



Great Salt Lake Integrated Model (GSLIM) An Integrated Water Resource Management Tool for the Great Salt Lake Watershed

Phase II – GSLIM Evaluation

Document Version 2

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Great Salt Lake Advisory Council



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for the Great Salt Lake Watershed**

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Acronyms and Abbreviations

BCSD	Bias Corrected Statistical Downscaling
CII	Commercial, Industrial, and Institutional
CMIP5	Coupled Model Intercomparison Project Phase 5
GPCD	gallon(s) per capita per day
GSL	Great Salt Lake
GSLIM	Great Salt Lake Integrated Model
M&I	Municipal and Industrial
NLCD	National Land Cover
RCP	Representative Concentration Pathway
UDWRe	Utah Division of Water Resources
USGS	United States Geological Survey

1. Introduction

The immense value of Great Salt Lake (GSL) is clear to anyone who has experienced its unique nature firsthand or considers its role in our day-to-day lives. Some value the vast open space of the lake, the opportunity for a nearby escape from the bustle of life, the innumerable birds, or the amazing sunsets. For others the lake also represents their means to support their family, a source of lake effect snow that provides an invaluable water supply or ski days, or simply a veritable \$1.3B/year regional economic engine (Bioeconomics 2012). All of us, however, realize indirect benefits of GSL whether it be through our food (such as, supporting suitable microclimate to support agriculture, providing raw materials for fertilizers, and supporting brine shrimp as food stock for fish and shrimp we eat) or other basic conveniences we enjoy (such as, aluminum cans, batteries, road salt, and so forth). Regardless of a person's point of view, GSL is a critical fixture of our geography, culture, and economy – it is part of what makes this Utah.

It is hard to imagine a lake like GSL disappearing. Recent analyses indicate a general decline in GSL water levels (11 feet) due to our use of water (Wurtsbaugh et al. 2016); all accentuated by our recent drought and near record low lake water levels in 2016 and 2018. The worldwide decline and loss of similar saline lakes (AECOM 2019) provides further

perspective on the possibility (UDNR 2013), the consequences (SWCA 2012; ECONorthwest 2019), and the opportunities we have (Governor's Water Strategy Advisory Team 2017; SWCA 2017). The lake is not lost, but a new and more complete understanding of GSL is needed before it is too late. Policymakers and planners must understand the scope of potential risks and opportunities to enable the growth that is envisioned, protect the resources and livelihood we enjoy, and avoid the significant costs of an emergency response. This study takes a first step toward accomplishing this.

Policymakers and planners must understand the scope of potential risks and opportunities to enable the growth that is envisioned, protect the resources and livelihood we enjoy, and avoid the significant costs of an emergency response.

The objective of this Great Salt Lake Integrated Model (GSLIM) Evaluation study was to update and utilize the GSLIM to begin to understand the sensitivity of GSL's water levels and salinity to potential changes in its watershed.

2. GSLIM Model Updates

The GSLIM, completed in 2017, represented a leap forward in the capability of resource managers and policymakers to understand how changes in GSL's watershed might influence GSL and its resources. This GSLIM Evaluation study updated the GSLIM to include new growth and climate projections and improve the model's capability to forecast future changes in GSL's watershed. Most importantly, this effort defined a range of plausible future conditions for GSL's watershed, integrated these scenarios into the GSLIM, and developed relative comparisons of how future growth, climate, and water management alternatives might affect GSL.

It is important to note that the GSLIM cannot predict the future. Models are, at best, qualitative predictors of future conditions. Their real value is helping policymakers and planners think about and better understand a complex system like GSL's watershed. They help identify interrelationships between different variables, alerting users to things perhaps not previously considered (such as, unintended consequences of trying to do something beneficial), and helping make decisions today in the face of uncertainty.

Version 1.10 of the GSLIM was delivered to the Utah Division of Water Resources (UDWRe) in August 2017. The model was subsequently reviewed, revised, and updated through an interactive process with UDWRe and version 1.12 was delivered in early 2019. Several upgrades were made to the GSLIM as part of this study to produce version 1.13. GSLIM upgrades included improving the model's capability to

simulate climate variability, water conservation in the Municipal and Industrial (M&I) and Agriculture sectors as well as cloud seeding programs.

GSLIM was developed as a series of integrated modules within the core GSLIM (Figure 1). Each river basin – Bear, Weber, and Jordan Rivers – are represented by a separate River Basin module. Inflow from each River Basin module is filtered through a second module representing the wetland complexes that exist at the interface between each river basin and GSL. The Lake module represents the lake itself and characterizes each of the four main bays: Gilbert (South Arm), Farmington, Bear River, and Gunnison (North Arm) bays. Dividing the model into these modules facilitated integrating existing data and models, as well as completing future updates and use by stakeholders within each river basin. The upgrades to the River Basin and Lake modules completed as part of this GSLIM Evaluation study are summarized as follows.



Figure 1. Great Salt Lake Integrated Model - General Structure

2.1 River Basin Module

The following upgrades were made to the River Basin modules:

- Updated algorithm and dashboard to allow selection of a simulation period within the climate database (1950-2013) and a start year for a given model run.
- Input data development:
 - Population projections data development for years 2017, 2030, and 2060
 - Climate projections for 2030 (2016-2045) and 2060 (2046-2075) periods
 - Cloud seeding project locations
- Scenario land use input data development:
 - Urban footprint implementation for population 2030 and 2060
 - Reduction of irrigated agriculture
- User-defined dashboard updates:
 - M&I dashboard: population scenario options
 - Climate dashboard: climate projection options and cloud seeding augmentation options

More details on the assumptions made for these changes will be described in Section 4.

2.2 Lake Module

Upgrades to the Lake module are listed as follows. Many of the updates are related to the extension of the simulation period:

- Updated annual evaporation factors in GSL_Input.xlsx file for years 1950 – 1986 and 2013. Annual evaporation rates were calculated by implementing Livneh et. al. (2015) maximum and minimum temperature data into Hargreave’s equation for three locations at Saltair, Bear River Bird Refuge, and Utah Lake at Lehi. Locations are based on method implemented for the GSLIM calibration period of 1987 – 2012.
- Monthly precipitation values were developed for years 1950 – 1986 and 2013 based on Livneh et. al. (2015) data for locations at Tooele, Salt Lake City Airport, and Ogden Sugar Factory.
- Extended Salt Lake City Water Treatment Plant (that is, Water Reclamation Facility) discharge time series for the period 1950 - 2013. All monthly values, except between 1987 – 2012 are equal to the long-term monthly average.

- Updated shorebird habitat area calculation to include GSL open water areas with a water depth of 0-7 inches rather than 0-12 inches. This does not account for shorebird habitat outside of the open water of GSL.
- Updated North Arm and South Arm water surface elevation initial conditions to January 1, 2019 values based on United States Geological Survey (USGS) gages 10010100 and 10010000, respectively.
- Initial salinity values for January 1, 2019 were estimated from USGS gage data. The initial salinity for the North Arm was estimated from data from USGS station 10010100 Great Salt Lake near Saline, Utah for December 20, 2018. The initial salinity for the South Arm was estimated from data from USGS gage 410644112382601 from the average of values reported for December 6, 2018 and January 30, 2019. The initial salinity for Bear River Bay was estimated from conductivity data values from USGS station 10126000, Bear River at Corinne, on January 1st, 2019. The initial salinity for Farmington Bay was estimated from conductivity data values from USGS station 410401112134801 GSL Farmington Bay Outflow at Causeway Bridge on January 1st, 2019.

3. Historical and Recent Lake Elevation

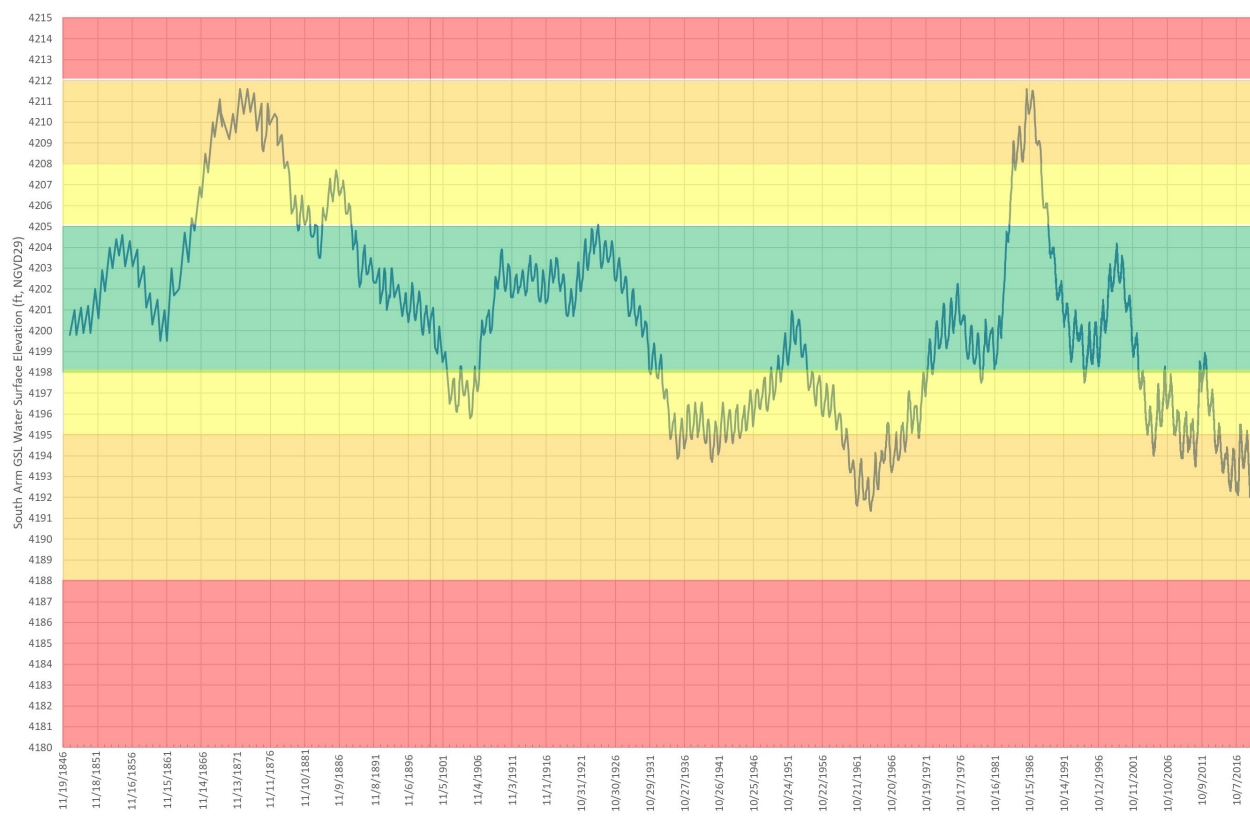
GSL has undergone major fluctuations in water surface elevation over the past century (Figure 2). GSL water levels have responded to the variability in hydroclimate and human development patterns throughout the watershed. Periods of above average inflow from the Bear River, Weber River, and Jordan River watersheds cause the lake level to increase, as it did

during the historical floods in the mid-1980s. Conversely, low lake levels have resulted in period of below average inflow as have occurred in the mid-1930s, during the 1960s, and during our current drought.

Although variable water management and climate cause GSL water surface elevations to fluctuate seasonally and annually, inertia developed over successive years and decades also plays an important role in long-term lake levels.

Four elevations zones were developed for use in this study based on an evaluation of resource function at a range of lake levels as summarized in the GSL Comprehensive Management Plan (UDNR 2013). The “green” zone suggests a typical management zone with an optimal elevation range to support GSL resources; the “yellow” zone suggests a transitional management zone with less than optimal, but still functional, lake levels; the “orange” zone suggests an extreme management zone with lake levels that could substantially impact many GSL resources; and the “red” zone represents extreme conditions not previously observed and likely resulting in significant impact upon GSL resources. The variability of historical lake levels has spanned the green, yellow and orange zones, while the GSL levels were primarily in the low yellow and orange zones during the past two decades. The 2013 GSL Comprehensive Management Plan only considered lake levels within the green, yellow and orange zones.

Figure 2. Historical Great Salt Lake Water Surface Elevation in South Arm
Elevation Zones to Assess Lake Levels



Source: South Arm Lake elevations as measured at U.S. Geological Survey (USGS) Station 10010000, Great Salt Lake at Saltair Boat Harbor, Utah (USGS 2019).

4. Simulated Scenarios and Assumptions

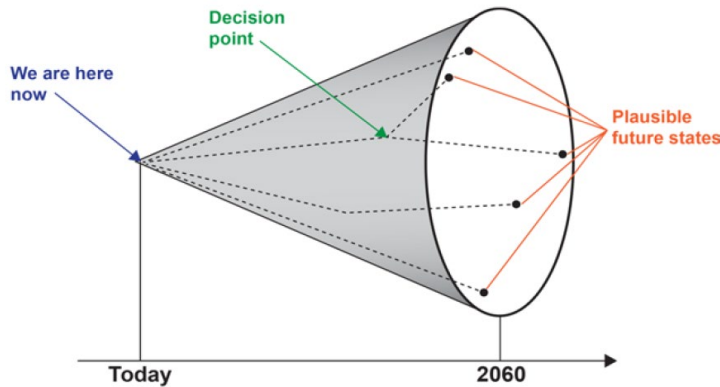
4.1 Scenario Planning Approach

Management of water resources is a complex interplay between natural and human systems, driven by forces such as climatic, demographic, economic, social, institutional, political, and technological factors. The precise trajectory of this interplay over time, and the resulting state of the physical system, are uncertain and cannot be represented by a single view of the future (that is, models cannot predict the future). Considering this broad uncertainty, scenario planning can be used to consider and portray the broad range of plausible futures in a manageable number of scenarios and to explore different trajectories of how the future may unfold. Well-constructed scenarios can facilitate an effective assessment of future risks and the development of mitigation and adaptation options and strategies. Scenario approaches have been widely applied in water planning and management, from global to regional scales, although specific methodologies have varied considerably. The scenario planning approach was used for the GSLIM Evaluation study.

Figure 3 illustrates the scenario planning approach. At present, there is an understanding of the current state of water management in GSL’s watershed. For the future, a range of plausible futures, represented by the funnel, can be identified. The suite of scenarios used in the planning effort should be designed to be sufficiently broad to span the plausible range of future states.

Jacobs proposed an initial “strawperson” set of scenarios to be evaluated using the GSLIM and reviewed them with the GSL Advisory Council’s steering committee on May 8, 2019. The scenarios were revised and finalized for use in the study described as follows.

Figure 3. Conceptual Representation of the Uncertain Future of a System



4.2 Simulated Scenarios

The scenarios described in Table 1 were defined as a means to portray and consider a wide range of future conditions, explore how the future may unfold, understand which drivers influence the lake the greatest, and begin to consider alternative management strategies.

Each scenario was evaluated for the projected population in 2030 and then again for the projected population in 2060 as defined by the different drivers (that is, variables) described as follows. Climate was used as the dynamic variable allowing the model to forecast how GSL could respond to these changes.

Table 1. Simulated Scenarios with Great Salt Lake Integrated Model

Driver	Baseline Historic	A. Baseline – Future	B. State Water Strategy	C. Adaptive Innovation	D. Hot Growth
Population	2017 Population estimated based on 2010 Census Tract; population growth % by 2017	2030 and 2060 projected population estimated based on 2017 report	2030 and 2060 Population (2017)	2030 and 2060 Population (2017)	2030 and 2060 Population (2017)
Climate	Observed data, period extension, 1981-2013	Monthly P and T adjustments for each subarea to represent median 2030 and 2060 projections (50 th percentile)	Same as A	Same as A	Same as A, except from Temperature 75th percentile and Precipitation 25th of 2030 and 2060 projections
M&I Water Use	Traditional Indoor water use: GPCD 60 – 80	Traditional Indoor water use: GPCD 60-80	2040 Water Conservation Goals: GPCD 50 (31% reduction)	2060 Water Conservation Goals: GPCD 40 (45% reduction)	2060 Water Conservation Goals: GPCD 60 (14% reduction)
	Large Lots 65% efficiency and 80% turf	Large Lots 65% efficiency and 80% turf	Smaller Lots 80% efficiency and 50% turf	Smaller Lots 80% efficiency and 20% turf	Smaller Lots 70% efficiency and 80% turf
Agriculture Water Use	2017 Use Rates	2017 Use Rates	Assume 20% reduction of irrigated agriculture land	Assume 30% reduction of irrigated agriculture land	Assume 10% reduction of irrigated agriculture land
Cloud Seeding	No increase	No increase	10% increase in program areas	15% increase in program areas	5% increase in program areas

Notes:

GPCD = gallon(s) per capita per day

4.3 Assumptions

4.3.1 Climate Variability

Climate variability is a major driver influencing the watershed and lake elevations. Projections indicate potential future warming and changes in precipitation patterns. For the baseline historic climate input data, the model used historical (1981-2013) daily precipitation, maximum and minimum temperature, 12-km grid estimated from 6-km resolution grid (Livneh et al. 2015). The previous version of GSLIM used historic data from the period of 1989-2013. The updated model GSLIM version updated the algorithm to allow the user to simulate from a selected initial year within the period 1950-2013. The default input data start date used in this study was January 1, 1981.

For the future scenarios, the climate input data was developed based on monthly scaling factors by subarea computed using Coupled Model Intercomparison Project Phase 5 (CMIP5) Bias Corrected Statistical Downscaling (BCSD) downscaled ensemble climate model projections centered at 2030 and 2060, representing three Representative Concentration Pathways (RCPs) (RCP 4.5, RCP 6.0, and RCP 8.5).

The BCSD downscaled climate model projections were obtained from Downscaled CMIP3 and CMIP5 Climate and Hydrology Projections prepared by U.S. Bureau of Reclamation (Reclamation) and others (Reclamation 2013). These BCSD downscaled climate change projections are consistent with that were used in the 2016 SECURE Water Act Report to Congress (Reclamation 2016) synthesized Reclamation studies for basins across the western United States, and Colorado River Basin Climate and Water Supply Assessment Update.

Table 2. Projected Average Change in Climate Across Great Salt Lake Watershed Subareas
2030 and 2060 average projections for each simulated scenario

Driver	Period	Baseline Historic	A. Baseline Future	B. State Water Strategy	C. Adaptive Innovation	D. Hot Growth
Precipitation (%)	2030 (2016-2045)	0%	+3.3%	+3.3%	+3.3%	-0.8%
	2060 (2046-2075)	0%	+6.2%	+6.2%	+6.2%	1.1%
Maximum Temperature (°C)	2030 (2016-2045)	0°C	+1.4°C	+1.4°C	+1.4°C	+1.9°C
	2060 (2046-2075)	0°C	+2.8°C	+2.8°C	+2.8°C	+3.5°C
Minimum Temperature (°C)	2030 (2016-2045)	0°C	+1.5°C	+1.5°C	+1.5°C	+1.9°C
	2060 (2046-2075)	0°C	+2.8°C	+2.8°C	+2.8°C	+3.6°C

Figure 4 shows the added check box and drop-down menu (see orange rectangle) to select the climate projection year and the percentile projection for precipitation and temperature. Monthly precipitation and temperature scaling factors were developed from 76 downscaled climate model projections to modify historical meteorological inputs used in the baseline model. Climate projection scaling factors for precipitation and temperature were developed for each sub-area over two future periods centered at 2030 and 2060. Table 2 shows the average value across all subareas within the GSL basin. These subarea scaling factors were used to derive a scaling factor by grid that was used to modify the baseline historic gridded precipitation and temperature (maximum and minimum).

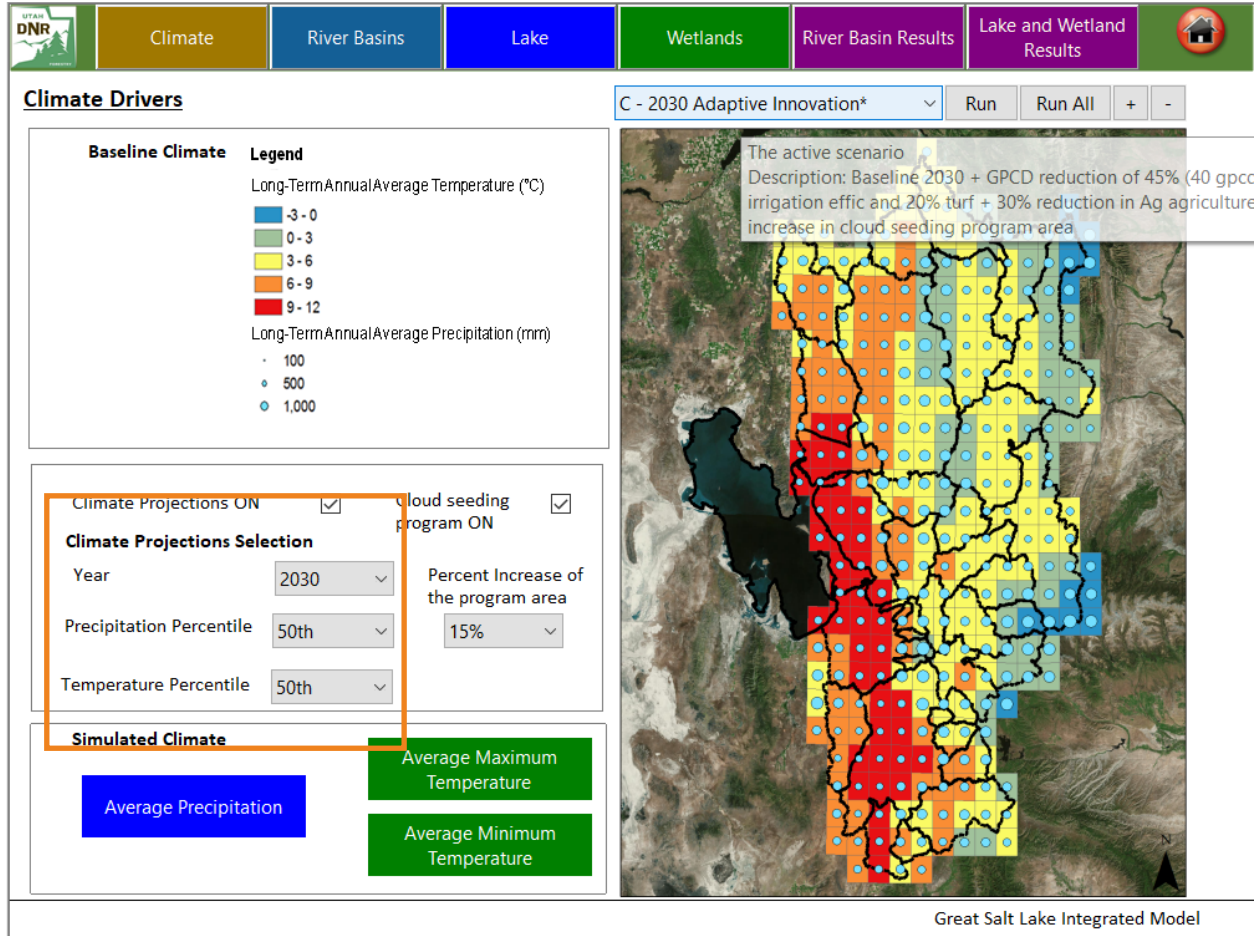
4.3.2 Watershed Population

The watershed’s population and its growth drives M&I indoor and outdoor water demand throughout the watershed. Population estimates for 2017, 2030, and 2060 were required to develop and evaluate the scenarios described above. Figure 5 shows the added drop-down menu (see yellow rectangle) to select the population year for a simulated scenario. The Kem C. Gardner Policy Institute prepares long-term demographic and economic projections to support informed decision making in the state. The Utah Legislature funds this research, which is done in collaboration with the Governor’s Office of Management

and Budget, the Office of the Legislative Fiscal Analyst, the Utah Association of Governments, and other research entities (Perlich et al. 2017). As can be observed in Figure 6, statewide population projections suggest nearly doubling 2015’s population by 2060: 5.6 million.

Figure 4. GSLIM Climate Drivers Dashboard

Assumptions for Scenario C with median 2030 climate projections (50th percentile)



UDWRe provided Jacobs with population estimates for each of the watershed’s subareas within the state of Utah for 2017, 2030 and 2060 based upon the 2015-2065 Governor’s office population projections. The following procedure was used to develop population estimates for subareas with some of their area located in the states of Wyoming and/or Idaho:

- The 2010 subarea population that was part of the previous version of GSLIM’s input dataset was aggregated into river basin population (Bear, Jordan, Weber) to be used as the river basin reference population.
- Using the 2015-2065 Governor’s office counties’ population projections, the river basin population for years 2017, 2030 and 2060 was estimated based on county’s area falls into each of the river basins.
- River Basins’ growth exponential rate (k) was developed for the periods of 2010-2017, 2010-2030 and 2010-2060 by river basin.

$$P_T = P_0 e^{k(\text{Year} - 2010)}$$

- Estimation of subarea population for year 2017, 2030 and 2060 was made applying the growth exponential rate to the 2010 subarea population.

Table 3 shows the population input data used in the GSLIM v1.13.

Figure 5. Population Projections Alternatives Selection
 GSLIM Municipal and Industrial Controls Dashboard

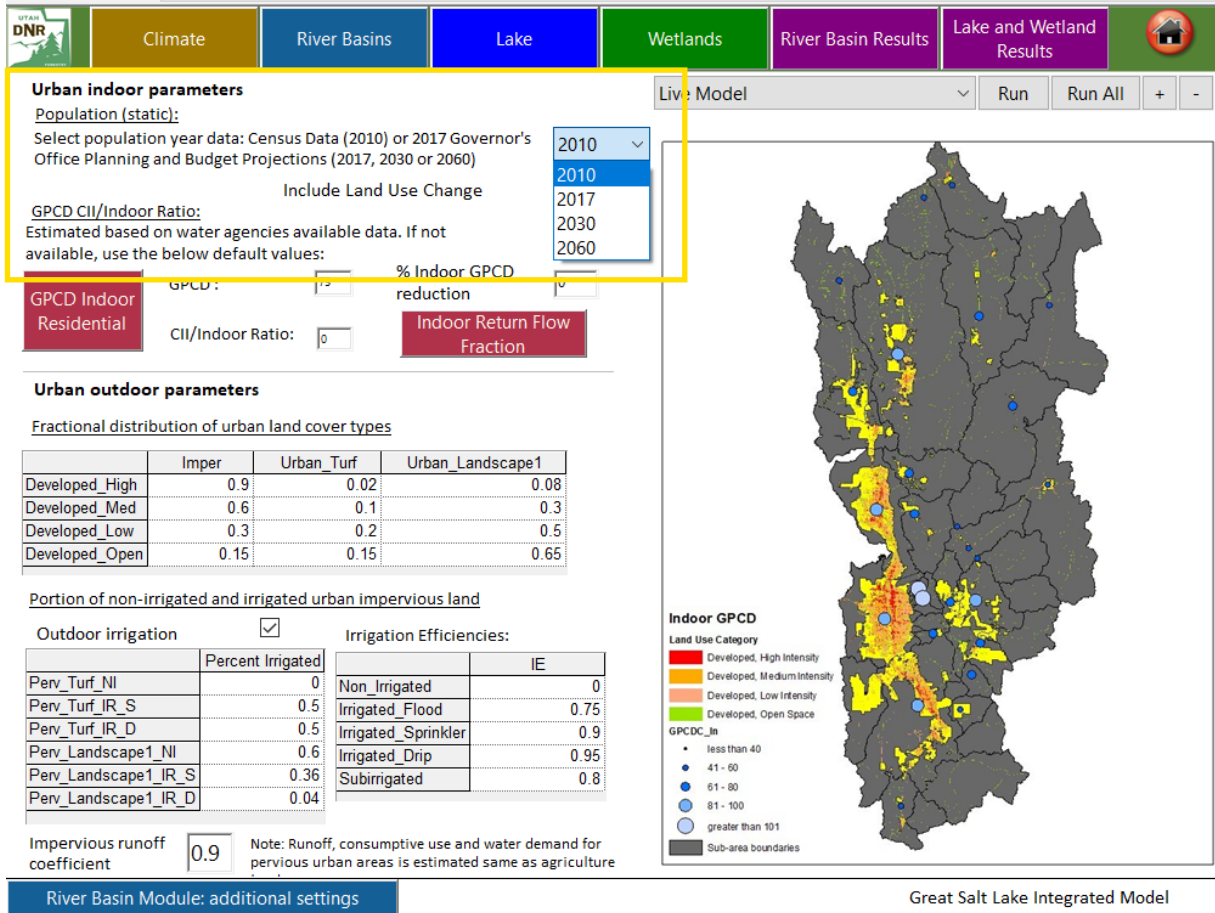


Figure 6. River Basin Population Projections and Period Growth Rates
 Estimated based on the 2015-2065 Governor's office population projections

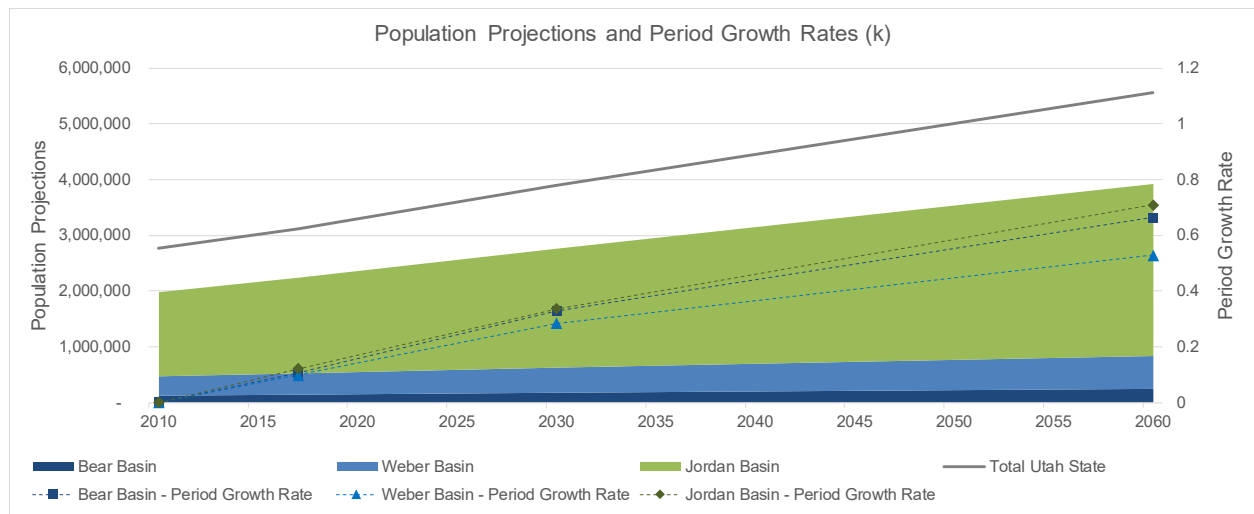


Table 3. Estimated Population by Subarea
Great Salt Lake Watershed

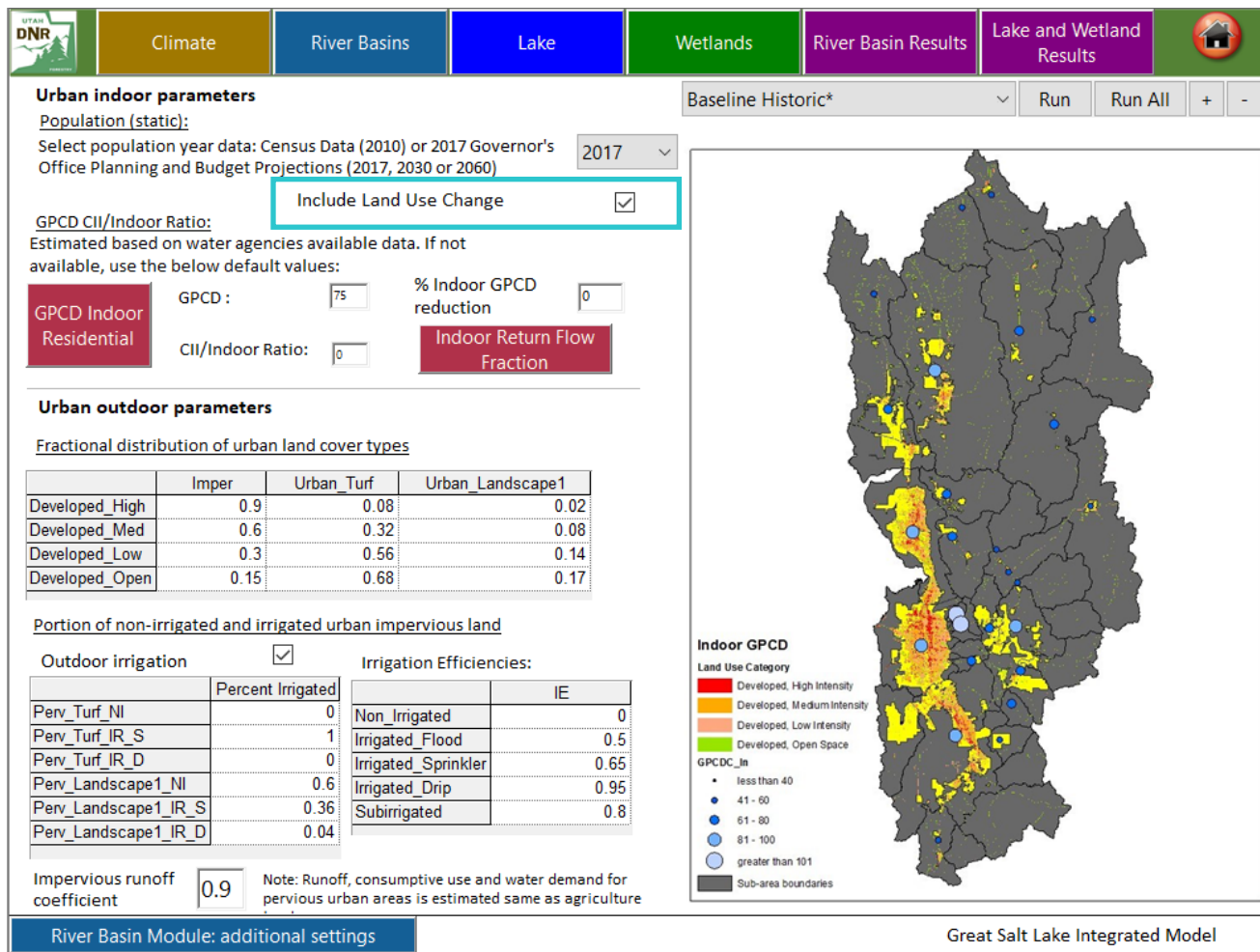
Subarea	2010	2017	2030	2060
Bear Lake	3,792	4,218	5,276	7,363
Soda Springs	1,776	1,976	2,471	3,449
Oneida	2,940	3,271	4,091	5,709
Cache Valley	124,648	138,651	173,414	242,027
Malad	1,751	1,948	2,437	3,400
Tremonton*	18,478	19,721	22,383	28,370
Brigham City*	25,802	28,991	34,942	45,855
Cokeville	1,508	1,678	2,098	2,929
Thomas Fork	1,762	1,960	2,452	3,422
Evanston	11,068	12,312	15,399	21,491
Randolph	1,850	2,058	2,574	3,593
Oakley	532	592	741	1,033
Kamas Valley*	6,168	11,132	15,985	26,545
Chalk Creek*	1,347	1,513	1,752	2,563
Echo*	1,804	2,074	2,480	3,143
Lost Creek*	79	88	242	343
East Canyon*	24,931	22,348	25,998	29,689
Morgan*	7,116	9,052	14,276	20,147
Ogden Valley*	4,295	4,913	6,014	7,624
East Shore*	532,762	595,356	704,364	902,530
Salt Lake Valley*	1,029,773	1,128,496	1,308,102	1,650,955
City Creek	2,807	3,102	3,733	4,767
Emigration Creek*	794	719	727	787
Parleys Creek	1,908	2,109	2,538	3,240
Millcreek	3,186	3,521	4,237	5,410
Big Cottonwood Creek	2,808	3,103	3,735	4,769
Little Cottonwood Creek	1,565	1,730	2,082	2,658
Salt Creek	702	794	984	1,428
Nephi*	7,690	8,576	13,498	22,119
Soldier Summit	2,303	2,603	3,226	4,684
Diamond Fork	179	203	251	365
Hobble Creek	116	132	163	236
Woodland	2,067	2,336	2,895	4,204
Provo River*	21,894	31,115	48,113	78,982
Wallsburg	563	637	789	1,145
Vivian Park	39	45	55	80
Utah Valley*	480,863	578,386	780,217	1,290,345
Cedar Valley*	21,906	32,331	66,833	197,897
Total Great Salt Lake Watershed population	2,355,572	2,663,790	2,281,567	4,635,296

Note: Subareas with asterisk (*) correspond to information provided by UDWR

4.3.3 Land Use Change

Projections of how land use will change in the future were not available during development of previous versions of GSLIM, therefore, it was previously assumed that land use within the watershed would not change with population growth. Land use; however, is expected to change as population increases and urban areas are expected to increase in size and density. Figure 7 shows the updated M&I controls dashboard (see blue rectangle) with the check box to include land use change due to population growth for a simulated scenario. This box is checked for each of the five scenarios evaluated in this study.

Figure 7. Land Use Change Alternative: Population Growth Footprint
 GSLIM Municipal and Industrial Controls Dashboard



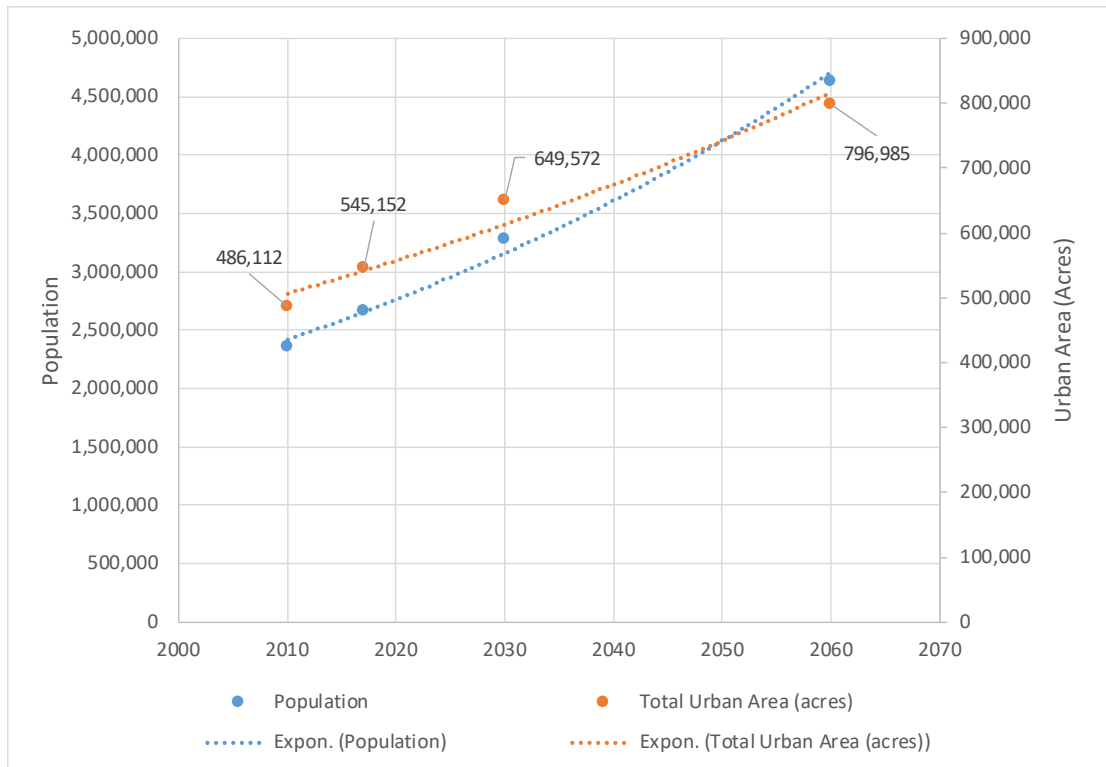
A simplified approach was developed for use in this study to reflect potential land use changes and resulting changes in water demand in the watershed. Land use changes were forecasted as follows:

- It was assumed that population densities for the various urban land use categories will not change. It was assumed that 1 acre of new urban area was required for every new five people.
- It was assumed that changes in land use (such as, expansion or reduction in land use types) will be proportional to changes in population.
- The additional developed land was distributed within the four urban (that is, developed) land use categories assuming the same subarea distribution pattern from existing (2010) land use. These categories are described in the National Land Cover Database (NLCD) as:
 - High density developed

- Medium density developed
- Low density developed
- Open developed
- Required additional developed land use by grid was estimated to meet the subarea urban expansion estimated above.
- To ensure total area consistency, the same additional land use developed land was subtracted proportionally from all non-urban categories except from the following:
 - Woody Wetlands
 - Emergent Herbaceous Wetlands
 - Deciduous Forest
 - Evergreen Forest
 - Mixed Forest
 - Open Water
- If the existing non-urban category area in a grid was less than the estimated urban land expansion area, the additional urban area was restricted, and the urban density was increased to accommodate the additional population.

Figure 8 shows the estimated population and total urban area input data used in the GSLIM v1.13 for each of the simulated periods: 2017, 2030, and 2060. The simulated expansion of the developed land is: 59,040 acres, 163,459 acres, and 310,873 acres to accommodate the projected population increase at 2017, 2030, and 2060 respectively.

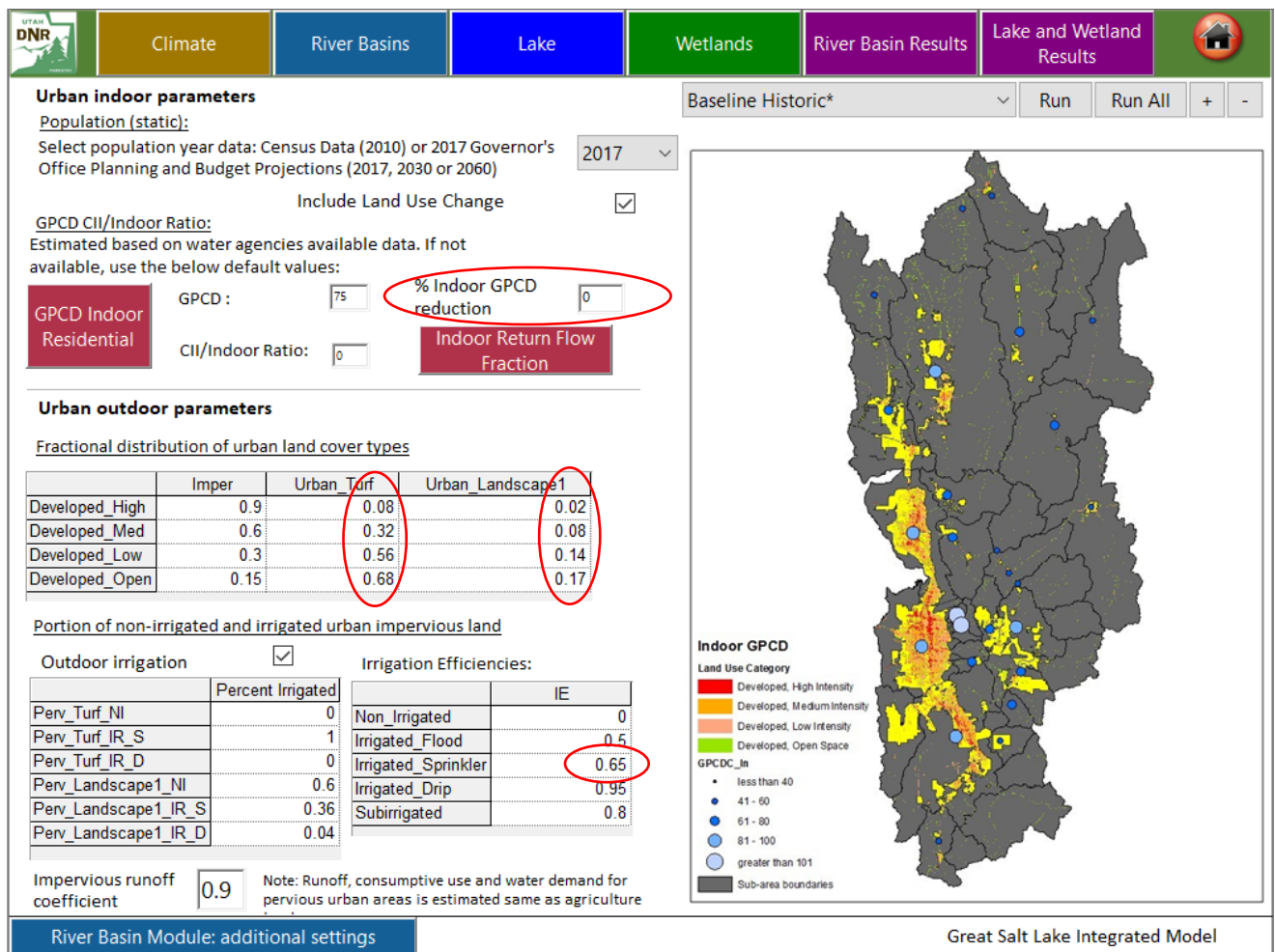
Figure 8. Projected Population and Urban (Developed Land) Area



4.3.4 Municipal and Industrial Water Use

The GSLIM dashboard for M&I Simulations settings shown in Figure 9 was used to update the indoor and outdoor water use assumptions for the simulated scenarios. The red circles indicate the assumptions that were modified: percent of GPCD reduction, percent of turf in the urban land covers (and commensurate change in urban_landscape1), and sprinkler irrigation efficiency for turf.

Figure 9. Municipal and Industrial Simulation Settings
 GSLIM Municipal and Industrial Controls Dashboard



4.3.4.1 Indoor Water Use

The GSLIM estimates the indoor M&I water demand by subarea based on its population, residential indoor water use in terms of GPCD and Commercial, Industrial, and Institutional (CII)/residential ratio. For the baseline scenarios, the GPCD and CII/residential ratio were estimated for 26 subareas estimated based on water suppliers' information provided by UDWR during the first model version development. The historic baseline GPCD ranges from 60 to 80 GPCD and a default value of 75 GPCD was used for nine subareas without available information. For the future scenarios, a reduction to the GPCD was estimated to meet the draft UDWR report Utah's Regional M&I Water Conservation Goals (HAL et al. 2019). These reduction percentages were incorporated the dashboard for the user to modify (see Figure 9). The percent reductions for each scenario that were simulated were:

- State Water Strategy: 50 GPCD simulated as a 31 percent reduction from baseline
- Adaptive Management: 40 GPCD simulated as a 45 percent reduction from baseline

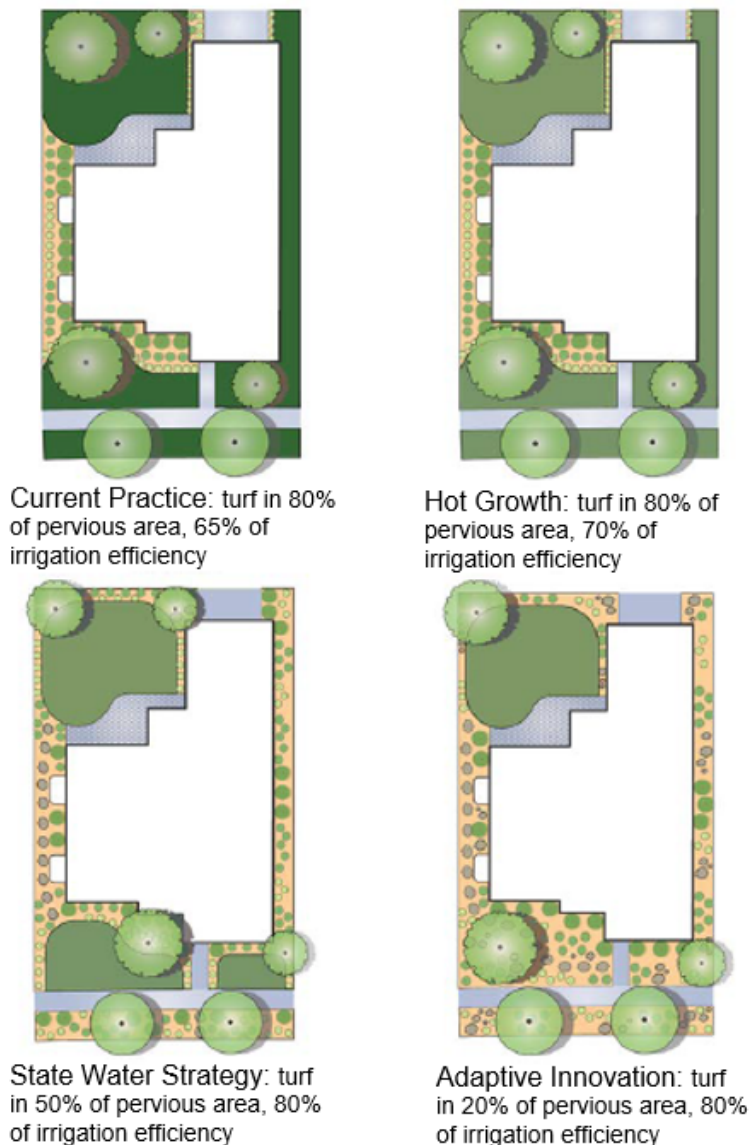
- Hot Growth: 60 GPCD simulated as a 14 percent reduction from baseline

4.3.4.2 Outdoor Water Use

The GSLIM estimates the outdoor M&I water demand based on the cover type and irrigation efficiency of the impervious area within the urban area (developed land). The applied water is estimated at the grid level and aggregated by subarea. As discussed previously, the 2011 NLCD dataset (Homer et al. 2015) identifies four developed land use categories: high, medium, low, and open. The GSLIM assumes a percentage of developed land that correspond to pervious area based on NLCD dataset land use category descriptions: 10, 40, 70, and 85 percent respectively. For each scenario a defined irrigation efficiency and a percentage of turf covering the pervious area for each category are simulated to be consistent with the draft UDWR report Utah's Regional M&I Water Conservation Goals (Figure 10) (HAL et al. 2019).

Figure 10. Municipal and Industrial Outdoor Water Use

Assumptions of turf percentage and irrigation efficiency for simulated scenarios



Source: Adapted from Utah's Regional M&I Water Conservation Goals, DRAFT v4 (HAL et al. 2019)

The total urban area in the historic baseline is 486,112 acres out of which, 296,602 acres (61 percent) correspond to impervious land. The total assumed percentages (fraction of the pervious area) for the turf area and landscape area for each scenario are shown in Table 4. Note that both the turf and landscape area ratios must be adjusted for each scenario (Figure 9). The outdoor irrigation efficiency was updated by changing the “Irrigated_Sprinkler” field (Figure 9) to the appropriate value for the scenario. The irrigation efficiency for turf area was assumed as follows:

- Baseline: 65 percent
- State Water Strategy and Adaptive Innovation: 80 percent
- Hot Growth: 70 percent

Table 4. Municipal and Industrial Outdoor Use Assumptions

Percent of total area to simulate target turf cover in urban areas

Develop Land Category	Turf as Percent of total area (%)	Landscape as Percent of Total Area (%)	Turf Area by Category (acres)	Total Area (acres)
80% of pervious area in developed land: Baseline and Hot Growth Scenarios				
High	8	2	3,901	237,281
Med	32	8	39,540	
Low	56	14	91,162	
Open	68	17	102,678	
50% of pervious area in developed land: State Water Strategy Scenario				
High	5	5	2,438	148,301
Med	20	20	24,713	
Low	35	35	56,976	
Open	43	43	64,174	
20% of pervious area in developed land: Adaptive Innovation				
High	2	8	975	59,320
Med	8	32	9,885	
Low	14	56	22,791	
Open	17	68	25,669	

4.3.5 Agricultural Water Use

There are numerous methods available to optimize agricultural water use and reduce agricultural water depletions (such as, improved irrigation efficiencies, changes in crop type, shortened seasons, and so forth). Reductions in irrigated agricultural land were used in the GSLIM scenarios to reflect reductions in agricultural water depletions. The GSLIM input land use dataset was pre-processed to convert irrigated agriculture to non-irrigated agriculture. The gridded land use input file for the 2030 and 2060 future baselines, already reflecting a reduction on irrigated land to account for the urban footprint expansion, were modified to reduce the irrigated agriculture land use by 10, 20, and 30 percent per Table 1. Table 5 summarizes the baseline irrigated land areas and the reductions simulated. The converted irrigated area was distributed proportionally into the agriculture non-irrigated land.

Table 5. Simulated Agriculture Water Use*Baseline irrigated agriculture and reduction areas simulated in scenarios*

River Basin	Irrigated Agriculture (acres)	10% Irrigated Agriculture Reduction (acres)	20% Irrigated Agriculture Reduction (acres)	30% Irrigated Agriculture Reduction (acres)
Baseline Historic - 2017				
Bear	531,027	53,103	106,205	159,308
Weber	84,474	8,447	16,895	25,342
Jordan	116,680	11,668	23,336	35,004
Total Great Salt Lake Basin	732,181	73,218	146,436	219,654
Baseline Future - 2030				
Bear	527,071	52,707	105,414	158,121
Weber	75,507	7,551	15,101	22,652
Jordan	100,362	10,036	20,072	30,108
Total Great Salt Lake Basin	702,940	70,294	140,588	210,882
Baseline Future - 2060				
Bear	519,263	51,926	103,853	155,779
Weber	67,047	6,705	13,409	20,114
Jordan	78,549	7,855	15,710	23,565
Total Great Salt Lake Basin	664,860	66,486	132,972	199,458

4.3.6 Cloud Seeding

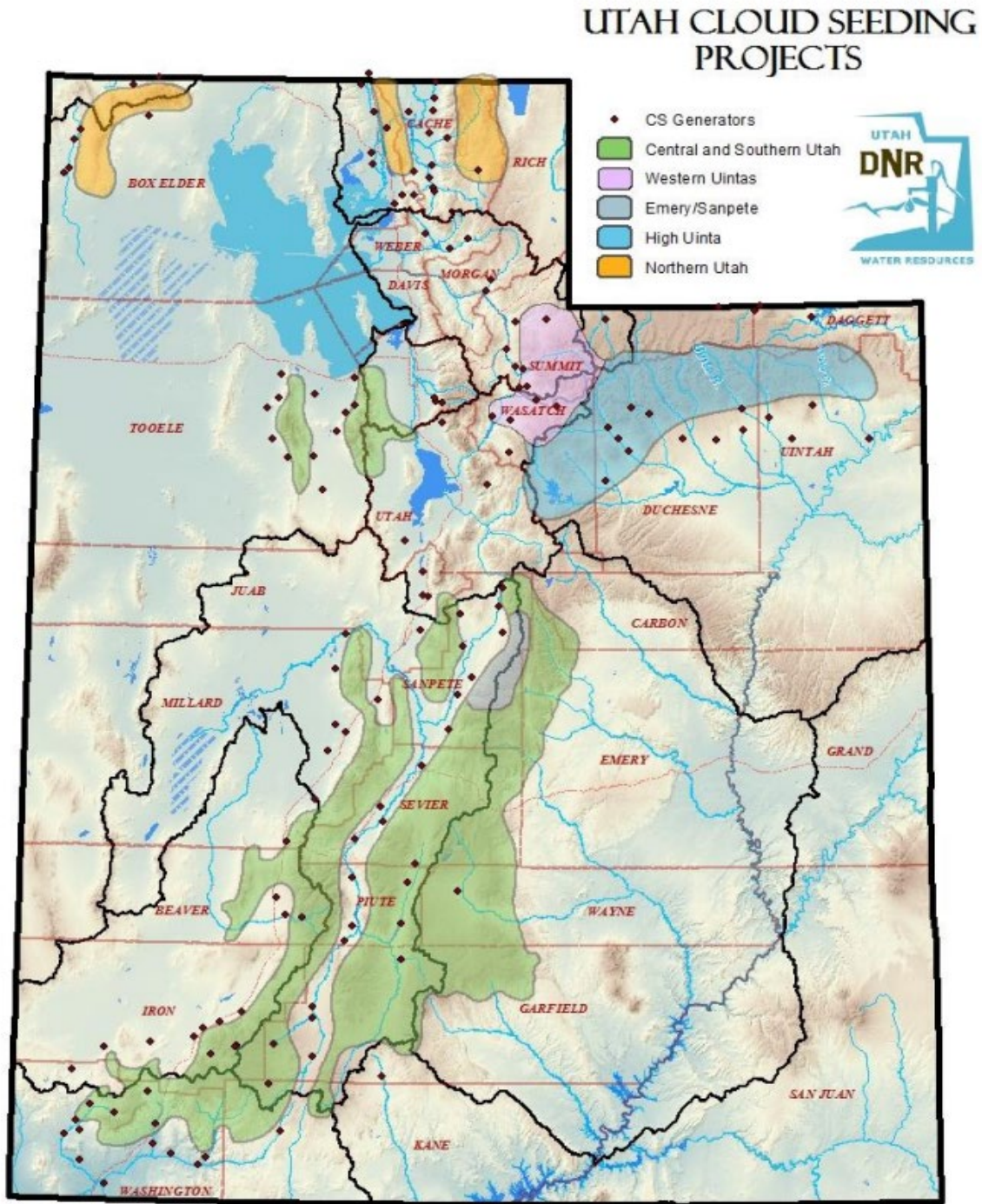
Proponents of ongoing cloud seeding efforts believe programs in Utah have resulted in precipitation increases of between 7 and 20 percent, at costs of less than \$20 per acre-foot. These costs compare very favorably with traditional water resource development projects. The GSLAC steering committee desired to determine if an increase in investment in cloud seeding could make a substantial difference in available water supply to GSL.

Existing cloud seeding projects in Utah are shown in Figure 11. The previous GSLIM model included historical cloud seeding as reflected in historic precipitation. The GSLIM, v1.13, includes an upgrade to reflect augmentation of two ongoing cloud seeding projects in Utah. These projects and the subareas that they include are as follows:

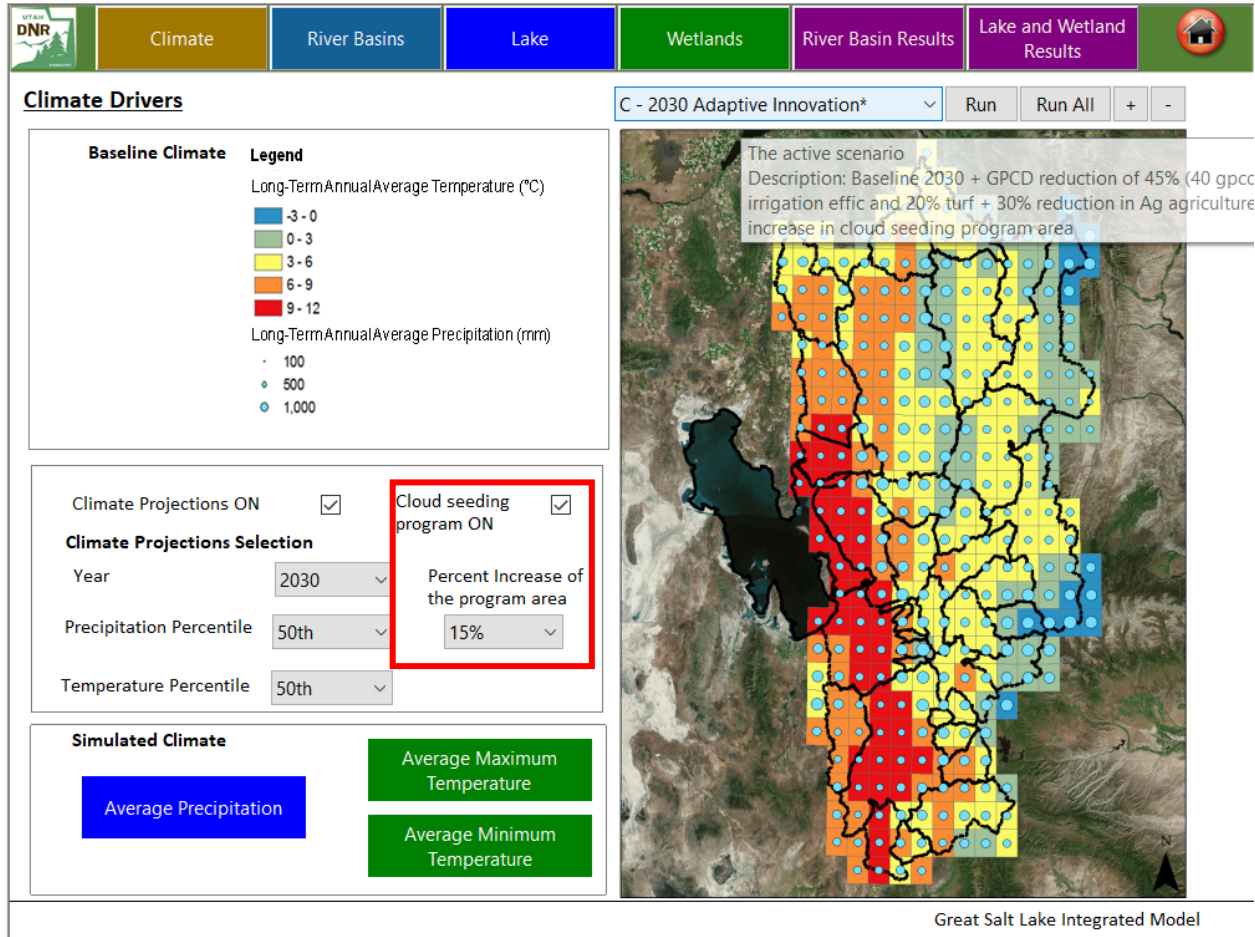
- Northern Utah: Cache Valley, Malad, and Tremonton
- Western Uintas: Oakley, Woodland, Provo River, Wallsburg

The increase of program areas is simulated as a precipitation percent increase of 5, 10, and 15 percent during November through March period for the overlying subareas. Figure 12 shows the GSLIM updated climate driver dashboard to allow the user to select a percent increase.

Figure 11. Utah Cloud Seeding Projects



Source: UDWR 2019.

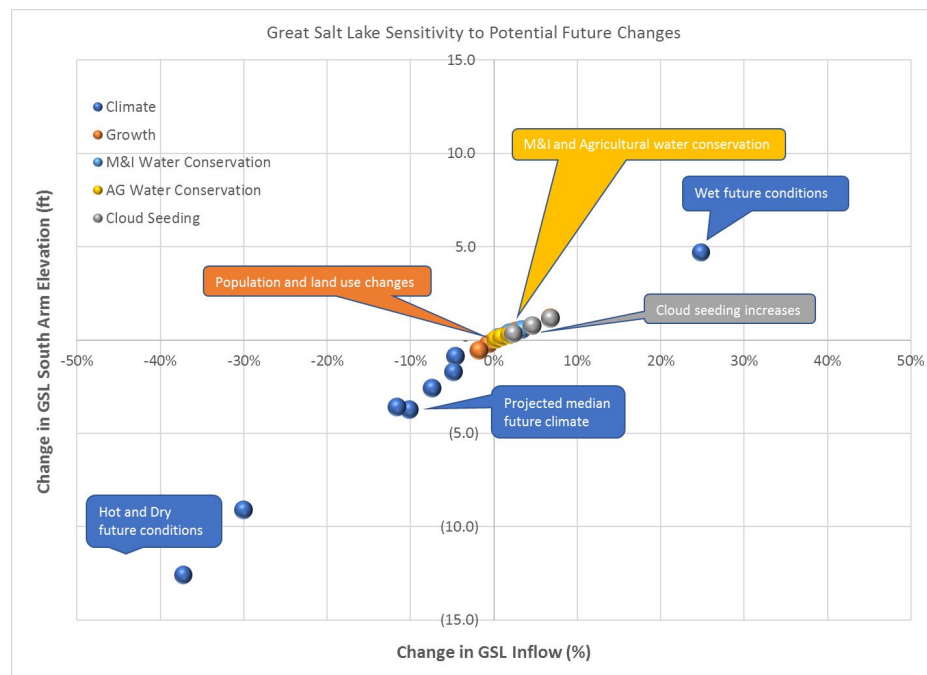
Figure 12. GSLIM Climate Drivers Dashboard
Assumptions for Scenario C with 15 percent increase of the cloud seeding program


5. Results

5.1 Sensitivity Simulations

This study began with an initial evaluation of the relative sensitivity of the GSL water surface elevation to potential future changes in the watershed. The drivers of change selected included: climate/hydrology, population growth and land use changes, agricultural and M&I water conservation measures, and cloud seeding. Figure 13 illustrates the potential impact of changes in each of the drivers on GSL inflow and water surface elevation. Projected changes in climate/hydrology have the largest impact on lake elevations, ranging from over 12 feet of lake decline under a hotter and drier future to a nearly 5-foot increase with a wetter future. The best estimate of future climate/hydrology at 2030 suggests a nearly 4-foot lake level decline. Population growth and associated land use changes suggest modest lake declines of less than 1 foot with no land conversions to an increase of almost 1.5 feet with agricultural-to-urban land conversions. Municipal and agricultural water conservation measures each have the potential to increase the lake levels by almost 1 foot, depending on the level of implementation. Each driver; however, does not change by itself. They occur in any number of potential combinations. A scenario planning approach was implemented to allow planners to evaluate plausible combinations of the drivers.

Figure 13. Great Salt Lake Sensitivity to Potential Future Changes
Percent Change in South Arm Elevation and Inflows to the Great Salt Lake



5.2 Deterministic Simulations

The scenarios described previously combine several of the main drivers to help explore how the future may unfold and begin to consider alternative management strategies. Each scenario was evaluated separately for the projected population in 2030 and 2060 as defined by each scenario, i.e., population, urban land use and density were kept constant over time at either the forecasted population in 2030 or 2060. Starting lake levels were set at January 1, 2019 recorded value of 4192.3 feet (NGVD29) and GSLIM scenarios were simulated for the period of 2019-2051 using a repeat of the historic 1981-2013 climate. Adjustments to climate, population/land use, agricultural and municipal/industrial water use, and cloud seeding were made to reflect each particular scenario. The simulation period was set to January 1, 2019 – December 31, 2051 for each of the scenario runs.

A Baseline Historic scenario was developed using conditions (that is, population, land use, water use, and so forth) in 2017 (dashed black line in the following figure) as a means to compare the relative difference among the alternative scenarios. The Baseline Future for 2030 assumptions (scenario A, black line) suggest a 3- to 4-foot decline primarily associated with continued climate variability and growth (see Figure 14). Improvements in water use efficiency, water conservation, and increases in cloud seeding envisioned in the State Water Strategy scenario (scenario B, purple line) reduce the lake level declines to about 2 feet under 2030 assumptions. The more aggressive water use efficiency, water conservation, and cloud seeding measures envisioned in the Adaptive Innovation scenario (scenario C, yellow line) suggest that lake levels could be managed within 1 to 2 feet of the baseline conditions. However, the considerable uncertainty associated with future climate/hydrology, as expressed in the Hot Growth scenario (scenario D, maroon line) suggest that lake levels could continue to drop below the 4,183 feet elevation at which point the south arm and north arm would be essentially hydraulically disconnected.

Deterministic scenarios were also developed for the 2060 assumptions as shown in Figure 15. The Future Baseline for 2060 (scenario A, black line) shows a decline of about 4 feet as compared to the 2017 Historic Baseline (dashed line). As under the 2030 assumptions, the State Water Strategy and Adaptive Innovation scenarios (scenarios B and C) result in less decline in lake levels but are still lower than the Historic Baseline. Under the high level of warming and reduced precipitation associated with the 2060 Hot Growth scenario (scenario D), lake levels are below the 4,183 feet elevation earlier in the simulation period than under 2030 assumptions and are sustained at this low level for much of the period; the south arm and north arm would be essentially hydraulically disconnected.

Figure 14. Great Salt Lake Surface Elevation Deterministic Results from 2030 Future Scenarios
South Arm Elevation

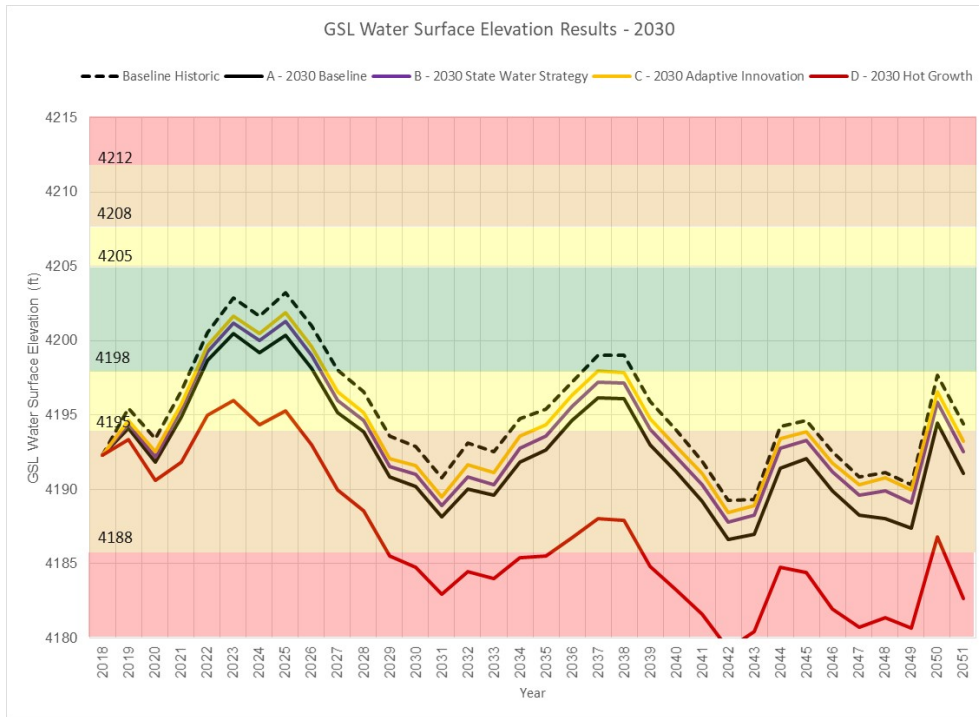


Figure 15. Great Salt Lake Surface Elevation Deterministic Results from 2060 Future Scenarios
South Arm Elevation

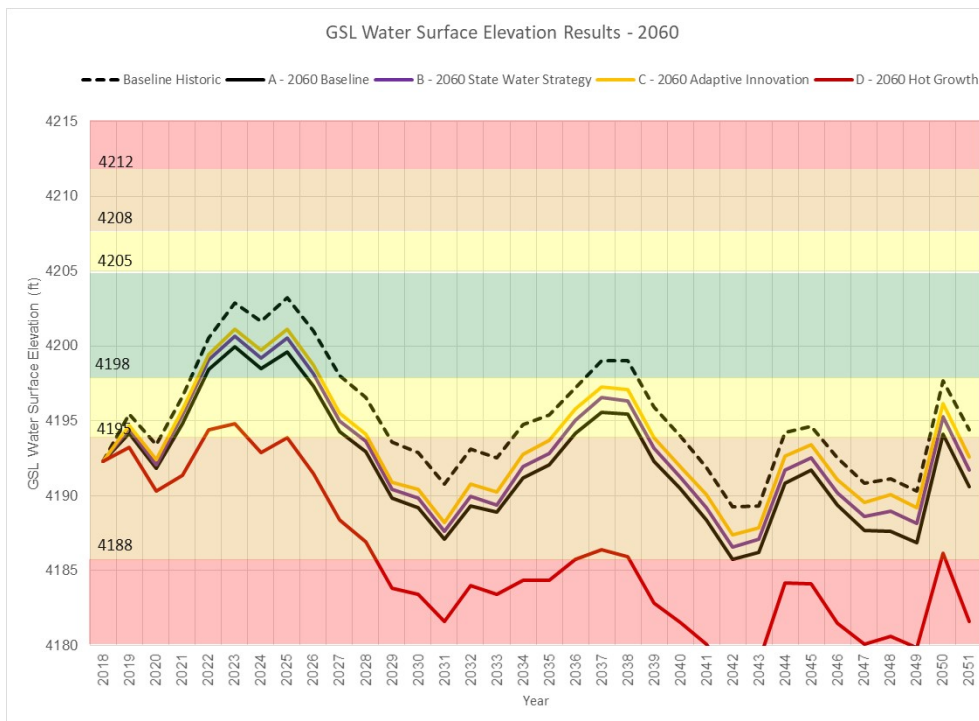


Table 6 shows the changes in total GSL inflow and south arm lake elevation for each of the scenarios under 2030 and 2060 assumptions as compared to the Historic Baseline. All scenarios at both time periods result in water surface elevations that are lower than the Historic Baseline. The declines for the 2030 and 2060 Baseline Future scenarios are largely the result of climate/hydrology and growth changes. The actions considered under the State Water Strategy and Adaptive Innovation scenarios mitigate for much of the lake level declines, but still show declines of up to 2 feet at 2030 and nearly 3 feet by 2060. Lake level declines of over 10 feet are simulated for the Hot Growth scenario.

Table 6. Simulated Scenarios Deterministic Results

Inflows to the Great Salt Lake and South Arm Elevation Changes from Historic Baseline

Scenario	Change in GSL Inflows (%)	Change in GSL South Arm Lake Elevation (ft)
2030 Period		
A - 2030 Baseline Future	-10	-3.3
B - 2030 State Water Strategy	-5	-1.9
C - 2030 Adaptive Innovation	1	-1.2
D - 2030 Hot Growth	-38	-11.7
2060 Period		
A - 2060 Baseline Future	-7	-3.8
B - 2060 State Water Strategy	-3	-2.7
C - 2060 Adaptive Innovation	2	-1.8
D - 2060 Hot Growth	-36%	-12.8

Output summaries for both the 2030 and 2060 scenarios are included in Appendix A. These summaries include additional results such river basin outflows and depletions, lake level and salinity outcomes for all four bays, and lake wetland, shorebird habitat, and exposed playa areas.

5.3 Stochastic Simulations

Stochastic simulations were also developed for each of the scenarios under 2030 and 2060 assumptions. While the deterministic simulations include only one hydrologic sequence, the stochastic simulations include 33 different hydrologic sequences and are used to express the range of uncertainty in GSLIM outcomes. Figures 16 and 17 show the South Arm lake level results for the stochastic simulations. In each figure, the lines show the mean result of the 33 realizations while the grey banding shows the interquartile range (25th to 75th percentile) and the 10th to 90th percentile range of results for the Future Baseline (scenario A). For ease of visualization, the uncertainty range is not shown for other scenarios. However, the uncertainty range for these scenarios is similar to that for scenario A.

As shown in the figures, the uncertainty range, primarily associated with interannual hydrologic variability, is large. The interquartile range of results is roughly plus or minus 4 feet as compared to the mean result. The 10th and 90th percentile range adds another 3 feet to the upper range and about 1 foot to the lower range. This large range suggests that individual annual results are primarily driven by the natural hydrologic variability in the system. However, the annual and decadal trends are driven by the assumptions in water management across the scenarios. The State Water Strategy and Adaptive Innovation scenarios show lower mean lake levels than the Future Baseline but are within the interquartile range of the Future Baseline. Only the Hot Growth scenario shows a mean result that is continuously lower than even the uncertainty range of the Future Baseline. The simulation for the Hot Growth scenario for 2060 was not able to complete due to the drying of the lake under certain hydrologic sequences and thus is not shown in Figure 17. However, as shown in the deterministic simulation results, this scenario results in the lowest lake levels and hydraulic disconnection between north and south arms.

Figure 16. Great Salt Lake Surface Elevation Stochastic Results from 2030 Future Scenarios
End of the Year (top) and End of the Month (bottom) South Arm Elevation

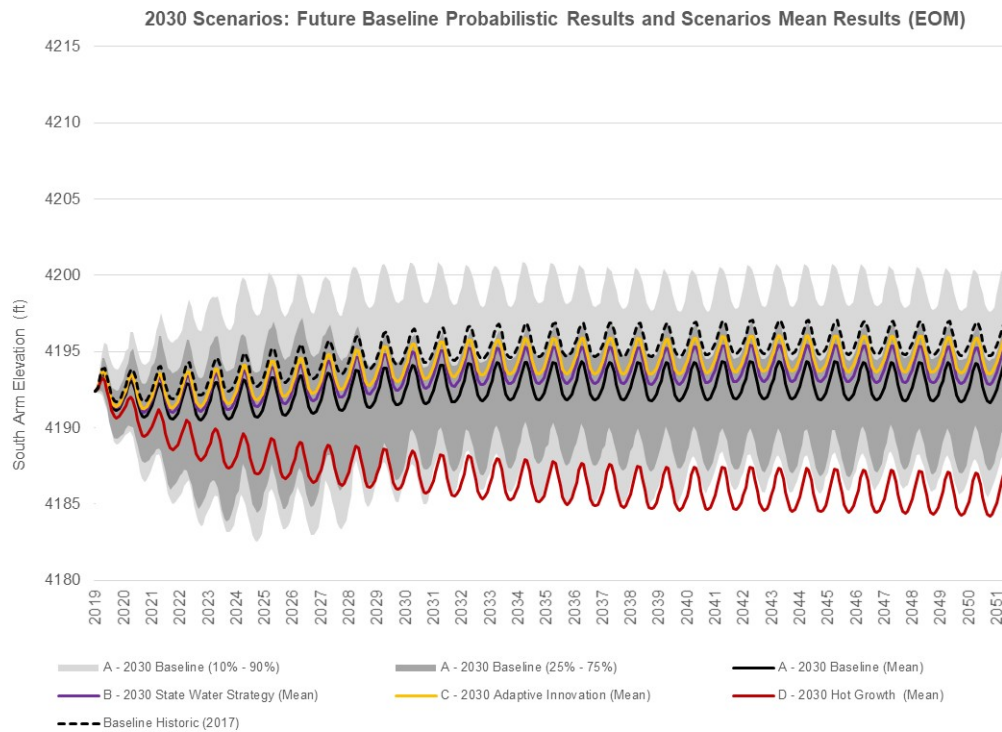
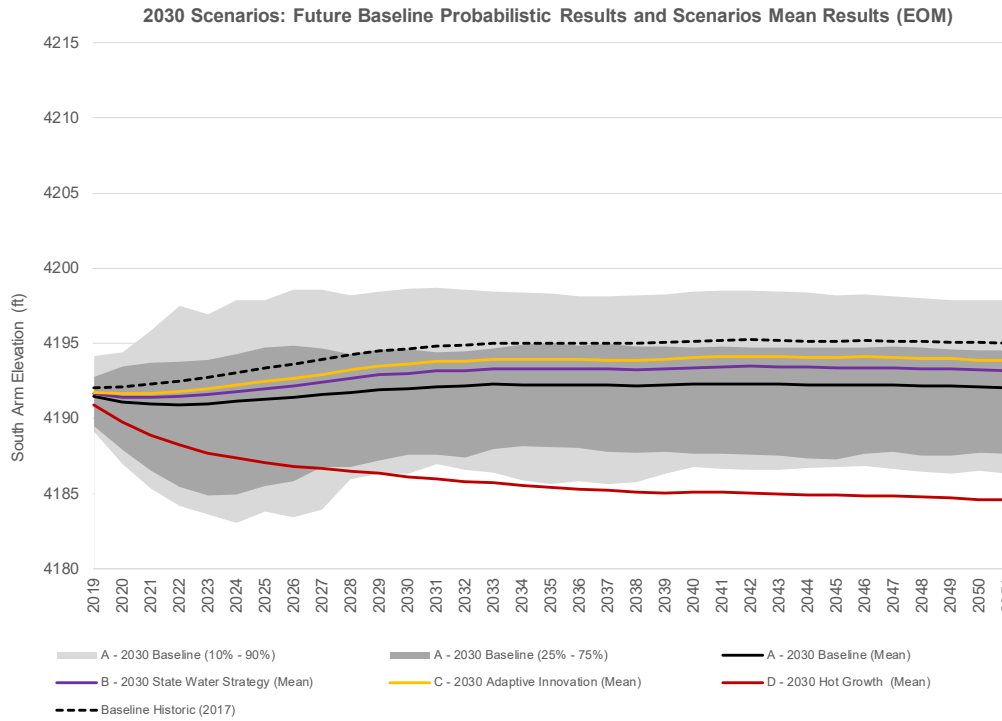
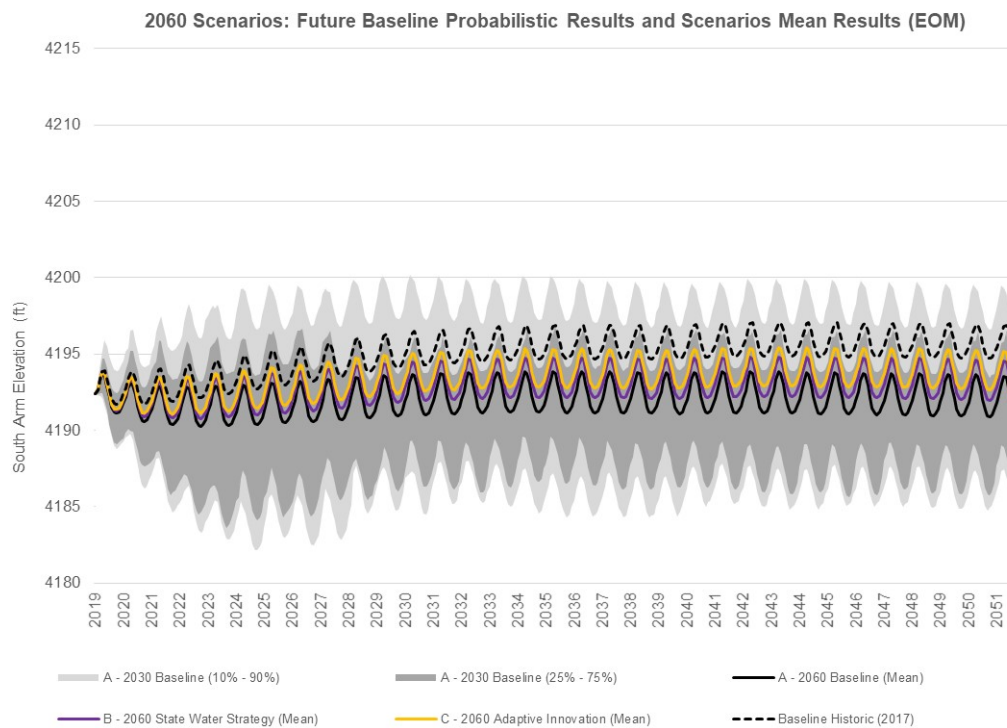
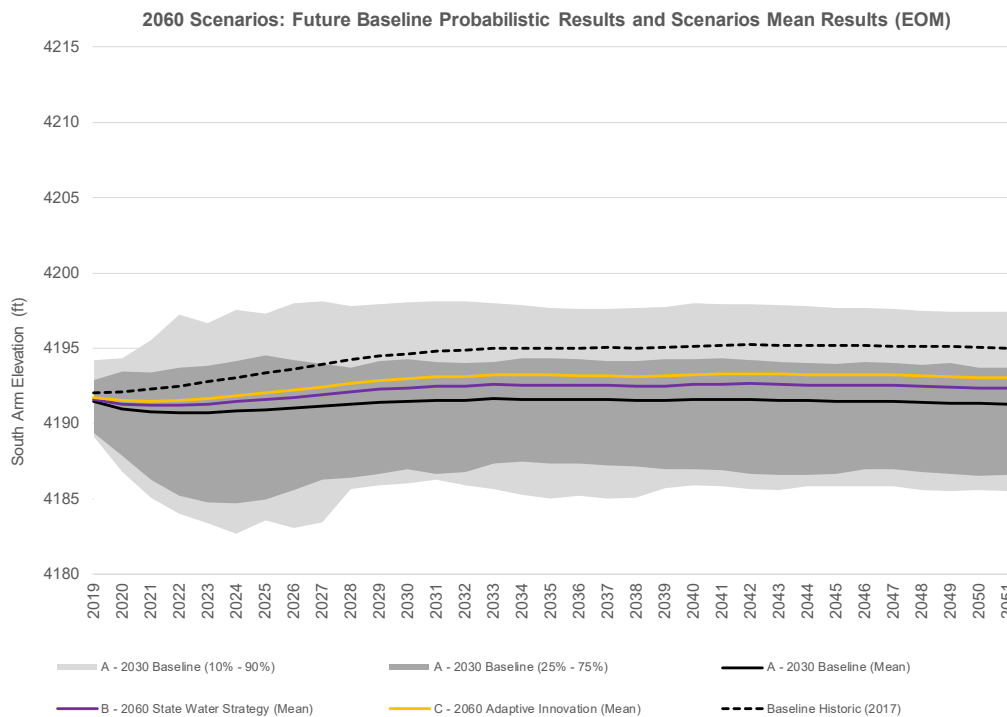


Figure 17. Great Salt Lake Surface Elevation Stochastic Results from 2060 Future Scenarios
End of the Year (top) and End of the Month (bottom) South Arm Elevation



6. Key Takeaways

The key summary points based on these GSLIM simulations are as follows:

- Considerable inertia exists in the Great Salt Lake system; its trajectory takes time to change. For example, current lake levels are near all-time historical lows due, in part, to more than a decade of relatively dry conditions and declining lake levels.
- Stochastic simulations suggest that individual annual results are primarily driven by natural hydrologic variability in the system. However, the long-term trends appear to be driven by climate and water management.
- Future projections using the scenarios defined in this study suggest continued declines in lake water levels. This suggests that lake levels will continue at the margins of critical thresholds for many of the lake's resources.
- Effective growth planning and water management can make a positive difference; however, there is no "quick fix". Minimizing potential impacts will require implementation of a coordinated and concerted effort. Changing the trajectory of a complex system takes time; waiting may make doing so more challenging.

7. Recommendations

Based on the work developing the GSLIM simulations for this effort and based on the results of the model scenarios, the following recommendations are offered:

7.1 Water Management

- 1) A regional, coordinated planning process should be implemented to develop integrated water resource management strategies that consider the entire watershed.
- 2) Scenario planning should continue to be used to maximize opportunities, better understand potential consequences, and minimize risks.
- 3) Strategies should be executed to incentivize and increase municipal and industrial water conservation.
- 4) Strategies are needed that optimize agricultural and outdoor water use while maintaining or improving agricultural production, accounting for benefits of return flows, and protecting natural systems. They are all connected.

7.2 Further Develop GSLIM's Capabilities

- 5) Further develop the model's capabilities in concert with planners and managers from communities throughout the Great Salt Lake watershed, including:
 - a. Update integration of land development into population forecasts to better allow for dynamic modeling of population change into the future.
 - b. Incorporate updated groundwater data and how this water resource will be used into the future.
 - c. Improve how surface water reservoirs are simulated in response to wet and dry years.
 - d. Update how Great Salt Lake salinity and evaporation are represented within the model.
 - e. Extend historical climate datasets back to 1950 to improve forecasting capabilities of the model.
 - f. Develop additional scenarios to evaluate combinations of strategies to reduce future water depletions. Include potential development of wastewater effluent reuse and the Bear River Development Project in the scenarios.
 - g. Integrate financial benefits and costs and dust emissions into the model.
- 6) Develop plans to monitor and forecast lake level conditions for up to 5 to 10 years in the future in order to respond with sufficient lead time to critical conditions.

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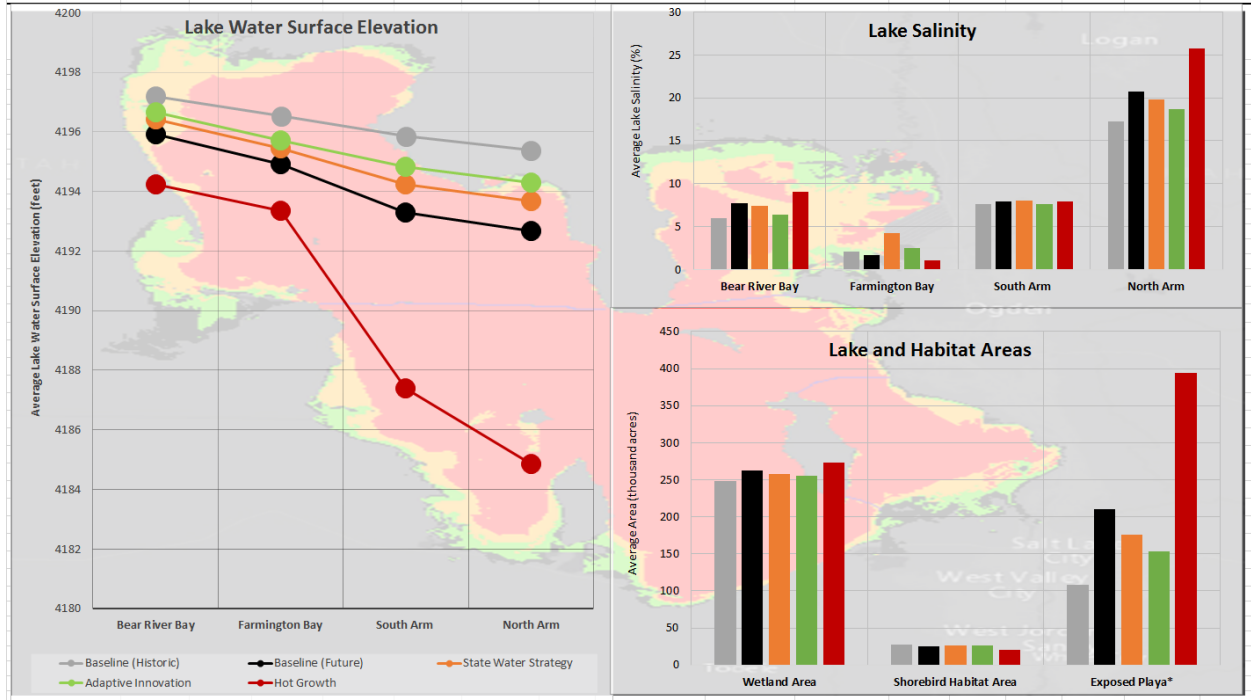
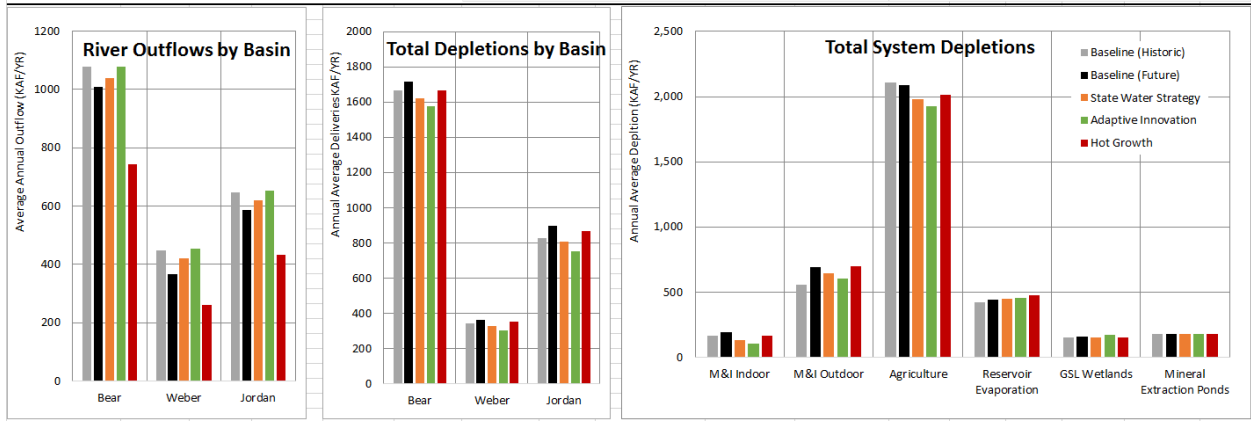
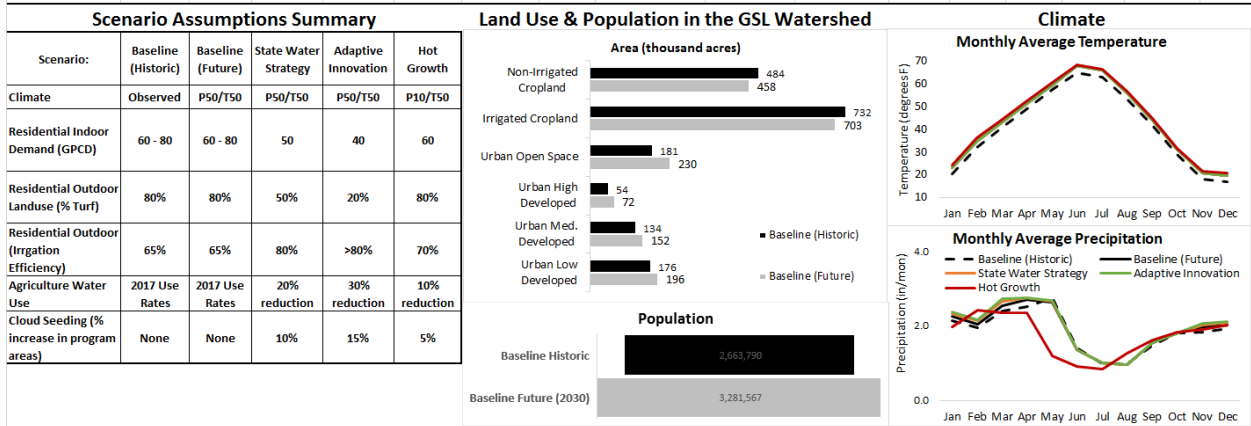
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Appendix A

Summary Output from GSLIM Scenarios

Great Salt Lake Integrated Model 2030 Projections



Great Salt Lake Integrated Model 2060 Projections

