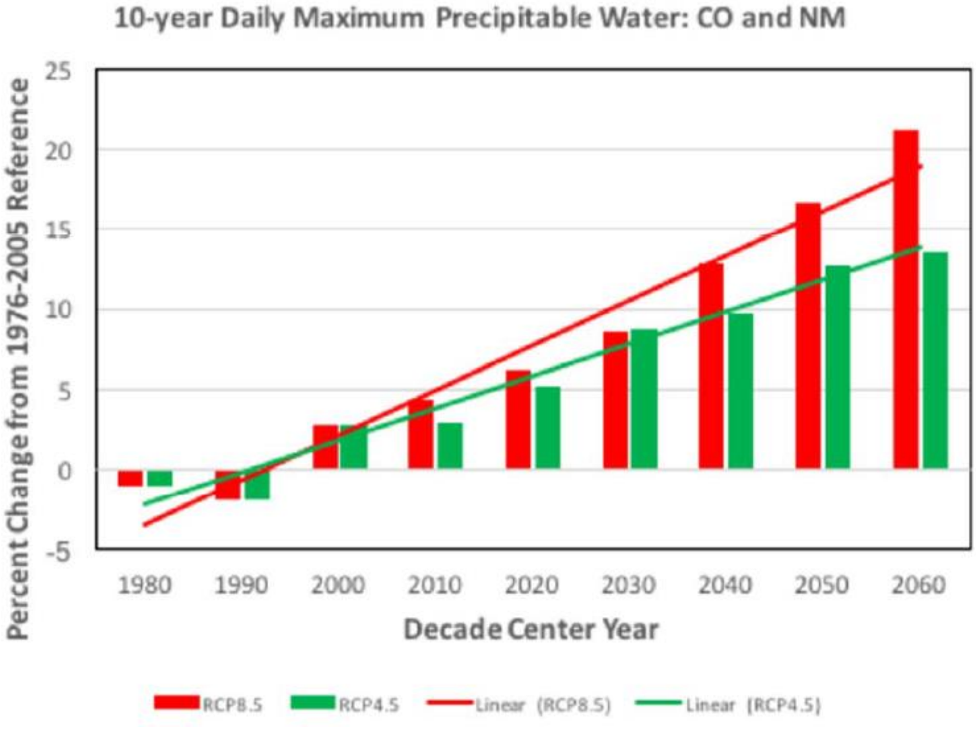
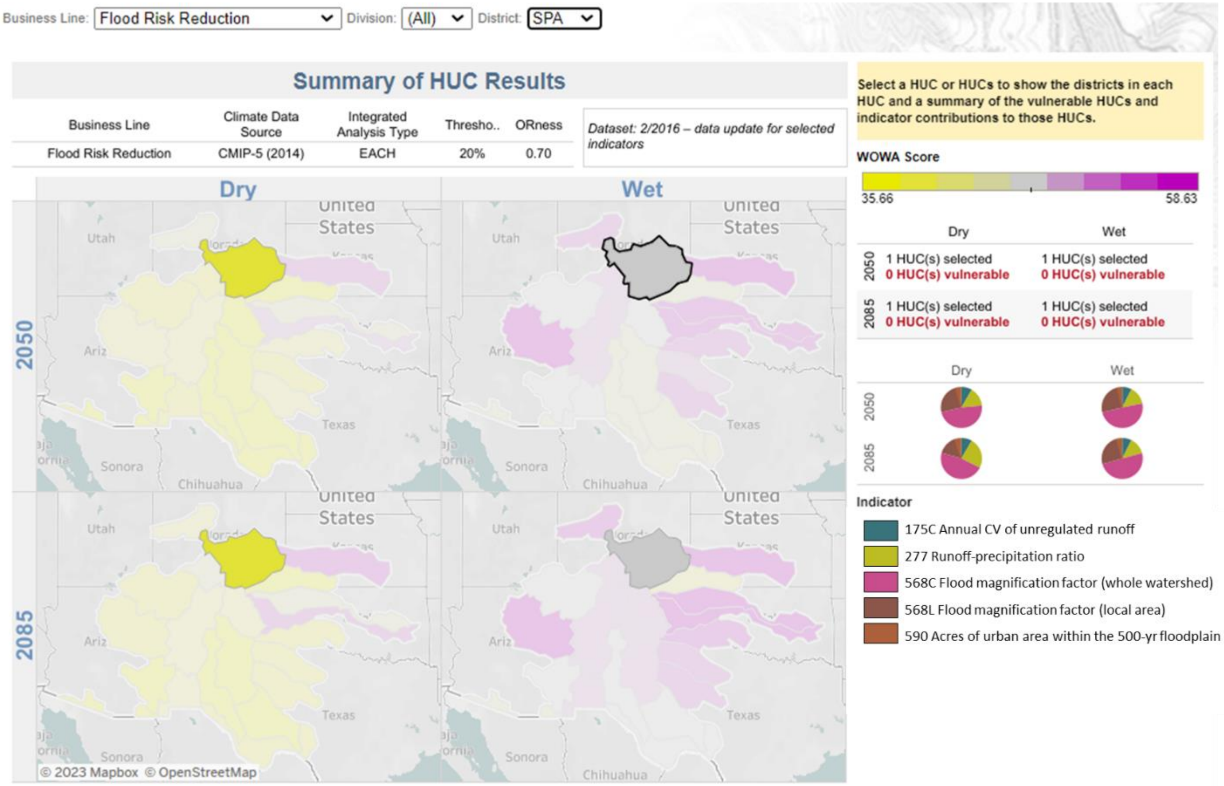


Figure 5 Change in precipitable water by mid-century (Mahoney et al. 2018).

These changes are broadly reflected in the changes to annual maximum 1-day precipitation (Figure 3) and annual mean 1-day streamflow (Figure 4) in the USACE CHAT. Under RCP 4.5 there is a small (0.06 in.) but statistically significant increase in annual average maximum 1-day precipitation under the lower emissions scenario, and a statistically non-significant increase of 0.03 in. under the RCP 8.5 by 2100. In both datasets, this change is dwarfed by two orders of magnitude by the variability in projected future maxima under both scenarios. Annual-mean 1-day streamflow is unchanged under RCP 4.5, and declines significantly under the RCP 8.5 (by a mean of 0.04 cfs) by 2100. The change in average is an order of magnitude smaller than the inter-annual variability.

Consistent with no trend to a slight decline in trend in projected future flows, the USACE Civil Works Vulnerability Assessment Tool shows no significant change in future flood risk in the region relative to the rest of the United States under either the wetter or drier future scenarios (Figure 6). Future flood risk vulnerability is based on projected changes in annual coefficient of variation of unregulated runoff, modeled changes in runoff relative to precipitation, modeled changes in flood runoff during common (10% chance) events and changes in urbanization (which reflects changes in the amount of impermeable surfaces in a watershed). Of these factors, the ones with the greatest change in the future are increases in flood magnification factor, which represents larger 10% flows in the future relative to the present.

A key uncertainty for summer precipitation and therefore for runoff contributing to flows in the project area is that the evolution of the NAM is highly uncertain, and this is the driving reason for model divergency on future precipitation. There is some consensus is that it may shift to later in the summer, peaking in September and October rather than August and September (Cook and Seager 2013).



Business Line: Flood Risk Reduction
Division: (All)
District: SPA

Summary of HUC Results

Business Line	Climate Data Source	Integrated Analysis Type	Thresho..	ORness
Flood Risk Reduction	CMIP-5 (2014)	EACH	20%	0.70

Dataset: 2/2016 – data update for selected indicators

Select a HUC or HUCs to show the districts in each HUC and a summary of the vulnerable HUCs and indicator contributions to those HUCs.

	Dry	Wet
2050	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable
2085	1 HUC(s) selected 0 HUC(s) vulnerable	1 HUC(s) selected 0 HUC(s) vulnerable

Figure 6 Watershed Vulnerability Assessment Tool results for SPA. HUC 1102-Upper Arkansas River is the roughly circular HUC in the center top of the image.

4.1 Summary of Future Conditions

Over the 21st century, there is model consensus in projections of warm climates relative to average for the period 1971-2000. Statewide, under the RCP 4.5 average annual temperatures are projected to warm by ~2.3°F to ~7°F by 2050 relative to the average temperature for the period 1901-1960, and by ~2.5 to ~9.0°F by 2100 (mean = ~5°F); under the RCP 8.5 temperatures are projected to increase 2.5°F to 8.0°F by 2050, and approximately 7 to 15°F by 2100 (mean = ~11°F; Frankson et al. 2022:Figure 1).

Warmer temperatures are likely to alter the water balance in the project area, and in the watersheds that provide water to Colorado Springs. In the project area, warmer temperatures will likely increase evapotranspiration, resulting in reductions in soil moisture and surface water persistence. Hotter summer temperatures may exceed the thermal limits of desired plant and animal species and affect the long-term viability of habitats being restored.

Warmer temperatures in the mountains may reduce water supply through effects on the snowpack, increased reservoir evaporation rates, and changes in surface runoff. It is reasonable to anticipate that these changes might lead to reductions in municipal and industrial water supply that would alter patterns of outdoor water use and wastage within the city limit, impacting base flows at the restoration site. Where water pools on the project site, warmer air temperatures may raise water temperatures, reducing water quality.

Projected changes in precipitation are equivocal, with some models projection decreased annual precipitation by no more than 10% to increases of no more than 20%. There is some model agreement around projections of increased winter precipitation. In the Arkansas Valley, this is accompanied by 5-10% decreases in July and August precipitation, the two wettest months (Lukas et al. 2014, Frankson et al. 2022). Precipitable water in the atmosphere is projected to increase (Mahoney et al. 2018) and extreme precipitation events (e.g., 0.2 AEP), such as those typical in the summer season, may double in frequency (Kharin et al. 2013, Janssen et al. 2014, Janssen et al. 2016). The combination of less overall summer precipitation and concentration of that precipitation into bigger events may also mean more days with precipitation of a trace or less. Importantly, some studies indicate that the onset of the monsoon may be delayed by as much as a month (Cook and Seager 2013), potentially lengthening the early summer dry season and increasing the share of runoff that occurs once many plants have ended their growth for the year.

For the project area, these increases in precipitation variability will create opportunities for water storage but also create water supply challenges in some seasons (early summer) and years. Reductions in soil moisture will create challenges for establishing and maintaining vegetation outside the riparian and aquatic zones.

5 - Residual Risk

Residual risks are identified risks that still exist after a project is implemented that may be greater in the future than expected or indicated, or existing risks that cannot be completely managed by the implementation of the project. Table 1 lists the identified residual risks for this project.

Table 1: Residual Risk due to changing conditions in the future.

Feature or Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Development of wetland and native plantings	Extended periods of drought	Wetland drying up; water temperature increasing, insufficient water for native plants	Reduction of wetland function, habitat destruction, native plant loss	Moderate, although this is mitigated through conservative species selection (drought resilient), a series of grade control structures that have easier adaptive management, and using conservative low flows to design the project.
Development of wetland and native plantings	Increased temperature minimums, averages,	Wetland drying up; water temperature increasing,	Reduction of wetland function, habitat destruction,	Moderate, the viability of the native plant species is more contingent on water saturation versus temperature, making the wetland more resilient to changes in

	and maximums	induced stress on native flora	native plant loss, and increase of invasive species.	temperature. This is further mitigated through the actions mentioned in the cell above.
Water Supply	Extended periods of drought	Decreased streamflow is possible if extreme drought conditions occur.	Reduced availability of water to the site	Moderate, future conditions models show a reduction in surface water flows in the Fountain Creek watershed. This site is also fed by “urban drool” that comes from people watering lawns, industries that use water, etc. If an extreme drought occurs, there is a possibility that urban drool runoff would also decrease but not completely due to the dense urban development.

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