APPENDIX I: WATER MANAGEMENT STRATEGY ASSESSMENT AND VULNERABILITY EVALUATION

I.1. Selecting Water Management Strategy Portfolios

The goal of the water management strategy assessment and vulnerability evaluation and selection process is to identify portfolios of water management strategies that, when combined with Austin's core water supplies from the Colorado River and Highland Lakes, will provide a robust and reliable source of water to meet Austin's demands over the 100-year planning horizon, from 2030-2120. Austin Water has many potential water management strategies that could extend and supplement its core water supplies sourced from the Colorado River. These strategies, compiled from the list of candidates considered in Water Forward 2018 (WF18), include conservation, potable and non-potable reuse, water supply storage, and the development of new water sources.

These Water Management strategies are organized into groupings, referred to as portfolios. The evaluation and selection process seeks to identify the best portfolios for Austin Water to address reliability across a wide range of future scenarios while also considering costs and other planning objectives outlined in the Guiding Principles of Water Forward 2024 (WF24). The entire process is referred to as the Water Management Strategy Analysis and Vulnerability Evaluation, or WAVE.

A reliable portfolio meets Austin's water needs over the 100-year planning horizon. These needs are modeled estimates of water supply shortages in each decade if Austin Water implemented no new water management strategies. The needs in each decade vary based on the modeling scenarios, which reflect the wide range of possible future conditions. The WAVE considers varying levels of Austin demand, of basin-wide or regional water supply development, and of climate change impacts over the 100-year planning horizon. The Texas Commission on Environmental Quality (TCEQ) Water Availability Model (WAM), the state's surface water rights model, is used to evaluate Austin water needs.

I.2. Water Management Strategy Evaluation

The WAVE proceeds in two components, 1) a Water Management Strategy Evaluation and 2) a Vulnerability Analysis and Adaptive Management Plan. The first component addresses the water supply needs of the first 50 years of the WF24 planning horizon, from 2030 to 2080.

The water management strategy evaluation begins by considering a large number of possible portfolios for 2080. Since there are many types of water management strategies that can be combined in various ways, the number of portfolios is very large. Each potential portfolio is evaluated using a simulation modeling tool (described below) in each of the hydrologic scenarios for 2080 assuming a high estimate for Austin's demand and a low estimate for regional supply development. These demand and supply assumptions are relaxed in the vulnerability analysis.

Figure I - 1 shows the results of these simulations. The figure shows the performance score, as discussed below, of each portfolio as a function of its cost. The performance scores indicate how well each portfolio addresses Austin's water needs over a wide range of conditions. Most portfolios are shown with a light blue dot. However, a small number of portfolios have a performance score and scaled cost that places them along the frontier edge of the scatter plot.

These portfolios, called the Pareto set, are plotted in dark blue and represent all the best-performing portfolios offering differing tradeoffs among cost and performance. For any of these best-performing portfolios, it is not possible to improve performance without also increasing cost. Note that a Pareto set was determined using each of the constituent metrics which form the overall performance score. The constituent metrics and performance score are discussed below. The x-axis of Figure I - 1 WAVE Analysis Results shows the overall performance score, rather than each constituent metric, and thus some of the dark blue dots do not fall directly on the frontier edge.

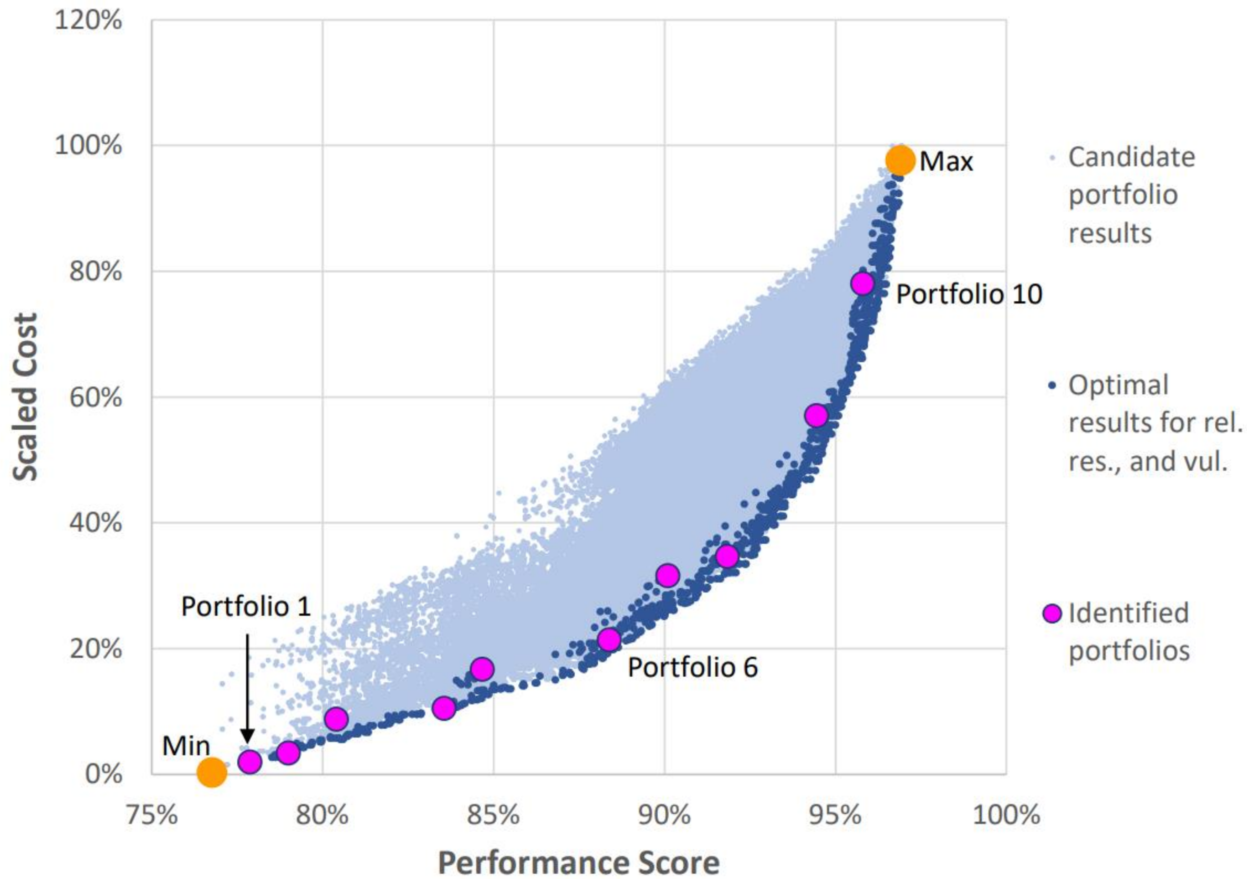

Figure I - 1 WAVE Analysis Results

The performance score shown along the horizontal axis of Figure I - 1 is the average of three metrics: reliability, resiliency, and vulnerability. Collectively, the performance score indicates the ability of the portfolio to satisfy Austin's water supply needs and the duration of low storage within Lakes Buchanan and Travis. A higher performance score indicates fewer shortages and fewer months of low lake storage during extreme drought conditions.

The three metrics are defined as:

- **Reliability:** measures the frequency of encountering water supply shortages during the simulation of future conditions. It is calculated as one minus the percentage of months with water shortages over the total number of months simulated.
- **Vulnerability**: measures the magnitude of water supply shortages. It is calculated as one minus the total volume of shortages divided by the total volume of Austin's demand during periods of simulated low lake storage.
- **Resiliency**: measures the duration of low lake storage and differs from the reliability and vulnerability metrics because this metric does not directly measure shortages in Austin's water supply. Instead, resiliency is calculated one minus the percentage of months that lake storage falls below 450,000 acre-feet over a 24-month period. A lake storage threshold of 450,000 acre-feet is used to assess the impacts of operating under the most restrictive levels of the drought contingency plan (DCP).

The reliability, vulnerability, and resiliency was calculated for each portfolio in each climate adjusted hydrology in 2080. The metrics are highly corelated over the hydrologies so that the ordering does not change. That is, the portfolio with the best reliability in a particular hydrology also has the best vulnerability and resiliency, the portfolio with the second best reliability has the second best vulnerability and resiliency, etc. The performance scores in Figure I - 1 are thus averaged over all the 2080 hydrologies. This assumption is relaxed below.

A modeling tool was created for WF24, known as the mini-WAM, to generate the results shown in Figure I - 1. These results represent millions of combinations of 2080 portfolios and future hydrologic scenarios. This number of simulations would be infeasible to complete within the full TCEQ WAM. However, time series inputs to the mini-WAM were derived from simulations of the full WAM without the portfolios. Pertinent output variables from the full WAM are used by the mini-WAM as inputs, including run-of-river availability for Austin's Colorado River water rights, water availability for storage in Lakes Buchanan and Travis, and water supply demands for Austin and LCRA customers.

I.3. Selecting Portfolios

The analysis next used the results in Figure I - 1 to select a set of ten best-performing portfolios for further evaluation. As shown in Table I - 1, each portfolio contains the same conservation and non-potable reuse strategies but differ in their combinations of potable supplies. The set of portfolios was chosen to represent a wide range of alternative cost and performance tradeoffs, as well emphasize diverse set of water management strategies and supply sources. The selected portfolios are numbered from 1 to 10 with higher portfolio numbers indicating higher performance scores and higher costs, as shown in Figure I - 1.

Table I - 1 Identified Portfolios for 2080

Category	Subcategory	Strategy	1	2	3	4	5	6	7	8	9	10
			2080 Portfolios									
Conservation		Utility-Side Water Loss Control	x	x	x	x	x	x	x	x	x	x
Conservation		Customer-Side Water Use Management	x	x	x	x	x	x	x	x	x	x
Conservation		Native & Efficient Landscaping	x	x	x	x	x	x	x	x	x	x
Non-Potable Reuse		Centralized Reclaimed	x	x	x	x	x	x	x	x	x	x
Non-Potable Reuse		Decentralized Reclaimed	x	x	x	x	x	x	x	x	x	x
Non-Potable Reuse		Onsite Reuse	x	x	x	x	x	x	x	x	x	x
Potable Supplies	Water Supply Storage	Aquifer Storage and Recovery	x	x	x	x	x	x	x	x	x	x
Potable Supplies	Water Supply Storage	New Off Channel Reservoir							x	x		
Potable Supplies	Water Supply Storage	New Off Channel Reservoir with Reuse									x	
Potable Supplies	Water Supply Storage	Decker Lake Off Channel Reservoir	x	x		x	x	x				
Potable Supplies	Potable Reuse	Direct Potable Reuse					x		x		x	x
Potable Supplies	Potable Reuse	Indirect Potable Reuse		x	x		x	x	x		x	x
Potable Supplies	Contr-acts	New Lower Colorado River Supply										
Potable Supplies	New Water Supplies	Brackish Groundwater Desalination				x	x	x	x	x	x	x
Potable Supplies	New Water Supplies	Seawater Desalination										x
Potable Supplies	New Water Supplies	Interbasin Transfer										x
Potable Supplies	New Water Supplies	Conventional Groundwater								x	x	x

I.4. Pathways Analysis

The analysis next stress tested this set of 10 best-performing portfolios against the best case and worst-case climate adjusted hydrologies. In the worst-case 2080 hydrology, all the portfolios shown in Figure I - 1 perform significantly worse. However, the 10 selected portfolios remain on the new Pareto surface. Thus, even in the worst-case hydrology they are all reasonable choices. In the best-case hydrology, all the portfolios deliver the best possible reliability, vulnerability, and resilience while some portfolios cost less than others. Thus, in the best-case climate, the lowest cost portfolios are preferable.

Next, the ten candidate portfolios were expanded to include build-out pathways for the planning horizons between 2030 and 2070. A promising pathway demonstrates high performance across each decade while avoiding overbuilding, known as cost regret. To calculate the cost regret, it is assumed that Austin Water will know by 2050 whether the 2080 climate adjusted hydrology will be the best-case hydrology. If Austin Water learns the 2080 hydrology will be best-case, it is assumed the City could stop adding or expanding any additional water management strategies after 2050. Thus pathways that defer adding or expanding water management strategies after 2050 reduce their potential cost regret. However, such strategies may degrade their performance in 2030, 2040, and 2050 because they will have deployed fewer water management strategies.

The analysis thus considers three to six pathways for each 2080 portfolio, representing different deployment speeds for the underlying strategies. Each pathway is evaluated to determine how closely it approaches the Pareto surface of performance and costs in each decade. For each 2080 portfolio, the pathway with the best balance between performance and cost regret was chosen. Table I - 2 Portfolio 6 Potable Water Supply Strategy Yields shows the chosen pathway to Portfolio 6.

Table I - 2 Portfolio 6 Potable Water Supply Strategy Yields

	Estimated Yield (Acre Feet per Year)					
Strategy	2030	2040	2050	2060	2070	2080
Aquifer Storage and Recovery	0	44,500	44,500	44,500	44,500	44,500
Lake Water E. Long Off Channel Reservoir	0	18,300	18,300	18,300	18,300	18,300
Indirect Potable Reuse	***	***	22,400	22,400	22,400	22,400
Brackish Groundwater Desalination	0	0	0	0	20,000	40,000
TOTAL	0	62,800	85,200	85,200	105,200	125,200

Once the pathways are chosen for each 2080 portfolio, the performance metrics and cost of each pathway are evaluated along with the multi-criteria objectives for each decade of the 2030-2080 period. Since the number of modeling scenarios was narrowed, it was feasible to use the full WAM in this step to calculate the performance metrics. Portfolio 6 achieved the highest score based on the multi-criteria objectives, as shown in

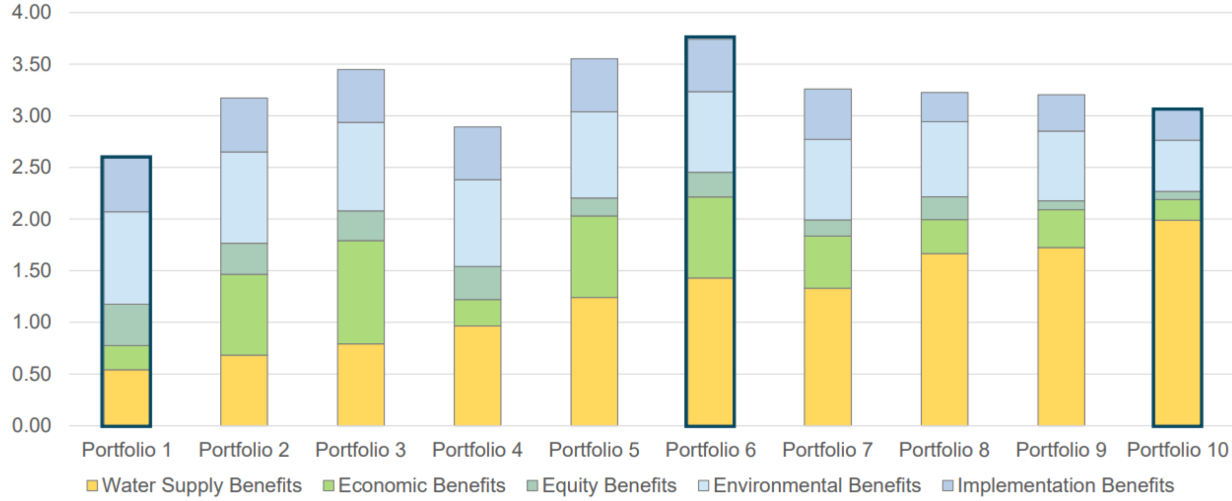

Figure I - 2, and is selected as the preferred portfolio option. Note that this additional level of portfolio evaluation according to the multi-criteria objectives is a separate, but complementary, step to the WAVE process, which focuses on portfolio performance and costs.

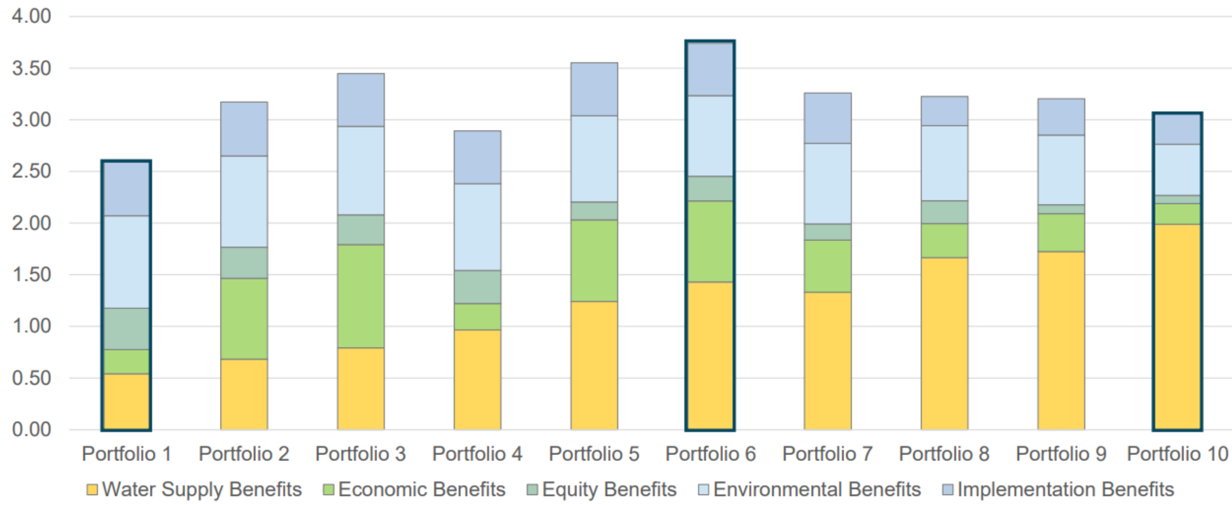

Figure I - 2 Portfolio Scores for 2030 – 2080

I.5. Vulnerability Analysis and Adaptive Management Plan

The first WAVE component identified a preferred 2080 portfolio and build-out pathway from 2030 to 2080 to reach that portfolio. In this second WAVE component, the selected 2080 portfolio is expanded to address Austin water needs for the second half of the 100-year planning horizon, which extends from 2080 to 2120, against the backdrop of regional water supply development and climate change conditions. Recognizing that uncertainty increases with time, and especially in the second half of the 100-year planning horizon, the second WAVE component identifies an Adaptive Management Plan, which monitors changing conditions and provides alternative pathways to build upon the recommended portfolio according to observed conditions around the 2080 decade.

To inform this Adaptive Management Plan, the second WAVE component employs a Vulnerability Analysis. The use of "vulnerability" as a descriptor for this analysis does not indicate that the same-named performance metric, as defined in the previous section, is the only consideration. Rather, the Vulnerability Analysis refers to stress testing the performance of alternative portfolios over a wide range of plausible futures and using the results to inform the design of the Adaptive Management Plan.

The second WAVE component begins with an evaluation of a large set of portfolios for 2120 which all build on Portfolio 6. All the 2120 portfolios considered are constrained to contain the same or greater yields of 2080 conservation, reuse, and water supply strategies that contained in Portfolio 6 in 2080. The performance score for each portfolio, based on the three metrics, was calculated from the mini-WAM simulations which included the range of future climate change conditions, similar to the Water Management Strategy Evaluation.

This calculation yields a Pareto tradeoff curve, similar to Figure I - 1, that identifies the set of best performing portfolios in 2120. These best-performing portfolios lie in four clusters with different combinations of cost and performance. The analyst team selected one representative portfolio from each of the first three clusters, which offer a mix of different supply strategies and cost/performance tradeoffs. The fourth strategy is not included here because it provides only small performance improvement for additional cost. As described below, this fourth strategy is used in this analysis as the reference point for the best possible performance Austin Water could achieve in each 2120 scenario regardless of cost.

Table I-3 shows three alternatives for expanding the water supply strategies in 2120 that are included in the Adaptive Management Plan. The alternative portfolios are identified as A, B, and C, where the performance and costs increase with the lettering. The first four rows of Table I-3 include the same supply strategies as included in Table I - 2 for the decade of 2080. However, alternatives A, B, and C increase some of the yields for these four strategies.

Table I-3 also includes two new rows for the additional water supply strategies needed to ensure adequate performance given the range of potential demands, regional supplies, and climate change conditions in 2120. The additional supplies are grouped into two categories: supplies that derive from sources independent of the hydrology of the Colorado River Basin, and supplies that may be developed from sources within the basin. Examples of supplies that are independent of the basin include seawater desalination or inter-basin transfers. Examples of supplies that may be developed from sources within the basin include additional supply contracts with LCRA or additional Austin potable reuse strategies.

Table I - 3 Portfolio 6 Potable Water Supply Strategy Yields, 2080 and 2120

	Estimated Yield (Acre Feet per Year)			
Strategy	Portfolio 6 2080	Portfolio 6A 2120	Portfolio 6B 2120	Portfolio 6C 2120
Aquifer Storage and Recovery	44,500	44,500	83,000	44,500
Lake Water E. Long Off Channel Reservoir	18,300	18,300	18,300	18,300
Indirect Potable Reuse	22,400	33,600	22,400	44,800
Brackish Groundwater Desalination	40,000	40,000	40,000	40,000
Additional Colorado River Basin - Independent Supply	0	20,000	20,000	60,000
Additional Colorado River Basin Supply	0	0	35,000	30,000
TOTAL	125,200	156,400	218,700	237,600

Next, a Vulnerability Analysis was conducted on the alternative portfolios A, B, and C by evaluating their costs and performance scores in each of three levels for Austin demand, each of three levels for regional supply, and the full range of climate projections all out to 2120. The climate projections were grouped by three levels of global emissions, indicated as low, medium, and high. As described in WF24 Climate and Hydrology Analysis appendix, these three levels correspond to: Shared Socio-Economic Pathway (SSP) 1-2.6, SSP 2-4.5, and SSP5-8.5.

The comparative performance of each alternative portfolio in each scenario was then calculated. This comparative performance (also known as the 'regret') is the percentage difference between the performance of a portfolio in a given future and the best possible performance in that future if Austin Water deployed all possible water supply strategies in 2120. It is useful to consider this comparative performance because the absolute level of performance differs significantly over the scenarios, some of which are very stressing in 2120.

Table I - 4 shows the results. Portfolio 6C performs best over all the scenarios and is often within a few tenths of a percent of the best possible performance. Portfolio 6B performs well over many scenarios, but it can deviate by 5% or more from the best possible performance in scenarios with top demand or in many scenarios with medium or high climate change. Portfolio 6A only performs well compared to the best possible performance if the climate in 2120 is close to the historical 20th century climate in the Austin region.

Table I - 4 Comparative Performance of Portfolios 6A, 6B, and 6C in 2120

		Low Demand			Med Demand			Top Demand		
	Group A	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply
Climate	Historical	0.3	0.1	0.0	1.1	1.1	0.4	3.3	2.1	2.3
	Low	5.6	4.5	5.6	7.2	5.7	6.0	10.5	8.5	10.4
	Med	6.5	5.0	4.9	8.5	8.3	10.8	9.9	11.6	12.6
	High	5.2	6.4	6.9	7.5	5.8	5.1	9.8	8.4	9.6

		Low Demand			Med Demand			Top Demand		
	Group B	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply
Climate	Historical	0.2	0.1	0.0	0.9	0.6	0.3	1.5	0.9	1.2
	Low	4.6	3.4	3.7	5.0	4.6	5.1	6.9	5.6	7.6
	Med	3.6	2.8	3.8	5.3	5.5	6.4	5.9	7.8	9.3
	High	2.8	4.2	5.1	4.5	3.4	2.5	6.2	4.3	5.1

		Low Demand			Med Demand			Top Demand		
	Group C	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply	Low Supply	Med Supply	Top Supply
Climate	Historical	0.0	0.0	0.0	0.1	0.1	0.1	0.3	0.3	0.0
	Low	1.0	0.9	0.9	0.7	0.7	0.5	2.0	0.7	0.9
	Med	0.8	0.7	1.2	1.1	1.1	1.2	2.1	2.4	3.1
	High	1.2	1.7	1.8	1.7	0.7	0.7	1.0	0.8	0.5

	= 0%
	=< 5%
	> 5%

We can now use the results in Table I - 3 and Table I - 4 to identify "signposts" to inform which pathway would be better suited to address the conditions that are observed to be emerging in the long-term future. Figure I - 3 Adaptive Management Pathways shows the resulting adaptive management pathways to expand Portfolio 6.

Beginning with the Portfolio 6 configuration for 2080, the first set of choices shown in the figure relates to climate conditions. If the climate conditions are similar to the 1940-2020s historical hydrology, then the top pathway is selected and Portfolio 6A is the best choice. If climate conditions differ from historical, then three best pathways are considered. Each additional fork in the adaptive management pathway in Figure I - 3 considers Austin's demands and the development of regional supply projects. The pathways lead to the right side of the figure to a selection of Portfolio 6A, 6B, or 6C.

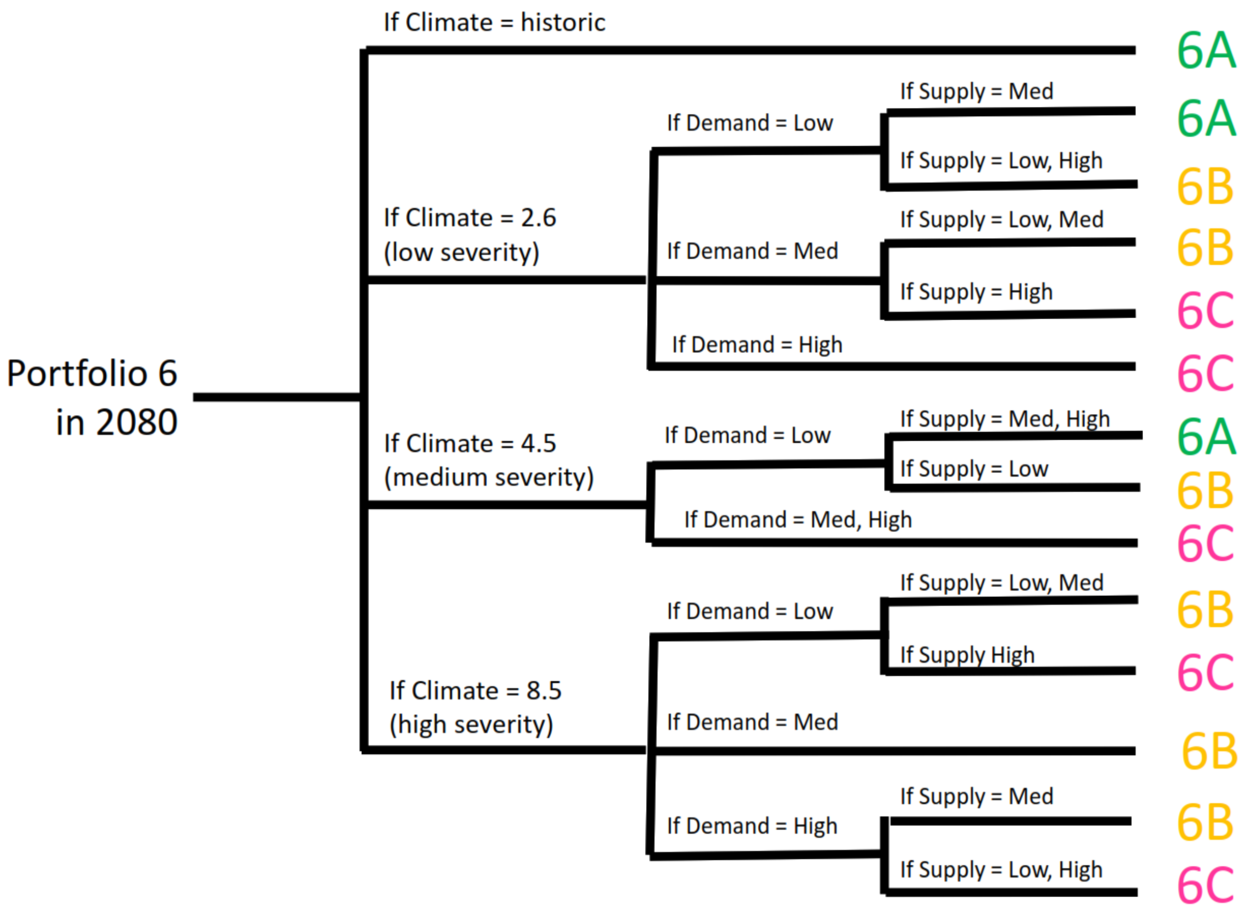

Figure I - 3 Adaptive Management Pathways