**INTRODUCTION**

**Bottom-Up Approach to Vulnerability Analysis**

Utah State University, is undertaking a bottom-up approach (Brown et al. 2012) to assess vulnerability of the District’s water system to climate, streamflow, demographic operational, and other factors identified. The bottom-up approach identifies individual factors and combination of factors where the water system succeeds and fails to meet delivery criteria. The bottom-up approach identifies key thresholds that show the system’s vulnerabilities. The bottom-up assessment will work as follows.

1. **Identify Factors that Affect System Vulnerability.** Seven key factors have been identified for use in the vulnerability assessment study. The factors identified as follows:

1 –Hydrology

2 – Population Growth

3 – Per-Capita Water Use

4 – Agricultural-to-Urban Water Transfers

5 – Landscape Evapotranspiration

6 – Reservoir Sedimentation

7– Reservoir Evaporation and Reservoir Precipitation

For each factor that may affect system vulnerability, a range of values are selected to test.

1. **Develop Scenarios.** Sampling is used to select particular combinations of factors and levels ensure that scenarios will reveal important tradeoffs among factors.
2. **Run RiverWare Model.** To analyze the effect of the selected factors on the District’s water system RiverWare model input files are developed. For each scenario, model input files are created containing the necessary hydrologic, demographic, water use target, and water management input to run UDWRe’s RiverWare model for the Weber River Basin, The RiverWare model generates streamflow, reservoir storage, water deliveries and shortages. These results are disaggregated over time and location.

*Intro to intro* Throughout the past decade more research has gone into droughts into determining how they will occur (Reference). The severity of a drought and it effect on mankind in the modern world is based on how long the drought is the and how drastic the drought is.

These factors will be assessed to determine what combination of factors will result in a predefined system failure. The metrics and definition of system failure include values that are below set values found in the reliability, the resilience, and the vulnerability of the system (Loucks et al.,2005). Reliability, resilience and vulnerability are calculated as shown in Equations 1, 2 and 3.

Reliability =

= (1)

Resilience = (2)

Vulnerability = (3)

Weber Conservancy district has determined in prior studies that their current water system will be able to manage a two-year drought, going from full reservoirs to empty reservoirs with no inflows (WBCD, 2009??). This study takes a more in-depth approach considering a variety of inflows (drought periods/ severity), and the resulting effects on the system. Finding where the stressed areas of the system are.

**RiverWare Introduction**

RiverWare is a water resource/water system modeling software. The Utah Division of Water Resources constructed a Weber River Model using FORTRAN in the 90’s. *(RiverWare/Colorado State, 20xx).* The Utah Division of Water Resources used that Fortran model to create a new model using the RiverWare program at the platform. This RiverWare model is the model used for this study.

Previous studies have been done using the RiverWare model. This study is run through a MRM (Multi Run Model). A concurrent MRM model using input traces is used to separate and aggregate the different inputs.

**Methodology**

1. **Preprocessing** 
   1. Hydrology

Hydrology scenarios used are taken from existing datasets. The three scenarios data sets used are: 1. Historically measured gage data 2. Reconstructed Paleoflow data and 3. Climate projected data from the Weber Basin Drought Contingency Study. Using the given datasets, it is determined that a 30 year segment size for the inflow data provides a good sample size. A range of sample sizes from 1 year to 60 years was considered. A 1-year sample size is to narrow of a spectrum, 60 years is to broad.

*UPDATE Figures!!*

Figure 0.0

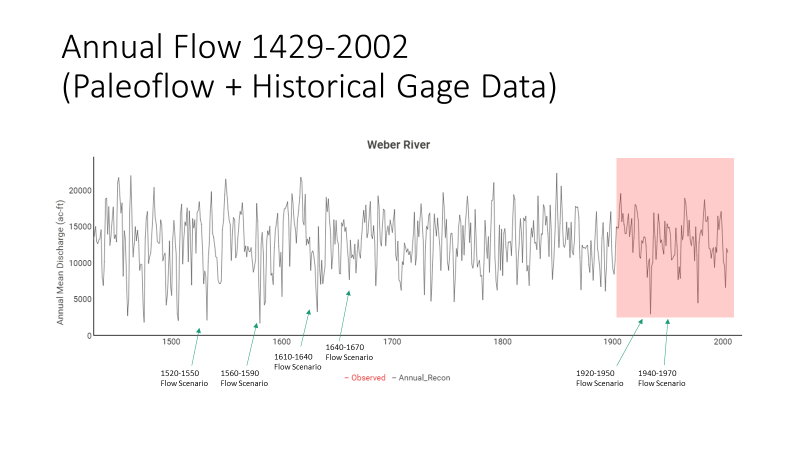
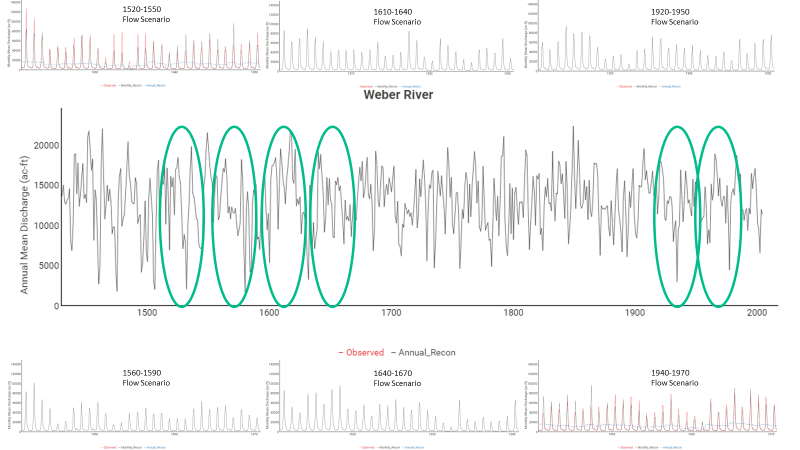
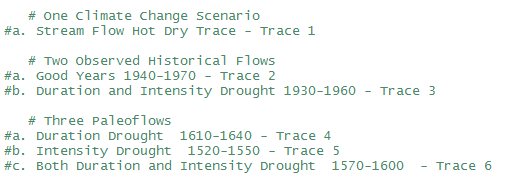


Figure 0.0



The three scenarios are shown in six selected inflow scenarios. The scenarios are chosen based on the following criteria. 

* 1. Population Growth

Increased population scenarios 2015, 2070, and 2150 (build out scenario from 2011 WBWCD TAZ study). Population include values for each county, a base case of the 2015 population and the projected 2070 population and 2150 population. The total scenario populations for the District for each year are shown in Table #.0

**Table #.0 – Total District Population Values Used**

|  |  |  |
| --- | --- | --- |
| **Denotation for Change** | **Population (Persons)** | **Reference** |
| Same | 623,960 | (UDWR, 2015) |
| Increase | 978,500 | (WBCD, 2013) |
| Drastic Increase | 1,263,000 | (WBCD, 2013) |

**Service Areas and Populations per Service Area**

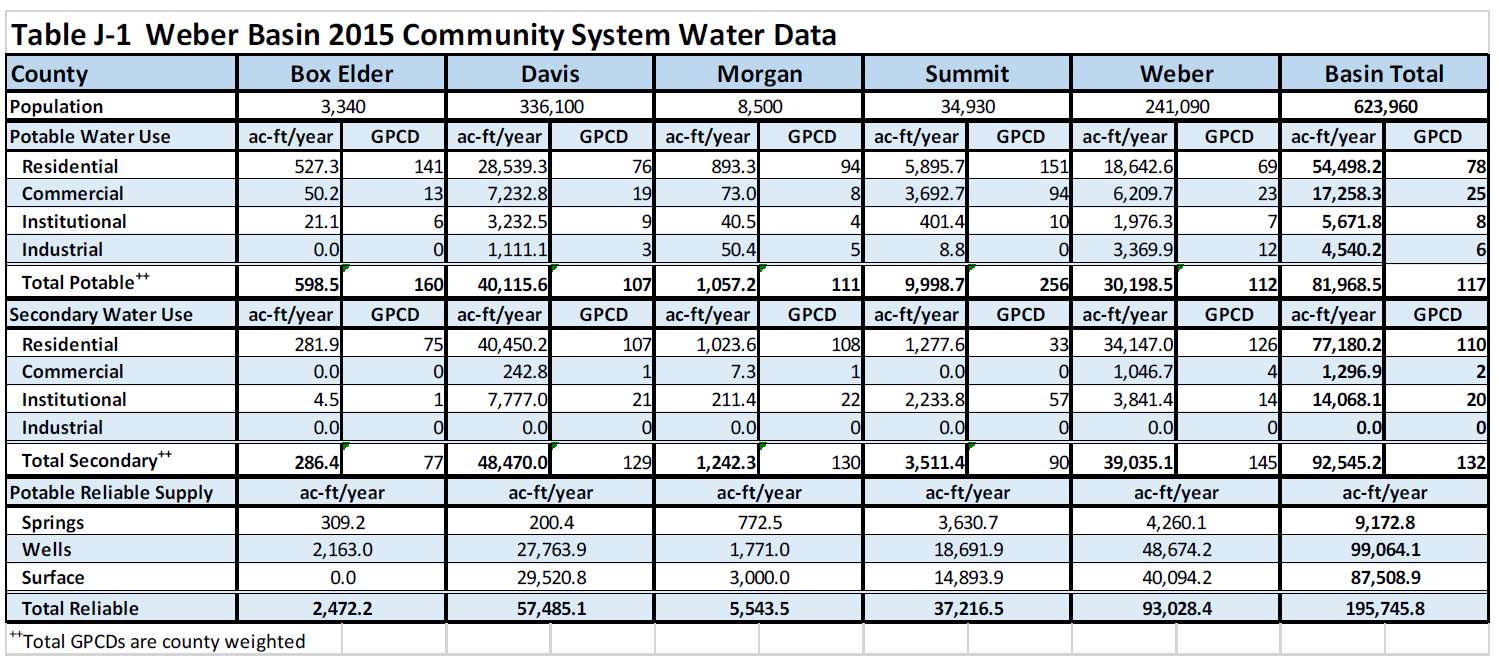
The district’s RiverWare model consists of 20 Service Areas if no changes are made for conservation and only population is taken into effect Table #.0 shows the demands by year.

**Table #.0 – Annual Demand by Service Area**

|  |  |  |  |
| --- | --- | --- | --- |
| **Service Areas** | **Annual Demands 2015-2150 (ac-ft)** | | |
| **2015** | **2070** | **2150** |
| SA1 Weber Provo Diversion Canal |  |  |  |
| SA2 Oakley to Wanship |  |  |  |
| SA3 Wanship to Echo |  |  |  |
| SA4 Echo to Devils Slide |  |  |  |
| SA5 Lost Creek |  |  |  |
| SA6 Devils Slide to Stoddard |  |  |  |
| SA7 Park City |  |  |  |
| SA8 East Canyon |  |  |  |
| SA9 Stoddard To Gateway |  |  |  |
| SA10 Gateway Canal |  |  |  |
| SA11 Davis Weber Canal |  |  |  |
| SA12 Weber Basin Project Ogden Valley |  |  |  |
| SA13 Ogden Brigham and S Ogden Highline Canals |  |  |  |
| SA14 Ogden River Below Pineview |  |  |  |
| SA15 Slaterville |  |  |  |
| SA16 Warren Canal |  |  |  |
| SA17 Ogden Bay Bird Refuge |  |  |  |
| SA18 GSL Minerals |  |  |  |
| SA19 Gateway to Slaterville |  |  |  |
| SA20 Additional WB Demand\*\* |  |  |  |
| **TOTALS** |  |  |  |
| *\*Annual demands come from WBWCD records, not Water Rights* | |  |  |
| *\*Used for potential growth scenario modeling* |  |  |  |

* 1. Per-Capita Water Use

Per Capita Secondary and Per Capita Municipal water use projections are from the 2025 water usage goals of Utah (Utah.gov), and an arbitrary 40% total per capita water usage reduced. Industrial water use is lumped in with Municipal water per capita due to the great variation in the industrial water use among the different district service areas (WBWCD, 2013).



* 1. Agricultural-to-Urban Water Transfers

Agricultural Conversion to Municipal Water Use: Primarily looking at the decreased amount of agricultural use as Municipal water is calculated using population and per capita amounts. Considering WBWCD 2016 report on increased Population and the Division of Water Resources current study into Agricultural water use conversion over the entire state of Utah. Much of the Division of Water Resources data and methodology is from the Wasatch Front Regional Council’s population planning for the Wasatch Front. Other resources describing agricultural conversion is Endter-Wada et al., 2019 report on Urbanization.

* 1. Landscape Evaporation

Evapotranspiration, study done. Evapotranspiration can vary largely throughout the district. A 15% change in outdoor water usage is implemented as the top range for the effect that evapotranspiration could change water usage. The University of Utah found that climate change is projected to increase temperatures throughout the district which will increase the amount of evapotranspiration. But additionally, climate change will increase the amount of rainfall. Therefore, it was concluded that households may increase their per-capita water usage in the future due to plants and surfaces losing more water, or households may decrease their per-capita usage due to the increase of rainfall. To represent the range of possible events outdoor per-capita usage is modeled as increasing by 15%, staying the same and decreasing 15%.

* 1. Reservoir Sedimentation

There are two types of sedimentation, long-term sedimentation & short-term sedimentation. Long-term sedimentation is the accumulation of sediment through normal processes over large periods of time. For example, the filling of a reservoir with sediment taking decades in not hundreds of years. Short-term sedimentation is the quick accumulation of sediment over a short period of time. A typical short-term sediment time period is the movement of sediment during one or two storms. Short-term sedimentation is largely attributed to flashfloods, and particularly floods after wildfires. With wildfire severity becoming a larger issue in the Western United States the sedimentation due to fires. The effect of these wildfires is being taken into account in this study. See Figure ## (Depicting wild fire severity)

**Figure #.# (*Wildfire severity)* Murphy, 2017?**

Sedimentation varies to the extreme and is largely dependent upon watershed characteristics and in the case of sedimentation due to fires wildfire characteristics. Because of the high variability it can be hard simulate for the entire district. For this study both long-term and short-term sedimentation time periods are considered. By using a bottom up approach, we consider a range of values that should provide a good representation of sedimentation types.

No study of sedimentation has currently been done for the District.

The district has eight reservoirs objects depicting the districts 9 reservoirs (See Table #). According to the Patrick Belmont and Brendon Murphy sedimentation due to fires has a high impact on reservoir volume. The range of values selected for sedimentations effect on the system include a 0% change to reservoir volume, 10% decrease in reservoir volume and 30% decrease in reservoir volume. These values of decreased reservoir volume are implemented in RiverWare for the whole 30 years that are simulated.

Belmont and Murphy, 2019 suggest that the small reservoirs withing the district such as Smith & Morehouse and Casey are more severely impacted by sedimentation. They stated that 100% of the reservoir could be affected by a short-term sedimentation event. Echo reservoir 10% reservoir reduction is on the upper end of how reservoirs could be affected.

Therefore, the selected ranges of sedimentation are a good bottom up approach.

Sedimentation flows into reservoirs can reduce reservoir storage drastically. “Projections indicate future increases in wildfire will cause sediment yields to at least double in 35% of western watersheds by 2050” (Sankey et al., 2017). “1% of watersheds are projected to have > 1000% increases in sediment yield” (Sankey et al., 2017). Increased sedimentation in the Western United States is a growing issue as wildfires.

The variability of sedimentation yields into reservoirs is extremely large. The sedimentation is based on the individual characteristics of each watershed and reservoir (Moody and Martin, 2001, 2009). Without doing individual sediment flow study for each watershed no precise values for the effect on the Districts system can are implemented. Therefore, a range of possible sedimentation values is arbitrarily selected for this study. The range of a 0% percent reduction to 50% reservoir capacity. The implementation of reservoir capacity percent reduction is within the Weber River Basin Water Conservancy RiverWare water system simulation program. Implementation of the reservoir capacity implemented within the reservoir data object.

* 1. Reservoir Evaporation and Reservoir Precipitation

1. **RiverWare Implementation**
   1. Hydrology

The RiverWare model has 19 inflow gage objects. RiverWare inputs the gage object data using a monthly time frame. These inflow values are what are used to show the variability of hydrology for the district. Three types of inflow data are used to show the range of inflow values. Historically observed data, Paleoflow reconstructed data, and Projected Climate data constructed by the Western Water Assessment, and the Weber Basin Water Conservancy District.

30 years of inflow data was used as the inflow input parameter. A study was done to help select the inflow sample size. A range of sample sizes from 1 year to 60 years was considered. See Figures… It was determined that the 30-year sample size provides a good representation

* 1. Annual Demand

Demand is input into the RiverWare Model using an Annual Demand Values for 20 different service areas defined in the original Fortran Model. ***Input Table-5 from the UDWR RiverWare Model Description.*** (McGettigan and Melcher, 2018). For the bottom-up approach a range of Annual Demands is found after pre-analysis of subfactors. To compute different scenarios of demands, several subfactors are implemented. These subfactors are: population, per-capita indoor water usage, per-capita outdoor water usage, evapotranspiration and agricultural conversion.

* 1. Reservoir Sedimentation
  2. Reservoir Evaporation and Reservoir Precipitation