COLORADO
Colorado Water Conservation Board
Department of Natural Resources

SWSI
Statewide Water Supply Initiative

Statewide Water Supply Initiative Update
Technical Memorandum

Prepared for: Colorado Water Conservation Board
Project Title: SWSI Update

Subject: Recommended Methodology for Developing SWSI Population Scenarios
Date: June 29, 2017 (Revised July 13, 2018)
To: Colorado Water Conservation Board
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Section 1: Methodology Objectives

One of BBC's responsibilities under SWSI Task Order 2 is to develop a methodology for developing alternative population projection scenarios. Population projections, by basin and for the state as a whole, are the primary driver in the municipal and industrial demand projections which will be developed by Element Water. This memo provides BBC's recommendations regarding the development of alternative population projections for SWSI.

Section 2: Background on Previous Methodologies

2.1 Overview of Methodologies used in SWSI 2010

As documented in Appendix H, "State of Colorado 2050 Municipal & Industrial Water Use Projections", alternative population scenarios through 2050 were also developed for the previous SWSI effort. That work, primarily conducted in 2008-09, required both extending the county and state population projections available at the time from the State Demography Office (SDO) from 2035 to 2050 and developing alternative high and low scenarios.

Harvey Economics, in collaboration with the SDO, essentially sought to extend the existing SDO projections using a similar approach to the methods the SDO used to develop their forecasts (which at the time covered the period of 2005 through 2035). Those methods included developing economic (e.g. employment) forecasts for the state and each county to develop estimates of future labor demand. Future labor demand was then compared to projected future labor supply based on an extended cohort component demographic model similar to the SDO's demographic model. In areas where labor demand was projected to exceed available labor supply, additional net in-migration was assumed to occur in order to balance the labor markets. In situations where labor supply was projected to exceed labor demand, net out-migration was assumed to occur to balance the labor markets.

The need to extend the SDO's projections from 2035 to 2050 also served as the basis for developing the alternative high growth and low growth scenarios. In the previous SWSI effort, the population scenarios all assumed the same growth (the SDO forecast) through 2035. However, the high growth scenario incorporated more aggressive economic/employment growth assumptions for the extension from 2035 through 2050, while the low growth scenario incorporated lower economic/employment assumptions from 2035 through 2050 compared to either the high scenario or the medium scenario.

2.2 Methodology Enhancements for SWSI Update

Two factors suggest it would be beneficial to modify the approach to developing the alternative population projection scenarios for this SWSI update:

- First, the SDO population projections are now available through 2050 (which remains the endpoint for this SWSI update). It is no longer necessary to extend the SDO projections in order to create the middle, or base case, population projections.
- During the scenario planning workshop held in early March 2017, CWCB (and other members of the SWSI team) suggested it would be beneficial to find a simpler approach for developing the alternative scenarios that would be easier to explain and involve fewer assumptions.

After further discussions with other members of the study team and the SDO, BBC recommends taking a more simplified approach to developing the alternative population scenarios for this SWSI update. While the previous approach was methodologically rigorous in producing an internally consistent set of employment and population forecasts, only the population numbers were actually used in deriving the future water demand forecasts. Moreover, development of alternative employment forecast scenarios for various sectors in all 64 counties in Colorado inevitably involved making numerous assumptions about conditions far in the future that were based almost entirely on judgment. By avoiding these types of judgment based assumptions, the methodology recommended herein also avoids "picking winners and losers" in developing alternative population scenarios for smaller areas such as the basins and individual counties.

Section 3: Description of Recommended Methodology

After considering various options, BBC recommends that the alternative population forecasts be developed based on the existing SDO population forecasts that now span the entire SWSI study period and will provide the base case or middle projection, and probabilistic analysis of the potential variance around those forecasts to develop the high and low projections. The variance around the SDO projections can, in turn, be estimated from the historical population growth experience of the state, and each of its basins. As discussed later in this memo, these three sets of projections, with some modifications to the distribution of growth within the state, can be used to develop population forecasts consistent with the five planning scenarios developed in the State Water Plan.

3.1 Specific methodology

Under our recommended approach, only three pieces of information are required to develop probabilistic estimates of the potential range surrounding the "median" population projections produced by the SDO. Those information requirements are:

- The compound average annual growth rate implied by the SDO forecast. For example, for the State of Colorado as a whole, the SDO is forecasting a 2050 population of 8,541,540 residents. By comparing that projection to the 2010 population of 5,029,196, we can calculate the compound average annual growth rate over the 40 year period to be 1.333 percent per year.
- The historical standard deviation in population growth rates by decade. As shown in Table 1, from 1940 through 2010 the standard deviation in average annual population growth rates by decade for the State of Colorado was 0.634 percent.
- The historical compound average annual growth rate for the area being projected. As also shown in Table 1, from 1940-2010 the average annual compound growth rate for Colorado as a whole was 2.165 percent per year.

Table 1. State of Colorado Population Growth, 1940-2010 (Compound Average Growth Rate and Standard Deviation in Average Growth Rate by Decade)

State of Colorado Population Growth 1940-2010
(Compound Average Growth Rate and Standard Deviation by Decade)

Year	Population	Avg. Rate
1940	1,123,296	
1950	1,325,089	1.67%
1960	1,753,947	2.84%
1970	2,207,259	2.33%
1980	2,889,964	2.73%
1990	3,294,394	1.32%
2000	4,301,261	2.70%
2010	5,029,196	1.58%
1940-2010 Compound Growth Rate	2.165%	
Standard Deviation in Growth Rate by Decade		0.634%

Source: U.S. Census Bureau, 2017. Growth rates and standard deviations calculated by BBC.

Fundamentally, this approach relies on a couple of key assumptions:

- The compound growth rate for 2015 through 2050 derived from SDO population projections represents the median average annual growth rate forecast for each area. Out of a hypothetical million potential alternative futures, the future described in the SDO forecast would fall in the middle.
- The variability of growth rates in future decades (and corresponding potential variance around the SDO-based median forecast) can be estimated based on historical variability in growth rates by decade since 1940. However, BBC has further assumed that the "coefficient of variation" for the growth rates in each basin will remain the same in the future as they have been in the past. This means that the size of the standard deviation in each basin's future growth rate will change in proportion to the ratio of their projected median growth rate in the future to their median growth rate in the past. For example, if the median future annual growth rate is projected to be ½ of the historical annual growth rate, the future standard deviation by decade is also assumed to be ½ of the historical standard deviation.

The second assumption described above is both logical, and supported by the historical data.

BBC calculated the historical compound average annual growth rates for each of Colorado's 63 counties (excluding Broomfield[1]) from 1940 through 2010, and the historical standard deviations in growth rates by decade for each county. There was a correlation of 0.50 between the absolute values of the compound average annual growth rates and the standard deviations across all of the counties.

We also sorted the counties into quintiles based on their compound average annual growth rates and reviewed average standard deviation across each quintile. In the fastest growing quintile of counties, the historical compound average annual growth rate from 1940 to 2010 averaged 3.7 percent per year, while the standard deviations in growth rates by decade averaged 3.1 percent. In the slowest growing quintile of counties, the historical compound average annual growth rate from 1940 to 2010 averaged 0.1 percent per year, while the standard deviations in growth rates by decade averaged 1.3 percent.

3.1.1 Steps to implement this analysis

The following sequence of steps will be used to implement the analysis.

1. Calculate median compound average annual growth rate for the state (as shown in Figure 1) and each basin based on the SDO projections through 2050.

2. Estimate the standard deviation in future growth rates by decade for the state and each basin based on the following calculation:

   Future standard deviation = historical standard deviation (1940 – 2010) x projected median compound growth rate in future (2010-2050) / historical compound growth rate (1940 – 2010)

3. Use Monte Carlo simulation techniques to simulate alternative future populations for each area based on baseline compound average annual growth rate (from SDO projections) and estimated standard deviation in growth rates by decade. Each "run" for each geographic area will build to a 2050 population projection as follows:

   a. 2020 population = 2010 population (estimate from SDO) x (1 + X)^10, where X is a randomly drawn average annual growth rate from a normal distribution with its mean based on the compound growth rate from the SDO projections, and its standard deviation estimated based on step 2.

   b. 2030 population = 2020 population estimate (from step 3a) x (1 + X)^10, where X is another randomly drawn average annual growth rate from the distribution described in step 3a.

   c. Repeat step 3b until we reach 2050.

[1] Broomfield became a separate county in 2001. Prior to 2001 the City of Broomfield spanned four counties north of Denver. Given its relatively short history as a separate county, BBC did not include Broomfield in the analysis of historical correlations between county growth rates by decade and the standard deviation in those average growth rates across multiple decades.

4. Based on thousands of "runs", identify the estimated overall distribution of potential future population totals for the state and each basin in 2050.

To encompass a wide range of potential future population growth outcomes, BBC recommends using the 10% exceedance probability for the "high" projections and the 90% exceedance probability for the "low" projections. Based on these thresholds, we would estimate there is a 1 in 10 chance that the actual future 2050 population could be higher than the "run" with the estimated 10% exceedance probability, and a 1 in 10 chance the actual future 2050 population could turn out to be lower than the "run" with the estimated 90% exceedance probability.

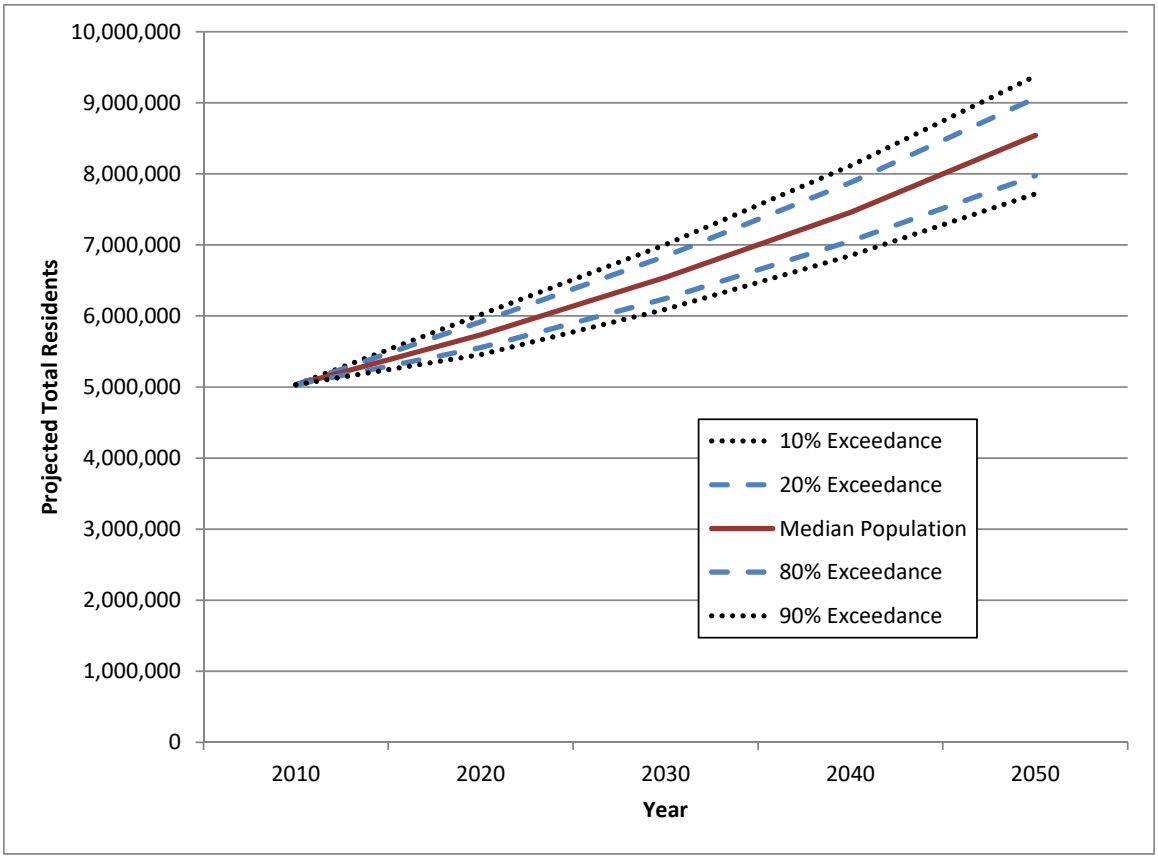
3.1.2 Statewide Population Example

To more specifically illustrate the application of this methodology, BBC implemented the proposed approach for the State of Colorado as a whole. Figure 1shows the resulting estimated range of possible future population totals for Colorado.

The SDO's current population projection for Colorado in 2050 is 8,541,540 residents. That projection is represented in Figure 1 by the red line labelled "median population", and would provide the middle or base case population scenario for SWSI.

Using the 10 percent exceedance probability for the high forecast, the 2050 population projection for that forecast would be 9,417,300. Using the 90 percent exceedance probability to represent the low forecast for future population, the low scenario would have a projected statewide population in 2050 of 7,742,773 residents.

Figure 1. Range of Potential State of Colorado Population Growth, 2010-2050 (Selected Exceedance Intervals)



Note: For simplicity in calculation and illustration, this example uses the average compound growth rate from the SDO statewide projections over the entire period, and does not reflect the declining growth rates from decade to decade embodied in the SDO projections. Consequently, the median population line is lower than the actual SDO projections for all years before 2050.

3.1.3 Application to Basins and Counties

The same methodology can be readily applied to generate potential ranges of variance in the future population projections for each of the basins and counties, with a couple of caveats and potential refinements.

In general, the smaller geographic areas represented by the basins have larger coefficients of variation in their historical population growth rates than the state as a whole. This implies that their population projections, under the methodology proposed in this memo, will also have larger variance (on a relative basis) than the state as a whole. Carried further, the larger variance in the basin population projections would mean that the sum of the basin populations for the high set of projections (the 10 percent exceedance probability) is greater than the overall statewide population projection for the same exceedance probability. Correspondingly, the sum of the low population projections for the basins (the 90 percent exceedance probability) is lower than the 90 percent exceedance probability estimate for Colorado as a whole.

It could be argued that these discrepancies are actually logical. There is no reason to believe that a future high population growth scenario for Colorado as a whole necessarily means that

every basin will be simultaneously experiencing high growth, and vice-versa for the low scenario.

However, it would be problematic from a planning standpoint to deal with a set of high growth projections for the basins that collectively exceed the high growth projection for the State (or vice versa for the low projections). BBC recommends dealing with this issue by constraining the high and low projections for the basins to sum to the statewide total. The constraint will be imposed by proportionally reducing growth in each basin (under the high population projections) as needed to make the sum of the basin projections match the statewide total – or proportionally increasing growth in each basin (under the low population projections) so that the sum of the basin projections matches the statewide low projections.

Alternative population scenarios for the state's individual counties will also be used in developing the SWSI municipal demand forecasts. The potential issues regarding consistency between the statewide population projections and projections for the smaller areas would be even greater at the individual county level. Consequently, we do not recommend developing probabilistic population forecasts for the individual counties. Instead, we recommend apportioning the basin population projection scenarios to their component counties based on each county's share of the median, SDO projections for its basin.

Six of Colorado's 64 counties include lands located in more than one basin. Current and projected future populations for these counties will be divided between the relevant basins using the same proportions utilized in the 2010 SWSI population projections.

Section 4: Developing the Five SWSI Population Scenarios

During the previous SWSI process, and the creation of the State Water Plan, five alternative future scenarios were developed. These scenarios were entitled "business as usual", "weak economy", "cooperative growth", "adaptive innovation", and "hot growth."

As described in the State Water Plan, each of the five scenarios includes distinctive assumptions regarding future demographic growth. The following are excerpts from the descriptions of each scenario specifically related to population growth, and the manner in which BBC recommends that the population projections be produced for each scenario.

4.1 Business as Usual Scenario

- Excerpts from State Water Plan description:
  "Recent trends continue into the future. Few unanticipated events occur. The economy goes through regular cycles, but grows over time. By 2050, Colorado's population is close to 9 million people. Single family homes dominate, but there is a slow increase of denser developments in large urban areas."
- Recommended implementation:
  Use the current SDO state and county projections for 2050. BBC met with the SDO on 5/30/2017 and confirmed that this scenario is consistent with the assumptions embodied in their forecast. As noted in Section 2.1 of this memo, the SDO projections are based on a sophisticated combination of a cohort component demographic model and regional employment forecasts throughout the state. Further, the SDO projections are regularly reviewed with local governments and planners, and modified (as necessary) based on local input. The SDO projections are also the "official" population

projections for the State of Colorado and are used for a variety of purposes, including the distribution of funds to local governments.

4.2 Weak Economy Scenario

- Excerpts from State Water Plan description:
  "The world's economy struggles, and the state's economy is slow to improve. Population growth is lower than currently projected, slowing the conversion of agricultural land to housing… Many sectors of the state's economy, including most water users and water-dependent businesses, begin to struggle financially."
- Recommended implementation:
  Use the statistically-derived low growth projections. These projections are consistent with an overall reduction of future growth in Colorado. Based on the methods used to develop the low growth projections, areas with the most consistent growth histories (through booms and busts) would see the smallest reductions in their projected growth relative to the SDO forecasts, while areas that have historically been the most vulnerable to economic busts would see larger reductions in their projected growth.

4.3 Cooperative Growth Scenario

- Excerpts from State Water Plan description:
  "Environmental stewardship becomes the norm. Broad alliances form to provide for more integrated and efficient planning and development. Population growth is consistent with current forecasts. Mass transportation planning concentrates more development in urban centers and mountain resort communities, thereby slowing the loss of agricultural land and reducing the strain on natural resources compared to traditional development."
- Recommended implementation:
  Constrain overall growth to statewide SDO projections. Define mountain resort communities and urban centers. Increase projected 2015-2050 BAU population growth in mountain resort communities by 20%, increase projected 2015-2050 BAU population growth in urban centers by 10%. Adjust other areas (basins and counties) to maintain overall state totals from SDO projections.
- Recommended definitions of mountain resort communities: Grand, Summit, Eagle, Garfield, Routt, Pitkin, Gunnison, San Miguel, and La Plata counties.
- Recommended definitions of urban centers: Denver, El Paso, Pueblo, Boulder, Larimer, Weld, and Mesa counties.

4.4 Adaptive Innovation Scenario

- Excerpts from State Water Plan description:
  "A much warmer climate causes major environmental problems globally and locally… Colorado is a research hub and has a strong economy. The relatively cooler weather in Colorado (due to its higher elevation) and the high-tech job market cause population to grow faster than currently projected… The warmer climate reduces global food production, increasing the market for local agriculture and food imports to Colorado. More food is grown locally, increasing local food prices and reducing the loss of agricultural land to urban development… More compact urban development occurs through innovations in mass transit."

- Recommended implementation:
  Use statewide forecast from high growth projections. Use unconstrained[2] high growth forecast for urban center counties (see definitions recommended for Cooperative Growth Scenario) and reduce forecast as needed in other areas to balance to state totals.

4.5 Hot Growth Scenario

- Excerpts from State Water Plan description:
  "A vibrant economy fuels population growth and development throughout the state... A much warmer global climate brings more people to Colorado with its relatively cooler climate. Families prefer low-density housing and many seek rural properties, ranchettes, and mountain living. Agricultural and other open lands are rapidly developed… Communities struggle unilaterally to provide services needed to accommodate the rapid business and population growth."

  Recommended implementation:
  Use statistically-derived high growth projections, which project disproportionate population increases in the state's more rural areas (due to their greater historical variability in population growth and their higher growth rates during boom periods).

References

Harvey Economics, 2050 Population Projections for the State of Colorado Municipal and Industrial Water Use Projections, Colorado Water Conservation Board, 2010.

Colorado Division of Local Governments, State Demography Office. Preliminary Population Forecasts by Region and County, 2010 – 2050. 2016.

Colorado Water Conservation Board, Colorado's Water Plan, 2015. Chapter 6.

[2] Unconstrained high growth projections refers to projections for these areas based on their basins' probabilistic high growth projections, prior to downward adjustments to force the sum of all of the basins' high growth projections match the statewide high growth projection.