City of Greeley Colorado

Integrated Water Resources Plan

City of Greeley Water & Sewer Department
August 2023

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ACRONYMS AND ABBREVIATIONS

AF	acre-foot/feet
Bellvue WTP	Bellvue Water Treatment Plant
Boyd WTP	Boyd Lake Water Treatment Plant
BTBN	Big Thompson Basin Network
CBT	Colorado-Big Thompson Project
CC	climate change
CIP	Capital Improvement Plan
City	City of Greeley
cfs	cubic feet per second
Demand Model	water demand model
DMS	Data Management System
Ft. Collins	City of Fort Collins
FCU	City of Fort Collins Utilities
GCM	Global Climate Model
GLIC	Greeley-Loveland Irrigation Company
Greeley	City of Greeley Water and Sewer Department
GSM	Greeley System Model
GW	groundwater
HMR	High Mountain Reservoir
IWRP	Integrated Water Resources Plan
LREGA	Long-Range Expected Growth Area
NA	Not Applicable
Northern Water	Northern Water Conservancy District
PBN	Poudre Basin Network
Poudre	Cache la Poudre
PVP	Pleasant Valley Pipeline
RCP	Representative Concentration Pathway
SME	Subject Matter Expert
T&P	Temperature and Precipitation
Terry Ranch	Terry Ranch Aquifer and Storage Recovery Project
TM	Technical Memorandum
W&S Board	Greeley's Water and Sewer Board
WADT	Water Acquisition Decision Tool
WRF	Water Research Foundation
WSSC	Water Supply & Storage Company
WSVS	Water Supply Vulnerability Study
WTF	water treatment facility
YOD	Years of Demand

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GLOSSARY

Baseline	Greeley's water supply conditions that are expected to exist in the near-term regardless of Integrated Water Resources Plan (IWRP) outcome
Box plot distribution	A standardized way of displaying the distribution of data where the solid line is the median value with the boxes extending to the 25th and 75th percentiles and the whiskers extending to the 5th and 95th percentile
Direct flow rights	A water right that diverts water directly from a surface stream for direct application to beneficial use
Entitlements	Water legally and physically available to Greeley
Interruptible Supply Use	A water right that can be used for its original decreed purpose and then can be intermittently used for a changed purpose
Native storage	The volume of water in the Terry Ranch Aquifer prior to injection or extraction
Non-potable water	Water that is not of a quality suitable for drinking, but can be used for other purposes such as irrigation
Planning Horizon	Represents key points in time for Greeley's water supply system
Planning Performance Criteria	Define when future water supply system performance was acceptable
Planning Scenario	Captures a range of possible future conditions for Greeley's water supply system summarized into a single narrative future
Potable water	Water that is of a quality suitable for drinking
Risk	Event or condition that could negatively affect Greeley's water supply system
Single-use water	A water right that can only be diverted and used for beneficial purposes once. The water cannot be rediverted or reused after the initial use
Spill	Water entitled to Greeley that cannot be captured or put to use in the surface water system
Storage shortage	If Greeley's surface water storage on April 1 of the next year would be less than the acceptable threshold
T&P Offset/Change	Change in long-term temperature and precipitation mean in a future climate compared to the historical climate.
Wholly consumable transbasin rights	A water right that is diverted in one river basin and used in another river basin for beneficial use. Transbasin water rights are 100 percent consumptive and can be reused to extinction

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EXECUTIVE SUMMARY

The City of Greeley Water and Sewer Department's (Greeley) Integrated Water Resources Plan (IWRP) is a long-term strategic water resources master plan that ensures sustainable and affordable water supplies for their customers now and into the future. This comprehensive plan integrates Greeley's water supply system and projected demands with possible future conditions around hydrology, climate change, and risks to Greeley's water supply system. The IWRP establishes a plan for triggering the Terry Ranch Project (a new aquifer storage and recovery project), a process for evaluating and strategically acquiring water rights, a 10-year Capital Improvement Plan (CIP), and an Adaptive Plan for Greeley to follow.

INTRODUCTION AND PROCESS

Historically, many water resource planning efforts focused on developing a firm yield based on a single set of historical conditions. Projects were selected and prioritized based solely on their ability to improve firm yield under this one set of conditions. Recent events have shown that future conditions are highly uncertain and that planning for a single future increases the risk of water supply failure. Greeley, building on a history of effective and prudent planning efforts, elected to complete an integrated planning process for this IWRP to better plan for an increasingly uncertain future.

In implementing an integrated planning process, the IWRP developed Planning Scenarios" that capture a range of possible future conditions for Greeley's water supply system. These were applied at key points in time (e.g., "Planning Horizons"). **Figure ES-1** shows the three IWRP Planning Horizons. The first of these defined what water resources projects are required for the next 10 years. The second identifies when to integrate the Terry Ranch Project. The third planning horizon establishes how to best use the Terry Ranch Project once it is fully integrated, and if that use is sustainable.

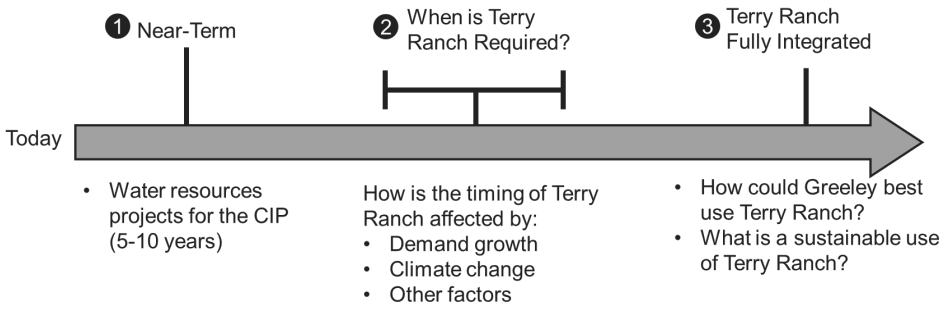
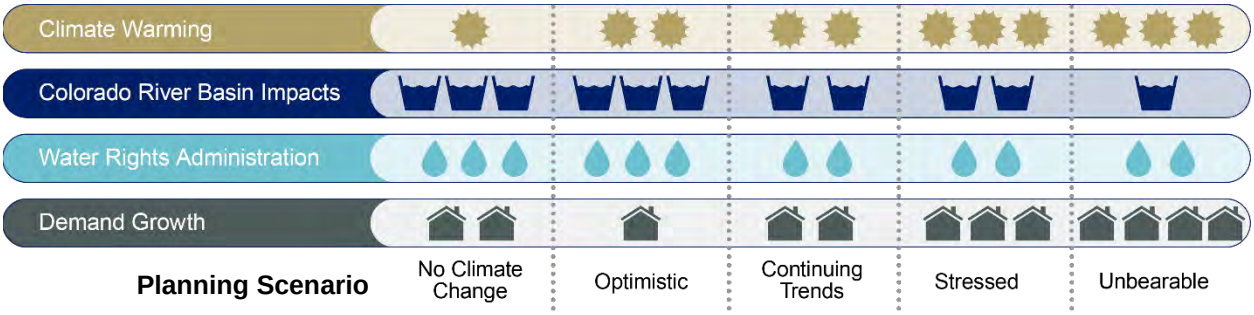


Figure ES-1. Planning Horizons Used in the IWRP

Due to the significant uncertainty around what the future water supply conditions could look like, the IWRP did not predict what future water supply condition is most likely to occur. Instead, a Planning Scenario methodology was applied that captures a range of possible future conditions for Greeley's water supply system. The Planning Scenarios and their associated conditions are shown graphically in **Figure ES-2**. The *Unbearable* planning scenario was the reasonable high bookend for Greeley's water supply

system and combines the hottest climate, the highest demand projections, and significant risk impacts. The *Stressed* planning scenario assumes the hottest climate, a lower demand projection, and moderate risk impacts. The *Continued Trends* planning scenario assumes a warmer climate, continued decreases in per capita water use, and moderate risk impacts. The *Optimistic* planning scenario assumes a warmer climate, the lowest demand projections, and least risk impacts. Finally, the *No Climate Change* planning scenario includes no climate change, a higher demand projection than *Optimistic* given that the lack of climate change would likely encourage higher Greeley growth, and low risk impacts.

Figure ES-2. Planning Scenarios Used in the IWRP



An important element in the IWRP was defining when future water supply system performance was acceptable, which the IWRP set using planning performance criteria. **Figure ES-3** presents the planning performance criteria and their acceptability definitions.

Figure ES-3. Planning Performance Criteria Used in the IWRP

Performance Criteria	Acceptable Performance
Are Greeley customers being significantly impacted?	Drought Restrictions used at any level no more than 20% of years and no more than 10% of years in Level 3
Greeley maintains sufficient emergency reserve.	April 1 storage volume has at least 6 months of indoor demands in 100% of years
Greeley meets critical water needs for public health.	Indoor demands are met 100% of the time

FUTURE CONDITIONS ASSESSMENT

The IWRP completed a risk assessment that identified, prioritized, and evaluated a comprehensive list of events that could impact Greeley's water supply system. This assessment identified four risk drivers, defined as major events or conditions that are outside Greeley's control that could impact their ability to provide sustainable water supply to their customers. The drivers identified for the IWRP were:

- The **Climate Change Impacts on Hydrology** driver captures risks that could change what Greeley's existing water rights yield and the timing of that yield compared to what has been experienced

historically. This is due to a combination of droughts of increased intensity, duration, and/or frequency compared to the historical record; runoff impacts; and the overall hydrograph from a warmer climate.

- The **Future Demand Uncertainty** driver captures risks that affect how much water demand Greeley's system would need to meet in the future and how water is used compared to historical usage. This includes population growth, outdoor water use variability, and climate change's impacts on demands.
- The **Water Rights Administration Complexity and Uncertainty** driver captures risks that affect Greeley's ability to change currently owned water rights, acquire new water rights, and yields from existing and future water rights. This includes increased competition for new water rights, the legal complexity of changing water rights, and uncertainty related to how water rights administration may change under a different hydrograph than historical.
- The **Colorado River Basin Issues** driver captures risks to Greeley's yields from the Colorado River Basin which could result in a variety of short- and long-term supply reductions or curtailments.

The *Climate Change Impacts on Hydrology* driver was further evaluated by developing new climate change hydrology that captures the potential impacts of long-term climate change and droughts of increasing intensity, duration, and frequency. An advanced modeling process was completed that quantified the impacts of long-term changes in temperature and precipitation to Greeley's entitlements (e.g., water legally and physically available to Greeley). **Figure ES-4** summarizes the conclusions from this analysis and the confidence of those conclusions.

Figure ES-4. Conclusions from the Climate Change Hydrology Analysis

Conclusion Statement	Confidence	Comment
Droughts of greater duration, frequency, and severity than observed droughts are possible under current climate.	**High**	*Results show these conclusions are consistent with other studies and make logical sense.*
Climates with less precipitation and or warmer climates will decrease Greeley's water supply system yields.	**High**	
Yields from Greeley's junior water rights and certain water supply systems could be vulnerable to changing agricultural demands.	**Moderate**	*It is likely that agricultural demand changes will impact Greeley's entitlements. It is unknown how agricultural demands will change.*
Climates with increased precipitation could increase Greeley's water supply system yields.	**Low**	*Impacts from hydrograph changes cannot be confidently modeled with existing tools.*

The *Future Demand Uncertainty* driver was further evaluated by developing new total demand projections (potable and non-potable) for Greeley at 2030, 2050, and 2070 under four demand scenarios. These four scenarios varied population growth, the extent to which irrigation increases in response to hotter and drier future climate conditions, the extent of future conservation, and the proportion of new housing units that are multifamily apartments and condominiums. **Figure ES-5** shows the new demand projections.

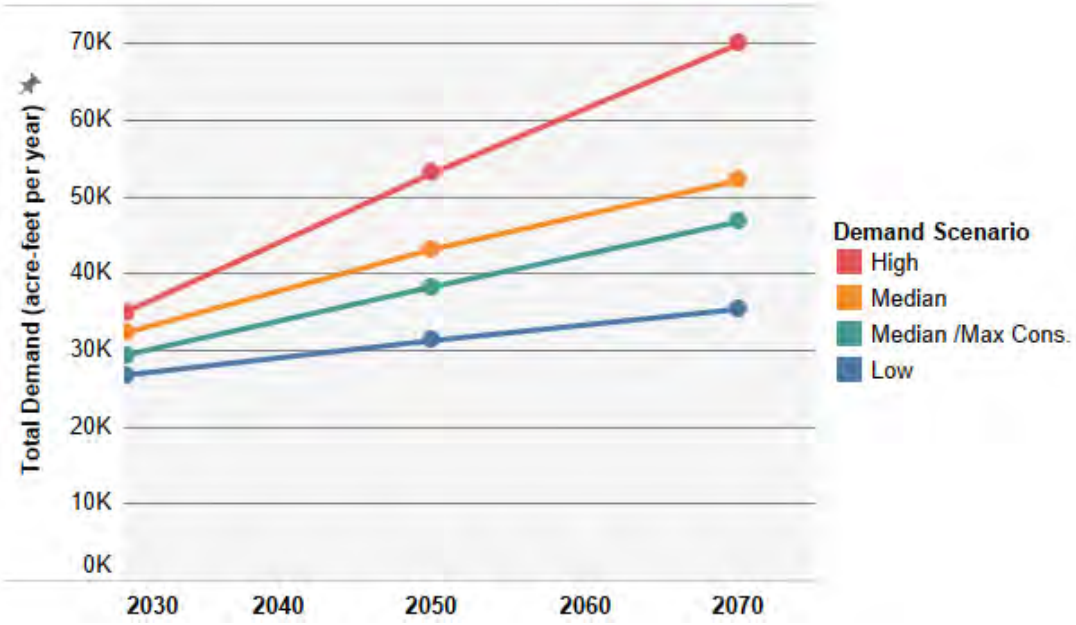


Figure ES-5. Greeley's Projected Future Water Demands

These demand projections are highly variable between the scenarios, with the difference between the high and low scenario increasing from 8,200 acre-feet per year at 2030 (33 percent of current demands) to 34,600 acre-feet per year at 2070 (137 percent of current demands). These demand projections assume that demand growth occurs immediately. However, Greeley's total demands have not grown significantly over the last 10 years.

TERRY RANCH TIMING AND INTEGRATION EVALUATION

The *Terry Ranch Timing* analysis determined that Greeley's water supply system without Terry Ranch can meet near-term Planning Scenario conditions. For example, in the *Continued Trends* Planning Scenario, Greeley's system without the Terry Ranch Project can accommodate an additional 10,000 acre-feet per year of demand—approximately 40 percent more demand than the current level. The IWRP could not confidently time the Terry Ranch Project implementation due to the lack of recent demand growth and the variability of future demand projections. In lieu of assigning a timetable to Terry Ranch Project implementation, Greeley will monitor demands and water supplies as part of the Adaptive Plan.

The *Terry Ranch Integration* analysis determined whether Terry Ranch operations would be sustainable under the Planning Scenarios. The IWRP defined Terry Ranch operations as sustainable if they can deliver drought supplies during while maintaining at least 80 percent of the 1.2 million acre-feet initial aquifer storage volume long-term. **Figure ES-6** shows the results of the Terry Ranch Integration Analysis. This table indicates what (if any) additional water resources were included, the percent of years drought response actions were used, the average annual Terry Ranch delta (injection minus extraction), and the percent of the 1.2 million acre-feet aquifer remaining at the end of an 86-year simulation period.

Results from the *Terry Ranch Integration* analysis show that the Terry Ranch Project can be operated sustainably in the *Continued Trends*, *Optimistic*, and *No Climate Change* planning scenarios. Sustainable operation in these planning scenarios will require some additional water supplies and retiming storage. Results from the *Unbearable* and *Stressed* Planning Scenarios show that under the hottest climate change projections and significant demand growth conditions, Terry Ranch Operations are not sustainable. Greeley can monitor climate and demand growth conditions as part of the Adaptive Plan and, if the most impactful future conditions emerge, can adjust the long-term water supply strategy.

Figure ES-6. Tabular Summary of Terry Ranch Integration Results

Planning Scenario	Additional Water Resources	% Years with Drought Response	Annual Terry Ranch Delta (acre-feet per year)	Ending Aquifer Volume (% of 1.2 million acre-foot Volume)
Unbearable	Retiming Storage + Moderate Water Acquisitions	100%	**-10,700**	**23%**
Stressed	Retiming Storage + Moderate Water Acquisitions	64%	**-6,500**	**53%**
Continued Trends	Retiming Storage + Moderate Water Rights	35%	**-1,200**	**91%**
Optimistic	None	12%	**+1,900**	**113%**
No Climate Change	Retiming Storage + Low Water Acquisitions	36%	**-1,900**	**86%**

Color Key Indicates Terry Ranch Sustainability Criteria: **Blue** has sufficient remaining aquifer storage percentage, **Orange** has insufficient remaining aquifer storage percentage

IWRP OUTCOMES AND RECOMMENDATIONS

The IWRP showed that Greeley is well-positioned to provide sustainable and affordable water supplies through an uncertain future. The IWRP's important outcomes and conclusions regarding Greeley's current, near-term, and long-term water supply system are summarized below:

- Greeley's current water supply system is resilient against the most likely near-term conditions, but additional water supplies are required to meet projected demands and to mitigate impacts from warmer climate conditions under current Terry Ranch sustainability criteria.
- With the Terry Ranch Project fully integrated, Greeley's water supply system is likely resilient against many possible future conditions including warmer climates, higher demands, and reduced yields. Greeley can sustainably utilize the Terry Ranch Project as a water supply source during droughts over the long-term when the Terry Ranch Project is coupled with some additional water resources.
- Balance implementation of the Terry Ranch Project with other water resources and non-water resources CIP needs to minimize financial risk and maintain affordable water supplies.
- If impacts from climate change are severe and tracking with the hottest projections, Greeley may need to consider additional long-term solutions (i.e., in addition to Terry Ranch).
- The most impactful drivers to Greeley's water supply system—demand growth and climate change impacts—will have long lead times that Greeley can monitor and adapt to.
- Terry Ranch cannot be confidently timed until Greeley sees sustained, significant demand growth.

Figure ES-7 shows the recommendations for Greeley to take upon IWRP completion.

Figure ES-7. Summary of IWRP Recommendations Used to Develop 10-year CIP and Adaptive Plan

Recommendation	Action
Change Water Rights	Greeley should continue changing existing water rights to municipal use as these will improve the reliability of the existing water supply system before the Terry Ranch Project is integrated.
Continue Strategic Acquisitions	Greeley should acquire water supplies that can be integrated into the current system and the Terry Ranch Project. These water supplies are required to meet projected demands, mitigate climate and risk impacts to the current water supply system, and improve Terry Ranch operations.
Develop Priority Terry Ranch Infrastructure	The Terry Ranch Project needs to be efficiently integrated into Greeley's water supply system once it is required. Greeley should continue incrementally implementing project components (pipelines, right-of-way, water rights) to ensure this project is readily available to Greeley.
Study Potential Conceptual Retiming Storage Options	The IWRP identified a retiming storage project as a potentially beneficial project to improve the sustainability of Terry Ranch operations. As the IWRP only included a conceptual definition of the project, Greeley should further define this project and align the concept with real facilities.
Implement Adaptive Planning to Monitor Drivers and Trigger Terry Ranch	While the IWRP showed Greeley's water supply system is resilient against warmer futures and increased demands, it is still vulnerable to significantly stressful future conditions. Additionally, the IWRP could not confidently define when Terry Ranch is required due to uncertainty in demand growth. Greeley should implement an Adaptive Planning process that regularly updates IWRP outcomes and re-evaluates the Terry Ranch Timing.

1.0 INTRODUCTION AND SUMMARY OF FINDINGS

The Integrated Water Resources Plan (IWRP) for the City of Greeley Water and Sewer Department (Greeley) is a long-term strategic water resources master plan for Greeley that ensures sustainable and affordable water supplies for their customers. This comprehensive plan integrates Greeley's water supply system and projected demands with possible future conditions around hydrology, climate change, and risks to Greeley's water supply system. The IWRP establishes a plan for triggering the Terry Ranch Aquifer and Storage Recovery Project (Terry Ranch Project or Terry Ranch), a process for evaluating and strategically acquiring water rights, a 10-year Capital Improvement Plan (CIP), and an Adaptive Plan for Greeley to follow.

This report documents the process, assumptions, outcomes, and recommendations of Greeley's IWRP.

1.1 OBJECTIVES

The IWRP objectives were developed to align with priorities established by Greeley's City Council, shown in **Figure 1-1**. The IWRP is an actionable and adaptive master plan for Greeley's water resources that uses modern, defensible methods to develop a roadmap ensuring a sustainable water supply for the community through an uncertain future.

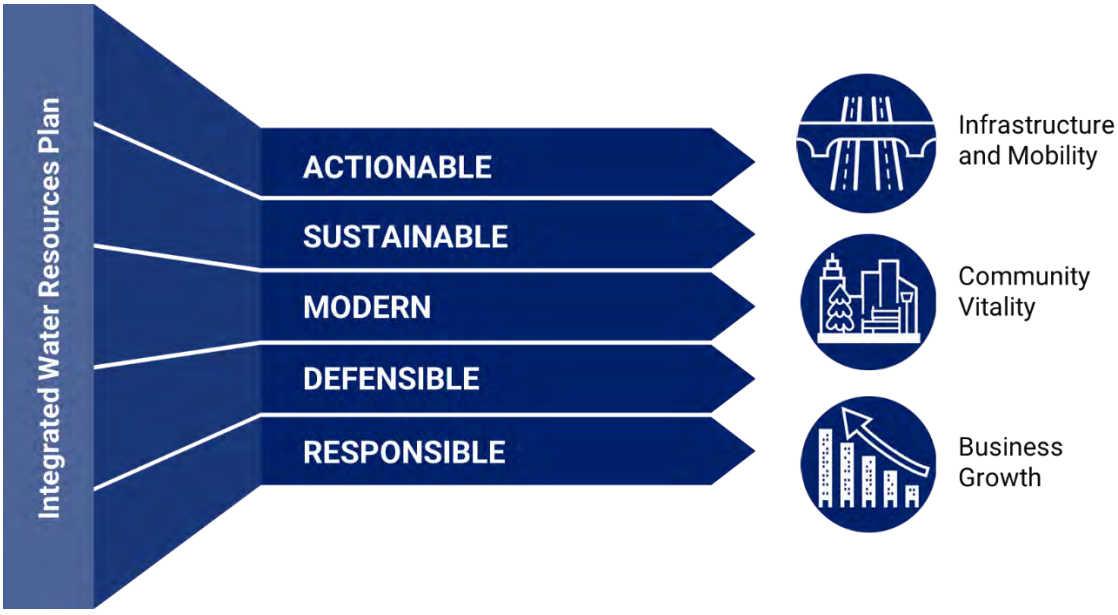


Figure 1-1. IWRP Objectives Aligned with Greeley's City Council Priorities

In addition to the overall future water resources strategy, the IWRP was tasked with developing the following new tools and plans for Greeley to use in future planning efforts:

- Updated Demand Projections
- Climate-Change-Influenced Hydrology Dataset
- Risk Assessment
- Water Acquisition Decision Tool
- Water Acquisition Strategy
- 10-year CIP
- Adaptive Plan
- Updated Greeley System Model with new Terry Ranch Project operations and Planning Scenarios

1.2 SUMMARY OF FINDINGS

At the outset of the IWRP, the following key questions were presented. The resulting analysis documented in this report supports the answer for each question.

Can Greeley's current water supply system reliably deliver water supplies to customers?

- The near-term 10-year analysis presented in Section 8 shows that Greeley's water supply system can meet current water demands across a range of projected warmer climates and even when considering current Colorado River Basin risks. The robustness of Greeley's water supply system is further improved as water rights that Greeley already owns are changed for municipal use.

What is Greeley's future water rights strategy?

- The Terry Ranch Timing results presented in Section 9.2 show that Greeley needs additional water rights to meet projected demands and mitigate impacts to the current water supply system. The Terry Ranch Integration results presented in Section 9.3 show that additional water rights that can be integrated into the Terry Ranch Project will improve the sustainability of that project in warmer climates with higher demands. Greeley will prioritize water rights that provide immediate water supply to the City and can be integrated into the Terry Ranch Project in the future. Due to the increasing cost and competition of water acquisitions, Greeley will continue to actively acquire new water rights as part of the 10-year CIP.

Will the Terry Ranch Project be a sustainable water supply source in the future?

- The Terry Ranch Integration results presented in Section 9.3 show that the Terry Ranch Project can provide a sustainable drought-resistant supply source for Greeley. This includes future conditions with warmer climates, higher demands, and impacts from water supply system risks.

When Is Terry Ranch Required?

- The Terry Ranch Timing results presented in Section 9.2 show that the Terry Ranch Project is not imminently required due to the robust nature of Greeley's current water supply system and the effectiveness of conservation strategies. As time progresses, Greeley will closely monitor demand

and supply conditions to ensure the Terry Ranch Project is up and running before it is required. However Greeley will complete high-priority Terry Ranch Project infrastructure as part of the 10-year CIP to make use of funding and land availability.

How can Greeley ensure their water supply system continues to provide sustainable and affordable water to their customers?

- The IWRP developed a variety of tools and plans for Greeley to use in future planning efforts. One key tool is the Adaptive Plan presented in Section 12.2, which defines five actions Greeley will take each year to re-evaluate IWRP outcomes and recommendations and adjust these recommendations accordingly.

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2.0 PLANNING PROCESS

2.1 INTEGRATED PLANNING OVERVIEW

Historically, many water resource planning efforts focused on developing a firm yield based on a single set of historical conditions. Projects were selected and prioritized based solely on their ability to improve firm yield under this one set of conditions. This process was effective for many years, due to the relative stationarity of climate and limitations in computing and data processing. Recent history and availability of new climate modeling data has shown that future conditions are highly uncertain and planning for a single future increases the risk of water supply failure. During this time, new approaches were developed that used improved computing to integrate many possible future conditions into water supply planning. This new approach creates a long-term plan that is more robust and adaptive against future uncertainty. It also helps ensure that communities have sustainable and affordable water supplies.

Greeley has a history of effective and prudent planning efforts, resulting in a water supply system that has been more resilient during droughts than most other communities in Colorado. Greeley has invested in tools, such as the Greeley System Model (GSM), and projects such as the Terry Ranch Project that built a solid foundation for future planning efforts. Leveraging those decisions, Greeley elected to complete an integrated planning process for this IWRP. This integrated plan used modern data-driven methods to develop a robust roadmap to help guide Greeley through an uncertain future.

2.2 PLANNING SCENARIOS AND HORIZONS

To implement an integrated planning process while focusing the IWRP analysis around its objectives, a set of Planning Horizons were defined that represent key points in time for Greeley's water supply system. In combination with these Planning Horizons, a set of Planning Scenarios were developed to capture a range of possible future conditions for Greeley's water supply system.

Figure 2-1 shows the three IWRP Planning Horizons. The first planning horizon represents near-term conditions and established what water resources projects are required in the next 10 years. The second planning horizon represents conditions just before the Terry Ranch Project would be required and informed what those conditions would be. The third and final planning horizon is when the Terry Ranch Project is fully integrated with Greeley's water supply system and established how the project could be used and if that use is sustainable. Section 8 presents the results of the near-term planning horizon and Section 9 presents the results of the Terry Ranch Timing and integration planning horizons.

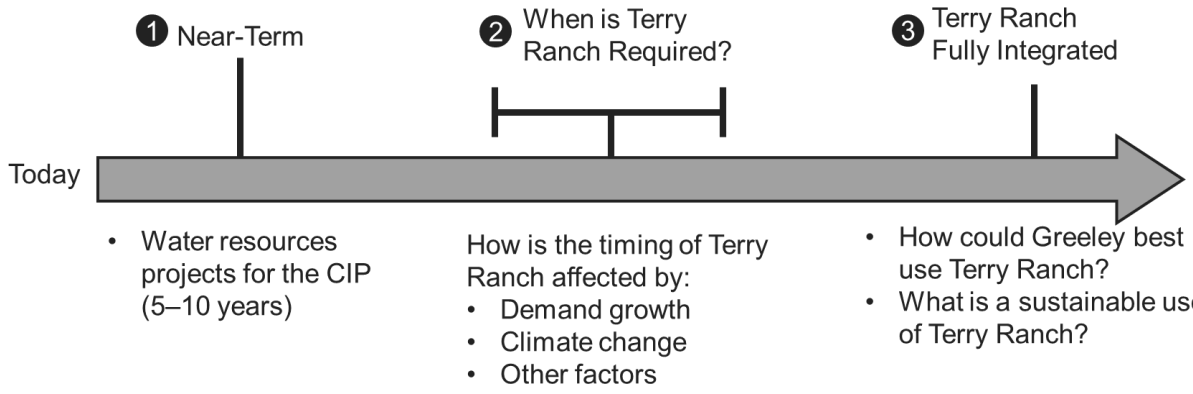


Figure 2-1. Planning Horizons Used in the IWRP

Due to the significant uncertainty around what the future could look like, the IWRP did not predict what future condition is likely to occur. Instead, a Planning Scenario methodology was applied that captures a range of possible future conditions for Greeley's water supply system. The GSM is simulated under these various possible future conditions, and results are holistically evaluated to inform the IWRP outcomes and recommendations. **Table 2-1** presents the five Planning Scenarios defined for the IWRP. A *No Climate Change* Planning Scenario was included to both serve as a low bookend of stressful future conditions and to establish the impact of climate change to Greeley by defining what could be required if climate change impacts are properly mitigated in the future.

Table 2-1. Planning Scenarios Defined for the IWRP

Planning Scenario	Description
Unbearable	Greeley's future demands have tracked with the most impactful future conditions: population has grown according to the highest forecast, climate has warmed rapidly, and impacts to Greeley's East Slope water rights and Colorado River supplies are the most severe.
Stressed	A rapidly warming climate and faster-than-expected population growth within established water providers such as Greeley exacerbates water availability issues. Greeley's water supply system must meet this increased demand among significant yield impacts.
Continued Trends	Recent trends in per capita water use, climate change, Colorado River basin issues, and competition for water rights continue.
Optimistic	Greeley's water supply system is less stressed than anticipated due to a combination of improved water conservation savings, diminished climate change impacts, and advantageous water rights yields.
No Climate Change	Without climate change, Greeley's water supply system would be less stressed and require less additional water resources.

The narrative Planning Scenarios were translated to future conditions Greeley's water supply system could experience for simulation in the GSM. These future conditions were the key drivers of future uncertainty identified during the Risk Identification and Assessment process described in Section 5. Each driver had specific possible future conditions that could then be varied in each Planning Scenario**. Table 2-2** presents the drivers and associated conditions available for the Planning Scenarios.

Table 2-2. Drivers Used to Define Planning Scenario Conditions

Driver	Description	Planning Scenario Settings
Future Climate Change	Captures the impacts to hydrology from the assumed future climate change.	• Hot (+8°F or +5°F) • Warm (+5°F or +2°F) • No Change
Colorado River Basin Risk Impacts	Combination of short- and long-term Colorado River Basin yield reductions and curtailments due to Colorado River Basin administration and Compact compliance.	<u>High Impacts to Yields</u> • 5-year 25% Reduction in CBT/Windy Gap • 1-year 100% Curtailment of CBT/Windy Gap • Chronic 10% Reduction in CBT/Windy Gap <u>Moderate Impacts to Yields</u> • 5-year 25% Reduction in CBT/Windy Gap • 1-year 100% Curtailment of CBT/Windy Gap <u>Low Impacts to Yields</u> • 2-year 25% Reduction in CBT/Windy Gap
Water Rights Administration Uncertainty and Increased Competition	Reductions in modeled water rights yield due to combination of inability to change water rights as assumed, ability to acquire new water rights, and/or reductions in yield due to administration changes.	• 10% Entitlement Reduction • No Entitlement Reduction
Water Demands	The future demand projection from Section 4.2.2 is assumed to occur.	• High Bookend • Median • Median with Maximum Conservation • Low Bookend

°F = degrees Fahrenheit

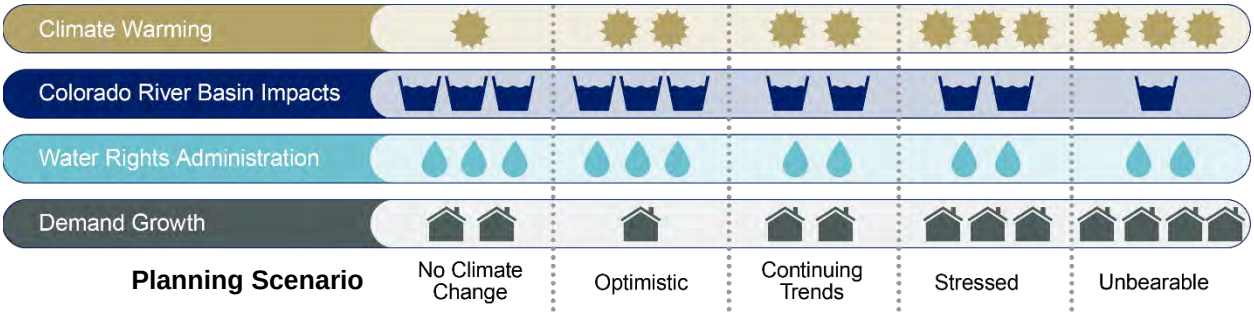
CBT = Colorado-Big Thompson Project

The Planning Scenarios with their conditions identified and used in the IWRP are summarized in detail in **Table 2-3** and shown graphically in **Table 2-4**. The *Unbearable* Planning Scenario was the reasonable high bookend for Greeley's water supply system and combines the hottest climate with the highest demand projections and significant impacts. The *Stressed* Planning Scenario assumes the hottest climate but with a lower demand projection and moderate risk impacts to water supplies. The *Continued Trends* Planning Scenario assumes a warmer climate, continued decreases in per capita water use, and moderate risk impacts to water supplies. The *Optimistic* scenario assumes a warmer climate, the lowest demand projections, and less entitlement impacts. Finally, the *No Climate Change* planning scenario includes a higher demand projection than *Optimistic* as the lack of climate change would likely encourage higher Greeley growth.

Table 2-3. Planning Scenarios and Conditions Used in the IWRP for Simulations

Planning Scenario Name	Climate	CO River Basin Risks	Water Rights Administration Impacts	Demands
Unbearable	Hot	High Impacts: 5-Year 25% Reduction 1-year Outage Chronic 10% Reduction	10% Reduced Entitlements	High Bookend
Stressed	Hot	Moderate Impacts: 5-Year 25% Reduction 1-year Outage	10% Reduced Entitlements	Median
Continued Trends	Warm	Moderate Impacts: 5-Year 25% Reduction 1-year Outage	10% Reduced Entitlements	Median w/ Decreased Per Capita Use
Optimistic	Warm	Low Impacts: 2-year 25% Reduction	Expected Entitlements	Low Bookend
No Climate Change	No Change	Low Impacts: 2-year 25% Reduction	Expected Entitlements	Median w/ Decreased Per Capita Use

Table 2-4. Graphical Representation of IWRP Planning Scenarios



2.3 GREELEY SYSTEM MODEL OVERVIEW

An important objective to the IWRP and a key component of an integrated planning process is using data-driven methods that transparently and clearly connect to outcomes and recommendations. For the IWRP, Greeley utilized its existing GSM to complete numerical water supply system simulations. This section summarizes the GSM and its application for the IWRP, which is described in detail in the IWRP Greeley System Model Technical Memorandum (TM), included in this volume as Appendix C.

The GSM is a MODSIM-based mass-balance model originally developed in 1992 that has been continuously upgraded and updated (Greeley 2021). The MODSIM simulation software platform has been applied to water supply planning efforts by water providers in Colorado (e.g., Colorado Springs Utilities, City of Fort Collins Utilities). The GSM has served as Greeley's water supply planning simulation model since its inception and, as such, its development and current configuration includes extensive institutional knowledge and expertise. The model was most recently upgraded to the newest version of MODSIM and paired with a Data Management System (DMS) in 2020, prior to the IWRP in 2020, further increasing its value to the IWRP.

The GSM simulates Greeley's water supply system on a monthly timestep for a period of 86 years. The scope of the GSM includes inflows of Greeley's legally and physically available water supplies (referred to as entitlements), raw water conveyance facilities (in-river, ditches, pipelines), raw water storage facilities (wholly owned reservoirs, storage accounts, gravel pits), raw water treatment plants (physical capacities), and demands (potable, non-potable demands, and large industrial). The GSM simulates transit losses, evaporation losses, and treatment process losses. The GSM does not simulate the conveyance of water supplies owned by other entities.

To develop Greeley's entitlements, the GSM uses outputs from the Poudre Basin Network (PBN) Model and the Big Thompson Basin Network (BTBN) Model. The PBN and BTBN Models were collaboratively developed by Greeley, the City of Fort Collins Utilities (Ft. Collins), and the Northern Water Conservancy District (Northern Water). The BTBN and PBN are MODSIM-based models that translate natural watershed runoff in the Big Thompson River and Cache la Poudre (Poudre) River Watersheds into entitlements for all water users in the basin. Greeley uses an intermediate tool to apply water rights ownership and conditions of ownership to develop inflow timeseries for the GSM. Greeley also receives water from Northern Water's Colorado-Big Thompson (CBT) Project, which is developed using Northern Water's CBT Quota model.

As part of the of the model upgrade, a DMS was developed to enhance Greeley's previously developed GSM. **Figure 2-2** shows how the DMS interacts with the GSM and the flow of data and information between them. The DMS is a .NET-based computer program that takes user inputs and automatically generates and completes desired GSM simulations. A key component of the DMS is a Microsoft structured query language (SQL) Server Database that stores input and output data from the GSM and a log of simulations completed with their corresponding assumptions. Data from the DMS can be extracted for analysis and visualization. The IWRP used the DMS to complete GSM simulations; IWRP results with their corresponding logs and settings are stored in the SQL Server Database.

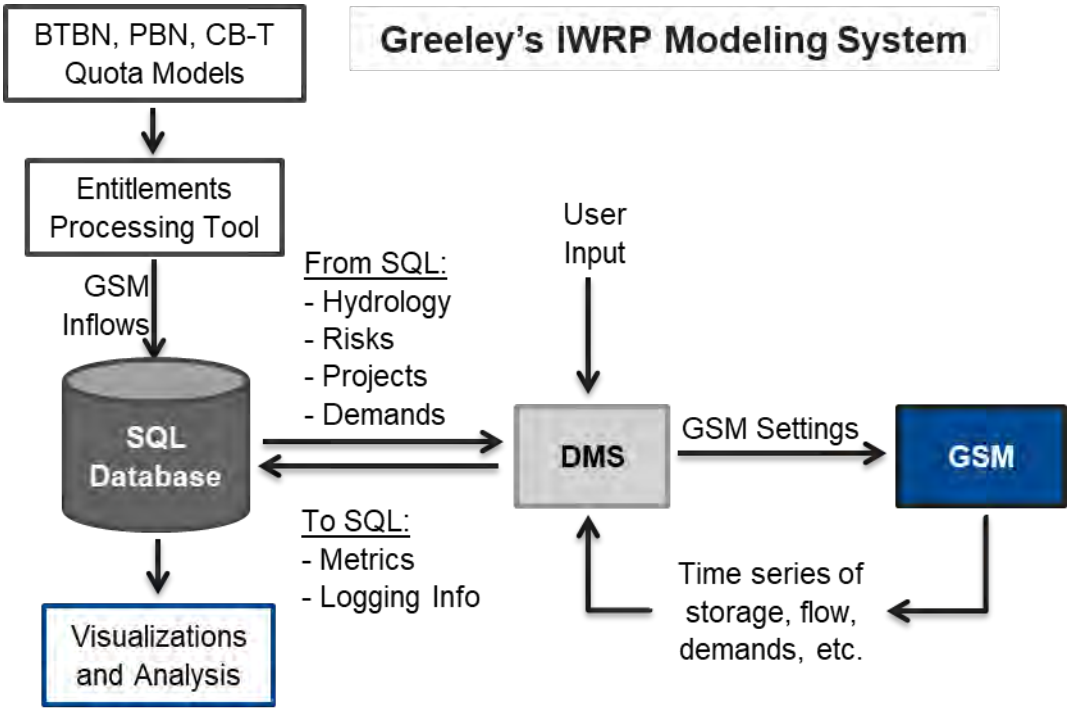


Figure 2-2. Configuration of Greeley's IWRP Modeling System

The IWRP baseline conditions reflect the water supply system that is expected to exist in the near-term regardless of IWRP outcomes. This baseline is different from the current water supply system condition that existed at the time of the IWRP. The baseline condition serves as a common point of comparison as future conditions are changed and evaluated.

Projects assumed to be in the baseline condition included Greeley's 8,000 acre-feet account in Chimney Hollow, the Equalizer Pipeline, and a winterized Boyd WTP. Of the High Mountain Reservoirs, Barnes and Peterson were assumed online for municipal use and Comanche/Hourglass and Twin were assumed to remain in agriculture. The baseline water rights portfolio assumed that all currently owned water rights are changed for municipal use by Greeley and that nearly all leases are returned for Greeley use. This baseline water rights portfolio assumes that all future changes will yield the same for Greeley as established outcomes.

2.4 WATER SUPPLY SYSTEM PERFORMANCE METRICS

To establish acceptable water supply system performance from results of the GSM simulations, the IWRP developed a set of planning performance criteria. **Table 2-5** presents the planning performance criteria, the associated GSM metric, and the acceptability threshold used in the IWRP to establish when performance of a GSM simulation was acceptable. The criteria were selected to reflect Greeley's existing Level of Service. The developed performance criteria and GSM metric are not being proposed in the IWRP as new or updated Level of Service.

Table 2-5. Planning Performance Criteria Used in the IWRP

Performance Criteria	GSM Metric	Planning Acceptability Threshold
Are Greeley customers being significantly impacted?	How often Drought Restrictions levels are used (presented in Figure 2-3.	20% (2 in 10 years) at Any Level 10% (1 in 10 years) at Level 3
Greeley maintains sufficient emergency reserve.	April 1 storage volume always has at least 6 months of indoor demands.	100%
Greeley meets critical water needs for public health.	Always meet indoor demands.	100%

The use of drought restrictions was included in the planning performance criteria to minimize how often Greeley's customers are impacted by watering restrictions. Greeley's current Drought Emergency Plan, updated in 2021, was implemented in the GSM according to the assumptions shown in **Figure 2-3**. On April 1 the GSM predicts the storage on April 1 of the following year by adding total entitlements to the current storage levels and subtracting out demands. For example, if the predicted storage is between 75 and 85 percent of annual demands, Level 2 restrictions are used. Acceptable performance is 20 percent of years in any restriction level or 10 percent of years in Level 3. Restrictions used in greater frequency may not be accepted by the Greeley community (increased bills, dead landscapes) and could lead to permanent changes to landscaping.

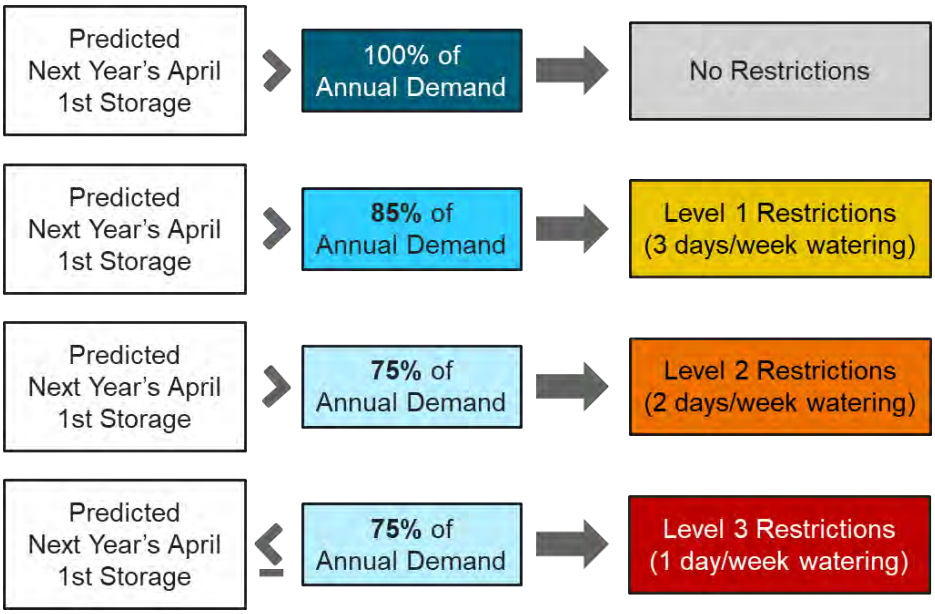


Figure 2-3. Implementation of Greeley's Drought Response Policy in the GSM

The emergency reserve planning performance metric was included to ensure Greeley has sufficient water supplies in storage in the event of an unplanned outage or natural disaster that severely disrupts the water supply system. Six months of indoor demands were selected as these types of emergency

disruptions could typically be addressed within that time horizon. Note that in calculating the storage volume for this metric, storage locations that cannot physically deliver water to Greeley's water system were not included.

The final component of the planning performance criteria was that Greeley's water supply system can always meet indoor demands. This is the critical performance criteria as any impacts to indoor water use could impact public health. As Greeley's water demands grow, the indoor components of those demands will grow as well.

2.5 INTERNAL AND EXTERNAL COORDINATION

In completing the IWRP, Greeley used a cross-disciplinary team of Greeley staff and consultants in close communication with Greeley's Water and Sewer Board (W&S Board). The IWRP included a Core Team that developed content and guided the overall IWRP process. The Technical Team, consisting of Subject Matter Experts (SME) in water rights administration, raw water operations, demand conservation, utility finance, groundwater, and water law reviewed IWRP progress and provided additional guidance and feedback for the IWRP. Finally, the Management Team consisting of Greeley leadership provided final review of IWRP outcomes and recommendations.

An important component of the IWRP was close communication with Greeley's W&S Board. W&S Board Members are council-appointed to five-year terms with no term limit in providing oversight of the Greeley Water and Sewer Department and making recommendations to Greeley's City Council for formal approval and adoption. The W&S Board was appointed with the duty, by the 1958 City Charter to "acquire, develop, convey, lease, and protect water and sewer assets, supplies, and facilities." Because of this unique role, W&S Board members have extensive knowledge of Greeley's water supply system and history. To leverage this knowledge, progress updates were given to the W&S Board throughout the IWRP process, with monthly updates provided as outcomes and recommendations were developed. Feedback from the W&S Board was regularly incorporated into the IWRP development.

The IWRP also developed a new set of materials for communication with Greeley's customers and the larger public. A public-facing summary of the IWRP was developed and is housed on Greeley's website.

3.0 EXISTING WATER SUPPLY SYSTEM

Greeley's existing water supply system, shown in **Figure 3-1**, is geographically diverse, obtaining water from four river basins (North Platte, Poudre, the Colorado, and Big Thompson). The system is also flexible and efficient, with multiple locations to store water and to use existing canals, ditches, and pipelines to deliver water to two treatment plants. Greeley is also developing priority infrastructure to utilize the Terry Ranch Project.

Greeley owns two water treatment plants, the Bellvue Water Treatment Plant (Bellvue WTP) and the Boyd Lake Water Treatment Plant (Boyd WTP). The Bellvue WTP is located near the mouth of the Cache La Poudre Canyon and the Boyd WTP is located south of Boyd Lake within the corporate limits of the City of Loveland. The Bellvue WTP receives water from Greeley's diversion from the Greeley Filters Pipeline on the mainstem of the Poudre as well as from Horsetooth Reservoir through the Hansen Supply Canal during the summer and the Pleasant Valley Pipeline (PVP) during the winter. The Greeley Filters Pipeline is located approximately 1 mile upstream from the Bellvue WTP. Greeley also owns units in the CBT Project and Windy Gap Project, taking water deliveries from those projects' water through facilities described above. Therefore, water entering the Bellvue WTP consists of any combination of the water from the Colorado, Poudre, or North Platte River Basins. The Boyd WTP receives water from the CBT Project, Windy Gap Project, or from the Greeley-Loveland Companies. These sources are diverted from the Big Thompson River through open irrigation canals into either Lake Loveland and then to Boyd Lake via the Big Barnes Ditch, or directly to Boyd Lake via the Greeley-Loveland Canal. The Boyd WTP is not currently winterized and is only operated as a peaking plant during the irrigation season (April through October).

North Platte River basin water consists of wholly consumable transbasin rights that are delivered to the Poudre River in one of two ways: through Bob Creek Ditch to the Roaring Fork drainage, or through the Laramie-Poudre Tunnel to the Poudre River 8 miles downriver of Chambers Reservoir. These supplies are diverted from the mainstem at the Greeley Filters Pipeline and delivered to the Bellvue WTP.

The Poudre Basin water consists of direct flow rights and native storage and is the foundation of Greeley's water supply. Greeley owns senior direct flow and storage rights on the upper mainstem including direct flow priorities and changed and unchanged agricultural water rights that are diverted from the river through the same diversion and pipelines described above and delivered to the Bellvue WTP. In addition, Greeley owns shares in Greeley Irrigation Company's Greeley Canal No. 3 and the New Cache la Poudre Irrigating Ditch Company. Both divert from the lower mainstem near Greeley; their water is used for non-potable irrigation and other non-potable uses in Greeley.

Colorado River Basin water consists of single-use and wholly consumable transbasin water and is primarily accessed through the CBT and Windy Gap Projects. Greeley can deliver CBT Project and Windy Gap Project water to the Bellvue WTP from Horsetooth Reservoir through the Hansen Supply Canal during the summer and the PVP during the winter. CBT Project and Windy Gap Project deliveries can also be diverted from the Big Thompson River and delivered to the Boyd WTP through the Greeley-

Loveland Companies' canals. Greeley is a participant in the Windy Gap firming project. At the time of this IWRP, Chimney Hollow Reservoir is under construction to improve the reliability of the Windy Gap Project.

Greeley's Big Thompson River Basin water consists of transferred agricultural direct flow and storage rights in addition to CBT Project deliveries that are treated at the Boyd WTP. Water is diverted from the Big Thompson River through either the Barnes Ditch or the Greeley-Loveland Canal. Both are components of the Greeley-Loveland Companies system, of which Greeley is a shareholder. The Barnes Ditch conveys water to Lake Loveland. Water from Lake Loveland can be conveyed to Boyd Lake through Horseshoe Reservoir, while the Greeley-Loveland Canal conveys water directly to Boyd Lake. The Boyd WTP draws water directly from Lake Loveland or Boyd Lake or a blend of the two reservoirs. Greeley can also receive water from the Greeley-Loveland Canal via a pump.

Greeley owns multiple reservoirs in the upper and lower Poudre Basin, comprising the majority of its owned water storage. In 1943, Greeley constructed the Milton Seaman Reservoir located on the North Fork of the Poudre. Six additional reservoirs—the High Mountain Reservoirs—were purchased by Greeley in 1947 from the Mountains and Plains Irrigation Company. The High Mountain Reservoirs were constructed in the 1920s, with the exception of Hourglass Reservoir which was constructed in 1898. Two of the High Mountain Reservoirs were expanded in the 1970s (Barnes Meadow and Peterson Lake Reservoirs). The six High Mountain Reservoirs combined with Milton Seaman Reservoir currently have a total active storage capacity of approximately 13,000 acre-feet, not including other conditional storage rights owned by Greeley. These reservoirs are entitled to fill once each year and, due to ice conditions, are not suitable for wintertime operations, except for the Barnes Meadow and Milton Seaman Reservoirs. Greeley also owns storage reservoirs in the lower Poudre Basin that are used within Greeley's non-potable system. In addition to the Poudre Basin reservoirs, Greeley owns shares in three interrelated agricultural water companies collectively known as the Greeley-Loveland Companies. These companies provide storage and delivery of water from the Big Thompson River to the Boyd WTF.

Greeley uses a non-potable system to meet outdoor/irrigation and other non-potable demands using direct flow and storage supplies currently delivered through the Greeley-Loveland Irrigation Company (GLIC) canal and the Greeley Irrigation Company Canal No 3. In the future, Greeley will expand its non-potable system outside of these two delivery canals as it also owns shares in the New Cache la Poudre Irrigating Ditch Company which delivers water through Greeley Canal No 2.

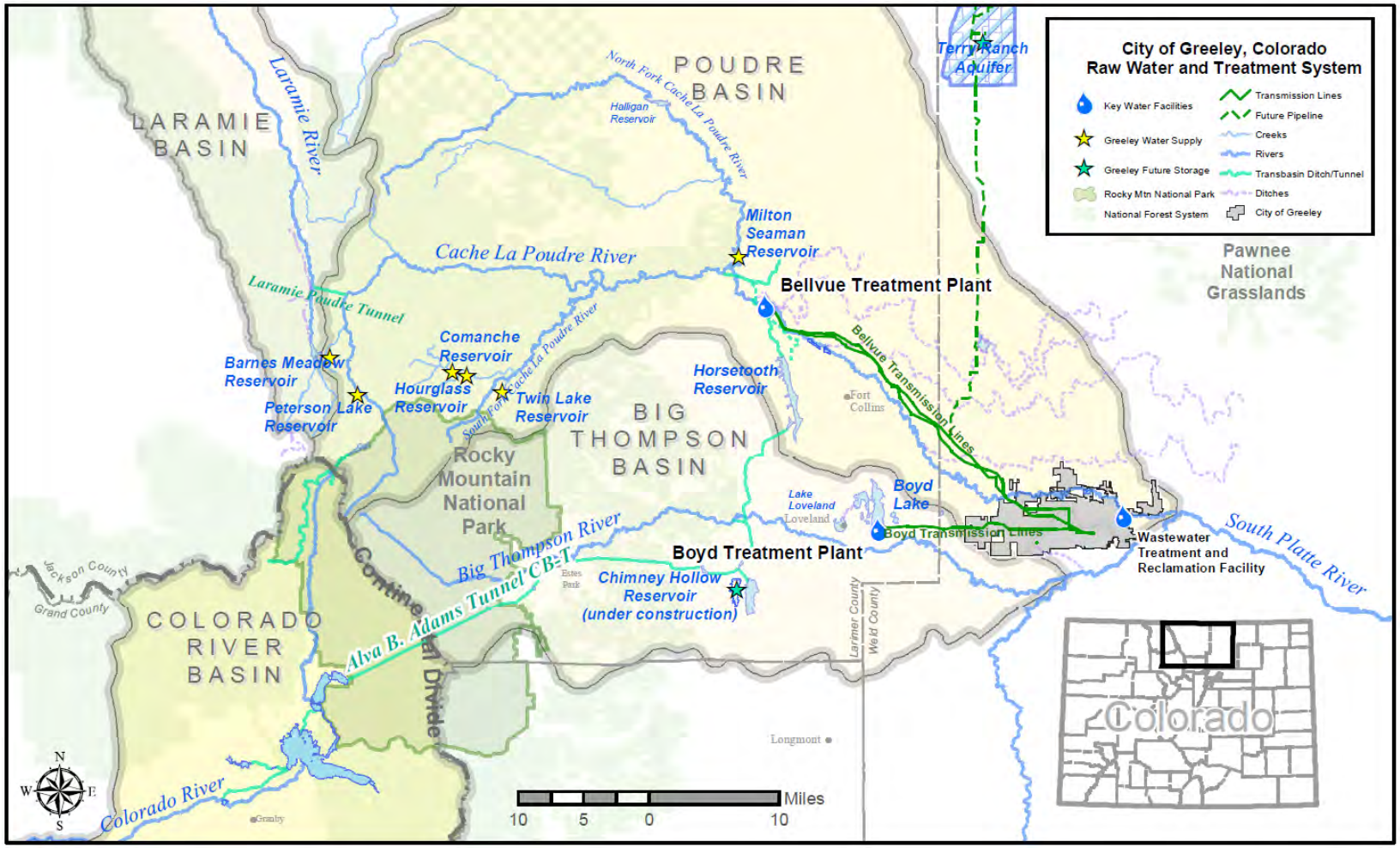


Figure 3-1. Map of Greeley's Current Water Supply System

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4.0 CURRENT AND PROJECTED WATER DEMANDS

This section describes Greeley's current water service area and demands and presents the methodology and results of the demand projections.

4.1 CURRENT SERVICE AREA

The City of Greeley (City), Colorado is located in Weld County approximately 60 miles northeast of Denver. The City is the eleventh largest community in Colorado, the second largest community in Northern Colorado and the business center for Weld County. The leading industries in Weld County are agriculture, manufacturing, energy production, health and wellness, and business services. The City hosts two academic institutions, the University of Northern Colorado and Aims Community College and is home to large industrial water users including JBS USA and Leprino Foods.

The City currently provides water services within the Greeley City limits and to a suite of outside service contracts. For planning purposes, the IWRP team chose to not include outside services into demands or modeling. IWRP demand projections were developed using The City's Long-Range Expected Growth Area (LREGA), as shown in **Figure 4-1**. This is the area outside the City limits where Greeley plans to provide water and sewer services. Although Greeley's population has grown by approximately 17 percent per capita in the last 25 years, demand has decreased by 11 percent compared to a 2012 peak. **Figure 4-2** shows Greeley's population and total water demands since 2010, highlighting this trend. This systemwide per capita demand trend is driven from single-family residents. Greeley's water conservation program has created efficiencies and consistencies among policies that have resulted in a 10 percent per capita decline in residential demand from 2012–2021. Replacements and retrofits of new high efficiency toilets, showerheads, washing machines and dishwashers have led to less use than in previous years. Savings from these existing residential homes has more than offset the increase in demand from new builds and business for almost 20 years. Greeley's Water Conservation team continues to innovate and identify water savings opportunities through programs that include a residential water budget, a turf replacement program, and most recently, leak detection with advanced metering infrastructure.

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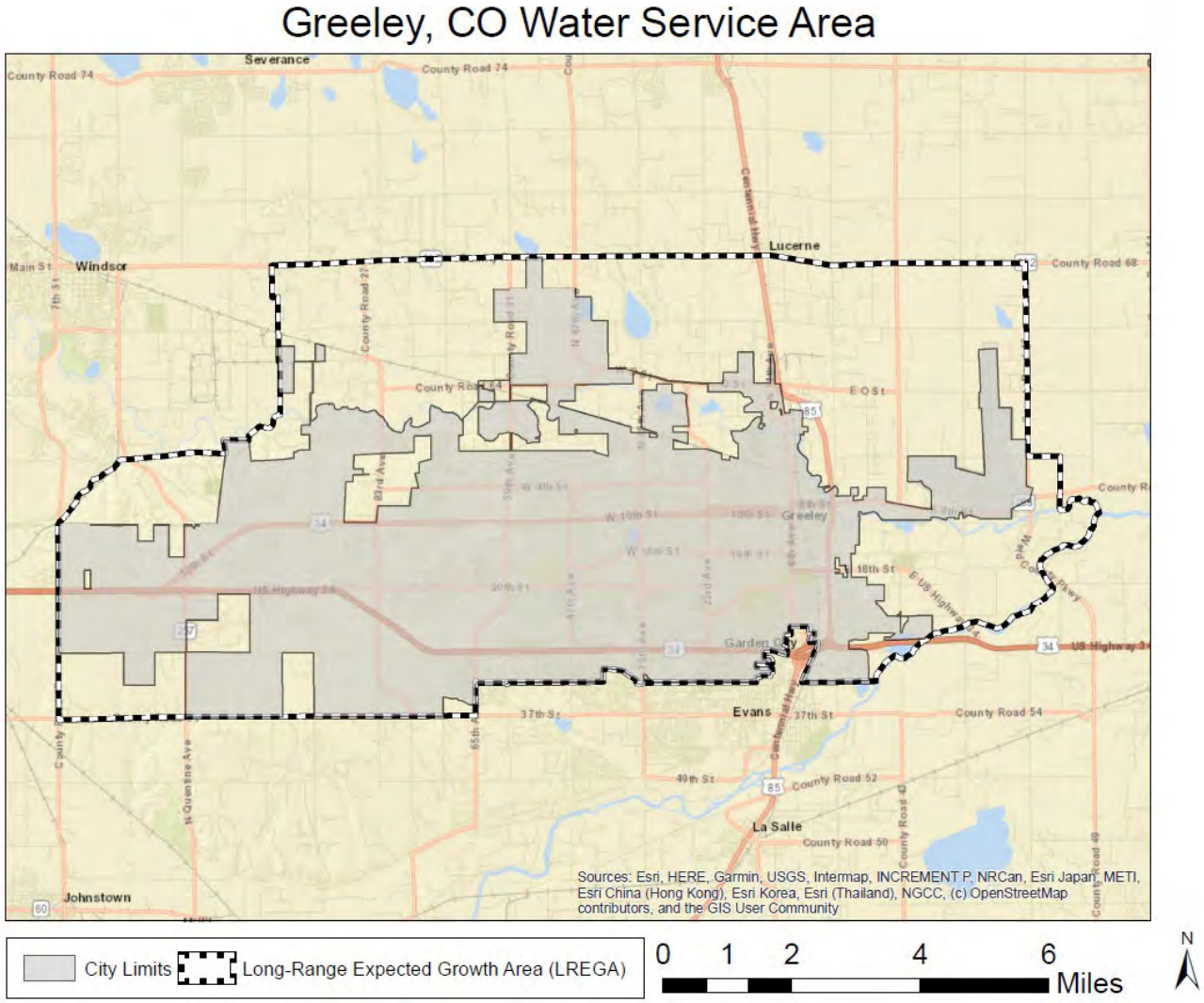

Figure 4-1. The City of Greeley's City Limits and LREGA

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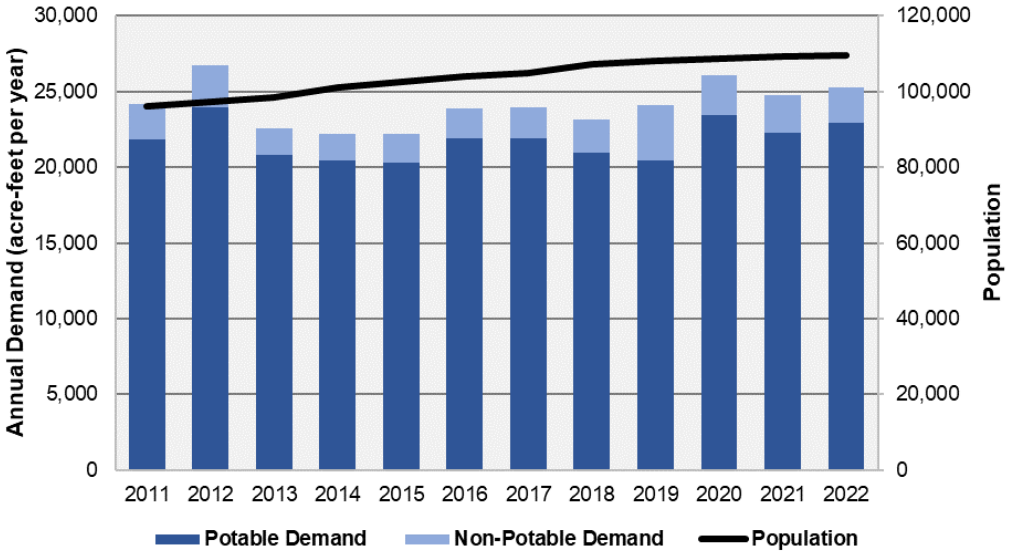

Figure 4-2. Observed Greeley Potable and Non-Potable Demands with Historical Population. The left axis corresponds to the bars and the right axis to the line.

4.2 IWRP PROJECTED DEMANDS

This section summarizes the IWRP demand projections, which are documented in the Demand Forecast TM included in Appendix B.

The IWRP demand projections used Greeley's existing water demand model (Demand Model) (BBC Research 2018). The model produces projections of annual indoor and outdoor water use by customer category (e.g., single family residential, multifamily residential, commercial) through 2070. The model only includes Greeley's retail customers and does not include water use by Greeley's wholesale customers who provide their own water resources (e.g., City of Evans, Town of Milliken, Town of Evans).

4.2.1 Population Projections

A significant contributor to future water use in Greeley is population growth. The IWRP team developed updated population projections for Greeley that incorporated the new information described below:

- Updated historical population data from the 2020 Census
- New projections from the Colorado State Demographers Office, which lowered Weld County population projections compared to those previously used in the Demand Model
- New features developed for the Technical Update to the Colorado Water Plan that allows different alternative county-level population forecasts to be developed based on the Colorado State Demographers Office projections.

The information above was used to develop population forecasts for three scenarios: Low, Medium, and High at 2050 and 2070. **Figure 4-3** shows the population projections for the three scenarios.

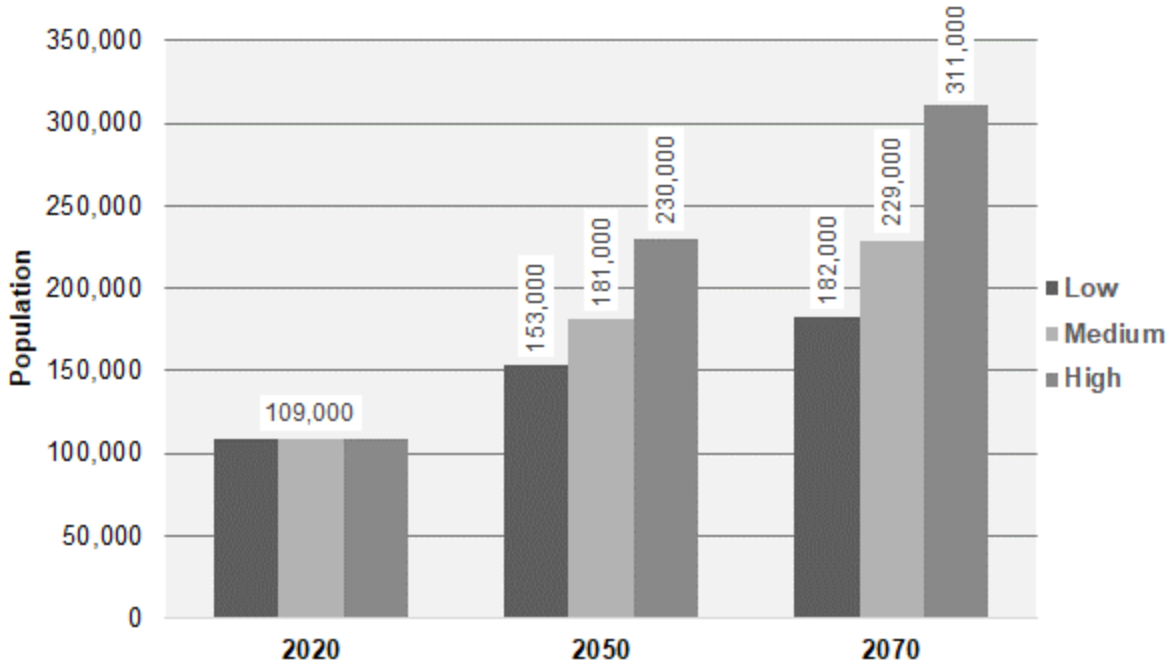

Figure 4-3. Greeley's 2020 and Projected Populations at 2050 and 2070

The IWRP also evaluated the potential timing of buildout in Greeley's LREGA and the potential City population at buildout. Buildout population and the timing of population will depend on many factors, but the IWRP varied residential unit density (in residential units per acre) and population growth rate (the previously used Low, Medium, and High scenarios) when assessing buildout. **Table 4-1** shows the buildout population for each density scenario.

Table 4-1. Buildout Population and Timing Projections

Density Scenario	Buildout Population
Current Residential Density (7.1 units per acre)	348,000
30% Increase in New Residential Density (9.2 units per acre)	421,000
50% Increase in New Residential Density (10.6 units per acre)	470,000

4.2.2 Demand Projections

Potable and non-potable demands were projected at 2030, 2050, and 2070 using the population projections described above for four demand scenarios. These four scenarios vary important factors that can impact future demands: the population growth scenario, the extent to which irrigation increases in response to hotter and drier future climate conditions, the extent of future conservation, and the proportion of new housing units that are multifamily apartments and condominiums. These factors were selected based on the prioritized demand risks described in Section 5. **Table 4-2** summarizes these four demand scenarios and how these factors were applied in them.

Table 4-2. IWRP Demand Scenario Settings

Demand Scenario	Population Scenario	Increase in Irrigation Rate due to Climate	Conservation (Price Increases)	Multifamily Share of New Housing Units
High Bookend	High Growth	37%	Level 2 (2%/year)	40%
Median Scenario	Medium Growth	25%	Level 1 (1%/year)	40%
Low Bookend	Low Growth	12%	Level 3 (3%/year)	50%
Median with Max Conservation	Medium Growth	25%	Level 3 (3%/year)	40%

The Demand Model develops separate forecasts for the portion of projected outdoor demands that will be met from non-potable sources, otherwise known as non-potable demands. The IWRP updated the non-potable forecast based on the 2021 Non-Potable Master Plan. **Table 4-3** shows the assumed percentages of outdoor demands that are non-potable by customer category that were applied to the demand forecasts. To align with the Non-Potable Master plan, the maximum non-potable demand regardless of scenario was set to a maximum of 7,100 acre-feet per year.

Table 4-3. Non-Potable Demand Forecast Assumptions

Customer Category	Percent of New Outdoor Demands from Non-Potable Supplies
Single-Family Residential	12%
Multifamily Residential	12%
Commercial	16%
City of Greeley	80%
Schools	60%
University of Northern Colorado	16%

The demand projections at 2030, 2050, and 2070 are shown by Demand Scenario in **Figure 4-4** and presented numerically in **Table 4-4**. Based on these projections, Greeley's demands at 2070 could vary between 35,400 and 70,000 acre-feet per year. The most significant contributor to this variability is population. Under these projections, Greeley's non-potable system will be fully built out by 2070 for all demand scenarios except the low bookend.

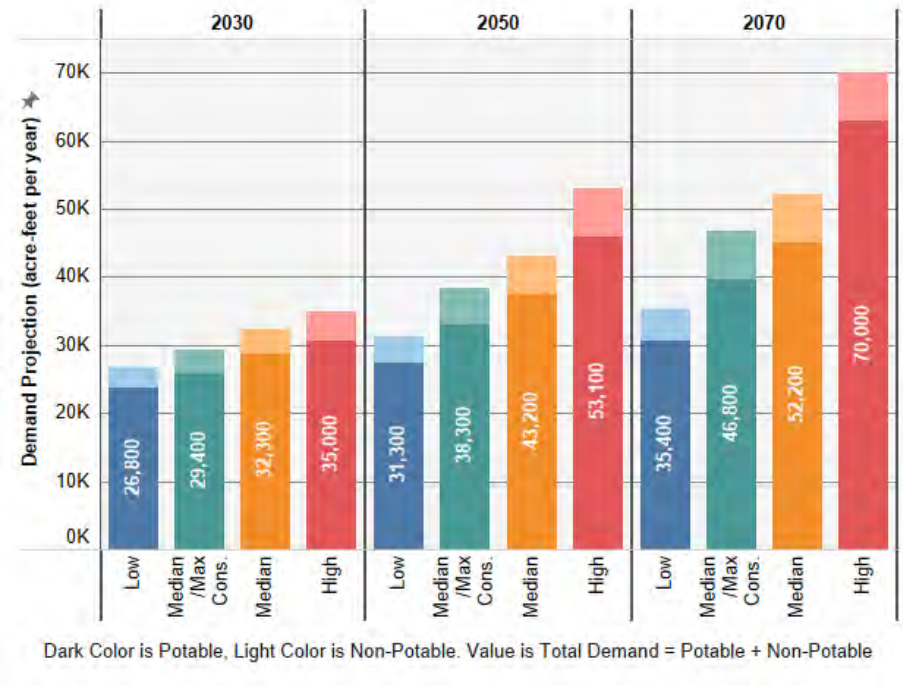

Figure 4-4. Greeley's Demand Projects at 2030, 2050, and 2070

Table 4-4. Greeley's Demand Projects at 2030, 2050, and 2070

		Demand Scenario			
Year	**Demand Type**	**Low Bookend**	**Median w/ Max Conservation**	**Median Scenario**	**High Bookend**
2030	Non-Potable	3,000	3,500	3,700	4,300
	Potable	23,800	25,900	28,600	30,700
	Total	**26,800**	**29,400**	**32,300**	**35,000**
2050	Non-Potable	4,000	5,300	5,700	7,100
	Potable	27,300	33,000	37,500	46,000
	Total	**31,300**	**38,300**	**43,200**	**53,100**
2070	Non-Potable	4,800	7,100	7,100	7,100
	Potable	30,600	39,700	45,100	62,900
	Total	**35,400**	**46,800**	**52,200**	**70,000**

Figure 4-5 compares growth in total demands between the four demand scenarios from 2030 to 2070. The variation in projected total demands (difference between High and Low Demand Scenario projections) increases from 8,200 acre-feet per year at 2030 to 34,600 acre-feet per year at 2070. This further emphasizes the significant variation and uncertainty in Greeley's potential future demands. These demand projections assumed demand growth occurs immediately. However, Greeley's total demands have not grown significantly over the last 10 years and are lower than the peak in the early 2000s, which further contributes to uncertainty. Developing a process to manage and track demand growth uncertainty will be a key component of the Adaptive Plan.

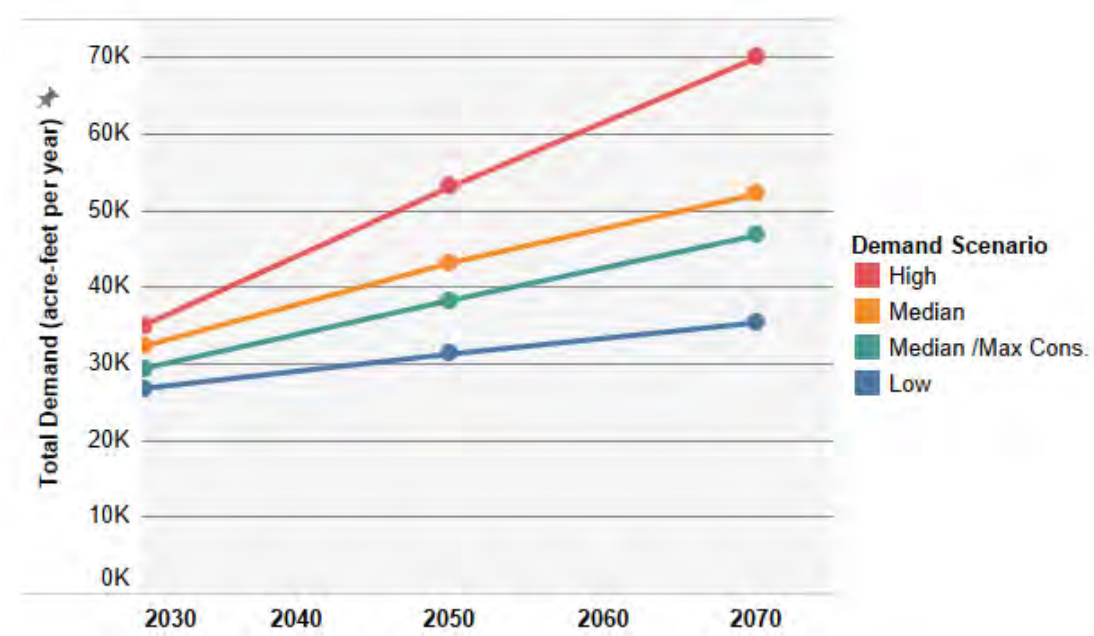

Figure 4-5. Comparison of Greeley's Demand Growth Between 2030 and 2070

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5.0 RISK IDENTIFICATION AND ASSESSMENT

5.1 METHODOLOGY

Risks to Greeley's water supply system were identified within five categories by a combination of Greeley staff, consultants, and a review of other studies and relevant published literature. These risks were then evaluated using a scoring survey. The purpose of the evaluation was to prioritize risks and identify which should be included in the IWRP.

The scoring survey had Greeley staff, stakeholders, and members of the Stantec team assign numerical likelihood and impact scores to the individual risks. Participants assigned scores from 1 to 5 using their perception of each risk according to the definitions in **Table 5-1**. The likelihood and impact scores were then multiplied together to compute a composite score. The composite scores were then used to prioritize risks for IWRP inclusion. Participants assigned scores individually and were not required to score every risk.

Table 5-1. Impact and Likelihood Scores and Definitions Used by Scoring Participants

Score	Impact Definition	Likelihood Definition
1	*Insignificant* – If the risk occurs the impact to the water supply system would be negligible.	*Rare* – the risk will only occur in exceptional circumstances.
2	*Minor* – If the risk occurs the impact to the water supply system would be minimal.	*Unlikely* – the risk will occur in occasional circumstances.
3	*Moderate* – If the risk occurs there would be a noticeable impact to the water supply system.	*Possible* – the risk will occur in some circumstances.
4	*Major* – If the risk occurs there would be substantial impact to the water supply system.	*Likely* – the risk will occur in a majority of circumstances.
5	*Extreme* – If the risk occurs there would be catastrophic impact to the water supply system.	*Almost Certain* – the risk will occur in almost all circumstances, or is imminent.

5.2 IDENTIFIED WATER SUPPLY SYSTEM RISKS

55 initial risks to Greeley's water supply system were identified by the Greeley staff and the Stantec team. These risks were grouped into five categories:

- **Climate Change and Hydrology**: Risks that relate to climate variability and other hydrologic factors, both short- and long-term, that can impact Greeley's water entitlements
- **Colorado River Basin Issues**: Risks that could affect Greeley's water supplies from the Colorado River Basin, including the CBT Project.
- **Demand**: Risks that could increase or decrease future water demands from what is projected, resulting in Greeley's water supply system being unable to meet water needs or being overdesigned
- **Infrastructure and Operations**: Risks that include impacts to how Greeley captures and delivers their water entitlements water to customers
- **Water Rights**: Risks that could impact how Greeley's existing and potential water rights could be acquired, changed, and/or administrated

The tables on the following pages show the risks identified for each category, a brief description, and the average impact, likelihood, and composite score from scoring survey participants. **Table 5-2** shows the Climate Change and Hydrology risks and scores. **Table 5-3** shows the Colorado River Basin issues risks and scores**. Table 5-4** shows the Demand risks and scores. **Table 5-5** shows the Infrastructure and Operations risks and scores. **Table 5-6** shows the Water Rights risks and scores.

Table 5-2. Identified Climate Change and Hydrology Risks with Corresponding Impact and Likelihood Scores

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
CC3	Extended Droughts	Droughts with duration and severity greater than Greeley's historical record occur. Would occur independent of Climate Change.	**4.2**	**4.2**	**18.1**	6.1
CC1	Colorado River Administration CC Impacts	Climate change would increase the frequency, duration, and intensity of droughts, reducing Greeley's available supply from Colorado River Basin. This would result in the Colorado River Basin risks occurring more often.	**3.8**	**4.2**	**15.8**	4.5
CC4	Hydrologic CC Impacts	More precipitation could occur as rain, runoff timing would compress and shift earlier in the season, resulting in net changes to volumetric yields and exchange availability.	**3.5**	**4.0**	**14.5**	4.6
CC5	Increased Extreme Events	Increased frequency and intensity of extreme events such as fire and flooding within Greeley's source basins would change the timing, quantity, and quality of water supply from those watersheds.	**3.0**	**4.0**	**12.2**	5.6
CC6	Municipal Water Use CC Impacts	Warmer temperatures increase water needs and increase the duration of the municipal irrigation season. Could also result in a change in landscaping practices, e.g., conversion of irrigated landscape to xeriscape.	**3.0**	**3.8**	**11.5**	3.9
CC2	Evaporation Rate CC Impacts	A warmer climate would increase evaporation losses from reservoirs.	**2.5**	**4.1**	**10.3**	2.5
CC7	Water Rights Administration CC Impacts	Yields from existing water rights would change due to the shift in runoff magnitude and timing. Operational assumptions around exchange, timing, and positioning of yields would change.	**2.5**	**3.7**	**9.5**	4

[1] Values shown are the average of the composite scores and not the product of the Average Likelihood Score and the Average Impact Score
ID = Identification
CC = climate change

Table 5-3. Identified Colorado River Basin Issues Risks with Corresponding Impact and Likelihood Scores

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
CR1	Colorado River Basin Administrative Actions	To comply with the Colorado River Compact/critical operational parameters (e.g., power pools in Lakes Mead and Powell), a variety of impacts to Greeley's Windy Gap and CBT yields could occur.	**4.2**	**4.6**	**19.1**	3.4
CR3	Chronic Yield Reduction: Windy Gap	Chronic 10% to 25% reduction in Windy Gap yields due to the effects of aridification in the Colorado River Basin. Reduction would be applied over the entire simulation period.	**3.8**	**3.7**	**14**	5.3
CR4	Chronic Yield Reduction: Windy Gap and CBT	Chronic, 10% to 25% reduction in Windy Gap and CBT yields due to the effects of aridification in the Colorado River Basin. Reduction would be applied over the entire simulation period.	**4.3**	**3.1**	**13.2**	2
CR10	Yield Reduction: Multi-Year	2-year 10% to 25% reduction of Windy Gap/CBT/WSSC yields as part of state-led coordinated effort.	**4.2**	**3.2**	**13**	5.5
CR8	Total Curtailment: Single Year, Windy Gap and CBT	1-year complete curtailment of Colorado River Basin yields could occur in the event of Compact Compliance failure.	**4.1**	**3.1**	**12.5**	6.9
CR11	Yield Reduction: Single Year	1-year 10% to 25% reduction of Windy Gap/CBT/WSSC yields as part of state-led coordinated effort.	**3.6**	**3.8**	**12.4**	4.5
CR5	Total Curtailment: Multi-Year, Windy Gap	2-year complete curtailment of Windy Gap yields could occur in the event of Compact Compliance failure.	**3.9**	**3.1**	**12.3**	6
CR9	Yield Reduction: Extended	5-year 10% to 25% reduction of Windy Gap/CBT/WSSC yields as part of State-led coordinated effort.	**4.7**	**2.7**	**12.1**	5.5
CR6	Total Curtailment: Multi-Year, Windy Gap and CBT	2-year complete curtailment of Colorado River Basin yields could occur in the event of Compact Compliance failure.	**4.5**	**2.6**	**11.8**	4.2
CR7	Total Curtailment: Single Year, Windy Gap	1-year complete curtailment of Windy Gap yields could occur in the event of Compact Compliance failure.	**3.4**	**3.4**	**11.8**	6
CR2	Emergency Municipal Demand Reductions	Greeley's water use would be significantly reduced as part of state-led effort to reduce demands on the Colorado River Basin. Only water use for public health and critical landscaping (e.g., mature trees) would be allowed.	**2.9**	**3.1**	**8.8**	3.4

[1] Values shown are the average of the composite scores and not the product of the Average Likelihood Score and the Average Impact Score
WSSC = Water Supply & Storage Company

Table 5-4. Identified Demand Risks with Corresponding Impact and Likelihood Scores

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
D10	Regional Water Issues: Long Term	Nearby communities experience long-term water reliability issues and City of Greeley decides to provide their water service.	**3.5**	**3.7**	**13.1**	5.3
D6	High Impact Water Rates	Higher rates to fund projects could cause demands to decrease due to affordability issues. Could also lead to political impacts where rates can no longer be raised.	**3.1**	**3.8**	**11.8**	5.6
D4	Demand Hardening	Long-term reductions in outdoor municipal water use reduces the proportion of total demand that is for outdoor use. This would reduce assumed savings from drought response measures.	**3.0**	**3.7**	**11.5**	4.8
D12	Service Area Expansion	The City of Greeley expands beyond the current service area, potentially increasing buildout demand.	**3.6**	**3.2**	**11.5**	3.9
D7	Increased Suburban Growth	The proportion of suburban growth is more than assumed in demand forecasts, increasing the proportion of overall demands that are outdoor demands.	**3.0**	**3.6**	**10.9**	4.4
D9	Increased Non-Potable System Growth	The non-potable system is not developed/built as assumed. Future demands assumed to be met from non-potable supplies instead are part of the potable system.	**2.9**	**3.5**	**10.3**	5.5
D13	Uncertain Industrial Demands	Large industrial demands could be added to the system, which would quickly increase the demands on the water system.	**3.4**	**3.0**	**10.2**	3.5
D2	Demand Growth Exceeds Forecast	Greeley's water demands could grow faster than anticipated due to a variety of conditions including rapid population growth and/or poor adoption of conservation practices.	**3.5**	**2.6**	**9.6**	4.5
D5	Demand Stagnation	Demands continue to remain relatively static for a longer period than assumed. This could affect the timing of CIP projects and reduce anticipated revenue, overburdening rate payers.	**2.8**	**3.3**	**9.4**	4.7
D8	Increased Urban Growth	The proportion of urban growth is more than assumed in demand forecasts, increasing the proportion of overall demands that are indoor demands.	**2.5**	**3.5**	**8.9**	3.5
D11	Regional Water Issues: Short Term	Nearby communities experience emergency water reliability issues and Greeley would provide water service to them for a short time.	**2.2**	**3.8**	**8**	3.6

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
D1	Conservation Program Ineffectiveness	Per capita water use does not decline as much as anticipated with the current water conservation program measures.	**2.9**	**2.4**	**7.1**	4
D3	Demand Growth Slower than Forecast	Greeley's water demand grows slower than anticipated due to conditions such as high rate burden, poor economic conditions, more rapid adoption of conservation practices, and new water fixture/irrigation technology.	**2.0**	**3.0**	**6.5**	5

[1] Values shown are the average of the composite scores and not the product of the Average Likelihood Score and the Average Impact Score

Table 5-5. Identified Infrastructure and Operational Risks with Corresponding Impact and Likelihood Scores

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
IO9	Increased Frequency/Severity of Wildfires: Poudre Watershed	Severe wildfires in Poudre watersheds would change the timing, quantity, and quality of water supply from those watersheds. July/August yields would be cut off completely for 3 of 10 years after a fire and would be reduced by 25% for the other 7 years. Barnes, Peterson, and Chambers would have a 50% reduction in storage capacity. Treatment costs would increase.	**3.5**	**4.2**	**14.8**	6.2
IO4	Degraded Surface Water Quality	Climate change creates frequent surface water quality issues such as algal blooms that reduce Greeley's ability to treat water.	**3.1**	**3.3**	**9.9**	3.3
IO17	Water Quality Regulation Changes	New/modified water quality environmental criteria (minimum flows, temperature standards, etc.) could be adopted that would affect Greeley's water rights and operations.	**2.7**	**3.6**	**9.8**	3.4
IO5	Environmental Permitting Problems	Failure to obtain the necessary federal or state environmental permits would make it impossible to implement a planned project.	**2.8**	**3.3**	**9.2**	3.8
IO2	Changes in Regional Agriculture	The regional agricultural economy is more or less robust than assumed, affecting the availability/pricing of water rights for Greeley. More robust regional agricultural economy would increase the likelihood of high water use industries.	**2.6**	**3.4**	**9.1**	5.5

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
IO1	Budget Instability	Temporary monetary crisis or revenue instability forces Greeley to lower use of energy-intensive infrastructure such as Terry Ranch.	**2.9**	**2.8**	**8.9**	6.2
IO11	Multi-Year Grand River Ditch Outage	Grand River Ditch is taken out of service for 3 years due to natural hazard (flood, landslide, etc.).	**3.0**	**2.8**	**8.6**	3.4
IO14	Regional Agricultural Water Use Practices	Changes in agricultural water use and growth practices change how Greeley's water rights yield due to shared ditch infrastructure, senior water rights calls, and reduced runoff from water-intensive irrigation practices.	**2.6**	**3.1**	**8.6**	6.2
IO8	High Mountain Reservoir Chronic Outage	Natural disasters or changes in regulations take Greeley's High Mountain Reservoirs permanently offline.	**3.3**	**2.5**	**8.3**	4.2
IO10	Multi-Year CBT Infrastructure Outage	Variety of risks to CBT infrastructure that could take it offline for a period of time. This effect would be captured via reduced or eliminated quota to Greeley.	**3.8**	**2.2**	**8.3**	3.7
IO13	Multi-Year Laramie-Poudre Tunnel Outage	Laramie-Poudre Tunnel is taken out of service for 3 years due to natural hazard (flood, landslide, etc.).	**3.0**	**2.8**	**8.3**	4.6
IO6	GW supplies cannot be used by Greeley	Greeley cannot utilize Terry Ranch for either GW supplies or storage.	**4.2**	**1.9**	**8.1**	3.9
IO7	High Energy Cost	High energy costs reduce Greeley's ability to use energy-intensive infrastructure such as Terry Ranch.	**2.7**	**3.0**	**7.7**	3.7
IO12	Multi-Year High Mountain Reservoir Outage	High Mountain Reservoirs are taken out of service for 3 years due to natural hazard (flood, landslide, etc.).	**3.2**	**2.3**	**7.5**	4
IO16	Terry Ranch Yield Limitations	Features of Terry Ranch such as neighboring owners over-drafting and/or inconsistent uranium presence in wells change the yield assumptions from the project.	**2.8**	**2.6**	**7.3**	3.4
IO15	Terry Ranch Interstate Compact	New interstate compacts or legal precedent changes how Greeley can use Terry Ranch.	**3.1**	**2.3**	**6.9**	2.5
IO3	Contamination Event	Contamination of a surface water supply source, storage facility, or Terry Ranch requires significant operational changes for 2 or more years.	**3.2**	**2.3**	**6.8**	3.4

[1] Values shown are the average of the composite scores and not the product of the Average Likelihood Score and the Average Impact Score
GW = groundwater

Table 5-6. Identified Water Rights Risks with Corresponding Impact and Likelihood Scores

ID	Risk Name	Risk Description	Average Impact Score	Average Likelihood Score	Average Composite Score[1]	Composite Score Standard Deviation
WR2	Competition for New Water Rights	New water rights would be more expensive and yield less than anticipated. Water rights that Greeley plans to acquire come off the market due to actions by other water providers.	**3.2**	**4.4**	**14.4**	5.3
WR1	CBT Operational Changes	Northern Water would no longer allow Greeley to carryover their CBT supplies.	**3.5**	**3.4**	**12.2**	4.2
WR6	Water Rights Change Complexity	Water rights that Greeley currently owns but has not changed to municipal use would have their yields reduced as part of the change process or could not be changed entirely.	**2.9**	**3.9**	**12**	5
WR3	Increased return flow obligations	Due to changes in future change cases or other water rights administration changes, Greeley must dedicate more water than planned to return flow obligations.	**2.7**	**3.3**	**9.7**	6
WR5	Terry Ranch Storage Ability	Water that is assumed to be storable in Terry Ranch would no longer be able to be stored there due to changes in water rights administration (e.g., wholly consumptive rights).	**3.3**	**2.6**	**9.3**	5.8
WR4	Reduced reusable effluent	Due to changes in water rights administration, treatment requirements, or operational changes, Greeley has less reusable effluent than planned.	**2.4**	**2.9**	**7.7**	4.4

[1] Values shown are the average of the composite scores and not the product of the Average Likelihood Score and the Average Impact Score

5.3 WATER SUPPLY SYSTEM RISK ANALYSIS

5.3.1 Comparative Analysis of Risks and Uncertainties

When prioritizing risks, the average likelihood and impact scores resulting the scoring survey were evaluated using the criteria shown in **Figure 5-1**. Risks with a composite score (calculated as likelihood times impact) greater than 10 were generally prioritized for the IWRP. Risks with composite score less than 5 were not prioritized for the IWRP. Risks with an impact score above 4 and likelihood score above 2 were prioritized for the IWRP regardless of the composite score. All other risks were evaluated on a case-by-case basis.

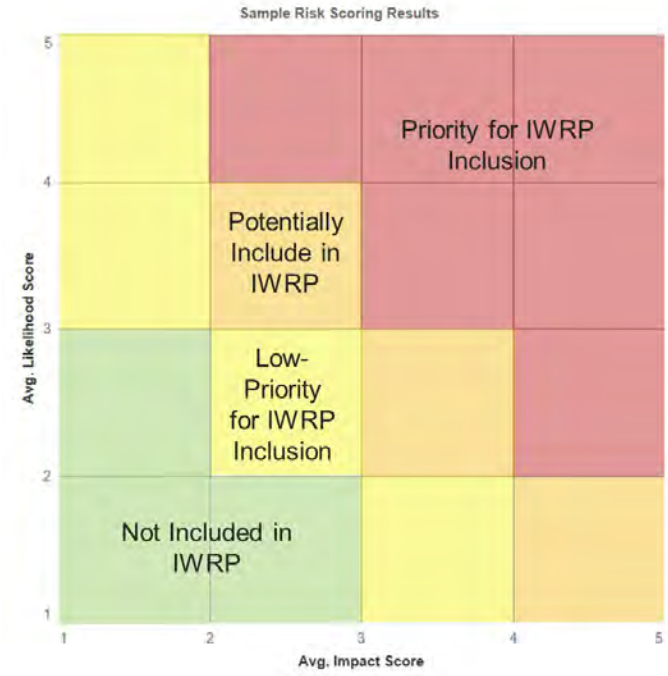

Figure 5-1. Overall Likelihood and Impact Criteria Used to Prioritize Risks

Figure 5-2 presents the likelihood and impact scores of the risks averaged across all scoring survey responses with the risk category shown as the color. Labels within each circle correspond to the risk ID of a risk that was prioritized for IWRP inclusion. In this figure, the closer a risk is to the top right corner the more likely and impactful it was perceived to be. Risks from all the categories were included in the IWRP.

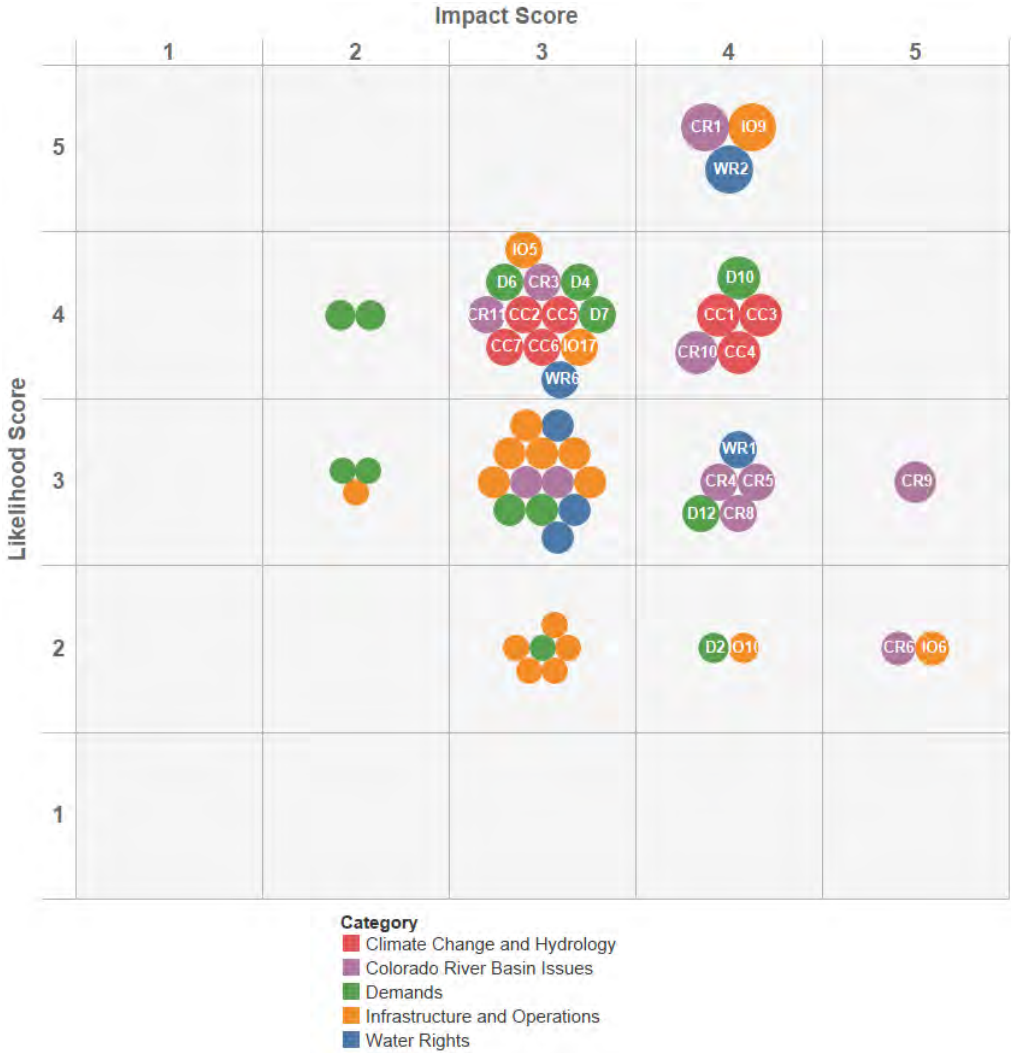

Figure 5-2. Average Impact and Likelihood Scores for Water Supply Risks

Another criterion evaluated when prioritizing risks for the IWRP was the variation of individual likelihood and impact scores. **Figure 5-3** (Climate Change and Hydrology, Colorado River Basin Impacts, and Demand risks) and **Figure 5-4** (infrastructure and Operations and Water Rights risks) show how many individual respondents assigned a likelihood/impact score of 1 to 5 for each risk (NA indicates a value was not assigned). The larger a bar is, the more respondents assigned the specified score. Risks with larger bars of a single color indicate agreement within respondents on the likelihood/impact score while four or more individual colors indicate variability of individual scores. Most risks showed minimal variation between individual scores, indicating that the respondents have similar perceptions of likelihood and impact for most of the risks. Risks that had scores from 1 to 5 given by respondents include: Total Curtailments of the Windy Gap and CBT systems, Demand Growth Slower than Forecast, and Service Area Expansion. This variation was considered and ultimately no changes were made to the prioritized risks.

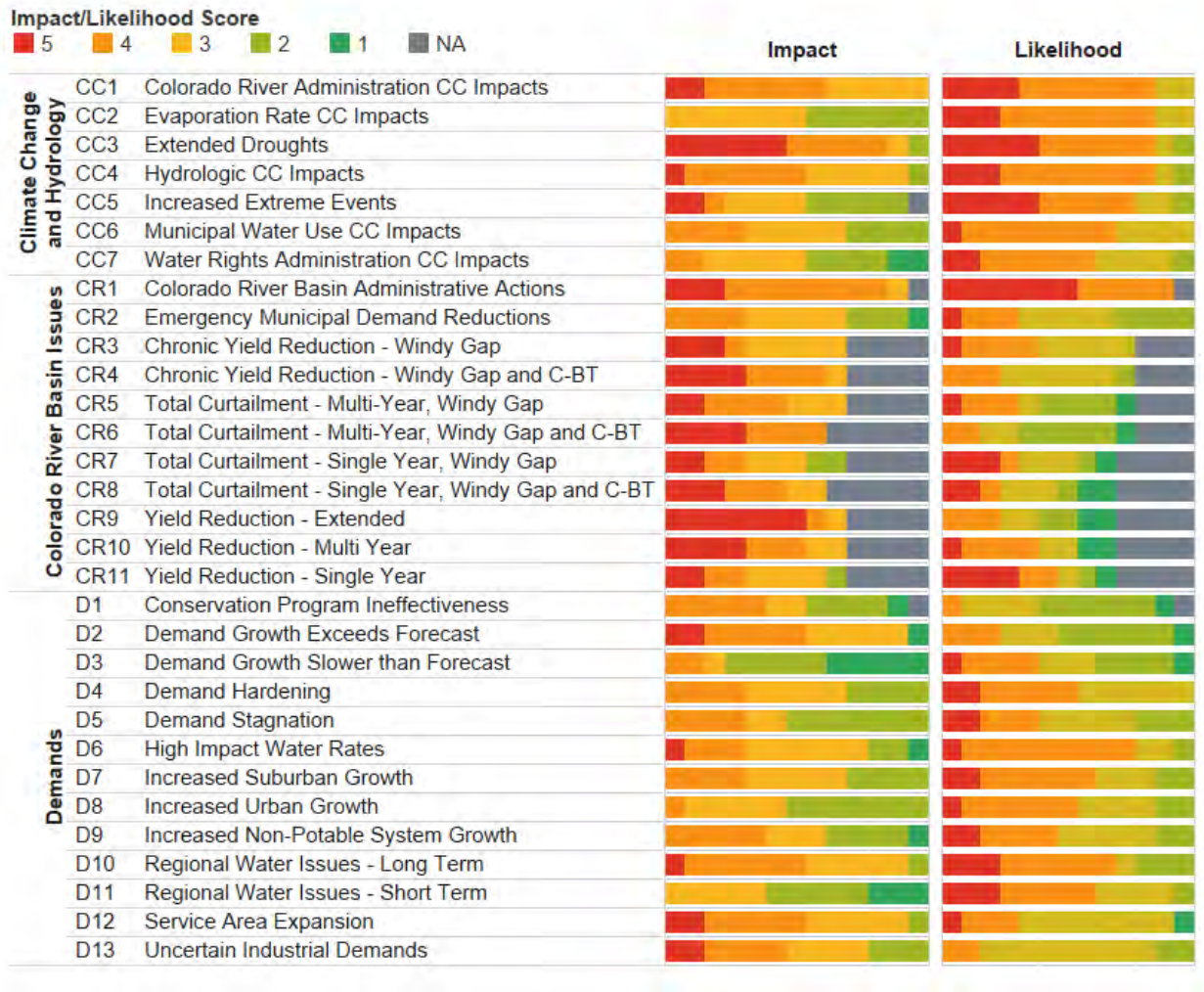

Figure 5-3. Variability in Individual Impact and Likelihood Scores for Climate Change Hydrology, Colorado River Basin Issues, and Demand Risks

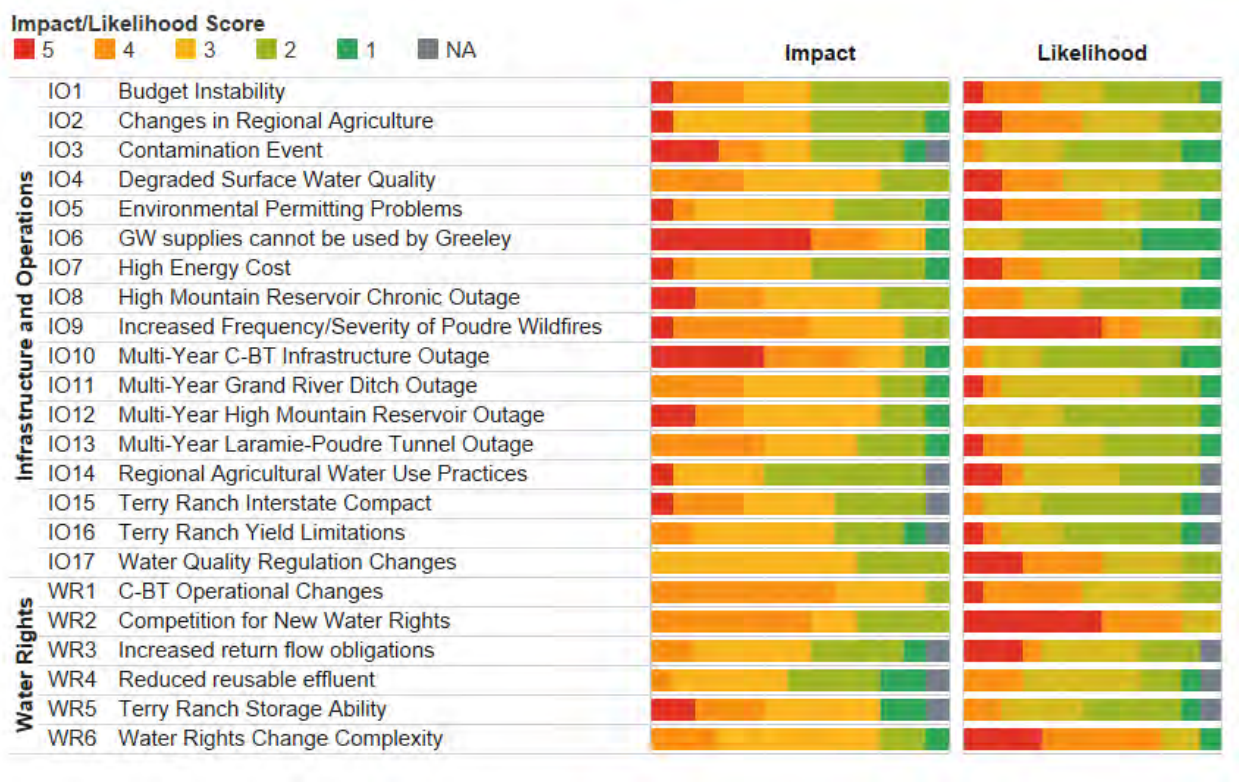

Figure 5-4. Variability in Individual Impact and Likelihood Scores for Infrastructure and Operations and Water Rights Risks

5.3.2 Prioritized Risks for IWRP Inclusion

Table 5-7 presents the water supply system risks prioritized for the IWRP using the analysis process described above, sorted by composite score. Impact and likelihood scores are the median across all responses. Prioritized risks were those that fell within the red region presented in Figure 5-1 (shown previously) and risks with an impact score greater than 4 paired with a likelihood score greater than 2. In total, 30 risks were prioritized for inclusion in the IWRP.

Table 5-7. List of Prioritized Water Supply Risks for IWRP

ID	Risk Name	Impact Score	Likelihood Score	Composite Score
CR1	Colorado River Basin Administrative Actions	5	4	20
IO9	Increased Frequency/Severity of Poudre Wildfires	5	4	20
WR2	Competition for New Water Rights	5	4	20
CC1	Colorado River Administration CC Impacts	4	4	16
CC3	Extended Droughts	4	4	16
CC4	Hydrologic CC Impacts	4	4	16
CR10	Yield Reduction: Multi-Year	4	4	16
D10	Regional Water Issues: Long Term	4	4	16
CR9	Yield Reduction: Extended	3	5	15
CC2	Evaporation Rate CC Impacts	4	3	12
CC5	Increased Extreme Events	4	3	12
CC6	Municipal Water Use CC Impacts	4	3	12
CC7	Water Rights Administration CC Impacts	4	3	12
CR11	Yield Reduction: Single Year	4	3	12
CR3	Chronic Yield Reduction: Windy Gap	4	3	12
D4	Demand Hardening	4	3	12
D6	High Impact Water Rates	4	3	12
D7	Increased Suburban Growth	4	3	12
IO17	Water Quality Regulation Changes	4	3	12
IO5	Environmental Permitting Problems	4	3	12
WR6	Water Rights Change Complexity	4	3	12
CR4	Chronic Yield Reduction: Windy Gap and CBT	3	4	12
CR5	Total Curtailment: Multi-Year, Windy Gap	3	4	12
CR8	Total Curtailment: Single Year, Windy Gap and CBT	3	4	12
D12	Service Area Expansion	3	4	12
WR1	CBT Operational Changes	3	4	12
CR6	Total Curtailment: Multi-Year, Windy Gap and CBT	5	2	10
IO6	GW supplies cannot be used by Greeley	5	2	10
D2	Demand Growth Exceeds Forecast	4	2	8
IO10	Multi-Year CBT Infrastructure Outage	4	2	8

5.4 RISK INCLUSION IN IWRP

The prioritized risks were further evaluated to collect and summarize common risks into drivers to incorporate into the IWRP Planning Scenarios. Drivers are major events or conditions that are outside Greeley's control that could impact their ability to provide sustainable water supply to their customers. The drivers identified for the IWRP are presented below. **Table 5-8** presents how these drivers were incorporated into the Planning Scenarios described in Section 2.2.

- The **Climate Change Impacts on Hydrology** driver captures risks that could change what Greeley's water rights yield and the timing of that yield compared to what has been experienced historically. This is due to a combination of droughts of increased intensity, duration, and/or frequency compared to the historical record, and impact on runoff and the overall hydrograph from a warmer climate.
- The **Future Demand Uncertainty** driver captures risks that affect how much water demand Greeley's system would need to meet in the future and how water is used compared to historical usage. This includes future built areas being different from historical ones, less outdoor water use, and potential regional demand needs.
- The **Water Rights Administration Complexity and Uncertainty** driver captures risks that affect Greeley's ability to change currently owned water rights, acquire new water rights, and how existing and future water rights may yield. This includes increased competition for new water rights, the legal complexity of changing existing rights, and uncertainty of how water rights administration may change under a different hydrograph than the historical hydrograph.
- The **Colorado River Basin Issues** driver captures risks to Greeley's yields from the Colorado River Basin which could result in a variety of short- and long-term reductions or curtailments of these supplies.

Table 5-8. Risk Driver Settings for Planning Scenarios

Driver Name	Incorporate Impact	Planning Scenario Settings
Climate Change Impacts on Hydrology	Change in temperature of future climate conditions compared to historical climate conditions.	• No Change • +2°F Warmer • +5°F Warmer • +8°F Warmer
Future Demand Uncertainty	Rate of population growth paired with per capita water use.	<u>Population Growth Rate:</u> • Planned Growth • Increased Growth • Decreased Growth <u>Per Capita Water Use:</u> • Highest Per Capita Use • Planned Per Capita Use • Lowest Per Capita Use
Water Rights Administration Complexity and Uncertainty	Reductions in modeled water rights yield due to combination of inability to change water rights as assumed, acquire new water rights, and/or reductions in yield due to administration changes	• No Change • 10% Reduction in All Yields

Driver Name	Incorporate Impact	Planning Scenario Settings
Colorado River Basin Issues	Combination of short- and long-term Colorado River Basin yield reductions and curtailments due to Colorado River Basin administration and Compact compliance.	<u>High Impacts to Yields</u> • 5-year 25% Reduction in CBT/Windy Gap • 1-year 100% curtailment of CBT/Windy Gap • Chronic 10% reduction in CBT/Windy Gap <u>Moderate Impacts to Yields</u> • 5-year 25% Reduction in CBT/Windy Gap • 1-year 100% curtailment of CBT/Windy Gap <u>Low Impacts to Yields</u> • 2-year 25% Reduction in CBT/Windy Gap

Table 5-9 shows how the prioritized risks were included in the IWRP. Certain risks were included as a driver for Planning Scenarios, as described above. Demand risks were primarily included by incorporating their potential impacts into the updated demand forecasts as described in Section 4. Hydrology risks were primarily included by incorporating their potential impacts into the updated hydrology as described in Section 6. Colorado River Basin impacts were explicitly modeled in the GSM. Water Rights risks were included in both the Planning Scenarios and in the water rights evaluation described in Section 10. Any risks that were not included using the above methodology will be included in the Adaptive Plan that will describe specific conditions to monitor and corresponding actions to trigger if the risk occurs.

Table 5-9. Methodology for Implementing Prioritized Risks in the IWRP

ID	Risk Name	IWRP Inclusion Methodology
CR1	Colorado River Basin Administrative Actions	Planning Scenarios
IO9	Increased Frequency/Severity of Poudre Wildfires	Adaptive Plan
WR2	Competition for New Water Rights	Water Rights Assessment Tool
CC1	Colorado River Administration CC Impacts	Planning Scenarios
CC3	Extended Droughts	IWRP Hydrology Dataset
CC4	Hydrologic CC Impacts	IWRP Hydrology Dataset
CR10	Yield Reduction: Multi-Year	Simulated in GSM
D10	Regional Water Issues: Long Term	Adaptive Plan
CR9	Yield Reduction: Extended	Simulated in GSM
CC2	Evaporation Rate CC Impacts	Adaptive Plan
CC5	Increased Extreme Events	IWRP Hydrology Dataset
CC6	Municipal Water Use CC Impacts	IWRP Demand Projections
CC7	Water Rights Administration CC Impacts	Planning Scenarios and WADT
CR11	Yield Reduction: Single Year	Simulated in GSM
CR3	Chronic Yield Reduction: Windy Gap	Simulated in GSM
D4	Demand Hardening	Adaptive Plan
D6	High Impact Water Rates	IWRP Demand Projections
D7	Increased Suburban Growth	IWRP Demand Projections
IO17	Water Quality Regulation Changes	Adaptive Plan

ID	Risk Name	IWRP Inclusion Methodology
IO5	Environmental Permitting Problems	Adaptive Plan
WR6	Water Rights Change Complexity	Planning Scenarios and WR Assessment Tool
CR4	Chronic Yield Reduction: Windy Gap and CBT	Simulated in GSM
CR5	Total Curtailment: Multi-Year, Windy Gap	Simulated in GSM
CR8	Total Curtailment: Single Year, Windy Gap and CBT	Simulated in GSM
D12	Service Area Expansion	Adaptive Plan
WR1	CBT Operational Changes	Adaptive Plan
CR6	Total Curtailment: Multi-Year, Windy Gap and CBT	Simulated in GSM
IO6	GW supplies cannot be used by Greeley	Adaptive Plan
D2	Demand Growth Exceeds Forecast	IWRP Demand Projections
IO10	Multi-Year CBT Infrastructure Outage	Adaptive Plan

6.0 FUTURE HYDROLOGY ANALYSIS

6.1 METHODOLOGY

The IWRP's future hydrology analysis developed a new climate change hydrology dataset to be simulated in the GSM. This new hydrology dataset improved the robustness of GSM simulations by incorporating impacts to Greeley's water supplies from droughts of different intensity, duration, and frequency in combination with impacts from long-term changes in temperature and precipitation. This analysis applied the methodology, tools, and data originally developed by Fort Collins during their Water Supply Vulnerability Study (City of Fort Collins Utilities [FCU] 2019). In applying that study to the IWRP, Greeley reviewed the decisions and assumptions made and determined that they were appropriate for IWRP application.

Figure 6-1 summarizes the methodology used to develop the climate change hydrology dataset. Each step is summarized in this section, with additional detail documented in the IWRP GSM TM, included as Appendix C. The climate-related decisions in the WSVS (i.e., selection of models, emissions scenarios, downscaling methodology) were made to align the WSVS with the methodology used in the Joint Front Range Climate Change Vulnerability Study (Water Research Foundation [WRF] 2012). Results of Global Climate Models (GCM), which project future temperature and precipitation (T&P) mean changes, were applied to the Poudre River Watershed source. This ensemble or spread of T&P changes was evaluated and combinations of T&P changes were used to develop the selected hydrology. A series of models was used to determine the water legally and physically available to Greeley (referred to as entitlements) for each T&P condition.

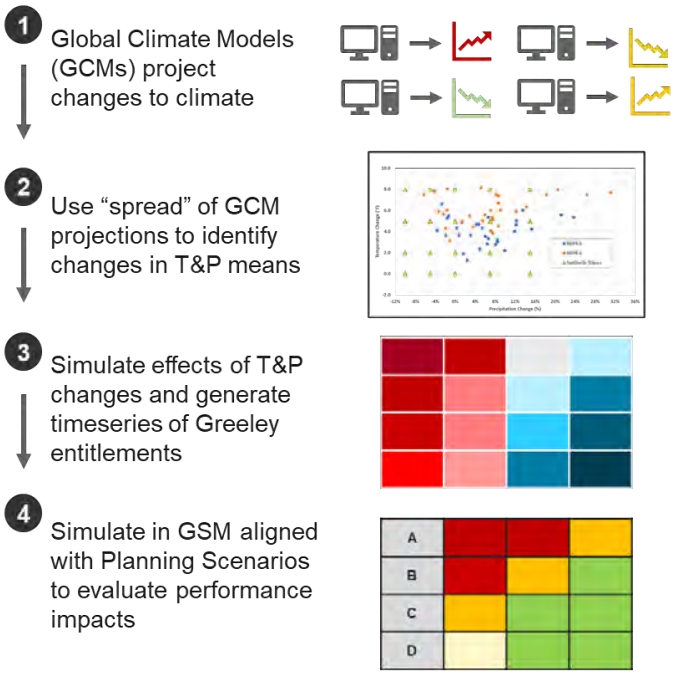

Figure 6-1. Summary of Climate Change Hydrology Dataset Development

The first step in developing the climate change hydrology dataset was establishing the long-term change in climate that could occur in Greeley's source watersheds. GCMs project how long-term changes in climate, specifically T&P, could occur based on different emission scenarios, warming trends, and other methodologies. This approach applied two emission scenarios to the full suite of available GCMs: Representative Concentration Pathway (RCP) 4.5 assumes emissions peak around 2040 and then decline, while RCP 8.5 assumes emissions continue to rise throughout the twenty-first century.

The T&P changes compared to historical climate conditions projected by the GCMs in the Upper Poudre Watershed between 2050 and 2074 for the two emissions scenarios described above is shown in **Figure 6-2**. The two respective GCMs used here project that the climate (i.e., mean annual temperature) will be 2°F and 8°F warmer but vary in mean annual precipitation projections, with some projecting a 5 percent drier climate and others projecting a 20 percent wetter climate or more. The yellow triangles in **Figure 6-2** are the combinations of T&P changes used in the IWRP. The selected T&P changes capture a majority of the T&P changes projected by the GCMs and include a drier condition (i.e., 10 percent less precipitation, the left-most column of yellow triangles) consistent with a conservative planning approach.

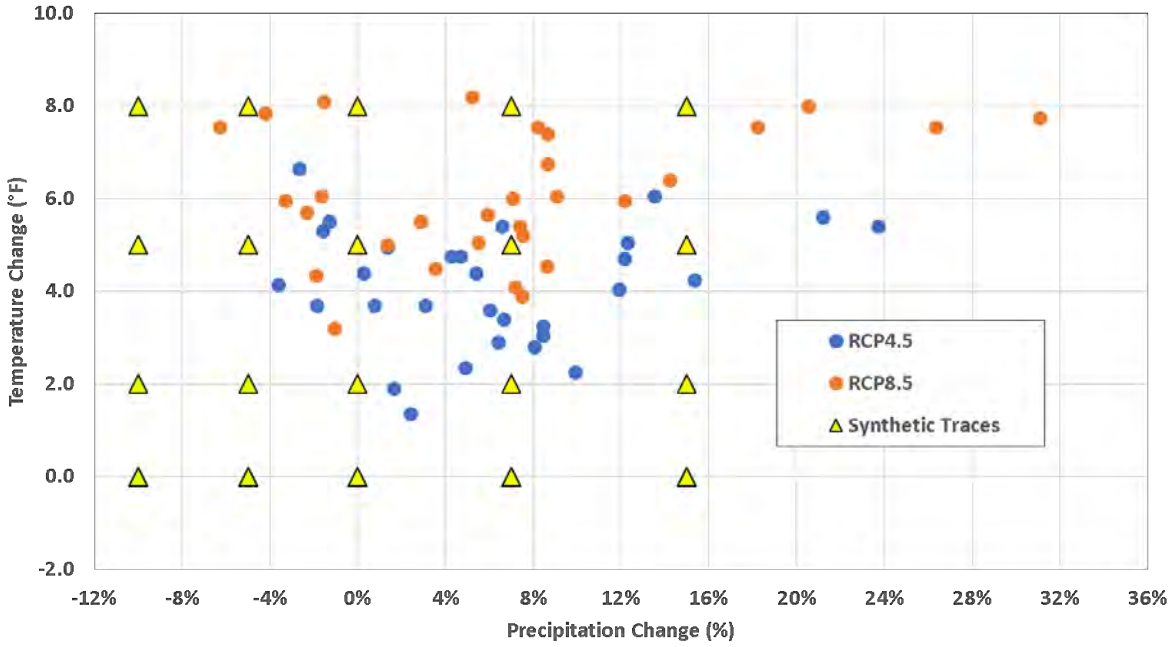

Figure 6-2. Projected Changes in T&P Means in the Upper Poudre Watershed Between 2050 and 2074

The selected T&P changes were applied to historical weather data and simulated in a hydrology model to generate natural watershed runoff in the Big Thompson, Colorado, and Poudre River Basins. The hydrology model developed for the Joint Front Range Climate Vulnerability Study (WRF 2012) was used to generate natural watershed runoff. Prior to applying the T&P changes, the historical weather data was re-sequenced to generate new potential drought conditions, with six sequences selected based on their unique drought conditions. Ultimately 120 timeseries of natural watershed runoff (20 T&P changes applied to six drought conditions) were generated.

To translate natural watershed runoff in the Big Thompson and Poudre River Watersheds into legally and physically available water supplies for Greeley (known as entitlements), the existing BTBN Model and the Poudre Basin Network (PBN) Model were applied. To determine Greeley's quota from the CBT Project, Northern Water's CBT quota model was applied. Because the PBN model includes all water users in the basin, the IWRP simulated the PBN model under the two future conditions described below:

- PBN Run 2, as defined in "Summary of NISP/HSWSP CTP Model Runs and Modeling Conditions" (CDM Smith 2013) was selected for the near-term.
- A modified version of the CTP PBN Run 8, "Summary of NISP/HSWSP CTP Model Runs and Modeling Conditions" (CDM Smith 2013) was selected for the long-term futures. These assumptions were further modified for the IWRP to exclude the expanded Seaman project and turn on CBT Carryover.

Initial simulations of the climate change hydrology in the BTBN and PBN models showed a significant increase of yields from junior water right systems under warming conditions. Analysis showed this

increase was due to the peak runoff shifting in time and becoming misaligned from the agricultural demands (which are a majority of the senior water rights in the basins). To prevent overestimation of entitlements from Greeley's junior water rights, the IWRP shifted agricultural demands in the BTBN and PBN models forward by one month for the +5°F and +8°F warmer climates, shown conceptually in **Figure 6-3**. Adjustments to agricultural demands outside this shift were considered but ultimately deemed to be outside the scope of this project.

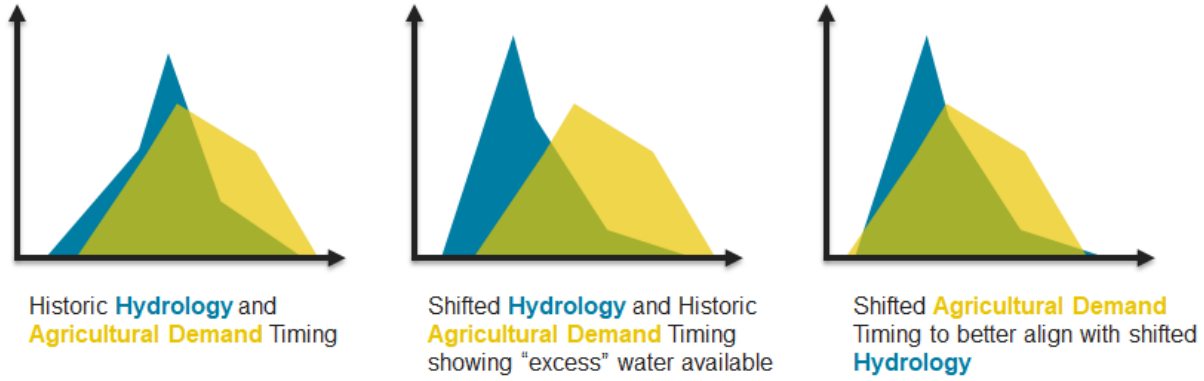

Figure 6-3. Conceptual Visual of Why Agricultural Demands Were Shifted for the IWRP

The final step in generating the climate change hydrology dataset was applying Greeley's water rights ownership and corresponding conditions to outputs from the BTBN and PBN models to determine Greeley's entitlements from those basins. Due to the effects of climate change on the timing and volume of runoff, monthly and annual volumetric limits associated with Greeley's water rights were applied to the results. These monthly and annual volumetric limits are based on historical hydrologic patterns. As climate change pushes the runoff season earlier in spring, Greeley could see reduced entitlements despite available water. Greeley's entitlements from the climate change hydrology dataset capture the potential effect of the administrative constraint.

The climate change hydrology dataset developed using the methodology described above robustly captures the impacts of climate change and new possible droughts to Greeley's entitlements.

6.2 DROUGHT CONDITIONS VARIABILITY RESULTS

This section presents how the different drought conditions selected for the IWRP could affect Greeley's entitlements before climate change is applied. Annual entitlement values shown in this section are determined from outputs of PBN, BTBN, and CBT Models. As part of the Ft. Collins WSVS, six timeseries of droughts were selected based on how the drought was characterized compared to historical droughts. These droughts were also selected to be, on average, more severe than historical drought conditions, in alignment with a conservative planning methodology. The six drought conditions and their corresponding historical characterization is shown in **Table 6-1**. As an example, **Figure 6-4** shows the timeseries of Greeley's annual entitlements for historical hydrology and Timeseries 63. In Timeseries 63, there is a three-year period near the end of the timeseries where total annual entitlements are at or below the 2002 value. This indicates a short and severe drought condition.

Table 6-1. Drought Timeseries Selected for the IWRP

Timeseries ID	Drought Characterization
15	Similar 10-year drought cycle to historical, greater severity
47	4 2002s in a 10-year period
52	Similar to Historical Drought Conditions
63	Back-to-Back-to-Back 2002s
67	Severe 5-year drought
95	Drought and aridification

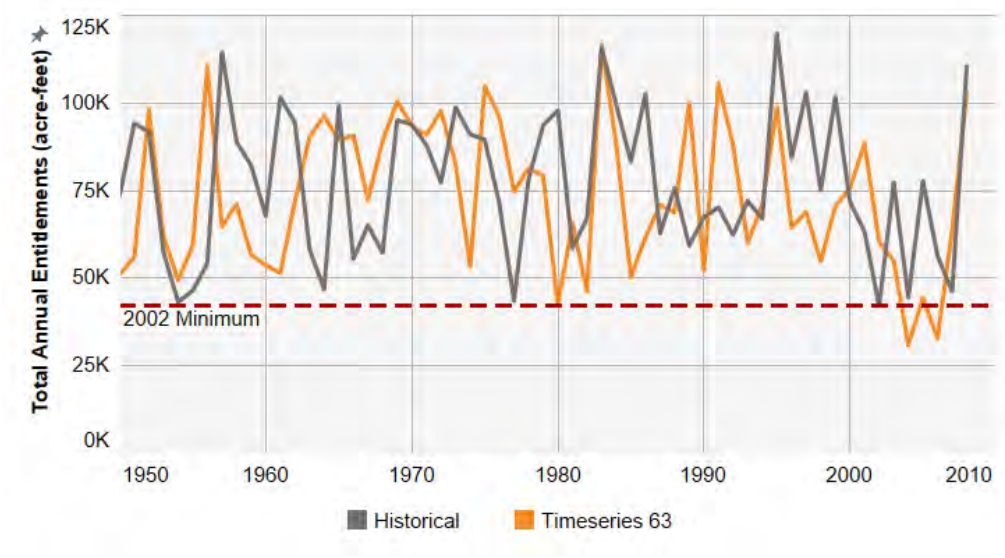

Figure 6-4. Annual Entitlements Timeseries of Historical and Synthetic Sequence 63

To numerically characterize drought conditions in the six drought timeseries, three statistics were evaluated: Greeley's annual entitlements plus the five-year and 10-year mean of those annual entitlements. These quantify the severity of individual years, mid-duration droughts, and longer-term drought cycles. **Figure 6-5** shows, using a box plot distribution, the variability of Greeley's annual entitlements for historical hydrology compared to the six drought timeseries. In a box plot distribution, the solid line is the median value with the boxes extending to the 25th and 75th percentiles and the whiskers extending to the 5th and 95th percentile. Comparing the distribution of the historical data to the drought timeseries shows how the six drought timeseries have more frequent occurrences of single-year entitlements below the 2002 minimum.

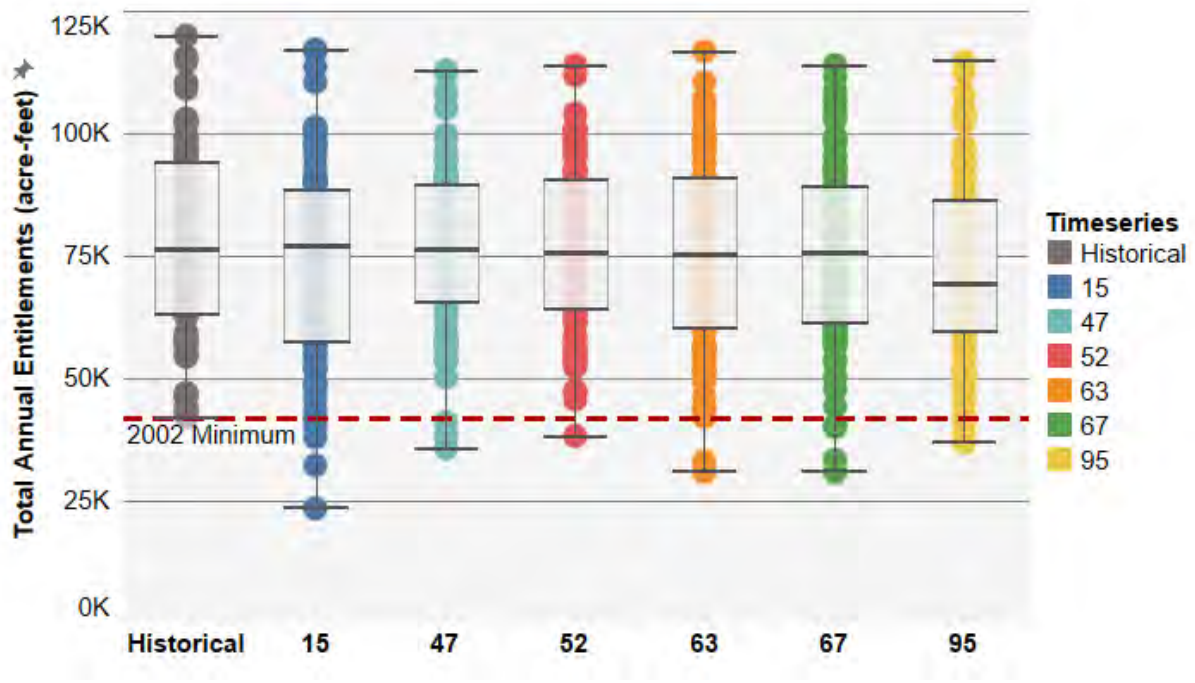

Figure 6-5. Distribution of Annual Entitlements for Historical and Synthetic Hydrology

Figure 6-6 shows, using a box plot distribution, the variability of the five-year and 10-year Greeley annual entitlements mean for historical hydrology compared to the six drought timeseries. Comparing the distribution of the historical data to the drought timeseries shows how the six drought timeseries have more severe mid- and long-term droughts compared to the historical record. For example, nearly all drought traces have many occurrences of a 10-year mean below the historical low of 69,000 acre-feet per year. A similar trend is seen in the five-year mean. This indicates the six drought timeseries have conditions with significantly drier mid- and long-term droughts.

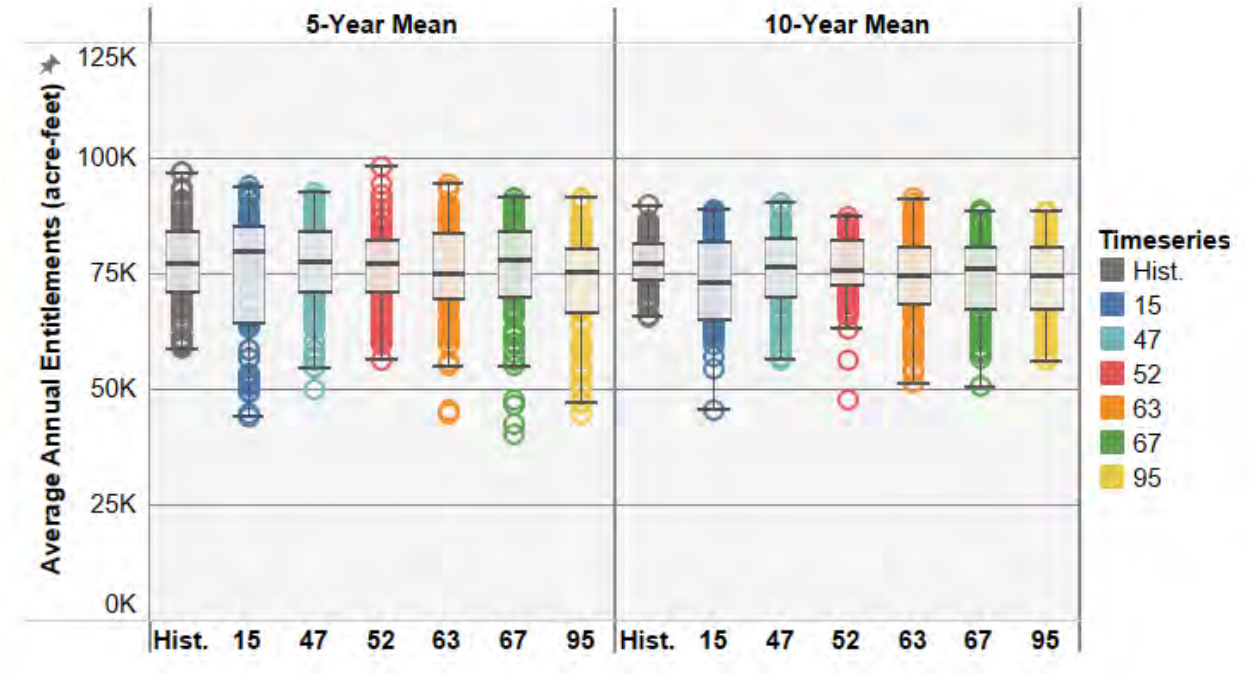

Figure 6-6. Distribution of 5-Year and 10-year Mean Annual Entitlements for Historical and Synthetic Hydrology

The results above show the six drought timeseries selected for the IWRP will stress Greeley's water supply system with droughts of greater intensity, duration, and frequency than the historical record. Using droughts of greater intensity, duration, and frequency than the historical record for planning is consistent with a conservative planning methodology.

6.3 LONG-TERM CLIMATE CHANGE RESULTS

This section presents how the climate-change-driven T&P mean changes could impact Greeley's entitlements from the three major systems (Poudre River, CBT Project, and Big Thompson River). Results presented are for Greeley's average annual entitlements, (e.g., legally and physically available water) displayed using a T&P Grid, and are shown conceptually in **Figure 6-7**. Each cell in the grid shows the average annual entitlement, averaged across the six drought timeseries described above, for a single T&P change condition.

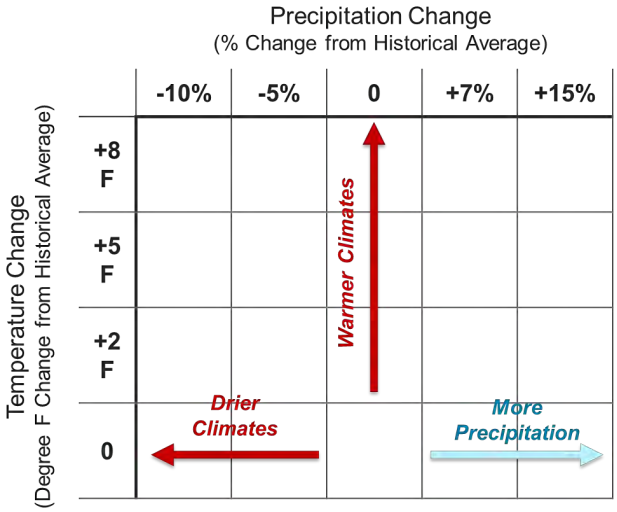

Figure 6-7. Example of T&P Offset Results Presentation Grid

Figure 6-8 shows the effects of climate change on entitlements across Greeley's entire water supply system. These results were used to develop the conclusion statements and associated confidence in those conclusion statements, shown in **Table 6-2**. In summary, Greeley's water supply system is vulnerable to warming and/or drying climates. Results indicate that increases in precipitation could offset impacts to Greeley's entitlements from a warming climate. However, there is significant uncertainty in how a shifting hydrograph could impact water use and administration. Additionally, the models used to allocate natural watershed runoff were not designed to account for a shifting hydrograph and may not simulate that impact with confidence. This is because demand patterns (both agricultural and municipal) and water right allocations are fixed based on historical use. It is possible that in response to a significantly shifted hydrograph, both demands and water right allocations could change. Thus, the effects of a warmer climate with increased precipitation on Greeley's entitlements cannot be confidently quantified. Because of these uncertainties, the IWRP did not include warmer climates with increased precipitation when developing future recommendations.

Total Water Supply System
Average Annual Entitlements (acre-feet per year)

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	50,800	59,200	67,500	76,600	83,500
+5F	51,000	59,000	67,100	75,700	82,200
+2F	58,800	68,100	75,400	83,600	88,300
0	59,300	68,300	75,400	82,600	87,200

Change from 0/0 Climate
Average Annual Entitlements & Percent

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-24,600 -33%	-16,200 -21%	-7,800 -10%	1,200 2%	8,100 11%
+5F	-24,300 -32%	-16,300 -22%	-8,300 -11%	400 0%	6,800 9%
+2F	-16,600 -22%	-7,300 -10%	0 0%	8,200 11%	13,000 17%
0	-16,100 -21%	-7,100 -9%	0 0%	7,200 10%	11,800 16%

Figure 6-8. Average Annual Total Water System Entitlements Incorporating Climate Change Impacts

Table 6-2. Conclusion Statements of Total System Climate Change Impacts

Conclusion Statement	Confidence	Comment
Droughts of greater duration, frequency, and severity than observed are possible under current climate	**High**	*Results show these conclusions, they are consistent with other studies, and make logical sense.*
Climates with less precipitation will reduce Greeley's water supply system yields	**High**	
Warmer climates will impact Greeley's water supply system	**High**	
Greeley's water supply system is more vulnerable to reductions in precipitation than warmer temperatures	**High**	
Reductions in precipitation could decrease Greeley's entitlements between 20% and 30%	**Moderate**	*Specific yield reductions are difficult to quantify, but values in this range are plausible*
Climates with increased precipitation will mitigate impacts of a warming climate	**Low**	*Impacts from hydrograph changes cannot be confidently modeled with existing tools.*

Greeley's total water supply system entitlements derive from three major systems, with the Poudre River System divided into an upper and lower portion based on how these supplies can be delivered to Greeley. The proportion of typical entitlements from each system is shown in **Figure 6-9**. Each system has unique dynamics which can be impacted differently by climate change. The following subsections detail climate change impacts to each of these three systems.

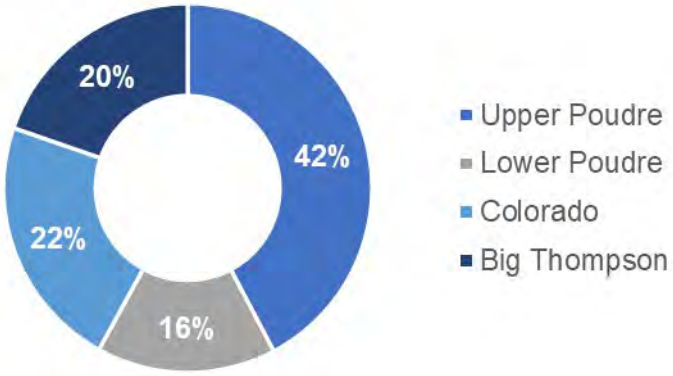

Figure 6-9. Distribution of Greeley's Typical Entitlements by Major System

6.3.1 Poudre River System Results

Figure 6-10 shows effects of climate change on Greeley's entitlements from the Upper Poudre System (e.g., locations west of Interstate 25). **Figure 6-11** and **Figure 6-12** shows the effect of climate change on subsystems within the Upper Poudre System. This system is vulnerable to warmer and drier futures and could see entitlement reductions between 10 and 35 percent under those conditions. Warmer conditions with increased precipitation, while showing an increase in entitlements, are difficult to quantify with confidence. The Poudre Direct and WSSC subsystems are the most resilient against climate change impacts due primarily to their seniority, though Greeley could still have some entitlement reductions under warmer and drier conditions. The High Mountain Reservoirs, Seaman, and Upper Gravel subsystems are the most vulnerable to climate change impacts, with entitlements significantly reduced if the climate warms by 5°F. This is due to the agricultural demands, which were shifted forward by one month in the 5°F and 8°F climate conditions. This is because these systems are more junior than direct Poudre rights. Other subsystems are moderately vulnerable to climate change impacts.

Upper Poudre System
Average Annual Entitlements (acre-feet per year)

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	19,700	22,400	25,300	30,100	35,400
+5F	18,700	20,900	24,300	28,900	34,600
+2F	22,800	26,600	30,500	36,000	40,200
0	22,500	26,300	29,800	35,200	39,600

Change from 0/0 Climate
Percent Change in Average Annual Entitlements

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-34% -10,200	-25% -7,400	-15% -4,500	1% 300	19% 5,600
+5F	-37% -11,100	-30% -8,900	-19% -5,600	-3% -900	16% 4,800
+2F	-24% -7,100	-11% -3,200	2% 600	21% 6,200	35% 10,400
0	-25% -7,300	-12% -3,600	0% 0	18% 5,300	33% 9,800

Figure 6-10. Average Annual Upper Poudre System Entitlements Incorporating Climate Change Impacts

Upper Poudre Subsystems
Average Annual Entitlements (acre-feet per year)

	Delta T	Delta P -10%	-5%	0	+7%	+15%
Poudre Directs	+8F	8,900	9,000	9,000	9,200	10,000
	+5F	8,900	8,900	9,000	9,200	9,900
	+2F	8,900	9,100	9,400	10,100	10,900
	0	9,000	9,100	9,400	10,200	11,100
HMR	+8F	1,500	2,400	3,400	4,900	6,100
	+5F	1,000	1,700	2,900	4,400	5,900
	+2F	2,600	3,900	4,900	6,100	7,000
	0	2,500	3,700	4,700	6,000	6,900
Seaman	+8F	700	1,400	2,500	4,400	6,300
	+5F	400	1,000	2,200	4,300	6,500
	+2F	1,600	2,900	4,300	6,300	7,700
	0	1,600	3,000	4,200	6,100	7,700
Upper Gravel	+8F	0	0	100	600	1,800
	+5F	0	0	200	700	1,800
	+2F	100	200	800	2,000	3,200
	0	100	200	800	2,200	3,400

Change from 0/0 Climate
Percent Change in Average Annual Entitlements

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-5%	-5%	-4%	-2%	6%
+5F	-6%	-6%	-5%	-3%	5%
+2F	-5%	-4%	0%	7%	16%
0	-5%	-4%	0%	8%	17%
+8F	-69%	-49%	-28%	4%	30%
+5F	-78%	-64%	-39%	-7%	25%
+2F	-44%	-17%	3%	31%	48%
0	-47%	-20%	0%	27%	48%
+8F	-83%	-67%	-41%	3%	50%
+5F	-89%	-77%	-48%	1%	53%
+2F	-62%	-31%	1%	49%	81%
0	-63%	-30%	0%	45%	82%
+8F	-100%	-96%	-83%	-32%	114%
+5F	-99%	-97%	-78%	-19%	114%
+2F	-94%	-74%	-8%	138%	289%
0	-90%	-77%	0%	159%	304%

Figure 6-11. Average Annual Upper Poudre Subsystems' Entitlements Incorporating Climate Change Impacts

Upper Poudre Subsystems
Average Annual Entitlements (acre-feet per year)

	Delta T	Delta P -10%	-5%	0	+7%	+15%
WSSC	+8F	3,900	4,200	4,500	4,700	4,700
	+5F	3,900	4,200	4,400	4,600	4,800
	+2F	4,100	4,400	4,500	4,600	4,600
	0	4,200	4,400	4,500	4,600	4,600
Larimer and Weld	+8F	3,700	4,300	4,700	5,200	5,300
	+5F	3,400	3,900	4,300	4,500	4,400
	+2F	4,300	5,000	5,500	5,600	5,600
	0	4,100	4,700	4,900	4,900	4,700
New Cache	+8F	1,000	1,100	1,100	1,200	1,200
	+5F	1,100	1,200	1,300	1,300	1,300
	+2F	1,100	1,100	1,200	1,200	1,300
	0	1,200	1,200	1,300	1,300	1,300

Change from 0/0 Climate
Percent Change in Average Annual Entitlements

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-12%	-5%	0%	4%	6%
+5F	-13%	-7%	-1%	4%	7%
+2F	-8%	-2%	1%	3%	4%
0	-7%	-3%	0%	2%	2%
+8F	-25%	-13%	-4%	6%	7%
+5F	-31%	-20%	-11%	-9%	-10%
+2F	-12%	2%	11%	15%	14%
0	-17%	-4%	0%	0%	-5%
+8F	-22%	-16%	-10%	-4%	-1%
+5F	-10%	-4%	0%	4%	6%
+2F	-13%	-11%	-6%	-3%	0%
0	-8%	-4%	0%	3%	4%

Figure 6-12. Average Annual Upper Poudre Subsystems' Entitlements Incorporating Climate Change Impacts (Continued)

Figure 6-13 shows the effect of climate change on Greeley's entitlements from the Lower Poudre System (e.g., locations east of Interstate 25). This system is vulnerable to drier climates but is likely resilient against warmer climates and changes to agricultural demand. This is due to the influence of return flows, which are greater at this reach of the Poudre, lessening the influence of snowmelt on the hydrograph.

Lower Poudre System
Average Annual Entitlements (acre-feet per year)

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	9,100	10,300	11,300	12,100	12,600
+5F	9,500	10,800	11,400	12,200	12,500
+2F	9,600	10,400	10,900	11,900	12,600
0	9,900	10,800	11,100	12,100	12,500

Change from 0/0 Climate
Percent Change in Average Annual Entitlements

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-18% -2,000	-7% -800	2% 200	9% 1,000	13% 1,400
+5F	-14% -1,600	-3% -300	2% 300	10% 1,100	12% 1,300
+2F	-14% -1,600	-6% -700	-2% -300	7% 800	13% 1,400
0	-11% -1,300	-3% -400	0% 0	8% 900	12% 1,300

Figure 6-13. Average Annual Lower Poudre System Entitlements Incorporating Climate Change Impacts

These results presented above were used to develop the conclusion statements and associated confidence in those conclusion statements, shown in **Table 6-3**. In summary, the Poudre System is vulnerable to climate change impacts, with the Poudre Direct and WSSC subsystems being the most resilient against climate change impacts. However, due to the difficulty in confidently simulating the impacts of climate change on the complex operations of the Poudre River Basin, there is significant uncertainty with the numerical impact values. One significant trend from the results is that the greater the seniority of the subsystem, the more resilient the subsystem is against impacts from climate change.

Table 6-3. Conclusion Statements of Upper Poudre System Climate Change Impacts

Conclusion Statement	Confidence	Comment
Poudre Direct and WSSC entitlements are the most resilient to climate change and agricultural demand timing impacts.	**High**	• *Greeley's ability to use entitlements will be evaluated from GSM results.* • *Uncertainties around results are captured in the 10% entitlement reduction risk.*
HMRs, Seaman, and Upper Gravel entitlements are the most vulnerable to climate change and agricultural demand timing impacts.	**High**	
Larimer & Weld and New Cache entitlements are moderately vulnerable to climate change and agricultural demand timing impacts.	**High**	
The Lower Poudre System is moderately vulnerable to climate change impacts but resilient to agricultural demand timing impacts.	**High**	
The changes in entitlements due to climate change will occur as simulated.	**Low**	*There is significant uncertainty in how long-term climate will impact hydrology, operations, and yields in the Poudre Basin*

HMR = High Mountain Reservoir

6.3.2 Colorado-Big Thompson Project System Results

Figure 6-14 shows effect of climate change on Greeley's entitlements from the CBT System (e.g., driven by the quota set by Northern). This system is vulnerable to warmer and drier futures and could see entitlement reductions between 5 and 35 percent under those conditions. Warmer conditions with increased precipitation show decreases in entitlements due to the methodology Northern Water uses to set the quota (e.g., it is supplemental water and greater precipitation could reduce the need for CBT water supplies and thus result in a lower quota). These results presented were used to develop the conclusion statements and associated confidence in those conclusion statements, shown in **Table 6-4**. It is important to note that events that could compound from warmer and/or drier conditions, such as a Colorado River Compact curtailment, are not included in these results. The IWRP is evaluating impacts from the Colorado River Compact curtailment as a separate risk, as described in Section 2.2.

CBT System
Average Annual Entitlements (acre-feet per year)

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	10,100	12,100	14,000	15,500	15,500
+5F	10,900	13,000	14,700	15,800	15,400
+2F	11,800	13,800	15,200	15,800	15,100
0	12,400	14,300	15,700	15,700	14,900

Change from 0/0 Climate
Average Annual Entitlements & Percent

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-36% -5,600	-23% -3,600	-11% -1,700	-1% -100	-1% -200
+5F	-31% -4,800	-17% -2,700	-6% -1,000	1% 100	-2% -300
+2F	-25% -3,900	-12% -1,900	-3% -500	0% 100	-4% -600
0	-21% -3,300	-9% -1,400	0% 0	0% 0	-5% -800

Note: Windy Gap Yields Not Included

Figure 6-14. Average Annual CBT System Entitlements Incorporating Climate Change Impacts

Table 6-4. Conclusion Statements of CBT System Climate Change Impacts

Conclusion Statement	Confidence	Comment
Greeley's entitlements from the CBT Project are vulnerable to hydrologic climate change impacts.	**High**	*Other climate change impacts (basin-wide, demand management, agricultural uses) are not accounted for in the climate hydrology. Impacts of curtailments of Colorado Basin supplies are captured as a separate risk.*
The changes in entitlements due to climate change will occur as simulated.	**Low**	*There is significant uncertainty in how long-term climate will impact hydrology, operations, and yields from the CBT Project.*

6.3.3 Big Thompson River System Results

Figure 6-15 shows effect of climate change on Greeley's entitlements from the Big Thompson System. **Figure 6-16** shows the effect of climate change on subsystems within the Big Thompson System. The system is vulnerable to warmer and drier futures and could see entitlement reductions between 15 and 50 percent under those conditions. Warmer conditions with increased precipitation, while showing an increase in entitlements, are difficult to quantify with confidence.

Evaluating the entitlement impacts of the Big Thompson subsystems highlights the sensitivity of these systems to a changing hydrograph and timing of agricultural demands. Entitlements from Boyd Lake, Loveland Lake, and Seven Lake inflows all increase in entitlements if climate warms by 2°F, but are then significantly reduced if climate warms by 5°F. This is due to the agricultural demands, which were shifted forward by one month in the 5°F and 8°F climate conditions. The Direct GLIC subsystem has a different behavior, but still exhibits high sensitivity to both climate warming and the timing of agricultural demands.

Big Thompson System
Average Annual Entitlements (acre-feet per year)

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	7,100	9,500	12,000	14,000	15,100
+5F	7,100	9,500	11,900	14,000	14,900
+2F	9,900	12,400	14,000	15,100	15,600
0	9,700	12,100	13,900	14,800	15,400

Change from 0/0 Climate
Average Annual Entitlements & Percent

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-49% -6,800	-31% -4,400	-13% -1,900	1% 100	9% 1,200
+5F	-49% -6,800	-31% -4,400	-14% -2,000	1% 100	7% 1,000
+2F	-28% -4,000	-11% -1,500	1% 100	9% 1,200	12% 1,700
0	-30% -4,200	-13% -1,800	0% 0	7% 900	11% 1,500

Figure 6-15. Average Annual Big Thompson System Entitlements Incorporating Climate Change Impacts

Big Thompson Subsystems
Average Annual Entitlements (acre-feet per year)

	Delta T	Delta P -10%	-5%	0	+7%	+15%
Direct GLIC	+8F	2,300	2,700	3,200	3,800	4,500
	+5F	3,300	3,900	4,600	5,500	6,200
	+2F	2,000	2,400	2,800	3,400	4,200
	0	2,700	3,200	3,800	4,500	5,400
Boyd Lake Inflows	+8F	1,200	2,100	3,100	3,400	3,200
	+5F	800	1,600	2,300	2,400	2,000
	+2F	2,800	3,800	4,200	4,000	3,400
	0	2,300	3,100	3,400	3,000	2,400
Lake Loveland Inflows	+8F	2,400	3,000	3,600	4,200	4,500
	+5F	2,100	2,700	3,200	3,900	4,300
	+2F	3,300	3,800	4,200	4,500	4,700
	0	3,000	3,700	4,100	4,500	4,600
Seven Lakes Inflow	+8F	1,200	1,700	2,200	2,700	3,000
	+5F	900	1,400	1,800	2,200	2,500
	+2F	1,800	2,400	2,800	3,200	3,300
	0	1,700	2,100	2,600	2,900	3,000

Change from 0/0 Climate
Average Annual Entitlements & Percent

Delta T	Delta P -10%	-5%	0	+7%	+15%
+8F	-40%	-28%	-16%	0%	19%
+5F	-13%	3%	22%	44%	64%
+2F	-46%	-36%	-25%	-10%	10%
0	-29%	-16%	0%	19%	43%
+8F	-64%	-37%	-8%	1%	-6%
+5F	-77%	-53%	-32%	-29%	-42%
+2F	-16%	13%	25%	19%	2%
0	-32%	-8%	0%	-11%	-30%
+8F	-41%	-26%	-13%	1%	9%
+5F	-50%	-35%	-21%	-4%	4%
+2F	-21%	-7%	2%	10%	14%
0	-26%	-10%	0%	8%	12%
+8F	-54%	-37%	-18%	1%	13%
+5F	-64%	-48%	-34%	-17%	-6%
+2F	-31%	-11%	5%	19%	25%
0	-36%	-19%	0%	9%	13%

Figure 6-16. Average Annual Big Thompson Subsystems' Entitlements Incorporating Climate Change Impacts

These results presented were used to develop the conclusion statements and associated confidence in those conclusion statements, shown in **Table 6-5**. It is important to note that events that could compound from warmer and/or drier conditions, such as a Colorado River Compact curtailment, are not included in these results.

Table 6-5. Conclusion Statements of Big Thompson System Climate Change Impacts

Conclusion Statement	Confidence	Comment
Greeley's entitlements from the Big Thompson System are vulnerable to climate change impacts.	**High**	*Due to the junior nature of the Big Thompson Subsystems Greeley has ownership in, entitlements are likely to be highly vulnerable to changes in water supply volume and timing changes. This could be compounded by how senior agricultural users change their water supply use in the future.*
Greeley's entitlements from the Big Thompson System are vulnerable to the timing of agricultural demands.	**High**	
Warmer climates with no change in precipitation or an increase in precipitation will increase Greeley's entitlements from the Big Thompson System.	**Low**	*There is significant uncertainty in how long-term climate will impact hydrology, operations, and yields within the Big Thompson River system.*

6.4 CONCLUSION

The IWRP's future hydrology analysis developed a new climate change hydrology dataset that captures the potential impacts of long-term climate change paired with droughts of increasing intensity, duration, and frequency. GCMs project changes in long-term T&P means for the Upper Poudre Watershed between 2050 and 2074 for both a moderate and high emissions scenario. GCM results indicate that future climates will be between 2°F and 8°F warmer with between 10 percent less precipitation and 15 percent more precipitation. This spread of T&P changes was applied to a series of models that quantified how changes could impact Greeley's entitlements (e.g., water legally and physically available to Greeley).

Evaluating how changes in long-term T&P means could impact Greeley's entitlements showed consistent impacts across the three major river basins. Greeley's water supply system is vulnerable to warmer and/or drier climates, with results indicating that these climates could reduce Greeley's entitlements. Some subsystems such as Poudre Direct and WSSC are more resilient against climate change impacts. Results from future climates that are warmer but have increased precipitation, while showing a potential increase in Greeley's entitlements, are highly uncertain. Warmer temperatures could alter the runoff pattern and hydrograph, and the effect of that shift on the complex operations within the Big Thompson River and Poudre River basins cannot be confidently modeled. The most significant operational uncertainty in these basins is how agricultural demands and their corresponding water rights administration might change in response to a warmer climate. Results from this analysis showed that impacts to Greeley's entitlements from changes in agricultural demands could be as significant as impacts from climate change, especially in more junior water rights systems.

Results from this future hydrology analysis highlighted both the vulnerability of Greeley's water supply system to climate change impacts and the significant uncertainty of those impacts. The IWRP addressed these using the techniques listed below:

- Multiple climate change futures with increased warming were selected for the planning scenarios.
- Climate change conditions with increased precipitation were not included in planning scenarios due to the significant uncertainty around effects on entitlements.
- Some planning scenarios included an additional 10 percent reduction in entitlements to capture the uncertainty in agricultural demand and water rights administration impacts.

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7.0 TERRY RANCH PROJECT EVALUATION

This section provides an overview of the Terry Ranch Project and presents the methodology and assumptions used to incorporate that project into the IWRP modeling. The information on the Terry Ranch Project presented in this section is limited to what was relevant for the IWRP; additional information on the Terry Ranch Project can be found in Greeley's Terry Ranch Project information section of the Water & Sewer Department website.

7.1 OVERVIEW OF TERRY RANCH PROJECT

The Terry Ranch Project will develop approximately 1.2 million acre-feet of non-tributary (i.e., does not flow from or to a surface water supply source) groundwater in northwest Weld County. The Terry Ranch Project is an aquifer storage and recovery project. In this type of project, treated surface water can be injected into the aquifer and stored and then recovered at a future time to be treated and delivered as water supply. Once brought online, Terry Ranch Project water will be used as a supply source during droughts when surface water supplies are stressed. Greeley plans to operate Terry Ranch sustainably, such that the aquifer supplies will be available to Greeley in perpetuity and would not be depleted.

The 1.2 million acre-feet of Terry Ranch Project water (referred to as Terry Ranch Project native supply) is already in the ground and is protected from droughts and other identified risks such as wildfires and Colorado River Compact curtailments. The same aquifer with the Terry Ranch Project native supply can also be used to store excess surface water supply by injecting treated water into the aquifer. This allows Greeley to use the same infrastructure facilities to inject excess surface water supplies during wet years and extract/recover water from the aquifer in drought years.

To use the Terry Ranch Project, Greeley will need to develop new conveyance, treatment, and wellfield infrastructure and integrate it into the existing water supply system. **Figure 7-1** shows the major infrastructure features and their locations. Terry Ranch water will be extracted from primarily new wells, treated at a new centralized plant, and transmitted to Greeley via a new transmission pipeline. Water from the Terry Ranch Project will be delivered to Greeley via the existing Bellvue Transmission System using a new intertie with the Terry Ranch Transmission Pipeline. Facilities will be bi-directional, where surface water supplies can be delivered via the Bellvue Transmission System and injected into the Terry Ranch Aquifer. Note that extraction and injection cannot occur simultaneously.

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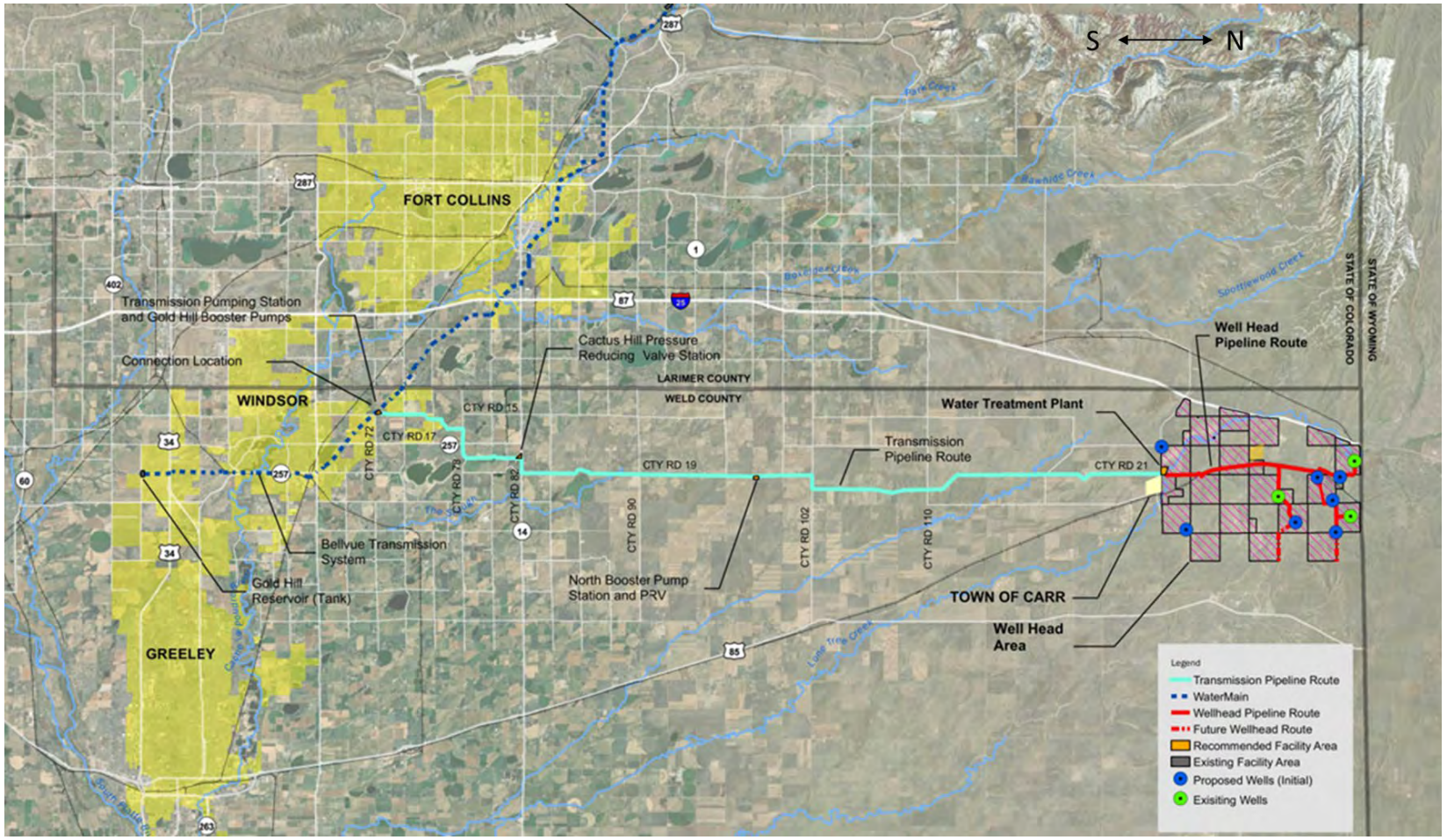

Figure 7-1. Terry Ranch Project Map. North is oriented on the right side of the map.

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7.2 SIMULATION IN THE GREELY SYSTEM MODEL

The IWRP evaluated a single Terry Ranch condition where it is fully developed and integrated into Greeley's water supply system. In practice, the Terry Ranch Project can be developed in phases which will be evaluated in future studies. In this condition, Terry Ranch can inject surface water supplies delivered via the Bellvue treatment plant and extract Terry Ranch native and injected supplies for delivery to Greeley up to the project's currently estimated maximum size. This section summarizes how Terry Ranch was implemented in and operated by the GSM for the IWRP. A more detailed description is included in the GSM TM, included as Appendix C.

Table 7-1 lists the key physical and infrastructure assumptions in the GSM of the Terry Ranch Project used for the IWRP. These assumptions were based on the maximum size Greeley could ultimately build Terry Ranch out to as well as the best understanding of the well operations at the time of the IWRP.

Table 7-1. Summary of Terry Ranch Facility Assumptions Used in the GSM

Terry Ranch Feature	IWRP GSM Assumption
Initial Native Storage Volume	1,200,000 acre-feet
Maximum Aquifer Storage Capacity	1,500,000 acre-feet
Number of Wells[1]	30
Total Extraction Capacity	30 cfs
Extraction Losses	7%
Total Injection Capacity	22.5 cfs
Minimum Injection Rate	25% of Injection Capacity
Injection Losses	2%
Greeley Drought Restriction Policy	Level 1 Trigger: 75% of annual demands Level 2 Trigger: 60% of annual demands Level 3: Not Used

[1] Maximum feasible number of wells at the time of the IWRP.

cfs = cubic feet per second

When operating the Terry Ranch Project, the GSM is limited in its ability to balance injection and extraction to/from Terry Ranch with the surface water supply system. This is due to the monthly timestep and the limitations of GSM logic in capturing the nuances of Greeley's system that real-life operators can account for. For the IWRP, the Terry Ranch Project operating logic in the GSM was developed to best address these limitations and is summarized below:

1. On April 1, determine if Greeley's surface water storage on April 1 of the next year would be less than 0.75 years of demand (YOD) (e.g., a storage shortage).
   a. If a storage shortage is projected, the GSM proactively extracts water over the next 12 months from Terry Ranch to make up the deficit.
   b. If next year's projected storage is greater than 1.0 YOD, the GSM proactively injects water into Terry Ranch between October and April such that the excess storage is injected into Terry Ranch.
   c. If next year's projected storage is between 0.75 YOD and 1.0 YOD, Terry Ranch is not operated proactively for injection or extraction.
2. If during any month there is water entitled to Greeley that cannot be captured in the surface water system (referred to as a 'spill') that can be physically moved to Terry Ranch, the GSM opens injection pathways to reactively inject this spill volume into Terry Ranch.
3. If during any month Greeley would experience a demand shortage, the GSM reactively extracts this demand shortage volume from Terry Ranch.
4. Terry Ranch must always be operated at a minimum rate of 130 acre-feet per month (based on 30 wells) to sufficiently cycle the wells. If injectable supplies are not available, then the GSM will extract water from Terry Ranch to meet this minimum rate.

7.3 SUSTAINABLE USE

A unique aspect of the Terry Ranch Project in the context of the IWRP is its native volume of approximately 1.2 million acre-feet, significantly higher than Greeley's current demands. This native volume could be further increased with injection of surface water supplies into Terry Ranch up to a total of 1.5 million acre-feet. As opposed to surface water supplies that can vary significantly from year to year and are vulnerable to climate change impacts, water from Terry Ranch can be extracted as needed even during the most severe droughts. Greeley plans to operate Terry Ranch sustainably such that the aquifer supplies will be available to Greeley in perpetuity without being depleted. Certain future conditions could require the additional water resources opportunities described in Section 7.4.

As the IWRP simulated Terry Ranch in the GSM and used quantitative results to evaluate the performance of the system, the sustainable use of Terry Ranch had to be established. The primary metric used to establish sustainable use of Terry Ranch was the percent of aquifer storage at the end of a GSM simulation compared to the initial aquifer storage volume of 1.2 million acre-feet. GSM simulations were 86 years long and contained a variety of hydrology conditions that alternate between droughts of differing intensity, duration, and frequency with wetter years. If after 86 years of operation, the Terry Ranch Aquifer volume was at least 80 percent of the initial water supply volume of 1.2 million acre-feet, the long-term operations of Terry Ranch were considered sustainable. These criteria are an initial planning threshold used for the IWRP and will be refined and updated as further Terry Ranch analysis is completed.

7.4 ADDITIONAL WATER RESOURCES OPPORTUNITIES INCLUDED

The Terry Ranch Project is Greeley's long-term new water supply source to deliver sustainable and affordable water through increasing demands, a changing climate, and other potential risks. Its superior performance compared to other large water supply projects was previously determined and as such, other large water supply projects were not evaluated in the IWRP. However, two water resources opportunities that could improve the sustainability of Terry Ranch if needed were evaluated in the IWRP and are described below.

- **Additional Surface Water Rights**: Greeley has developed a water rights acquisition strategy that bridges water supply needs prior to Terry Ranch Project completion using water rights that can be integrated into Terry Ranch or supplement Greeley's growing non-potable system. If needed, Greeley could pursue more water rights than what is included in the existing water rights portfolio. For the IWRP, two surface water right conditions (moderate acquisition of water rights and low acquisition of water rights) were available if Terry Ranch sustainability was insufficient.
- **Retiming Storage**: Terry Ranch can store Greeley entitlements that cannot be captured in the surface water supply system (referred to as spills). These spills typically occur for a short duration during the runoff season. Due to limitations in Terry Ranch delivery and injection infrastructure, not all spills can be captured using the baseline assumed infrastructure. Greeley could develop retiming storage that would capture these excess spills, store them, then gradually inject them into Terry Ranch when there is pipeline capacity. This retiming storage project was defined conceptually for the IWRP, with a maximum assumed capacity of 15,000 acre-feet. Post-IWRP analysis will further develop this retiming storage concept.

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8.0 NEAR-TERM 10-YEAR ANALYSIS RESULTS

The IWRP near-term analysis simulated Greeley's current and baseline water rights portfolio in the GSM across the IWRP Planning Scenarios. This analysis established the performance of Greeley's currently planned water supply system to highlight potential future vulnerabilities and their severity. The current and baseline assumptions are described in Section 2.3. The Planning Scenario conditions applied in the GSM are shown in **Table 8-1**.

Table 8-1. Near-Term Planning Scenario Conditions

Planning Scenario Name	Climate Change	Colorado River Basin Impacts	Water Supply System
Unbearable	5°F Warmer	High Impacts	10% Reduced Yields
Stressed	5°F Warmer	Moderate Impacts	10% Reduced Yields
Continued Trends	2°F Warmer	Moderate Impacts	10% Reduced Yields
Optimistic	2°F Warmer	Low Impacts	No Reduction
No Climate Change	No Change	Low Impacts	No Reduction

Table 8-2 shows the simulated performance for the current and baseline water rights portfolios across the five planning scenarios. Values shown contain the GSM results across the six timeseries presented in **Table 6-1**. Cell values are colored with respect to the planning performance criteria of 1) drought restrictions occurring in less than 20 percent of years, 2) Level 3 drought restrictions occurring in less than 10 percent of years, and 3) meeting indoor demands in 100 percent of years. Results show that the current water rights portfolio will be insufficient to meet the planning performance criteria under the conditions in the *Continued Trends*, *Stressed*, and *Unbearable* planning scenarios. With the baseline water rights portfolio, the performance of the system under the *Continued Trends* conditions meets the planning performance criteria. The *Unbearable* and *Stressed* Planning Scenarios, while not meeting the overall percent of years in drought restrictions performance criteria, are close to meeting the Level 3 drought restrictions criteria. Indoor demands are met in all planning scenarios regardless of water rights portfolio.

Table 8-2. Near-Term Analysis Performance Results

Water Rights Portfolio	Planning Scenario	Percent of Years in Drought Restrictions	Percent of Years in Level 3 Drought Restrictions	Percent Of Years With April 1 Storage > 6 Months Of Indoor Demand	Percent Of Years Meeting Indoor Demands
Current	Unbearable	86%	51%	99.8%	100%
	Stressed	76%	41%	99.6%	100%
	Continued Trends	33%	14%	100%	100%
	Optimistic	15%	4%	100%	100%
	No Climate Change	11%	1%	100%	100%
Baseline	Unbearable	38%	12%	100%	100%
	Stressed	32%	11%	100%	100%
	Continued Trends	7%	0%	100%	100%
	Optimistic	0%	0%	100%	100%
	No Climate Change	0%	0%	100%	100%

Color Key Indicates Planning Performance Criteria: **Green** Passes, **Yellow** is close to meeting, **Red** Fails

Figure 8-1 shows the April 1 total system storage and drought restriction level under the *No Climate Change* Planning Scenario with Greeley's current water rights portfolio for one of the six hydrologies simulated, which included back-to-back-to-back 2002 conditions. Under these conditions, the water supply system does not need drought restrictions except in year 55 when a single Level 2 restriction is required. This is at the very end of the severe drought conditions and demonstrates strong resilience.

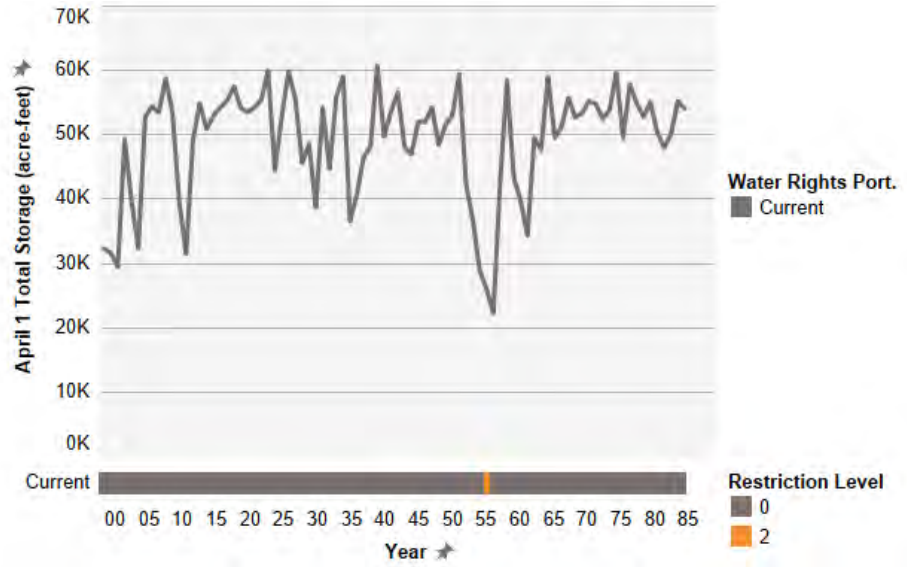

Figure 8-1. April 1 Storage Under No Climate Change Planning Scenario with Current Water Rights

Figure 8-2 shows the April 1 total system storage and drought restriction level under the *Continued Trends* planning scenario for the same sample hydrology as Figure 8-1 comparing the current and baseline water rights portfolio. With the current water rights portfolio, the water supply system needs three consecutive drought restrictions, including back-to-back level 3 restrictions during the severe drought period. When the baseline water rights are applied, the water supply system requires only a single level 2 restriction during the same drought period. This shows the benefit to the water supply system of changing all water rights as assumed in the baseline water rights portfolio.

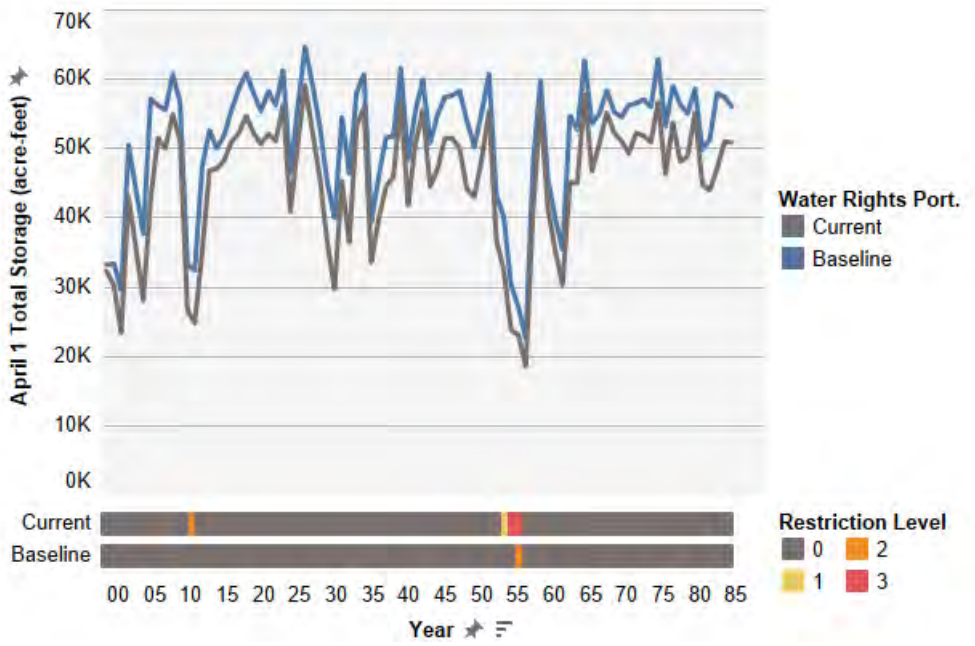

Figure 8-2. April 1 Total System Storage Under Continued Trends Planning Scenario Comparing Current and Baseline Water Rights

Results from the baseline analysis supported the conclusions below regarding Greeley's water supply system. Note that this analysis used Greeley's current demands of approximately 25,000 acre-feet, and the Terry Ranch Timing analysis described in Section 10.2 evaluates demand growth.

- The current water rights portfolio under current demand is sufficient to meet the planning scenario conditions anticipated to occur over the next decade. This includes conditions with mild warming and some Colorado River Basin risks.
- If the more stressful conditions of the *Continued Trends* planning scenario occur, Greeley will need the baseline water rights portfolio to meet planning performance criteria under current demands. This emphasizes the importance of Greeley changing existing water rights to municipal use in the near-term to improve robustness against more stressful futures.
- If the most stressful conditions in the *Unbearable* or *Stressed* planning scenarios occur, Greeley will need to do more than what is in the baseline water rights portfolio to meet planning performance criteria. This establishes the importance of the Terry Ranch Project to ensure a sustainable water supply for Greeley in the long-term.

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9.0 TERRY RANCH TIMING AND INTEGRATION RESULTS

The IWRP evaluated the Terry Ranch Project using two of the planning horizons. The Terry Ranch Timing analysis established the water supply system and demand conditions under which the Terry Ranch Project would be required. The Terry Ranch Integration analysis established how Greeley could use the Terry Ranch Project after it is fully integrated (e.g., extracting and injecting water at the maximum feasible capacity) and if that use was sustainable. The IWRP used results from the Terry Ranch Timing analysis to recommend an approach for triggering the Terry Ranch Project. Results from the Terry Ranch Integration analysis were used to identify other water resources opportunities that would improve Terry Ranch operations that Greeley may need to act on in the next 10 years.

9.1 METHODOLOGY

The methodology for the Terry Ranch Timing and Terry Ranch Integration analyses used related approaches and tools for consistent evaluation, but a different overall analysis process. The Terry Ranch Timing analysis focused on determining the maximum demand Greeley's baseline water supply system (without Terry Ranch) could meet while meeting the planning performance criteria described in Section 2.4. The Terry Ranch Integration analysis focused on determining whether the use of Terry Ranch once fully implemented is sustainable using the sustainability criteria descried in Section 7.3. Both analyses used the GSM to complete water supply system simulations and applied the planning scenarios.

In the GSM, the Terry Ranch Timing analysis simulated the planning scenario settings shown in **Table 9-1** across the baseline system described in Section 2.3 under annual potable demands from 28,000 acre-feet per year to 40,000 acre-feet in 2,000 acre-foot increments. Performance results were compared to the planning performance criteria defined in Section 2.4 to determine the maximum demand the baseline system could supply to Greeley. The climate conditions selected for the Terry Ranch Timing analysis reflected possible climates around the year 2040.

Table 9-1. Planning Scenario Settings for Terry Ranch Timing Analysis

Planning Scenario Name	Climate Change	Colorado River Basin Impacts	Water Rights Administration Impacts
Unbearable	5°F Warmer	High Impacts	10% Reduced Yields
Stressed	5°F Warmer	Moderate Impacts	10% Reduced Yields
Continued Trends	2°F Warmer	Moderate Impacts	10% Reduced Yields
Optimistic	2°F Warmer	Low Impacts	No Reduction
No Climate Change	No Change	Low Impacts	No Reduction

In the GSM, the Terry Ranch Integration analysis simulated the planning scenario settings shown in **Table 9-2** across the Terry Ranch Project assumptions described in Section 7.2. Performance results were compared to the planning performance criteria defined in Section 2.4 and the Terry Ranch sustainable use criteria identified in Section 7.3 to determine whether additional water resources opportunities could be required. The climate conditions selected for the Terry Ranch Timing analysis reflected possible climates around the year 2070.

Table 9-2. Planning Scenario Settings for Terry Ranch Integration Analysis

Planning Scenario Name	Climate Change	Colorado River Basin Impacts	Water Rights Administration Impacts	Total Demands (Potable + Non-Potable)
Unbearable	8°F Warmer	High Impacts	10% Reduced Yields	70,000 af/yr (2070 High Bookend)
Stressed	8°F Warmer	Medium Impacts	10% Reduced Yields	57,100[1] af/yr
Continued Trends	5°F Warmer	Medium Impacts	10% Reduced Yields	46,800 af/yr (2070 Median w/Decreased Per Capita Use)
Optimistic	2°F Warmer	Low Impacts	No Reduction	46,800 af/yr (2070 Median w/Decreased Per Capita Use)
No Climate Change	No Change	Low Impacts	No Reduction	57,100[1] af/yr

[1] This demand value was selected as it is approximately twice the current annual demands.

9.2 TERRY RANCH TIMING RESULTS

The Terry Ranch Timing analysis used performance metrics from the GSM simulations of the planning scenario conditions described above to determine the maximum annual demand the system can meet under each planning scenario. **Table 9-3** shows the maximum annual demand the baseline system can meet for each planning scenario. Values listed are estimations used for planning purposes and do not reflect the firm yield of Greeley's water supply system.

Depending on planning scenario conditions, the maximum demand the baseline system can meet varies between 32,600 acre-feet per year and 43,800 acre-feet per year. This compares to Greeley's recent total annual demands of approximately 25,300 acre-feet per year. These results show that even if future conditions are like those in the *Unbearable* planning scenario, Greeley's baseline system is sufficient to meet some demand growth. If future conditions are like those in the *Continued Trends* planning scenario, Greeley's baseline system can accommodate an additional 10,000 acre-feet per year of demand growth, which is approximately 40 percent more demand than current. These results show that while the baseline system can accommodate some demand growth, it is vulnerable if demand growth occurs rapidly or in combination with climate and risk impacts to water supply. Therefore, the Terry Ranch Project will be required for Greeley to meet projected future demands under a range of projected future conditions.

Table 9-3. Maximum Demand the Baseline System Meets while Maintaining Planning Performance Criteria for each Planning Scenario

Planning Scenario	Annual Potable Demand (acre-feet per year)	Annual Non-Potable Demand[1] (acre-feet per year)	Total Annual Demand (acre-feet per year)
Unbearable	28,000	4,600	**32,600**
Stressed	30,000	4,600	**34,600**
Continued Trends	32,000	5,800	**37,800**
Optimistic	36,000	5,800	**41,800**
No Climate Change	38,000	5,800	**43,800**

[1] Non-Potable demands are set based on annual potable demand. At certain demand thresholds, the non-potable demand was increased reflecting additional service area development.

A key outcome of this analysis was timing the Terry Ranch Project implementation using the demand results above. However, Greeley has not experienced demand growth over the last 10 years, as discussed in Section 4.1, and thus the IWRP cannot determine if the projected demand growth is going to begin immediately. In addition, the differences in projected 20-year demands between the high and low bookend scenarios is slightly less than Greeley's current annual demands. Thus, there is also significant uncertainty in the rate of demand growth when it starts to occur again. Because of these highly uncertain demand factors, the IWRP could not confidently time the Terry Ranch Project implementation. If the Terry Ranch Project is implemented before it is needed, it could unnecessarily overburden Greeley's customers with high water rates.

In lieu of being able to time Terry Ranch Project implementation, the IWRP identified a process Greeley can use to monitor demands and water supplies, which is detailed as part of the Adaptive Plan in Section 12.2. In this approach, Greeley will monitor observed demands and compare them to the estimated maximum demand the water supply system can meet. After demand growth occurs, Greeley can compare the rate of growth to what the water supply system can meet. This approach is visualized in **Figure 9-1**. In this figure, the solid green line is Greeley's observed total demand values, the green shaded area is a conceptual range of possible future demands, and the dashed green line as an example of the demand growth trajectory Greeley could experience. The gray and yellow lines show the maximum demand the baseline system can meet under the *No Climate Change* and *Continuing Trends* planning scenarios, respectively. Note that the x-axis after 2020 is conceptual and is not tied to actual future years.

Figure 9-1 shows that as the future evolves, the demand Greeley's baseline system can meet could gradually decrease as impacts from climate change and other risks occur. This is why the solid line decreases from the 2010 to 2020 value. Simultaneously, demand growth is expected to occur, though the exact start of growth and rate is unknown. Comparing the rate of demand growth to the water supply system conditions will provide Greeley sufficient foresight to start Terry Ranch implementation such that when it is required it will be fully completed.

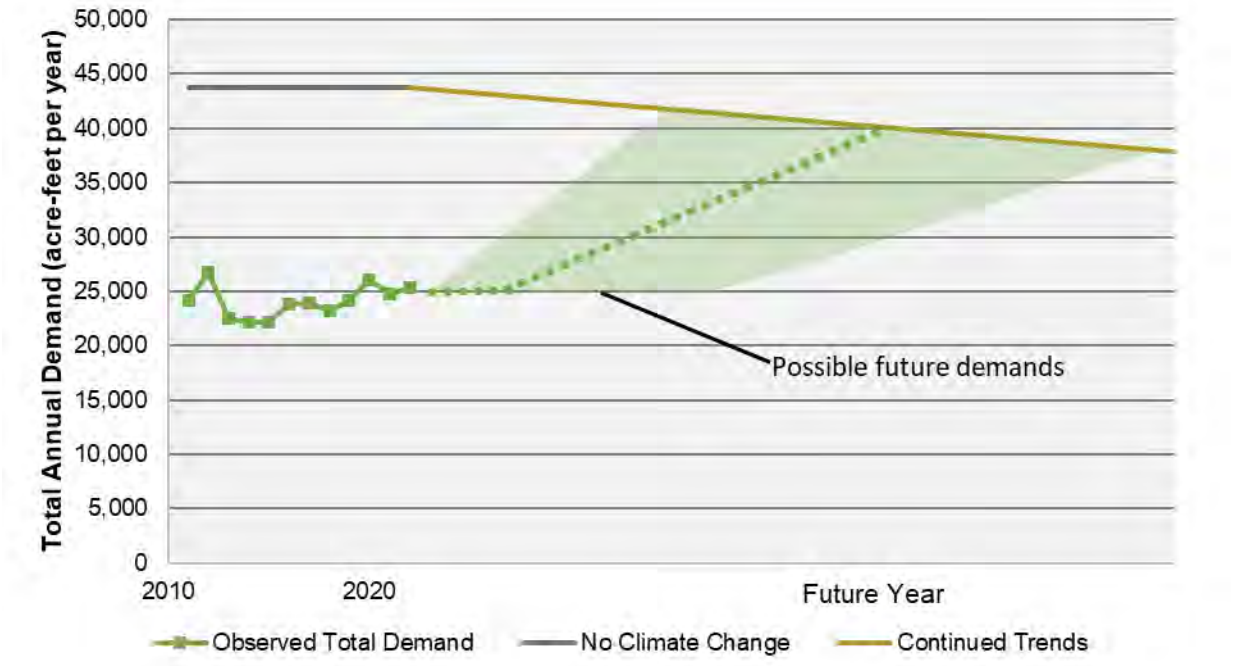

Figure 9-1. Conceptual Example of Timing the Terry Ranch Project Showing How Demands (Green Shaded Area/Dashed Line) Could Grow While the Water Provided by the Supply System Could Decrease (Gray And Yellow Line)

9.3 TERRY RANCH INTEGRATION RESULTS

The Terry Ranch Integration analysis used performance metrics and Terry Ranch sustainability results from the GSM simulations of the planning scenario conditions described above to determine whether Terry Ranch operations were sustainable long-term. In summary, Terry Ranch operations are sustainable if it can deliver sufficient supplies during drought to minimize drought restrictions while maintaining at least 80 percent of the 1.2 million acre-foot native aquifer storage volume long-term. This sustainability definition was developed as a planning criterion for the IWRP to evaluate future conditions, and could be altered in the future if desired. **Table 9-4** shows the results of the Terry Ranch Integration analysis by planning scenario. This table indicates what (if any) additional water resources were included, the percent of years Greeley drought restrictions were used, the average annual Terry Ranch Delta (injection minus extraction), and the percent of the native aquifer remaining at the end of the 86-year simulation.

Table 9-4. Tabular Summary of Terry Ranch Integration Results

Planning Scenario	Additional Water Resources	% Years with Drought Response	Annual Terry Ranch Delta (acre-feet per year)	Ending Aquifer Volume (% of 1.2 million acre-foot Volume)
Unbearable	Retiming Storage + Moderate Water Acquisitions	100%	**-10,700**	**23%**
Stressed	Retiming Storage + Moderate Water Acquisitions	64%	**-6,500**	**53%**
Continued Trends	Retiming Storage + Moderate Water Rights	35%	**-1,200**	**91%**
Optimistic	None	12%	**+1,900**	**113%**
No Climate Change	Retiming Storage + Low Water Acquisitions	36%	**-1,900**	**86%**

Color Key Indicates Terry Ranch Sustainability Criteria: **Blue** has sufficient remaining aquifer percentage, **Orange** has insufficient remaining aquifer percentage

Results from the Terry Ranch Integration analysis show that the Terry Ranch Project can be operated sustainably in the *Continued Trends*, *Optimistic*, and *No Climate Change* planning scenarios. Sustainable operation in these planning scenarios will require some additional water supplies and retiming storage. The percent of years in drought restrictions for the *Continued Trends* and *No Climate Change* planning scenarios are above the 20 percent performance planning criteria. As the Terry Ranch Project is a drought-resilient supply source, Greeley could change the current drought response policy by lowering the thresholds that trigger watering restrictions. How the drought response policy could change was not evaluated in this IWRP but should be considered in future studies. Simulations of the *Optimistic* planning scenario showed that the long-term Terry Ranch storage will be above the initial native aquifer storage volume. Comparing these results to the results of the *No Climate Change* planning scenario, which does not include climate change impacts but does include approximately 10,000 acre-feet more demand for water, highlights the sensitivity to annual demands. Completing the Terry Ranch Project at a lower total annual demand could help increase aquifer storage to be used as demand increases.

Results from the *Unbearable* and *Stressed* planning scenarios show that under these conditions, Terry Ranch Operations are not sustainable. Both planning scenarios use drought restrictions significantly more frequently than 20 percent of years, and the long-term aquifer storage is well below the 80 percent threshold. These results indicate that Greeley's water supply system with Terry Ranch is vulnerable to the conditions listed in those planning scenarios, which include the hottest climate change projections and significant demand growth. The vulnerable demand and climate conditions identified in these planning scenarios will likely emerge gradually over an extended period of time. Greeley can monitor these conditions as part of the Adaptive Plan and, if they emerge, can adjust the long-term water supply strategy.

How the Terry Ranch Project use is simulated in the GSM was also evaluated. **Figure 9-2** shows deliveries to Greeley from the two existing surface water treatment plants (in blue) and the Terry Ranch Project (in orange) under future conditions for one of the six hydrologies simulated, which included back-

to-back-to-back 2002 conditions. **Figure 9-3** shows the annual Terry Ranch extraction (orange, negative bars), injection (blue, positive bars), and the cumulative aquifer storage as a percent of the initial 1.2 million acre-foot native volume (black line). The first figure shows that Terry Ranch can be a significant supply source for Greeley during droughts, contributing up to 50 percent of needed supplies during the severe drought period. The second figure shows that in between these drought periods, the surface water supply system can inject excess supplies such that the aquifer volume almost fully recovers. These results indicate that the GSM is simulating the Terry Ranch Project as intended, that is, as a water supply source during droughts and a large storage bucket for excess surface water supplies outside of droughts.

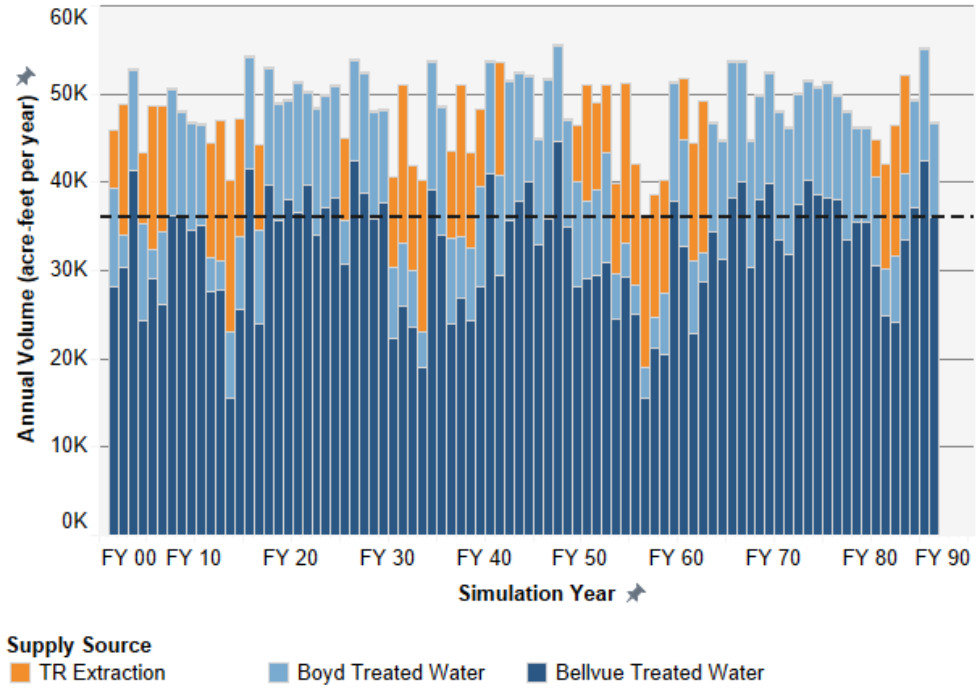

Figure 9-2. Met Demand Source Under Continued Trends Planning Scenario for Timeseries 63. Dashed line is annual demand under Level 2 watering restrictions.

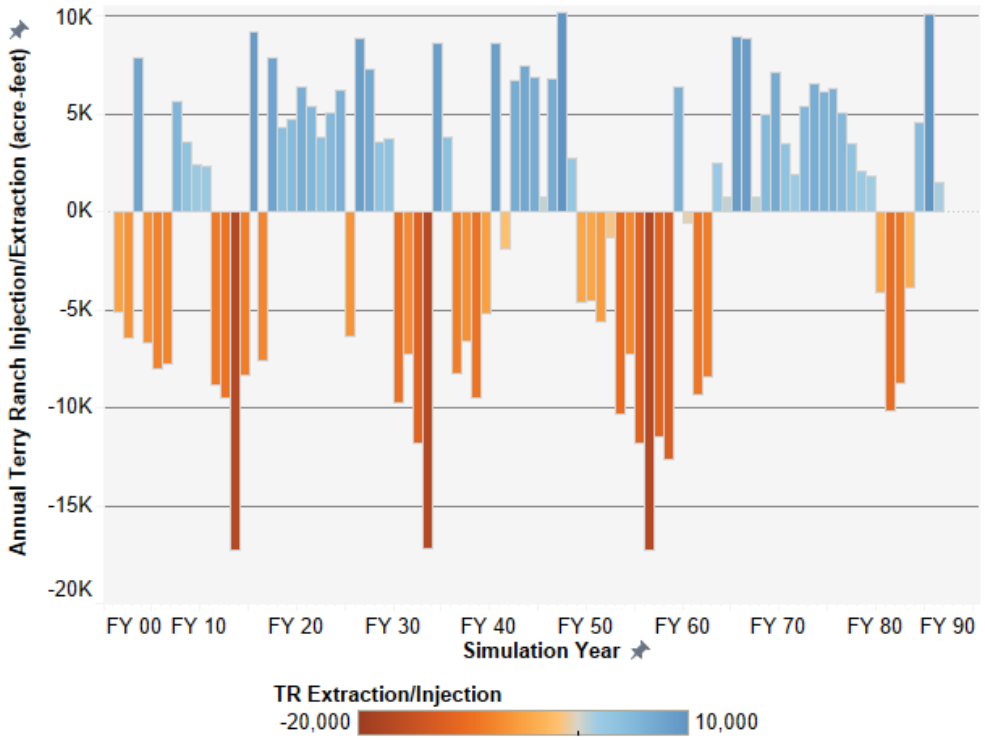

Figure 9-3. Terry Ranch Injection/Extraction Timeseries Under Continued Trends Planning Scenario for Timeseries 63. Left axis corresponds to bar chart and right axis corresponds to line plot.

Figure 9-4 highlights the value of the additional water resources opportunities to achieving sustainable operations of the Terry Ranch Project. This figure shows the percent of the native Terry Ranch Aquifer level for the *Continued Trends* Planning Scenario under Timeseries 63. Including additional water rights and retiming storage with Terry Ranch without any additional projects (darkest line) preserves over 30 percent of the native aquifer level at the end of the 86-year simulation period compared to no additional acquired water rights and retiming storage (lightest line). This shows how these additional water resources will be essential to long-term sustainable operations of the Terry Ranch Project.

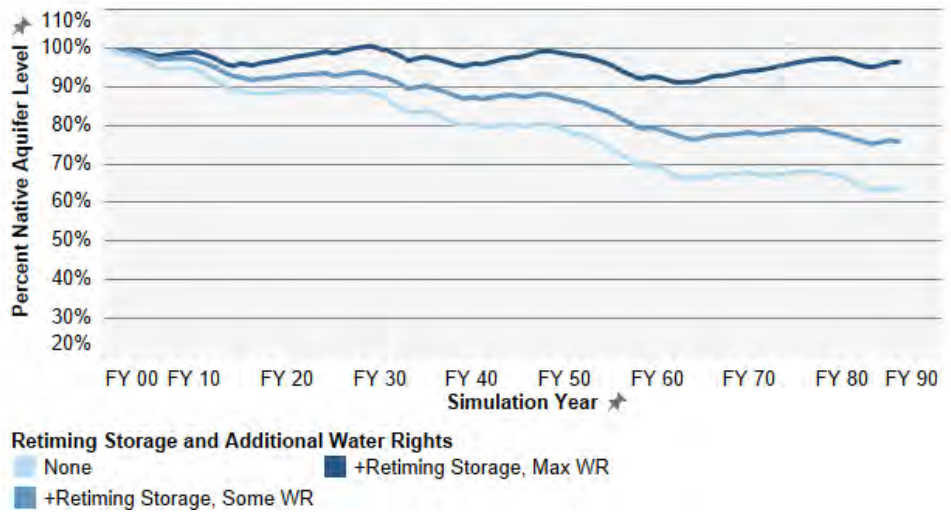

Figure 9-4. Use of Native Terry Ranch Aquifer by Retiming Storage and Additional Water Rights Combinations Under Continued Trends Planning Scenario for Timeseries 63

9.4 CONCLUSIONS

The IWRP evaluated the Terry Ranch Project using two approaches. The Terry Ranch Timing analysis established the water supply system and demand conditions under which the Terry Ranch Project would be required. The Terry Ranch Integration analysis established how Greeley could use the Terry Ranch Project after it is fully integrated. Results from these analyses showed the following conclusions:

- The Terry Ranch Project integrated into Greeley's water supply system is resilient against many possible future conditions including warmer climates, higher demands, and reduced yields. In those same future conditions, Greeley can sustainably use the Terry Ranch Project as a long-term water supply source during droughts with some additional water resources.
- Additional water resources opportunities such as water rights and retiming storage can significantly improve the long-term sustainability of the Terry Ranch Project in futures with warmer climates and/or significant demand growth. Under less stressful future conditions, the Terry Ranch Project is sustainable without these additional water resources opportunities.
- If impacts from climate change are severe and tracking with the hottest projections, Greeley may need to consider additional long-term solutions. These will have long lead times that Greeley can monitor and adapt to.
- Implementation of Terry Ranch cannot be confidently scheduled due to the significant uncertainty in when demands will grow and the rate of that growth.
- Greeley should use an adaptive plan to properly time Terry Ranch and monitor emerging climate and demand conditions.

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10.0 WATER RIGHTS EVALUATION

The future hydrology analysis presented in Section 6 showed that Greeley's current water rights portfolio is vulnerable to climate change impacts across the three major river basins. In addition, near-term analysis results in Section 8 and results from the Terry Ranch Project timing and integration analysis in Section 9 demonstrate that additional water rights will be required to meet projected demands. The IWRP therefore updated Greeley's water acquisition strategy. This section describes the Water Acquisition Decision Tool (WADT) developed to help Greeley target the most beneficial water resources and presents a general overview of Greeley's water acquisition strategy resulting from the development of the WADT.

10.1 WATER ACQUISITION DECISION TOOL

As part of the IWRP, the WADT was developed to help define Greeley's water acquisition strategy and to inform decisions on future updates to it. Another motivator for the WADT is to create a centralized location for water rights–related data and to improve knowledge transfer during future water acquisition strategy updates. The WADT is not designed to determine whether acquisitions are needed; rather it is an adaptable, data-driven tool to inform decision-making when evaluating potential acquisitions or when re-evaluating the acquisition strategy. Importantly, the tool will help track purchases and SME opinions over time.

The WADT identifies water rights in the Poudre River, Big Thompson River, and Colorado River basins as well as non-tributary groundwater rights as possible acquisition targets. These acquisition targets are divided into three different water right classes based on their acquisition strategy: Aggressive Acquisition, Active Acquisition, and Passive Acquisition. **Table 10-1** shows the criteria used to classify each water right and the overall acquisition strategy. A water right should meet most of the criteria to be assigned to a certain Class, but it is not necessary for it to meet all the criteria.

Table 10-1. Water Right Classification Strategies and Criteria in WADT

Water Right Class	Criteria	General Acquisition Strategy
Class 1	• Use for potable supply • Sources are from the upper Poudre River, Big Thompson, and Colorado River basins. Also, non-tributary groundwater rights to the extent that they can be integrated into Greely's potable water system • Ability to provide firm yield at existing Bellvue and Boyd WTFs • Relatively low regulatory risk; established history of changes in water court • Ability to meet return flows from existing supplies and infrastructure • Greeley already owns shares or has the ability to acquire a large number of shares or interest in the company	Aggressive Acquisition: Greeley is actively seeking acquisitions and is willing to make offers based on a predetermined offer price, subject to budget availability
Class 2	• Use for potable or non-potable supply • Sourced from upper/lower Poudre River or Big Thompson River basins. Also non-tributary groundwater rights to the extent that they can be integrated into Greeley's potable water system • Ability to provide firm yield at existing Bellvue and Boyd WTFs or for use in non-potable system. • Relatively low regulatory risk; may or may not have established history of changes • May have other issues that make it less desirable that Class 1 water • Ability to acquire a moderate number of shares or interest in the company • Price per AF is less than Class 1 rights	Active Acquisition: Greeley evaluates potential sales brought by sellers or brokers and executes only if Class 1 water is unavailable to buy, the water is priced at or below market, or the water has other positive attributes
Class 3	• Use primarily for non-potable supply or for meeting return flow obligations • Sourced from lower Poudre or Big Thompson River basins • Not required to be a firm supply • No or limited prior change cases in the system • May only be able to acquire smaller volumes of shares and interest in the company • Price per AF is less than Class 1 and 2 rights	Passive Acquisition - Greeley evaluates potential sales on a case-by-case basis and executes only if Class 1 and 2 water is unlikely to be available for the duration of budget. To purchase, Class 3 water should be priced below market or have some other positive attributes

AF = acre-foot/feet
WTF = water treatment facility

There are many variables that can be used when assessing water rights acquisitions. To define and organize these, the WADT defined five categories that are used to evaluate and prioritize water rights within the three water right classes. These categories are cost, reliability, availability, system integration, and water rights administration considerations. More categories may be added in the future if desired. Within each of these categories, the WADT defined discrete evaluation criteria and defines how to score water rights for each criterion. The evaluation criteria and their categories are shown in **Table 10-2**.

The WADT allows Greeley to assign individual scores for each evaluation criterion and then weight the scores between categories. Scores and weights can be adjusted based on departmental priorities, budget constraints, changes in acquisition strategy informed by IWRP updates, or other factors. The resulting weighted scores will help identify, target, and prioritize water rights for acquisition.

Table 10-2. Evaluation Criteria and Categories in WADT

Category	Evaluation Criteria
Cost	• Purchase Price • Integration Cost • Operation and Maintenance Cost
Reliability	• Potential Yield under Shifted Hydrograph • Seniority of Water Right • Vulnerability to Change of Water Right
Availability	• Availability of Water for Acquisition • Willingness of Owner to Sell • Risk of Price Escalation
System Integration	• Integration into Existing System • Integration into Terry Ranch • Time to Implement
Water Right Administration Considerations	• Legal Complexity • Ditch/Reservoir Company Considerations • Water Right Operational Flexibility

10.2 WATER ACQUISITION STRATEGY

Greeley has actively acquired raw water supplies through purchase of water rights and via its raw water dedication program. The primary focus of Greeley's past water acquisition strategy was to acquire water resources that were within Greeley's growth path and to obtain water resources that could be stored in an enlarged Milton Seaman Reservoir. The Terry Ranch Project has changed the focus of Greeley's water acquisition strategy to water supplies that improve the sustainability of that project as described in Section 7.4. The IWRP updated Greeley's acquisition strategy in parallel with developing the WADT using subject matter expertise on how potential water acquisitions can be integrated into Greeley's system and their associated characteristics (price, changeability, etc.).

The goals of the acquisition strategy include water supplies with the following features:

- Add security and redundancy to the water supply system prior to Terry Ranch implementation
- Improve the sustainability of the Terry Ranch Project
- Maximize and make the most efficient use of potable water supplies
- Allow for the retiming of water resources for use in the Terry Ranch Project
- Can be used in Greeley's non-potable system

The primary supplies that can be most easily integrated into the Terry Ranch Project are direct flow or storage rights in the upper Poudre River and Colorado River basins, and non-tributary groundwater rights. Although additional water supplies in the Big Thompson River basin cannot be currently integrated into the Terry Ranch Project, they can be used for direct potable use, storage, and non-potable use to decrease the immediate demands from and make most efficient use of the Poudre River and Colorado River potable supplies for integration into the Terry Ranch Project when needed. The water supplies on the upper Poudre River, upper Big Thompson River, and Colorado River basins have high demand, high increases in water right costs, and decreased availability relative to other supplies in those basins.

While Greeley should still pursue these more expensive water resources, reliance on these resources can be partially offset by integrating non-potable supplies into Greeley's acquisition strategy. Greeley's 2022 Non-Potable Master Plan identifies a goal of 15 percent of its future demands to be met by non-potable supplies. This goal will serve several purposes such as maximizing the use of untreatable water supplies, providing the lowest cost of water service to citizens, and making the most efficient use of potable water supplies that can be integrated into the Terry Ranch Project.

Northern Colorado has experienced a high population growth rate over the last decade, and this population growth is projected to continue. Because of this, regional demand for water rights has increased dramatically, resulting in decreased water rights acquisition availability, rapidly increasing costs, and increased competition. Additionally, water providers that historically relied on water from the mainstem of the South Platte River are also now acquiring water rights on tributaries such as the Poudre River because of the increased competition for water rights on the mainstem of the South Platte. It is anticipated that these challenges will continue or worsen as availability of water resources diminish across the entire South Platte River basin. Therefore, it is recommended that Greeley continue acquiring additional water rights as aggressively as possible given budgetary considerations and constraints.

The following are recommendations for Greeley to meet the water acquisition strategy goals identified in the IWRP while also preserving Greeley's agricultural heritage:

1. Acquire potable direct flow and storage supplies in the Poudre River, Big Thompson River, and Colorado River basins and non-tributary groundwater rights.
2. Acquire non-potable direct flow and storage supplies in the Poudre River and Big Thompson River basins.
3. The distribution of acquisitions between potable and non-potable can be dynamic if the availability of water resources for acquisitions warrants.
4. Pursue water rights that will permit Greeley to lease out water rights for decreed agricultural irrigation uses until such time as those water rights are needed by Greeley.
5. Pursue water rights that will allow for interruptible supply use to support the agricultural community while maintaining the water supplies for Greeley's use during droughts. These opportunities exist under a number of ditch systems within the Cache la Poudre River and Big Thompson River.
6. Pursue changes of water rights as quickly as possible given budgetary, personnel, and other constraints. This may result in Greeley obtaining a higher yield with more favorable terms and conditions than if Greeley waited to change the water rights in the future.

7. Prioritize agricultural leases for individual farms and ditch companies that connect to the Greeley economic zone and pursue recovery of higher value leases for industrial and augmentation water to support the CIP and water acquisition goals.

10.3 WATER ACQUISITION SUMMARY

The IWRP recommends that Greeley develop a water acquisition strategy to meet projected demand growth and mitigate the impacts from climate change and other risks to their existing water supply system. The goals of the acquisition strategy include water supplies with the following features:

- Add security and redundancy to the water supply system prior to Terry Ranch implementation
- Improve the sustainability of the Terry Ranch Project
- Maximize and make the most efficient use of potable water supplies
- Allow for the retiming of water resources for use in the Terry Ranch Project
- Can be used in Greeley's non-potable system.

The IWRP also developed the WADT, which provides Greeley a data-driven tool to help make informed decisions on water acquisition strategy to meet these acquisition strategy goals. The WADT is intended to be adaptive as it can be updated to reflect changes in market conditions, meet changing goals and strategies, and/or to include additional evaluation criteria.

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11.0 TEN-YEAR CAPITAL IMPROVEMENT PLAN

A water resources CIP was developed provide a timeline and estimated budget for implementation of the outcomes and recommendations from the IWRP. This section summarizes the CIP and lists its assumptions. The detailed water resources CIP is included Appendix A.

A 10-year planning horizon was used for this CIP, starting in 2024 and continuing through 2033. This does not capture the full implementation of recommendations identified in Greeley's IWRP. To the extent that additional CIP projects may be required beyond 2033, those needs are addressed in the discussion about the identified capital improvement plan projects below.

This CIP represents the Greeley Water Resources Department portion of project costs. Cost sharing opportunities with developers, funding partners, or other departments within Greeley do exist for some of the projects included in this CIP. Those cost sharing opportunities are described in further detail in the project descriptions below. Costs do not include internal City costs to complete projects. Internal City costs are defined as additional staff requirements associated with project development and implementation.

Project cost estimates presented within this CIP are in 2023 dollars. Project costs associated with reoccurring projects assume an annual escalation rate of 3 percent. Project costs were developed based on input from Greeley, existing cost estimates from previous CIPs, and actual spending by Greeley.

Overall project sequencing is based on input from Greeley staff on the interdependencies between projects and on progressive expansion of Greeley's water resources portfolio to meet or exceed the demand projections described in this IWRP.

The following key assumptions were made to develop this CIP:

- Land and/or easements will be required and ready for development of projects when needed.
- Cost associated with land acquisition/easements and rights-of-way are not included in this CIP.
- Estimated capital costs include costs associated with permitting, design, and construction management.
- Ancillary costs associated with capital projects such as pipeline connections, inlet and outlet structures, measurement, and controls were assumed to be included in the total project costs.
- Management of Greeley's water rights portfolio could include such things as maintenance of ditch and conveyance systems, regular measurement and recording of water deliveries, preparation of water accounting, land management for compliance with dry up or revegetation requirements. These ongoing compliance requirements are considered regular operations and maintenance and are therefore not included in this CIP.

Figure 11-1 presents the 10-year Water Resources CIP by project category and illustrates the annual and cumulative capital requirements associated with all water resource projects included herein through the 2033 planning horizon. A summary of the CIP-identified water resources projects and their corresponding categories are listed below. **Table 11-1** lists individual projects, their associated costs to

Greeley, and anticipated start dates. The total capital requirement for the recommended IWRP CIP between 2024 and 2033 is $134,480,000. Delays to the projects in this CIP may delay other projects and potentially result in Greeley not being able to meet demands. For this reason, this CIP should be reviewed and updated annually.

- **Terry Ranch Infrastructure**: Projects associated with implementing the Terry Ranch Project include pipeline installation and State Land Board wellfield development. This infrastructure is being developed using the first $62.5 million from the Wingfoot deal, plus Greeley's $12.5 million 20 percent match for a total investment of $74 million.
- **Water Rights Acquisition**: Greeley continues an opportunistic and strategic approach to acquiring water rights. The CIP includes an annual cost of $6 million per year with a 5 percent escalation factor.
- **Water Rights Development**: The legal and engineering costs associated with protecting existing water rights and changing new water rights at a rate consistent with the 2018 to 2022 expenditures. The CIP assumes $350,000 per year for legal costs and $275,000 per year for engineering costs, escalated at 3 percent per year.
- **Planning Studies**: Completing the planning studies identified in the IWRP includes $250,000 for the Storage Retiming Investigation in 2024 and 2025, $200,000 for Greeley's portion to update the PBN model, $300,000 for an update to the IWRP in approximately 2028, and $550,000 for a Terry Ranch Investigation Study after the IWRP update.
- **Water Resources Projects**: This includes a variety of additional water resources projects including continuation of investment into water conservation, infrastructure projects required for growing demands, infrastructure projects associated with water rights, and any retiming storage project. Water conservation programs should address environmental justice goals and provide sustainable landscaping opportunities to the entire community. Cost sharing opportunities exist for several identified water resources projects and should be further evaluated during project planning.

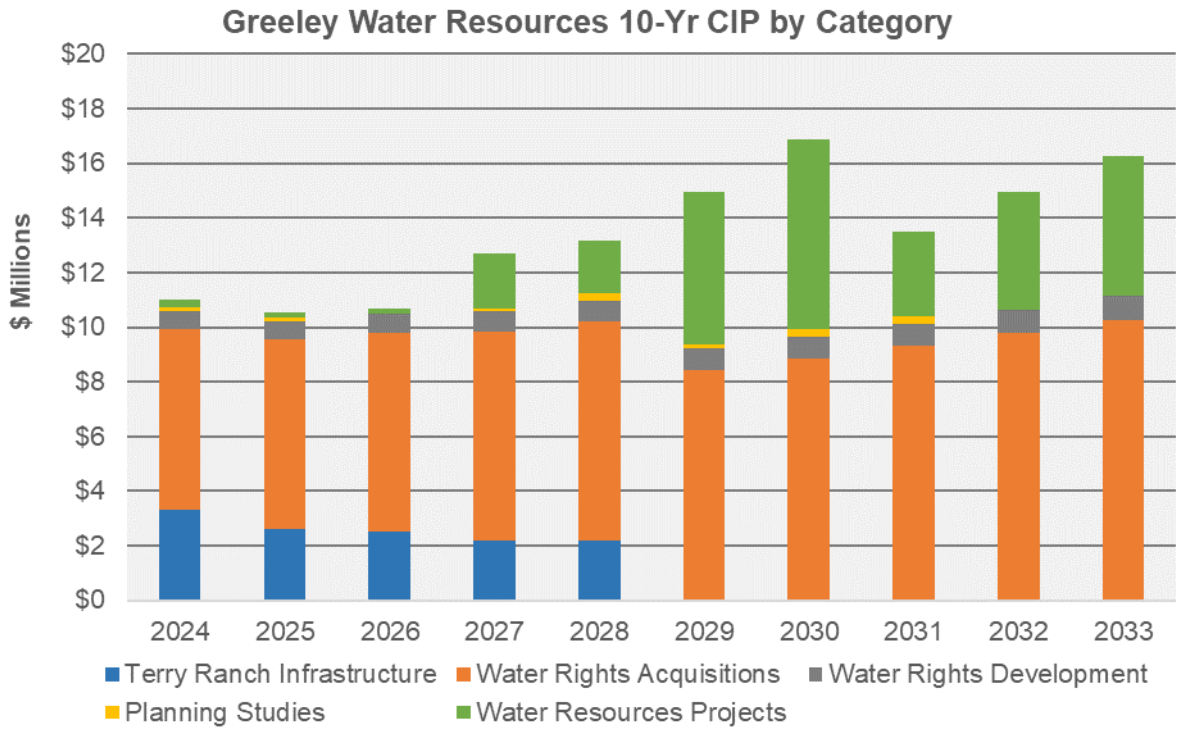

Figure 11-1. Water Resources 10-Year CIP Costs by Project Category

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Table 11-1. List of Water Resources CIP Project Costs and Details

Project Name	Start Year	Duration	Annual Project Cost	Total Project Cost	***Greeley (Water Resources Dept)***	*Developer / Funding Partner / Greeley non-WR Contribution*	***Greeley - Water Resources Dept Total 2024 to 2033***
Terry Ranch Infrastructure Projects							
Terry Ranch: Phase 1: Windsor to Hwy 14 Pipeline	2023	2 yrs		$31,250,000	***$6,250,000***	*$25,000,000*	***$3,125,000***
Terry Ranch Phase 1b: Pipeline Construction 2025 to 2026	2025	2 yrs		$25,000,000	***$5,000,000***	*$20,000,000*	***$5,000,000***
Terry Ranch Phase 1b: Pipeline Construction 2027 to 2028	2027	2 yrs		$21,875,000	***$4,375,000***	*$17,500,000*	***$4,375,000***
Terry Ranch Phase 2: Development	2034				***To be Determined***		
State Land Board Wellfield Development	2023	3 yrs		$1,500,000	***$1,300,000***	*$200,000*	***$300,000***
Sub-Total for Terry Ranch Infrastructure Projects							***$12,800,000***
Water Right Acquisition							
Acquisition of Agricultural Water Rights	2023	Every year	$6,000,000 per year w/ 5% escalation		***$6,000,000 per year w/ 5% escalation***		***$83,202,759***
Sub-Total for Water Rights Acquisitions							***$83,202,759***
Water Rights Development							
Water Rights Development: Legal Fees	2023		$350,000 per year w/ 3% escalation		***$350,000 per year w/ 3% escalation***		***$4,256,710***
Water Rights Development: Engineering Fees	2023		$275,000 per year w/ 3% escalation		***$275,000 per year w/ 3% escalation***		***$3,344,558***
Sub-Total for Water Rights Development							***$7,601,268***

Project Name	Start Year	Duration	Annual Project Cost	Total Project Cost	***Greeley (Water Resources Dept)***	*Developer / Funding Partner / Greeley non-WR Contribution*	***Greeley - Water Resources Dept Total 2024 to 2033***
Planning Studies							
Storage Retiming Investigation	2024	2 yrs		$250,000	***$250,000***		***$250,000***
Poudre Basin Model Updates	2027	2 yrs		$600,000	***$200,000***	*$400,000*	***$200,000***
Update to Greeley IWRP	2028	2 yrs		$300,000	***$300,000***		***$300,000***
Terry Ranch Integration Study	2030	2 yrs		$550,000	***$550,000***		***$550,000***
Sub-Total for Planning Studies							***$1,300,000***
Water Resources Projects							
Life After Lawn	2023	Every year	$150,000 per year w/ 3% escalation		***$150,000 per year w/ 3% escalation***		***$1,824,304***
Aerial Imagery and Planimetric Data Acquisition for Update to Residential Water Budget	2024	Every 3 years (2024, 2027, 2030, 2033)	$200,000 per update w/ 3% escalation		***$68,000 per update w/ 3% escalation***	*$132,000 per update w/ 3% escalation*	***$327,099***
Rehab of Poudre River Diversion Structure	2029	3 yrs		$8,000,000	***$8,000,000***	*Partnership Opportunities Should Be Evaluated*	***$8,000,000***
Poudre Raw Water Intake Pipeline Expansion - Between River Diversion and Bellvue Intake	2030	5 yrs total 2 yrs design and 3 yrs construction		$8,750,000	***$8,750,000***		***$8,750,000***
Assessment of the Raw Water Pipeline between Lake Loveland & Boyd	2033	1 yr		$200,000	***$200,000***		***$200,000***
Lower Latham Bypass Structure for Optimization of Water Rights	2027	4 yrs		$3,000,000	***$1,000,000***	*$2,000,000*	***$1,000,000***

Project Name	Start Year	Duration	Annual Project Cost	Total Project Cost	***Greeley (Water Resources Dept)***	*Developer / Funding Partner / Greeley non-WR Contribution*	***Greeley - Water Resources Dept Total 2024 to 2033***
Development of Overland Trail Gravel Pits	2023	7 yrs		$3,210,000	***$3,210,000***		***$3,175,000***
Expansion of Gravel Pit Storage at the Poudre Ponds Complex (Martin Marietta storage)	2027	4 yrs		$6,000,000	***$6,000,000***		***$6,000,000***
WSSC Return Flow Structures	2033	5 yrs		$2,500,000	***$2,500,000***	*Partnership Opportunities Should Be Evaluated*	***$500,000***
Sub-Total for Water Resources Projects							***$29,776,403***
TOTAL FOR ALL PROJECTS							***$134,680,431***

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12.0 RECOMENDATIONS AND ADAPTIVE PLAN

12.1 IWRP OUTCOMES AND RECOMMENDATIONS

Greeley's IWRP is a long-term strategic water resources master plan for Greeley that ensures sustainable and affordable water supplies for their customers. The IWRP is a comprehensive plan that integrates Greeley's water supply system (analyzed in Section 6) and projected demands (presented in Section 4) with possible future conditions around hydrology, climate change, and risks to Greeley's water supply system (shown in Section 5). The IWRP establishes a plan for triggering the Terry Ranch Project (Section 9), a process for evaluating and strategically acquiring water rights (Section 10), a 10-year CIP (Section 11), and an adaptive plan (Section 12.2) for Greeley to follow.

The IWRP analysis showed that Greeley is well-positioned to provide sustainable and affordable water supplies through an uncertain future if the water supply system is developed as planned. Past planning efforts and decisions have created a robust water supply system. The Terry Ranch Project, when complete, will likely be an effective drought supply source and can be operated sustainably long-term. The Terry Ranch Project is also flexible with respect to how it gets developed, with infrastructure incrementally completed such that when it is needed it can be integrated efficiently. The IWRP process also established several important outcomes and conclusions regarding Greeley's current, near-term, and long-term water supply system, shown below.

- Greeley's current water supply system is resilient against the most likely near-term conditions, but additional water supplies are required to meet projected demands and to mitigate impacts from warmer climate conditions.
- With the Terry Ranch Project fully integrated, Greeley's water supply system is likely resilient against many possible future conditions including warmer climates, higher demands, and reduced yields. In those same future conditions, Greeley can sustainably use the Terry Ranch Project as a water supply source over the long-term during droughts when the Terry Ranch Project is coupled with additional water resources.
- Balance implementation of the Terry Ranch Project with other water resources and non-water resources CIP needs to minimize financial risk and maintain affordable water supplies.
- If impacts from climate change are severe and tracking with the hottest projections, Greeley may need to consider additional long-term solutions (i.e., in addition to Terry Ranch and additional water supplies).
- The most impactful drivers to Greeley's water supply system—demand growth and climate change impacts—will have long lead times that Greeley can monitor and adapt to.
- Terry Ranch cannot be confidently timed until Greeley sees sustained, significant demand growth.

To ensure the IWRP outcomes hold true and continue providing sustainable and affordable water supplies, the IWRP includes the recommendations for Greeley summarized in **Table 12-1**. These recommendations were used to identify the water resources projects from the 10-year CIP in Section 11 and define the key actions of the Adaptive Plan defined in Section 12.2.

Table 12-1. Summary of IWRP Recommendations Used to Develop 10-year CIP and Adaptive Plan

Recommendation	Action
Change Water Rights	Greeley should continue to aggressively change existing water rights to municipal use as these will improve the security and redundancy of the existing water supply system before the Terry Ranch Project is integrated.
Continue Strategic Acquisitions	Greeley should acquire additional water supplies and prioritize the acquisition of water supplies that can be integrated into the current system and the Terry Ranch Project. These water supplies are required to meet projected demands and mitigate climate and risk impacts to the current water supply system. These additional water supplies will also help the Terry Ranch Project operate sustainably once integrated.
Develop Priority Terry Ranch Infrastructure	The Terry Ranch Project needs to be efficiently integrated into Greeley's water supply system once it is required. Greeley should continue incrementally implementing project components (i.e., pipelines, right-of-way, water rights) to ensure this project is readily available to Greeley.
Study Potential Conceptual Retiming Storage Options	The IWRP identified a retiming storage project as a potentially beneficial project to improve the sustainability of Terry Ranch operations. As the IWRP only included a conceptual definition of the project, Greeley should further define this project and align the concept with real facilities.
Implement Adaptive Planning to Monitor Drivers and Trigger Terry Ranch	While the IWRP showed Greeley's water supply system is resilient against warmer futures and increased demands, it is still vulnerable to significantly stressful future conditions. Additionally, the IWRP could not confidently define when Terry Ranch is required due to uncertainty in demand growth. Greeley should implement an Adaptive Planning process that regularly updates IWRP outcomes and re-evaluates the Terry Ranch Timing.

To develop Priority Terry Ranch infrastructure, Greeley is implementing the approach described below, primarily consisting of a phased pipeline installation. This approach was used to develop the 10-year CIP.

- Phase 1a Pipeline consists of installing the first 6 miles of Terry Ranch conveyance pipeline from Windsor to Highway 14. This phase is ongoing and is expected to be completed in 2025.
- Phase 1b Pipeline will continue to install Terry Ranch conveyance pipeline from the termination point of Phase 1a along the northern alignment. This phase is expected to start in 2025.
- State Land Board Wellfield development is installing and testing monitoring wells on the 16 sections owned by the State Land Board that are interspaced with the Terry Ranch Project property. The primary purpose of this effort is to secure the rights to the groundwater underlying the State Land Board parcels. This project is expected to be complete by the end of 2024.

12.2 ADAPTIVE PLAN

An important recommendation from the IWRP is that Greeley implements an adaptive plan after IWRP completion. This section presents an initial definition of what is included in Greeley's Adaptive Plan and how it will be implemented.

12.2.1 Purpose and Implementation

While the IWRP showed Greeley's water supply system is likely resilient against warmer futures and increased demands, it is still vulnerable to significantly stressful future conditions. Additionally, the IWRP could not confidently define when Terry Ranch is required due to uncertainty in demand growth. Therefore, the Adaptive Plan will serve to re-evaluate the outcomes, assumptions, and recommendations from the IWRP and the potential need for the Terry Ranch Project on an annual basis. The primary goal of the Adaptive Plan is to ensure Greeley continues planning for a future water supply system that delivers sustainable and affordable supplies to its customers. This Adaptive Plan focuses on trends and longer-term changes as opposed to near-term water supply conditions and operations which Greeley already monitors. To achieve this, the Adaptive Plan takes the five actions listed below based on the major IWRP outcomes and assumptions:

1. Monitor Significant Water Resources Drivers
2. Evaluate Terry Ranch Need
3. Update 5- and 10-year Terry Ranch Implementation Plan
4. Assess Water Rights Changes and Acquisitions
5. Review Other Water Resources Opportunities

The Adaptive Plan will have both formal and informal implementation protocols. Greeley staff plan to regularly update the Adaptive Plan and present updates to the W&S Board and other identified stakeholders on at least an annual basis. The Adaptive Plan update will focus on the five actions defined above and will include the topics and types of information presented in Section 12.2.2. As needed, Greeley staff will also provide updates on Adaptive Plan actions if conditions require it or at the request of the W&S Board.

12.2.2 Adaptive Plan Actions

This section presents how Greeley staff will complete each Adaptive Plan action. The content in this section is intended as a guide to start the Adaptive Plan and can be modified and updated as the Adaptive Plan progresses.

Action 1: Monitor Significant Water Resources Drivers

The IWRP developed outcomes and recommendations based on assumed future drivers for Greeley's water supply system. While the IWRP used a robust approach to capture possible future drivers, there could be new or significantly different future drivers than what was planned for. In this first action, Greeley's Adaptive Plan will 1) compare the future drivers assumed in the IWRP Planning Scenarios to recent experiences, and 2) determine if new drivers have emerged that could change IWRP outcomes.

The drivers used in the IWRP planning scenarios were climate warming, Colorado River Basin Impacts, Water Supply System Yields, and Demands. In the Adaptive Plan, Greeley staff will characterize recent trends of each driver. If recent trends fall outside the Planning Scenarios, then Greeley may consider re-evaluating previously developed outcomes using the observed conditions as a new planning scenario.

There are many future conditions that could impact Greeley's water supply system that were not included as a driver in the IWRP Planning Scenarios. The Adaptive Plan will complete a table, like the one shown in **Table 12-2**, identifying major trends or events that have occurred. If these trends or events are significantly different than IWRP assumptions, the Adaptive Plan could recommend a follow-up planning study to evaluate the potential changes to IWRP outcomes. The IWRP developed robust assumptions around many of these categories, and stressful events were assumed to occur—what is important is if an event is significantly different from what was assumed. For example, the IWRP developed three types of Colorado River Basin impacts that could occur because of larger Colorado River Basin issues. However, if a multi-year 100 percent curtailment of the CBT system is possible, the IWRP did not include that condition and Greeley could do a planning study focused on evaluating such a condition.

Table 12-2. Examples of Trends or Events That Could Occur

Category	Example Significant Trends or Events Outside IWRP Assumption
Colorado River Basin	• Multi-year CBT system 100% curtailment • Northern Water eliminates carryover storage option • Chimney Hollow Reservoir construction is halted
State of Colorado	• Water court decision that retroactively applies to changed water rights • Platte River Recovery Implementation Program non-compliance by Colorado water users, threatening Federal authorization
Poudre and Big Thompson River Basins	• A change case outcome is significantly worse than the 10% reduction assumed in the IWRP • A key source of future water supply becomes unavailable to Greeley • Glade Reservoir is constructed at largest proposed size, impacting junior water rights and operations in the Poudre Basin
Weld County	• A nearby community's water supply system at high risk of failure • Political climate around Terry Ranch becomes highly unfavorable • Large regional water project is constructed
City of Greeley	• A significant new water supply user (new residential development or industrial user) beyond the assumed growth occurs • Terry Ranch acceptance changes significantly • Water quality regulatory requirements cause Greeley to construct a new advanced water treatment facility

Action 2: Evaluate Terry Ranch Need

Greeley's most consequential water resources planning decision is when to begin implementation of the Terry Ranch Project and when the full project needs to be operational. When completed, this project will provide a drought-resilient supply source for Greeley. However full implementation of Terry Ranch will be expensive and completing it too soon could overburden Greeley's customers with high rates.

Due primarily to the high uncertainty around when future demand growth resumes and the rate of growth once it does resume, the IWRP could not confidently time the Terry Ranch implementation. Therefore, a key action in the Adaptive Plan will be re-evaluating the future Terry Ranch need and when the implementation of the project needs to begin. To assess this need, the Adaptive Plan will compare demand indicators to supply indicators and trigger potential actions as a result. **Figure 12-1**, which repeats Figure 9-1 shown in Section 9.2, conceptually shows why the Adaptive Plan will monitor these indicators. There is a wide spread of possible future demands as shown by the shaded area. At the same time, the demand Greeley's water supply system can meet while meeting the planning performance criteria could gradually diminish due to the effects of climate change, water rights administration, and other factors. This is why the solid line decreases from the 2010 to 2020 value. A future with high demand growth but a resilient water supply system could require the same Terry Ranch Timing as a future with low demand growth but high reductions in water supplies.

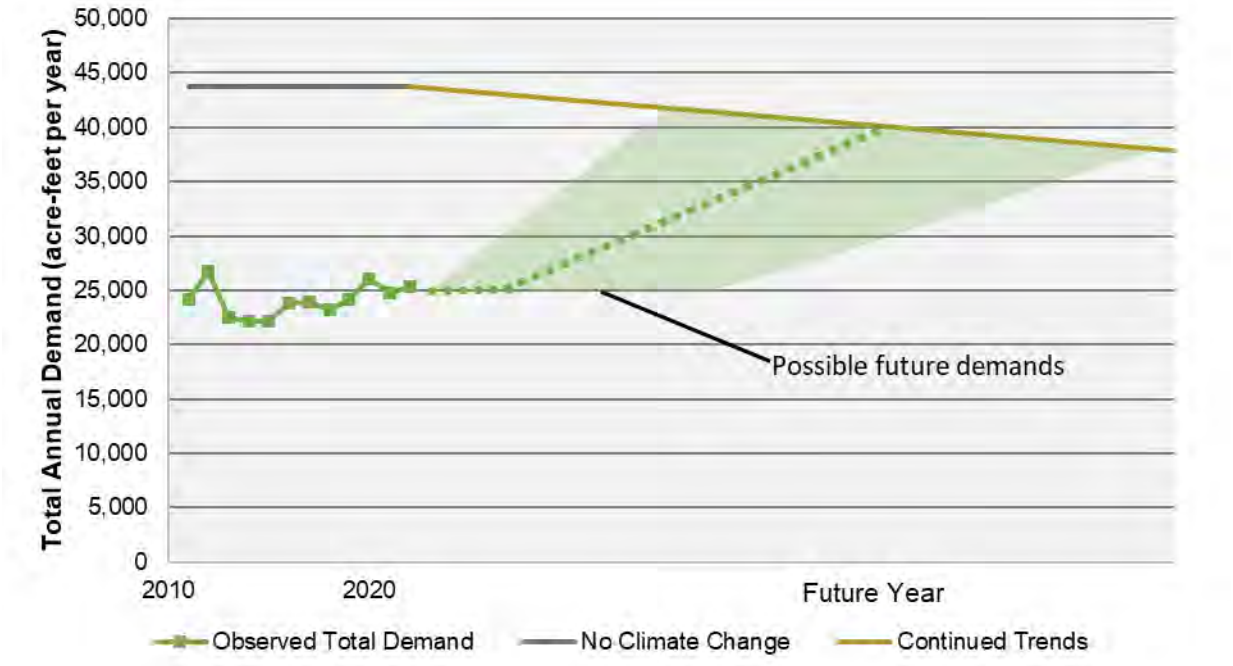

Figure 12-1. Conceptual example of timing the Terry Ranch Project showing how demands (green shaded area/dashed line) could grow while the water the supply system provides could decrease (grey and yellow line)

The purpose of the demand indicators is to establish if Greeley is experiencing significant, sustained growth in total water demand and the rate of that growth. If this demand growth is not occurring, the demand indicators will be used to anticipate if and when demand growth could resume. **Figure 12-2** is an example of how the Adaptive Plan could establish if significant and sustained demand growth is occurring. The total demand line and the year-to-year demand change bars show that since 2010 there has been minimal change in total demands. If year-to-year demand change occurs for three consecutive years and the cumulative volume of that change is greater than 2,500 acre-feet that could indicate sustained, significant demand growth. The criteria used in the Adaptive Plan may differ, but this process would establish the occurrence of sustained growth regardless of source (e.g., population, new industrial use, warming climate).

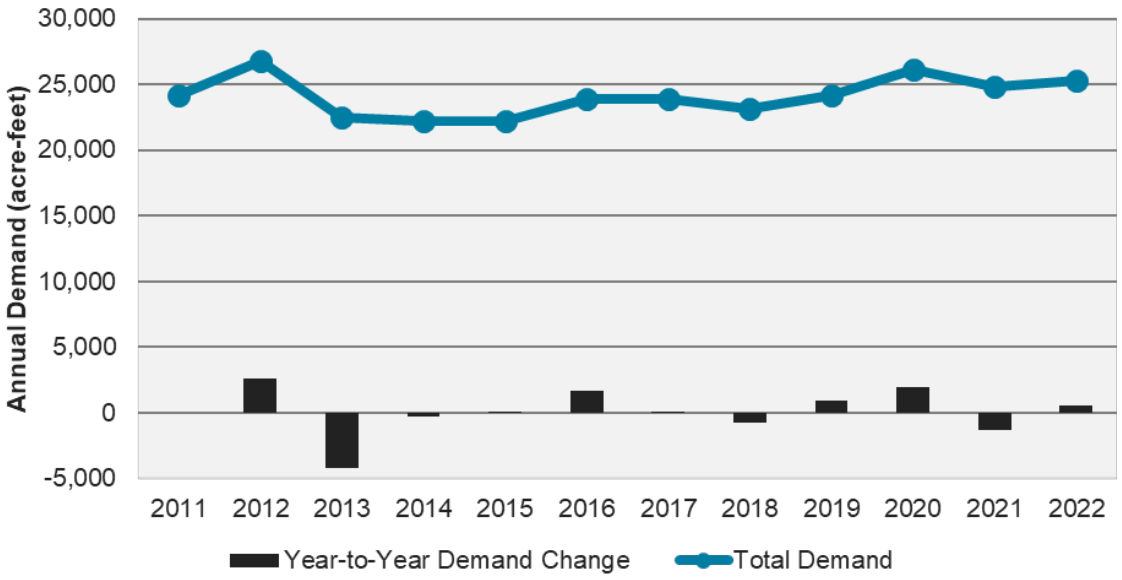

Figure 12-2. Historical Annual Total Demands and Year-to-Year Change

There are other demand indicators Greeley could use in the Adaptive Plan to monitor and assess future demands, which are described below. As the Adaptive Plan is implemented, these indicators may be updated with new indicators.

- **Residential Per Capita Demand**: This indicator will measure Greeley's residential per capita demands and if those values are reducing, varying significantly, or stagnant from year to year. Greeley's future demand growth will primarily be driven by residential use. Due to improved indoor and outdoor conservation since the 2002 drought, reductions in residential per capita use have been significant enough that overall water use was flat despite population growth. Eventually reductions in residential per capita use will reach a floor after which demand growth would occur with population growth.
- **Conservation Rebate Use**: This indicator will measure how customers are using the rebates Greeley makes available to reduce water use. While there are many factors that affect why customers make use of rebates, multiple years with minimal rebate use despite broad community outreach and incentives could further indicate conservation measures have reached a floor.

- **Drought Restriction Use**: The IWRP used a maximum drought restriction use of 20 percent of years in any level and 10 percent of years in Level 3. If Greeley has required drought restrictions at or in excess of those assumptions (e.g., 2-in-10 years at any Level and 1-in-10 years at Level 3), that could indicate a need for the Terry Ranch Project.

In addition to the demand indicators described above, the Adaptive Plan will also monitor supply indicators to establish if the yield from Greeley's water supply system is decreasing. These water supply indicators will emphasize the long-term trends of Greeley's water supply system given that Greeley already monitors near-term indicators such as snowpack. The Adaptive Plan will characterize the long-term health of Greeley's Colorado system, Upper Poudre System (e.g., west of Interstate 25), and the Big Thompson System into *Resilient*, *Vulnerable*, and *Degraded* (defined below) using the visual shown in **Figure 12-3**. In this figure, the solid arrow represents the current status of each system with the arrow outline representing the previous status. Statuses are defined as follows:

- Resilient: Yields from the system are consistent with IWRP assumptions and do not show signs of potential reduction.
- Vulnerable: Yields from this system are consistent with IWRP assumptions but do show signs of potential reduction if certain conditions emerge or persist.
- Degraded: Yields from this system are lower than IWRP assumptions.

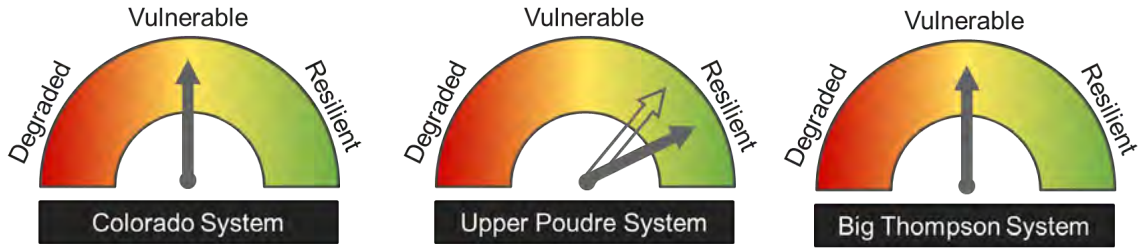

Figure 12-3. Example of How the Health of Greeley's Water Supply Systems Will be Described

The Adaptive Plan will also include a more detailed assessment of each system that justifies the overall system health characterization. **Table 12-3** lists examples of quantitative and qualitative indicators in each system that could be included in the Adaptive Plan.

Table 12-3. Examples of Qualitative and Quantitative Indicators to Establish System Health

System	Quantitative Indicators	Qualitative Indicators
Colorado	• CBT Quota History	• Political headlines and updates
Upper Poudre	• Native yields at canyon mouth • Greeley Poudre rights yield	• River commissioner report
Big Thompson	• GLIC allocations	• Natural disturbance tracking

Action 3: Update 5- and 10-year Terry Ranch Implementation

While full implementation of the Terry Ranch Project is not defined, Greeley will continue to incrementally implement key components of the larger project. This ensures that Greeley has the flexibility to fully implement the project when required by minimizing potential barriers such as right-of-way access, water rights ownership, and permits. The Adaptive Plan will update of Greeley's 5- and 10-year Terry Ranch Implementation strategy to account for any changing conditions with the project.

Figure 12-4 shows an example of what the Adaptive Plan update of the 5- and 10-year Terry Ranch implementation could look like. In this example the planned projects within the next five years are shown by major category, which at the time of the IWRP included pipe installation, the State Land Board water court process, and future need assessment that is part of the Adaptive Plan. Greater detail about each project will be elaborated with key updates provided. The Adaptive Plan will also include regular updates on Greeley's 10-year strategy including topics such as financial planning, partnerships, and other emerging factors. The Adaptive Plan's Terry Ranch Implementation update will be closely tied to and aligned with any corresponding update to the CIP.

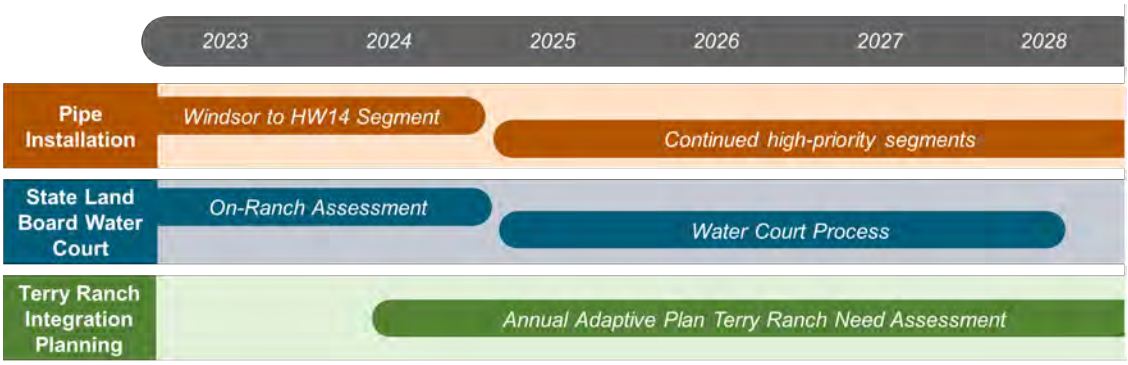

Figure 12-4. Example of Five-Year Terry Ranch Implementation Plan

Action 4: Assess Water Rights Changes and Acquisitions

The IWRP recommends that Greeley change currently owned water rights for Greeley use and continue strategically acquiring new water rights. There is significant uncertainty in the outcome of many water right changes and the competition and cost of acquiring new water rights continues to increase. The Adaptive Plan will assess how water rights changes and acquisitions are progressing compared to the IWRP goals and if changes are required.

To assess water right changes cases, the Adaptive Plan will include a figure like **Figure 12-5**. Greeley's existing water rights portfolio will be classified into four categories: available for use, long-term leases, change in-progress, or unchanged based on acre-foot estimations (e.g., the size of the wedge is an approximation of equivalent acre-foot volume as opposed to number of shares). As part of the Adaptive Plan, change case outcomes will be summarized and outcomes that are significantly different from what was assumed will be described.

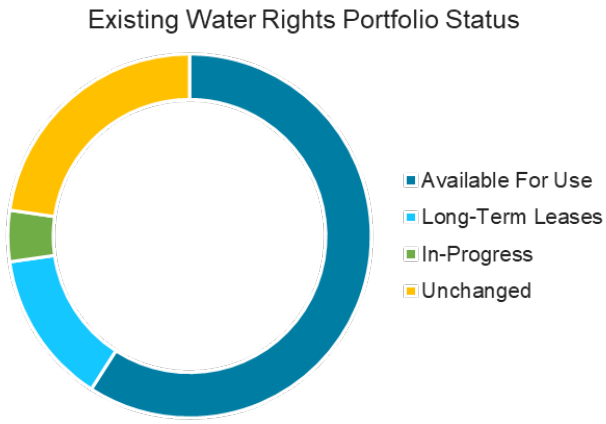

Figure 12-5. Example of How Greeley's Current Water Rights Portfolio is Characterized

Similar to the assessment of water right change case outcomes, the Adaptive Plan will also update Greeley's water rights acquisitions. Recent water right acquisitions and their purpose within Greeley's water supply system will be summarized. How water rights acquisitions are happening, and how that compares to Greeley's water acquisition strategy, will be characterized and any potential changes to that strategy discussed. The WADT will be updated as needed with new information or as acquisitions are made available to Greeley. This could include the portion of new water rights acquired for potable, non-potable, or multi-use purposes. Finally, the Adaptive Plan will include an update on the water rights landscape for the region including price changes, any major non-Greeley acquisitions, and other news that could potentially affect Greeley's acquisitions strategy.

Action 5: Review Other Water Resources Opportunities

The final action of the Adaptive Plan will be providing an update on other water resources opportunities beyond the Terry Ranch Project and water rights. Greeley will continue to invest in a variety of projects that improve the water supply system such as the non-potable system, conservation, and smaller-scale infrastructure projects. Status updates of these projects, such as function, schedule, and budget will be provided. In addition, the Adaptive Plan will provide an update on other regional projects that either could affect Greeley's water supply system or that Greeley could participate in.

An important part of this action will also be acting on new identified water resources opportunities. The Adaptive Plan will provide an update on new water resources opportunities such as decisions made, the results of any studies, and recommended next steps. For example, the IWRP identified retiming storage for Terry Ranch as a potentially effective new water resources project. Greeley is planning on evaluating in more detail retiming storage options after the IWRP. The Adaptive Plan will update what is learned from that study and any further recommendations.

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13.0 REFERENCES AND SUPPORTING DOCUMENTATION

13.1 SUPPORTING DOCUMENTATION

The following supporting documentation was developed during the IWRP and is included as Appendices to this report.

- Appendix A: Water Resources 10-year CIP
- Appendix B: Demand Forecast TM
- Appendix C: IWRP GSM Documentation TM
- Appendix D: IWRP Presentation Slides

13.2 REFERENCES

BBC Research & Consulting. *City of Greeley Population and Water Demand Projections*. 2018.

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