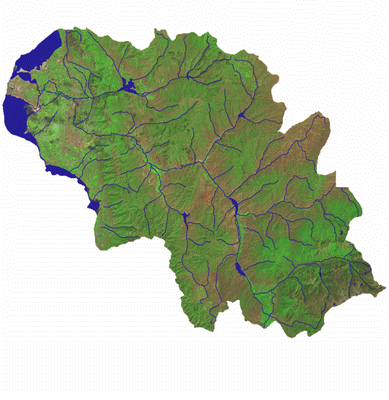
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| Utah Division of Water Resources |
| Weber River RiverWare Model |
| A Brief Description of the Utah Division of Water Resources Weber River RiverWare Model |

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| By Scott McGettigan P.E. & Tony Melcher  5-23-2018 |



# History of Model

The Utah Division of Water Resources’ first version of the Weber River Model was a FORTRAN model that was designed in the 90’s. The model was originally created to assist in the Bear River development simulations, and to gain a better understanding of the dynamic between the two basins under potential Bear River project scenarios. The model, however, has since been used for multiple purposes.

Between the time of its initial creation and its most recent update, the Weber River Model was mainly used to make historical runs based on past flow and diversion records. Potential changes to water demand or streamflows weren’t thoroughly explored.

Though valuable at the time, it was challenging to modify the FORTRAN model for various modeling alternatives. As a result, the model was converted to its current state, using the RiverWare platform.

# Current Model

As mentioned, the Weber River Model has been updated within the last several years to the RiverWare platform. This update has more easily allowed the opportunity to explore alternative scenarios with the model. Making adjustments to rules, reservoirs, inflows, demands, etc. is a much smoother process.

Even though the model has been updated, and how the user interacts with it has altered, much of the core in the model remains the same. The RiverWare version uses much of the same operating policies and settings as the FORTRAN version.

The Weber River Model is mainly a water supply model with the intended purpose being to explore how different scenarios may affect supply. The model is not intended to be an operations model for day-to-day purposes and shouldn’t be used as such. The model is best understood and applied to a higher level of evaluation. The model is most valuable when used to explore the long-term dynamics within the basin.

# Model Elements and Parameters

## Model Layout

The river is modeled from upstream to downstream, and contains representations of major reservoirs, reaches, and water users on the system. Many water users are combined into aggregate groups on sections of the river, especially higher in the system where there is a greater number of individual users. Large canal diversions, most of which are lower in the system, are typically modeled individually. Major tributaries are identified as single inflows while the smaller, ephemeral tributaries are grouped into single reach gains that accumulate downstream between gauges. Figure 1 shows a snippet of the model structure and domain as described.

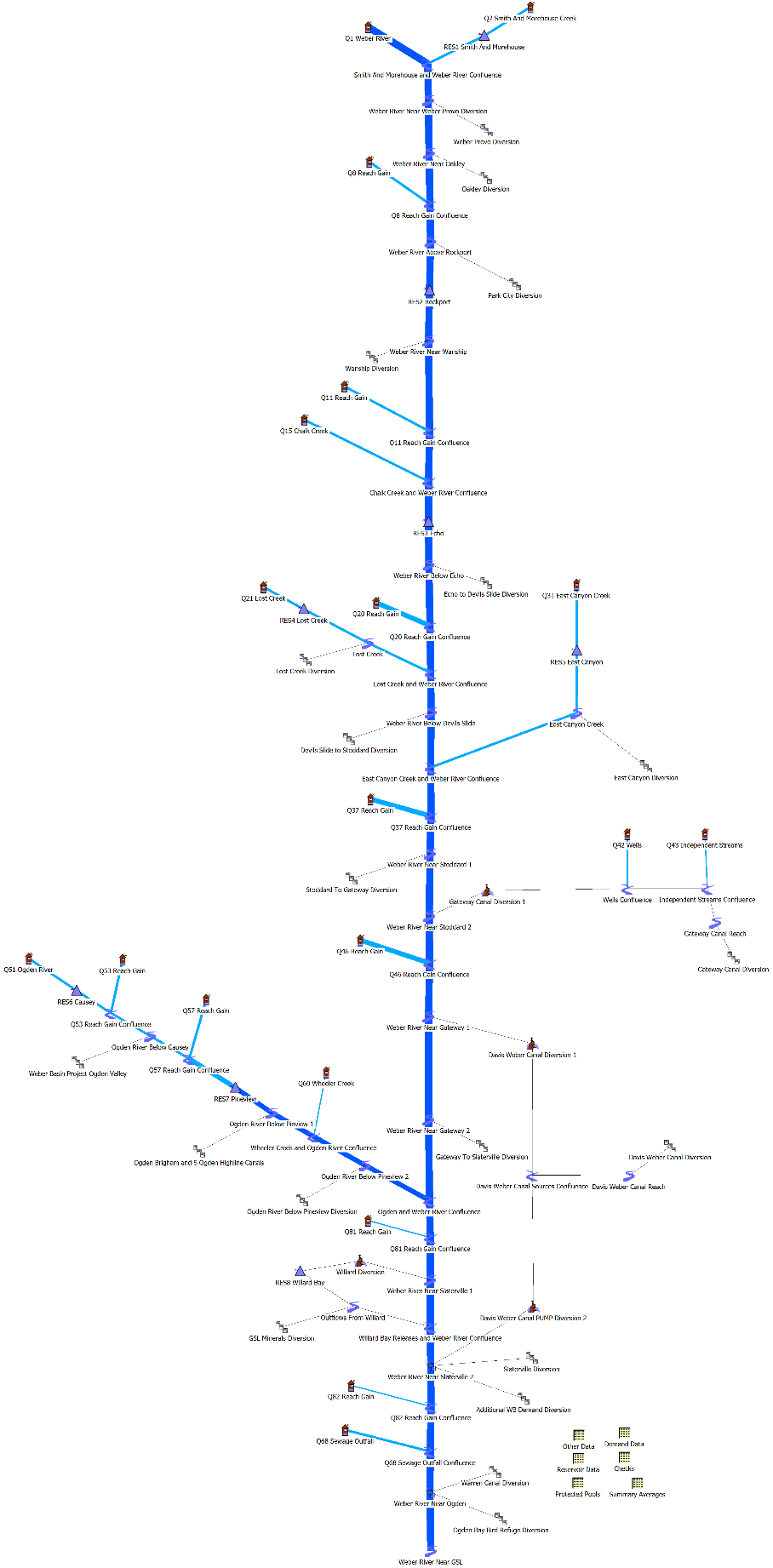


Figure 1 - Weber River Model RiverWare Layout

## Reservoir parameters

Much of the reservoir information regarding dead pools, minimum releases, and protected pools was obtained from Weber Basin Water Conservancy District (WBWCD) or verified by them. The stage-area-capacity tables and evaporation rates were, for the most part, transferred from the previous model. The following tables outline some of the essential reservoir parameters. It can also be noted that reservoirs were identified in the FORTRAN model using a nomenclature that has been preserved in the RiverWare model.

Table 1 - Monthly Reservoir Evaporation Rates



Table 2-Minimum Reservoir Releases



Table 3-Reservoir Protected Pools



Table 4-Minimum and Maximum Reservoir Storages



## General Model Parameters

Besides the parameters relating to specific objects in the model, there are a handful of other important general settings that should be noted. The model operates on a monthly time-step. The time series range is dependent on what scenario is being run, and is based on an October to September water year. The majority of the units for flow and volume are set to acre-feet, or acre-feet/month or some other form of U.S. customary units (however, RiverWare runs all calculations in SI units).

## Service Areas & Demands

Demands for the water users were developed from water rights diversion records. Water user records for every tracked user in the basin were grouped into the aggregate areas, or identified as being part of a major canal and totaled monthly for the period of record collected. These results were then available for use in historical runs, or to identify averages, maximum values, etc. to be used for scenario demands. The service areas used in the model are given in Table 5, with their associated average, maximum, and second highest demands. Maximum demands from this table were used in the model because they are conservative for the purposes of planning. Additionally, the maxima calibrated well with historic storage levels. These service areas are also identified using the naming scheme from the FORTRAN model.

Table 5 - Service Areas and Demands



## Model Inflows

Inflow boundary conditions are placed either at reach gains, or at the head waters of major tributaries within the model, and are produced by regression and a back calculation method to eliminate the effects of reservoir operations and diversions. The reach gains essentially represent the difference between two gauges (downstream minus the upstream) that have been corrected back to natural flow. Table 6 shows the inflow calculations specified by QX, which is the naming convention that has been maintained from the previous model.

The back calculation method referred to requires historical reservoir records, which came either from WBWCD or US Bureau of Reclamation (BOR). It also required diversion records, which came from the Utah Division of Water Rights (WRi). These records are essentially the same records used for producing area demands.

Obtaining inflows at gauged sites with incomplete records required a reference station with a more complete record that was used to extend all other gauges. This reference station is the Weber at Oakley Gauge (10128500). This gauge has the longest record on the Weber River and one of the longest in the State. Every gauge used to develop the model inflows is correlated with the Weber at Oakley gauge as the base station.

Table 6 - Model Inflow Calculations



## Operating Policies/Model Rules

Most of the policy that drives the model forward is based on a service area call structure that was established in the FORTRAN version of the model. This structure represents the early efforts of those who worked on the model in attempting to understand and generalize the way system operators respond to conditions on the river. The structure has been shared with WBWCD operators at various times to verify the approach and, for the most part, has been accepted as a reasonable way to generalize the way the system is operated. The core of the model rules revolves around this call structure and it is presented in Table 7.

Table 7 - Area Reservoir Call Order



# Inflow Scenarios

## Historic

Any historic scenario that is produced for the Weber River Model is based on a linear-regression of natural flows with the Weber at Oakley gauge as the base station. Every gauge that is used as a tributary or for a reach gain calculation is shown in Table 8 with their associated annual correlation R2 values. Annual correlation R2 values are shown, but monthly were actually used. Showing the annual gives an overall perspective on the relationship between the gauges. True historic correlated inflows can only be created for the range covered by the Weber at Oakley gauge which is 1905 – Present.

Table 8 - R2 Values for Annual Correlations with Weber at Oakley Gauge



## Paleo

Through the exceptional efforts made by a number of researchers from universities, including but not limited to USU and BYU, using their expertise in the fields of dendrochronology, statistics, and hydrology, the Weber at Oakley gauge has been extended back to the year 1429. This lengthening of the record is mostly made possible by the study of tree-rings on old-growth trees. The topic is well documented and can be studied more extensively in other publications.

In addition to the work done by these researchers to extend the Oakley gauge, USU has done further work to translate these extended annual flows to monthly flows, making it possible to implement into the Weber Model, and give a more detailed look into how earlier droughts occurred.

One of the major benefits of having the ability to look back so far into the past is the understanding of the level of preparation that be needed should certain hydrologic conditions be encountered. This record gives us a clearer window back into history and the chance evaluate it through modeling former hydrology with current and/or projected demands.

Using the paleo-flows required another set of regression equations be developed for every stream-gauge based on calculated flows for Weber at Oakley through the period which is historically recorded. The alternative correlation coefficients are presented in Table 9.

Table 9 - R2 Values for Annual Correlations with Reconstructed Weber at Oakley



## Climate Change

Exploring how potential climate changes could affect streamflow has become increasingly important to water managers in the west. For the Weber River, this is no exception. Western Water Assessment (WWA), a non-profit research program, that provides support to water planning activities, has developed a set of potential hydrologic scenarios that could be encountered based on global climate change models. Using downscaled CMIP5 climate traces, WWA has provided 5 climate pathways of flow on the Weber River. These pathways are: Hot-Dry, Warm-Dry, Hot-Wet, Warm-Wet, and Central-Tendency. Each scenario is a 30 year period of possible future hydrology representing 2030-2060. Plots of how each of these climate conditions might affect Weber at Oakley flow, and any shifts in the hydrograph, are shown in Figure 2. Each of the flow conditions shown in the figure were applied to the model at the main inflows using regression techniques similar to the ones used in applying the paleo-records.

Figure 2 - Weber at Oakley Climate Change Average Monthly Flows

## Base Operations/Conditions

Applying either the climate change or paleo inflows to the model produced base set of results for standard operations and current system facilities. The data for each of these ‘Base’ runs are presented in the following sections. With these base conditions there is a set of data to compare against with hypothetical changes to operations or the system.

### Paleo

A plot showing the total basin reservoir storage results for the base paleo scenario run covering the full available period is presented in Figure 3. The years covered are from October 1429 – September 2002. In subsequent sections, plots will be presented showing various drought response and mitigation actions. These actions will be compared to the results of this “base” plot, which will demonstrate the effectiveness of the action.

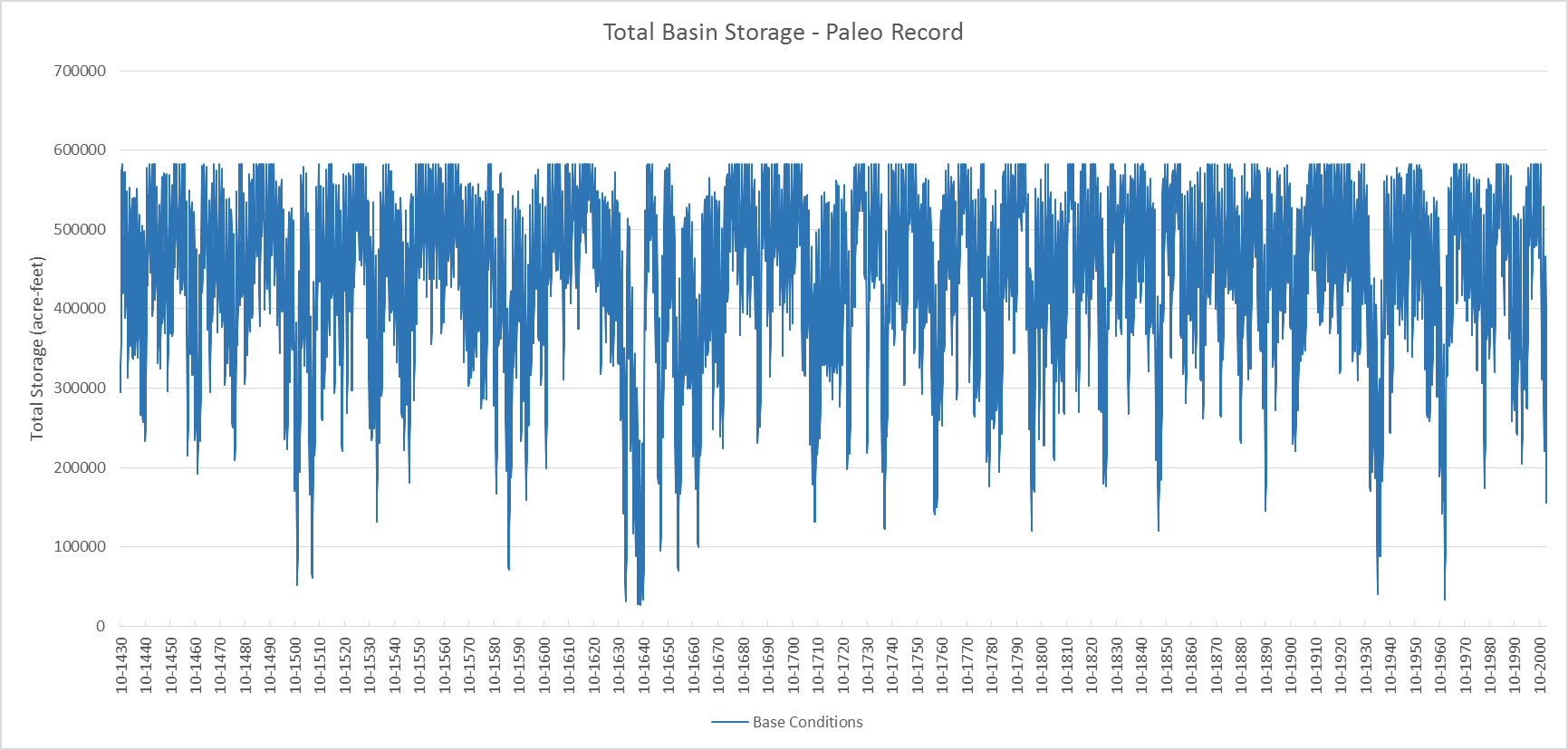


Figure 3 - Total Basin Storage Results for Paleo-flows Under Base Operations

### Climate Change

Applying each of the five climate scenario inflows to the model produces five different versions of the effects of climate change to the flow in river. The storage plots for these scenarios are shown in Figure 4. The model period is 30 years, representing the future years of 2030 – 2060. For the purposes of drought contingency planning the two wet scenarios are of less value, but are still presented and may be useful for context. The historical plot is also presented to give context. Historical in this sense refers to historical hydrology. Because the climate trace hydrologic conditions were derived from 1980 – 2010 conditions, adding this plot can shed some light on the implications of the other plots. As with the paleo base scenario, these climate change plots will also be used as a basis for comparison for each drought response and mitigation modeled in subsequent sections.

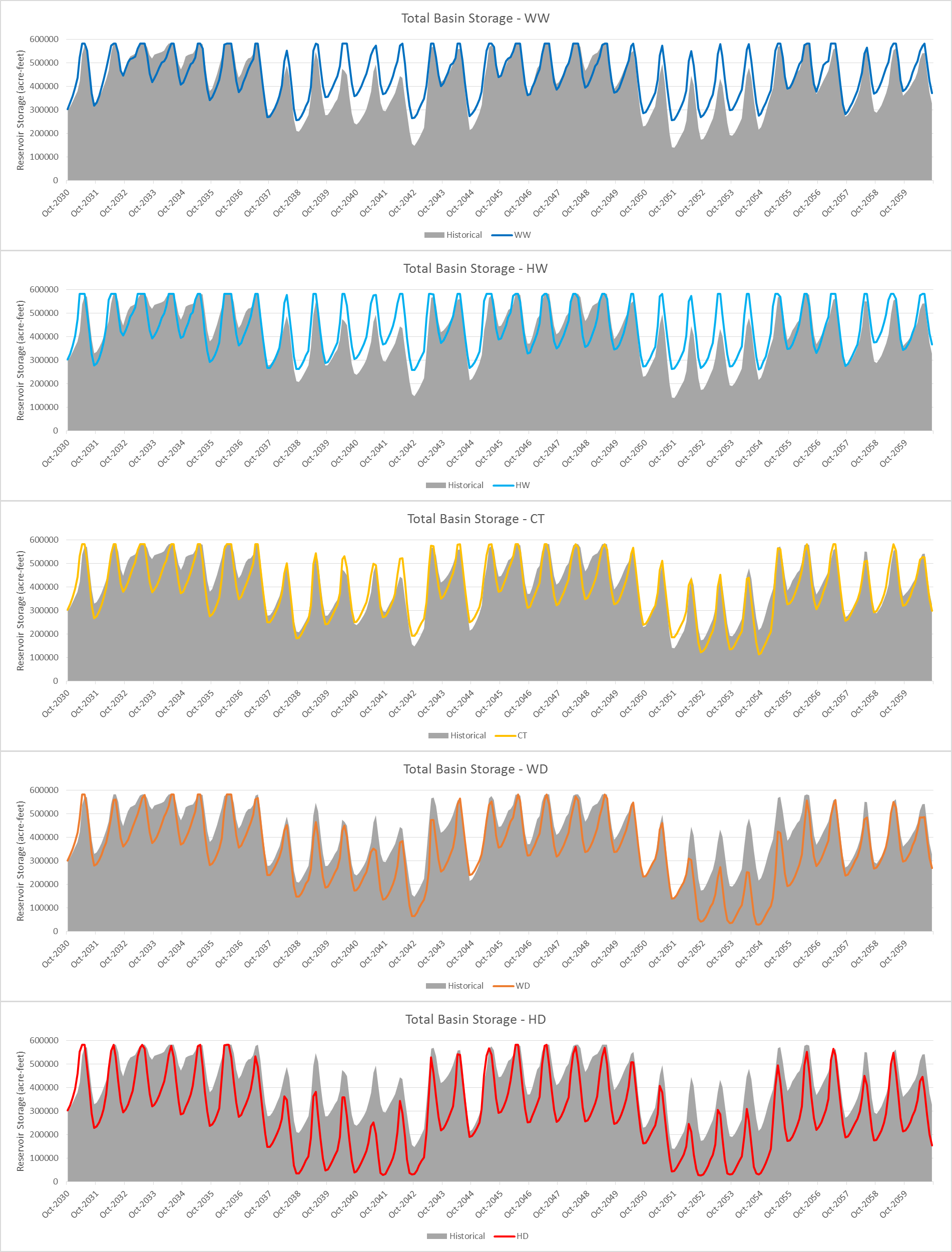


Figure 4 - Total Basin Storage with the Five Climate Change Pathways under Base Operations

# Action Scenarios

## Drought Mitigation

### Gravel Pit Reservoir

#### Scenario Description

For this scenario a 16,000 acre-foot off-stream reservoir was placed at the mouth of Weber Canyon where currently a gravel pit is operated. This potential reservoir could be used to address shortages during drought situations, and is modeled in this manner. The reservoir in the model was programed to cover only shortages seen for the Gateway Canal service area.

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Figure 5 – Screen Capture of Model Containing the Proposed Gravel Pit Reservoir

#### Scenario Assumptions

The stage-area-capacity table for this hypothetical reservoir is shown in Table 10, which was determined from a feasibility study done by Bowen Collins and Associates on behalf of WBWCD. The diversion capacity established by study was 13 cfs. Evaporation was set to the same rates as the Willard Bay. Calls from this by reservoir by SA10 – Gateway Canal would occur fourth in line, i.e. the alternative reservoir call order for SA10 would be: RES3 – Echo, RES2 – Rockport, RES4 – Lost Creek, *RES9 – Gravel Pit*. Being an off-stream reservoir, any reservoir inflows would need to come by way of diversions. Diversion requests to the reservoir were set to any available water in the river at any time of the year that would bring the reservoir to full.

Table 10 - Potential Gravel Pit Reservoir Stage-Area-Capacity Table



### Chalk Creek Reservoir

#### Scenario Description

For this scenario a 10,000 acre-foot reservoir was placed on the Chalk Creek tributary. This potential reservoir could be used to address shortages during extreme drought situations, and is modeled in this manner. The reservoir in the model was programed to cover only shortages seen for the Gateway Canal service area.

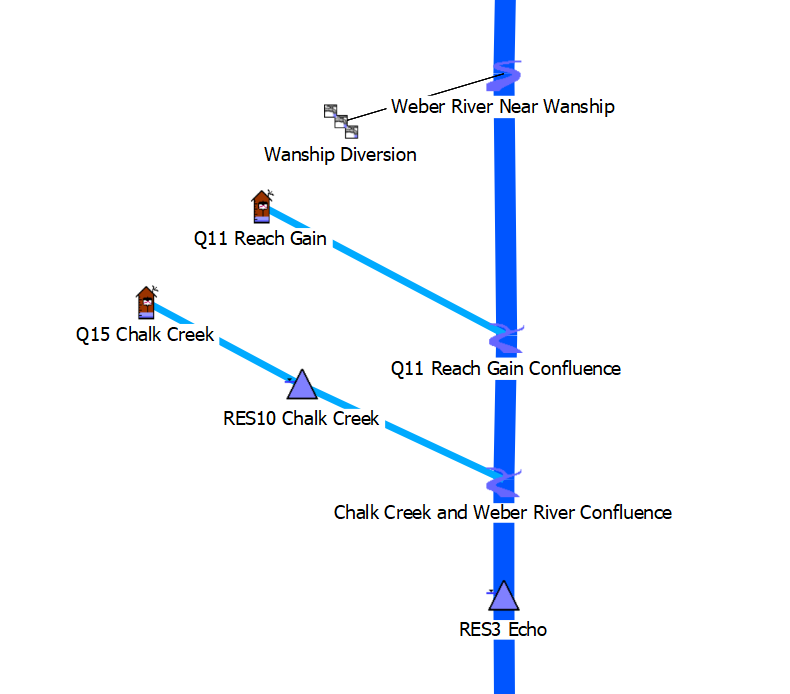


Figure 6 – Screen Capture of Model Containing the Proposed Chalk Creek Reservoir

#### Scenario Assumptions

The stage-area-capacity table for this hypothetical reservoir is shown in Table 11, which was provided by WBWCD. Evaporation was set to the same rates as the other reservoirs that are at approximately the same elevation. Calls from this by reservoir by SA10 – Gateway Canal would occur fourth in line, i.e. the alternative reservoir call order for SA10 would be: RES3 – Echo, RES2 – Rockport, RES4 – Lost Creek, *RES10 – Chalk Creek*.

Table 11 - Potential Chalk Creek Reservoir Stage-Area-Capacity Table



### Expanded ASR

#### Scenario Description

For this scenario ground water storage would be expanded to 10,000 acre-feet per year, and withdrawals would occur when needed. Currently the WBWCD ASR project is infiltrated at 2 cfs, and as of current date, no water has ever been recovered from the aquifer. Any water stored in the aquifer would be mandated by DWRi to take a calculated loss. Groundwater pumping from the aquifer was programed in the model to cover only shortages seen for the Gateway Canal service area.

#### Scenario Assumptions

A storage cap was placed on the aquifer of 30,000 acre-feet. This number was completely arbitrary, but necessary in order to keep the model running for the paleo scenario. The monthly diversions to be infiltrated are 1667 acre-feet over a six month period from March to August. There is no capacity set for pumping from the aquifer, other than the total volume available. The WRi mandated loss is calculated in this manner: the full amount of water is available after the first and second years of storage, every subsequent year any volume not used is assessed a 50% loss.

### Wastewater Reuse

#### Scenario Description

This is a very simple scenario in which wastewater reuse would be implemented at various areas in Davis and Weber counties, which would in turn alleviate the demand on the Gateway Canal for secondary water.

#### Scenario Assumptions

There are very little assumptions associated with this scenario. To replicate this concept in the model, the annual demand on SA10 – Gateway Canal, was reduced by 10,000 acre-feet, with the same demand pattern in place as in a standard scenario. Everything else was unchanged in the model.

## Drought Response

### Demand Management

#### Scenario Description

This is a fairly complicated scenario that involved many adjustments to the model and operating rules in order to function. The intent of this scenario is to respond to droughts with prescribed demand reductions, based on the condition of the system reservoirs. In taking this approach, WBWCD aims to protect its M&I supplies in times of severe shortage.

#### Scenario Assumptions

Most of the assumptions established for this scenario were derived from a table produced by WBWCD that outlined how and when reductions are to occur. Table 12 shows this this table with three categories of reductions defined by the colors Yellow, Orange and Red.

Table 12 - WBWCD Demand Management Triggers and Reductions



In addition to applying reductions at reservoir levels, as described in the previous table, the model attempts to forecast the potential risk of facing a reduction call on June 1st, based on March 1st storage levels and inflow. Two tables were developed by WRe that applied probability risks to ranges of storage and predicted inflows (Tables 13 and 14). The tables were created based on the paleo flow record and use total basin storage and “upstream storage” criteria. The more conservative of the total basin storage and the “upstream storage” criteria was determined during the model simulation and the corresponding reductions were applied. The first two columns of the tables represent all combinations of the 25th, 50th, 75th, and 100th percentiles of total upstream storage on March 1st (column 1) and the total natural runoff volumes between March 1st to June 1st to Pineview reservoir and the Weber River near the Gateway canal diversion (column 2). Probabilities of yellow, orange, and red advisory codes at June 1st are given in columns 3, 4, and 5 respectively.

This scenario implemented the most severe demand reduction given a probability greater than “0.” For example, if the March 1st total basin storage for a single year was 350,000 ac-ft and the runoff between March 1st and June 1st was 400,000 ac-ft then this case would correspond with row 2 of the Table 13. The corresponding probabilities are 8 percent for yellow, 0 percent for orange, and 0 percent for red. Similarly, if the March 1st upstream storage was 150,000 ac-ft then this case would correspond with row 2 of Table 14. The corresponding probabilities are 0, 0, and 0 for yellow, orange and red levels respectively. In this case, the yellow reduction would have been implemented, corresponding with Table 13 as it is more severe and the probability is greater than “0.” This demand reduction would then be implemented until the next year on March 1st when the reduction status would be updated.

Table 13 –Look-up Table for Total Basin Storage



Table 14 – Look-up Table for Total Upstream Storage



### Fallowing Program

#### Scenario Description

The fallowing scenario is similar in function and objectives to the demand management scenario, the main difference being that the reductions would occur through a paid fallowing program administered and funded by WBWCD. The target volume by the program would be 10,000 acre-feet.

#### Scenario Assumptions

Much of the assumptions and operations for this scenario are identical to the demand management scenario with a few exceptions, the program is modeled to initiate at the Orange reduction level and not have any other stages of response, only the target volume previously mentioned. Also, the service areas modeled with reduced demand are all agricultural. All other details for this scenario are described in the demand management scenario section.

## Additional Scenarios

### Increased Demand

#### Scenario Description

This scenario represents a projected increase in demand for various service areas based on a projected increase in population. Projections for this scenario are rough, but give a perspective of how sensitive the system is to non-climate related changes in conditions.

#### Scenario Assumptions

WBWCD provided the data and information that was compiled to form the demand increases. The following tables (Table 15 and Table 16) show some of the basic overall numbers from WBWCD summarizing demands and expected county ag conversion. All of these increases and conversions were distributed among selected service areas in the model in the manner outlined in Table 17. A base year of 2020 was chosen as to evaluate the increases because the initial demands in the model are already set to a conservatively high estimate.

Table 15 - Total WBWCD Demands for Future Years



Table 16 - Agricultural Conversion Estimates for Counties in Weber Basin



Table 17 - Distributed Service Area Demand Increases



# Scenario Results - Paleo

## Drought Mitigation

### Gravel Pit Reservoir

Water is rarely drawn from the proposed Gravel Pit Reservoir during the paleo simulation period. This may be due to the reservoir only being called on as a last resort, and the Gateway Canal service area not being as vulnerable to drought as other areas, due to its lower positioning in the system. Figure 7 is a plot of total storage for this simulation.

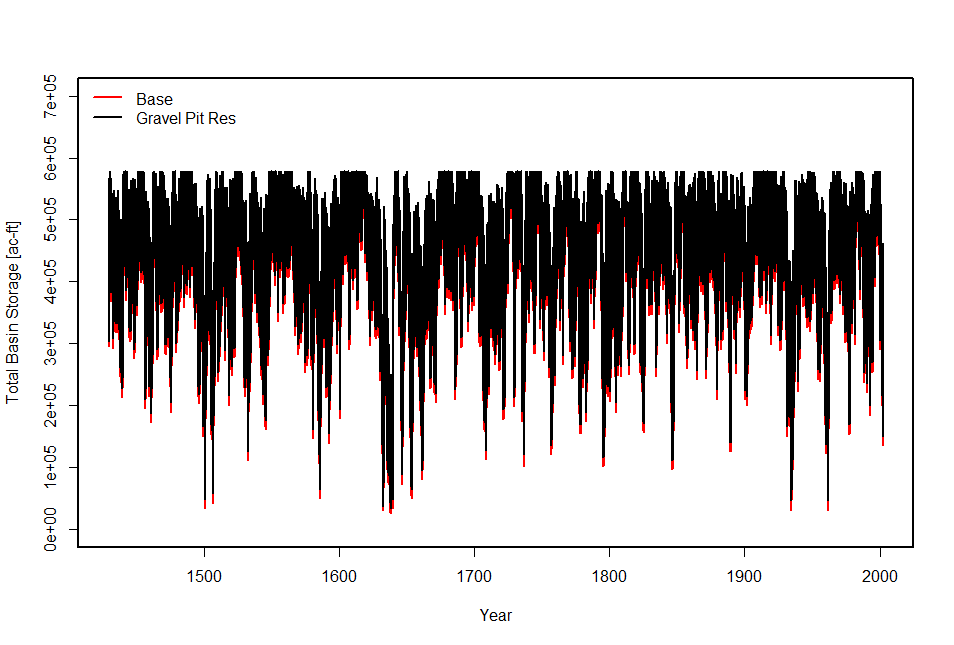


Figure 7 - Estimated Total Basin Storage with Gravel Pit Reservoir Storage

As can be seen in Figure 8, Gravel Pit storage would only be used during the 1630s drought, or during extreme drought conditions. There are however benefits to the additional storage during other drought years. While the reservoir was modeled as a “last resort” reservoir, in actual drought conditions the Gravel Pit storage can be used to lessen the impact of the drought on other reservoirs. This may prevent storages in the district’s reservoirs from reaching dead pool levels.

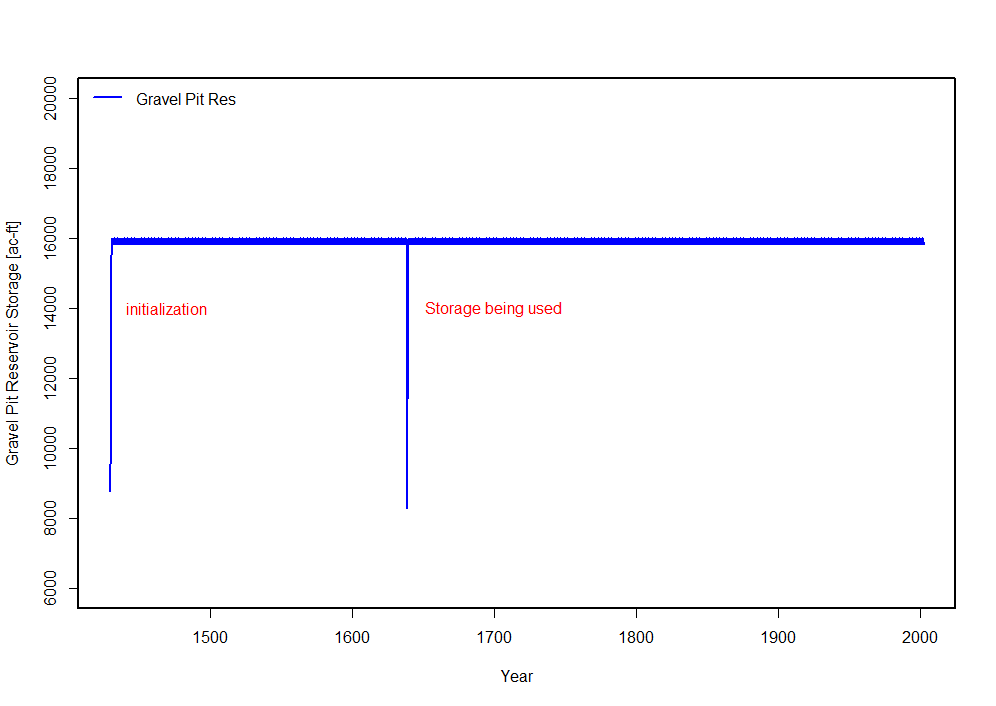


Figure 8 - Gravel Pit Reservoir Storage

### Chalk Creek Reservoir

Similar to the Gravel Pit Reservoir, water is rarely drawn from the proposed Chalk Creek Reservoir during the paleo simulation period. Again this may be due to the order in which the reservoir is called in the model and the Gateway Canal service low position in the system. Figure 9 shows a plot of the basin’s total storage for the Chalk Creek Reservoir scenario.

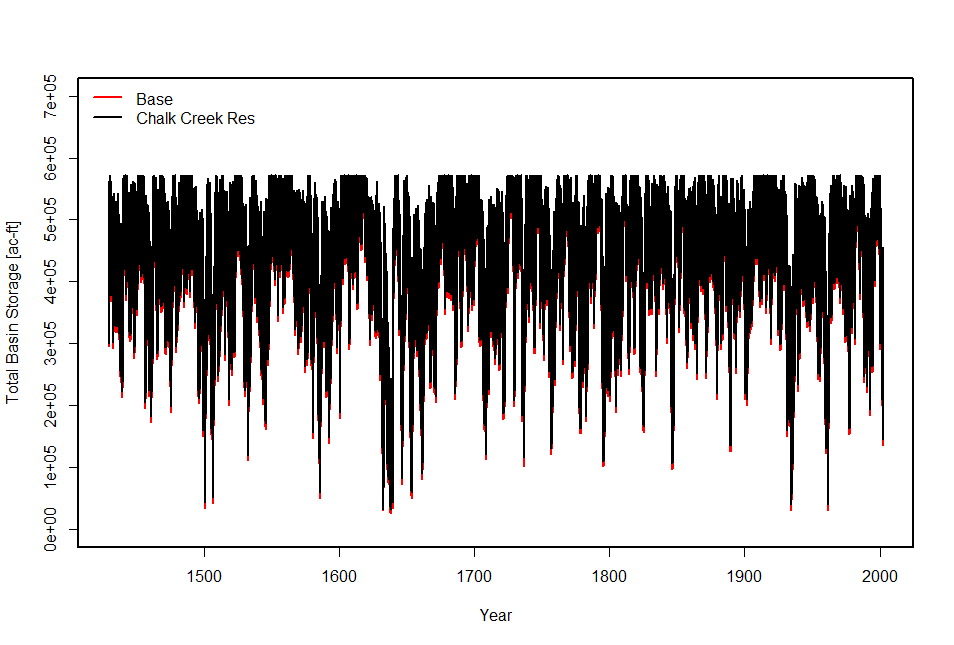


Figure 9 – Estimated Total Basin Storage with Chalk Creek Reservoir Storage

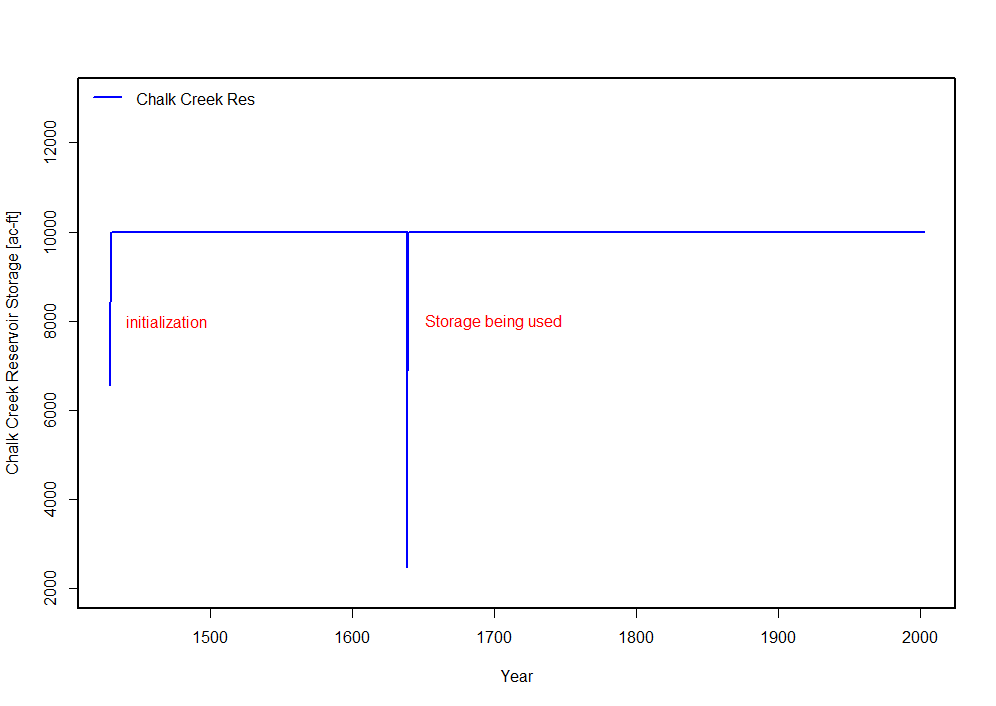


Figure 10 - Chalk Creek Reservoir Storage

Figure 10 shows that Chalk Creek Reservoir is only called during the 1630s drought, similar to Gravel Pit Reservoir. It should be mentioned that, like the Gravel Pit Reservoir, the Chalk Creek Reservoir is modeled as a “last resort” reservoir. These results don’t represent the benefit of the additional storage during all drought years. Again, the reservoir can be used to lessen the impact of the drought on other reservoirs. This may prevent storages in the district’s reservoirs from reaching dead pool levels.

### Expanded ASR

Similar to the Gravel Pit and Chalk Creek scenarios, the implementation of ASR in the Weber Basin model provides an overall increase of storage throughout the record period of about 30,000 acre-feet, as is shown in Figure 11. That available water, however, was only used during the 1630s drought to serve the Gateway Canal service area (Figure 12).

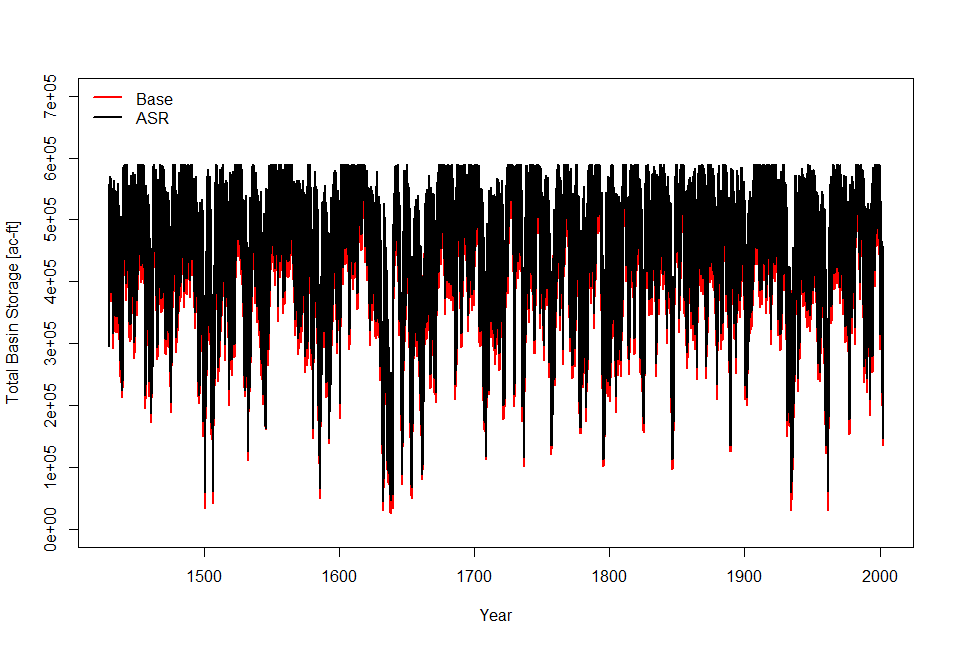


Figure 11 – Estimated Total Basin Storage with Aquifer Storage Recovery

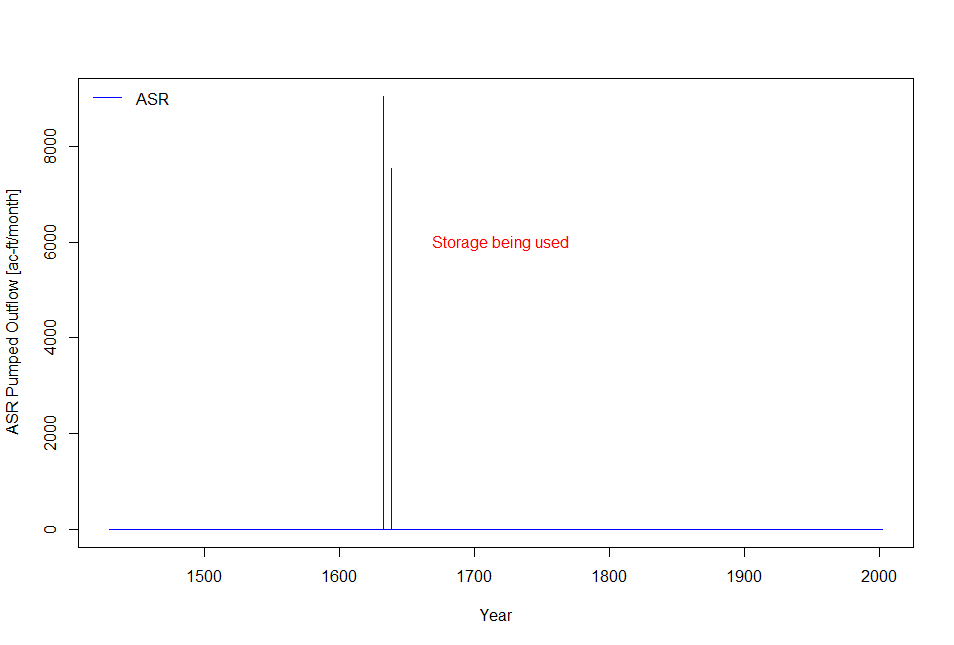


Figure 12 – Aquifer Pumped Outflow

### Wastewater Reuse

Implementing waste water reuse into the Gateway Canal service areas will make a measurable and meaningful benefit to the system. Storage can clearly be seen to be improved through-out the whole period, and not just during droughts. Figure 13 shows the plot for this scenario consistently above the base plot.

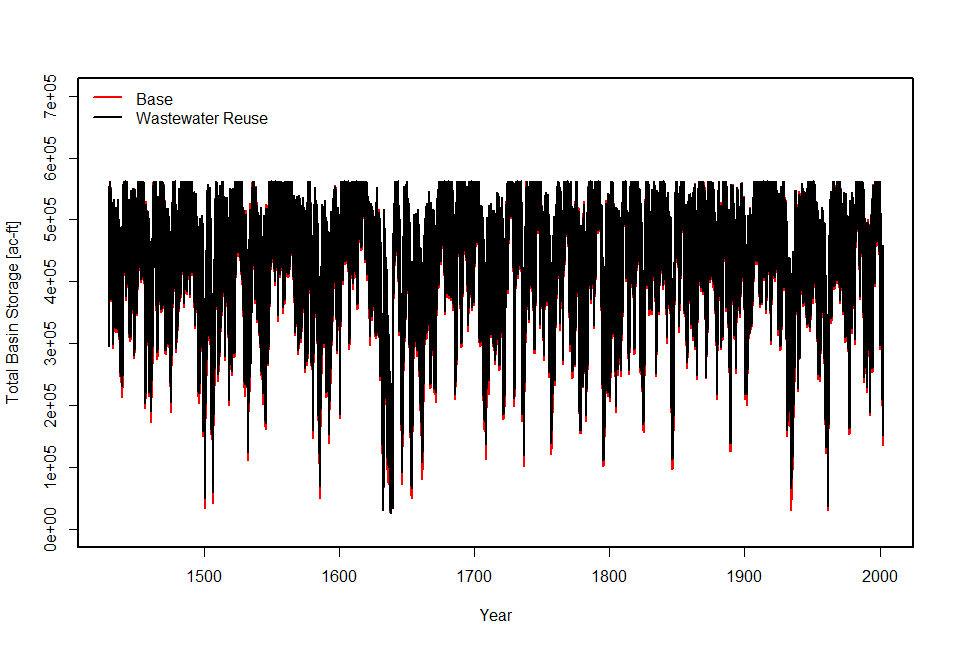


Figure 13 – Estimated Total Basin Storage with Wastewater Reuse

## Drought Response

### Demand Management

Demand reductions are effective in preserving storage during the times they are implemented. This requires that the storages at which reductions are implemented to be selected with a knowledge of the system’s response to historical droughts. At the current stages of response, reservoir storage is increased relative of the base scenario in moderate to extreme drought conditions. Figure 14 shows the benefit of sensibly selected storage thresholds for the paleo simulation period.

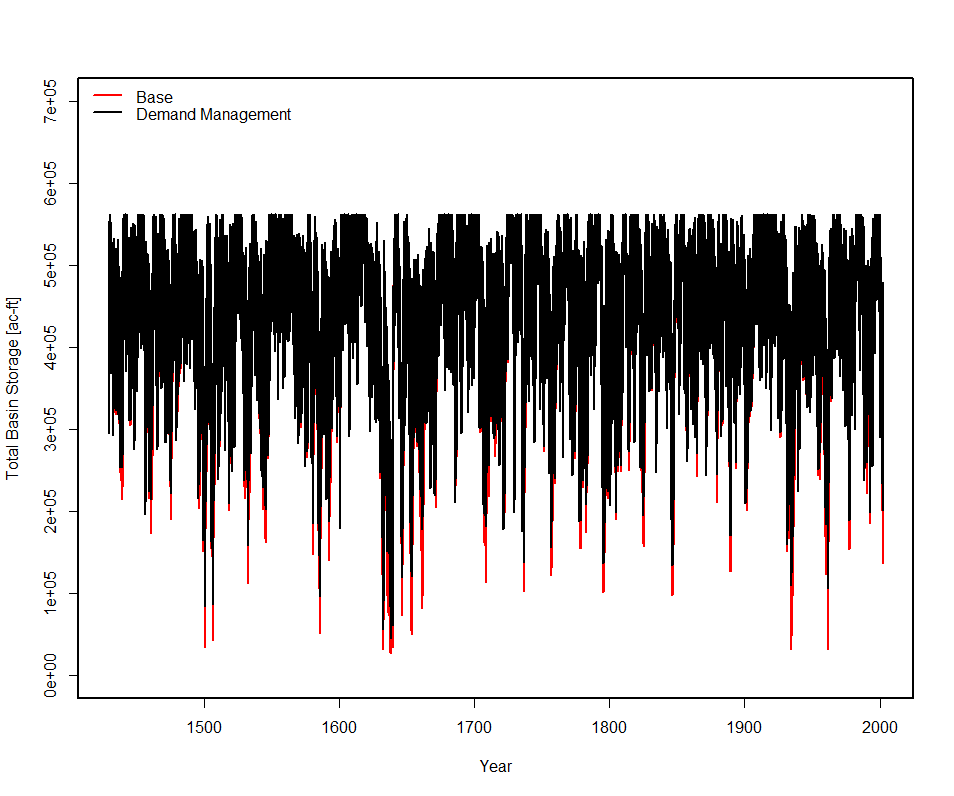


Figure 14 - Estimated Total Basin Storage with the Implementation of Demand Management Scenarios

### Fallowing Program

The fallowing program scenario results are similar to the demand management but increase total basin storage to a lesser degree. In the case of a more severe drought (e.g., 1630s), the water saved due to the fallowing program (10,000 acre-feet) is completely depleted. In Figure 15, it can be seen that storage is improved for a number of moderate droughts, but in the case of the 1630s, the fallowing program is not augmented to account for the extreme hydrological conditions.

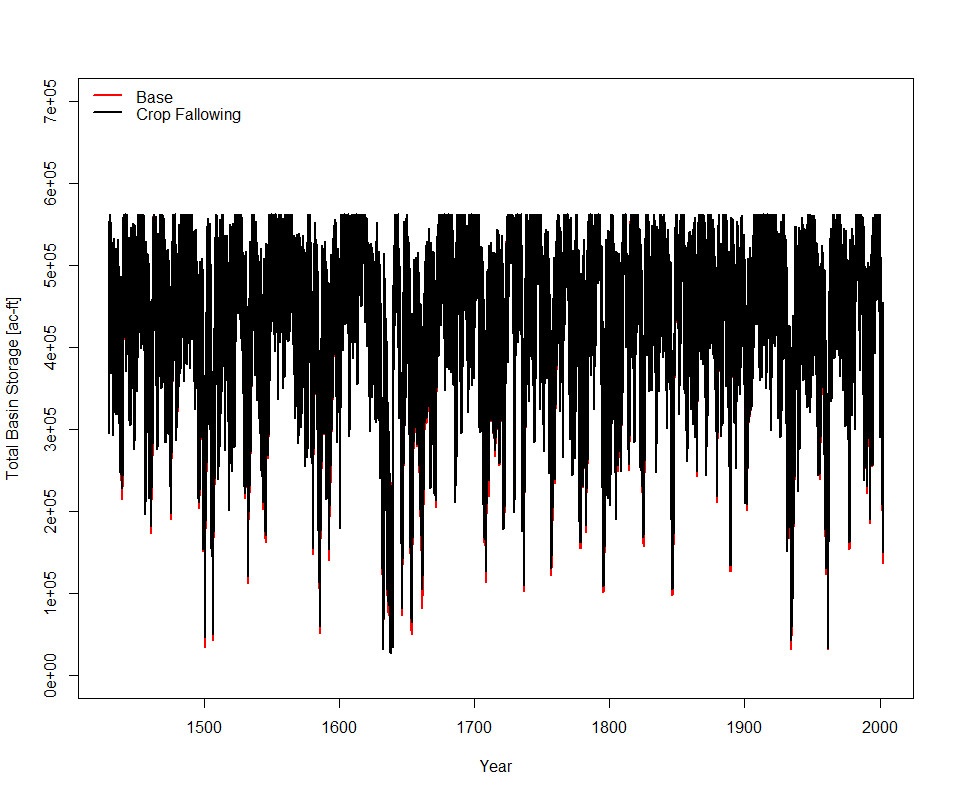


Figure 15 - Estimated Total Basin Storage with Demand Decreases from Crop Fallowing

## Additional Scenarios

### Increased Demand

As stated previously, results from the increased demand scenario show how responsive the system is to changes that are not climate related. It is clear from Figure 16 that changes that may seem relatively minor in comparison to total flow of the river can have noticeable impacts on the system as a whole. The total increase in volume for the scenario was only 22,500 ac-ft, but the impact is very apparent in the plot, as the dips in storage during droughts are more dramatic.

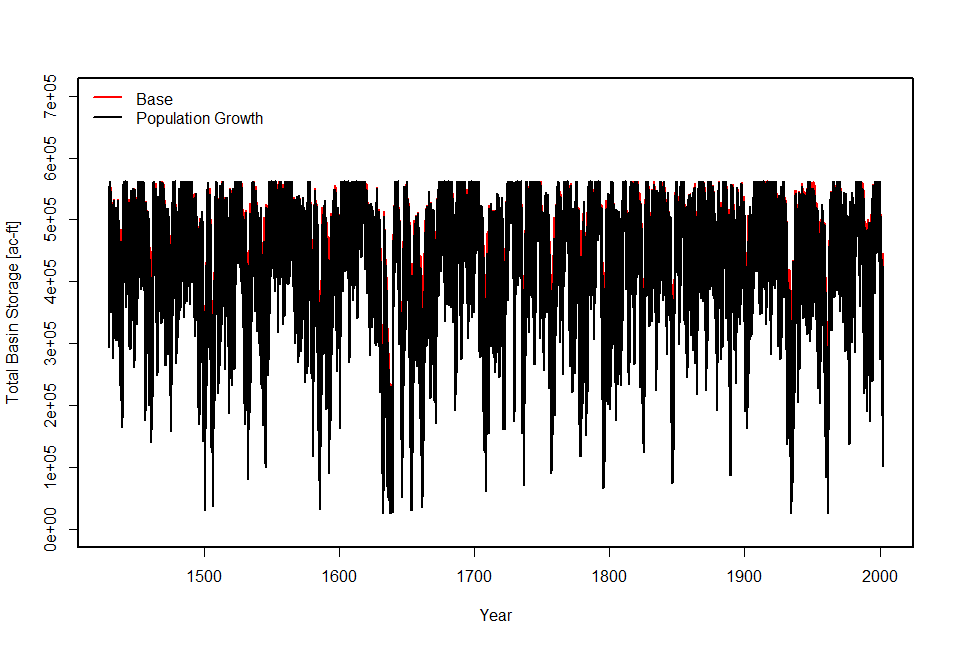


Figure 16 - Estimated Total Basin Storage with Demand Increases Due to Population Growth

# Scenario Results - Climate Change

## Drought Mitigation

### Gravel Pit Reservoir

Figures 17 and 18 show the total basin storage and storage of the Gravel Pit Reservoir subject to historical and the five climate change hydrologic scenarios. Storage from Gravel Pit Reservoir would be used only during warm-dry and hot-dry climate change scenarios. In the warm-dry scenario, the 17,100 acre-feet reservoir was emptied 1 of the 30 simulated years. In the hot-dry scenario, the reservoir was emptied 3 of the 30 simulated years. These results are based on the Gravel Pit Reservoir being operated as a last resort. In actuality, the Gravel Pit storage could be used to curb some of the effects of droughts in other climate scenarios as well. Much is dependent on how the Gravel Pit Reservoir is operated.

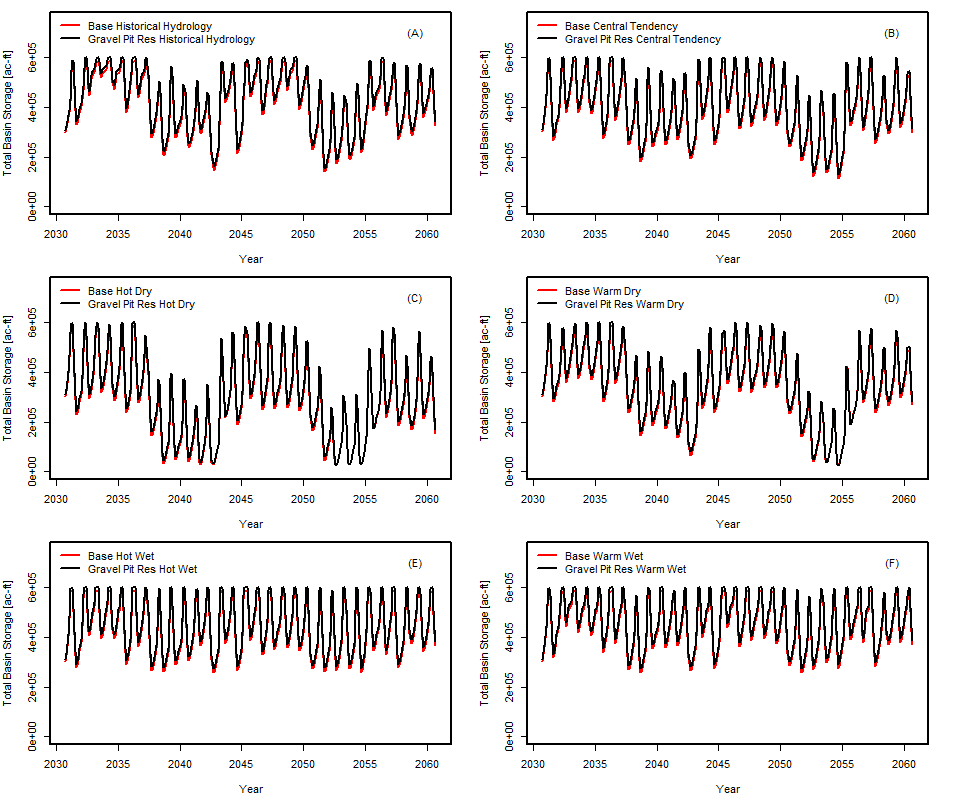


Figure 17 –Total Basin Storage including Gravel Pit Reservoir for the Historical Hydrology and the 5 Climate Change Scenarios

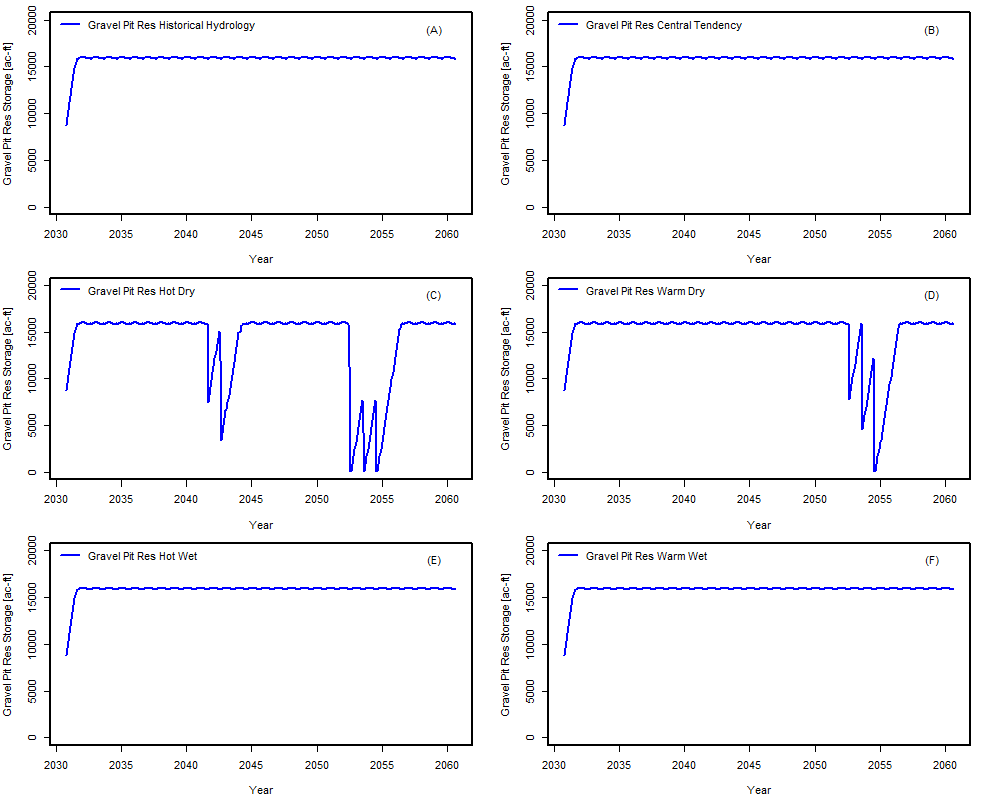


Figure 18 - Gravel Pit Reservoir Storage for the Historical Hydrology and the 5 Climate Change Scenarios

### Chalk Creek Reservoir

Figures 19 and 20 show the total basin storage and storage of the Chalk Creek Reservoir subject to historical and the five climate change hydrologic scenarios. Storage from Chalk Creek Reservoir would be used only during warm-dry and hot-dry climate change scenarios. In the warm-dry scenario, the 10,000 acre-feet reservoir was emptied 2 of the 30 simulated years. In the hot-dry scenario, the reservoir was emptied 4 of the 30 simulated years. Again, these results are based on the Chalk Creek Reservoir being called as a last resort. In actuality, the Chalk Creek Reservoir storage could be used to curb some of the effects of droughts in other climate scenarios as well. Much is dependent on how the Chalk Creek Reservoir is operated.

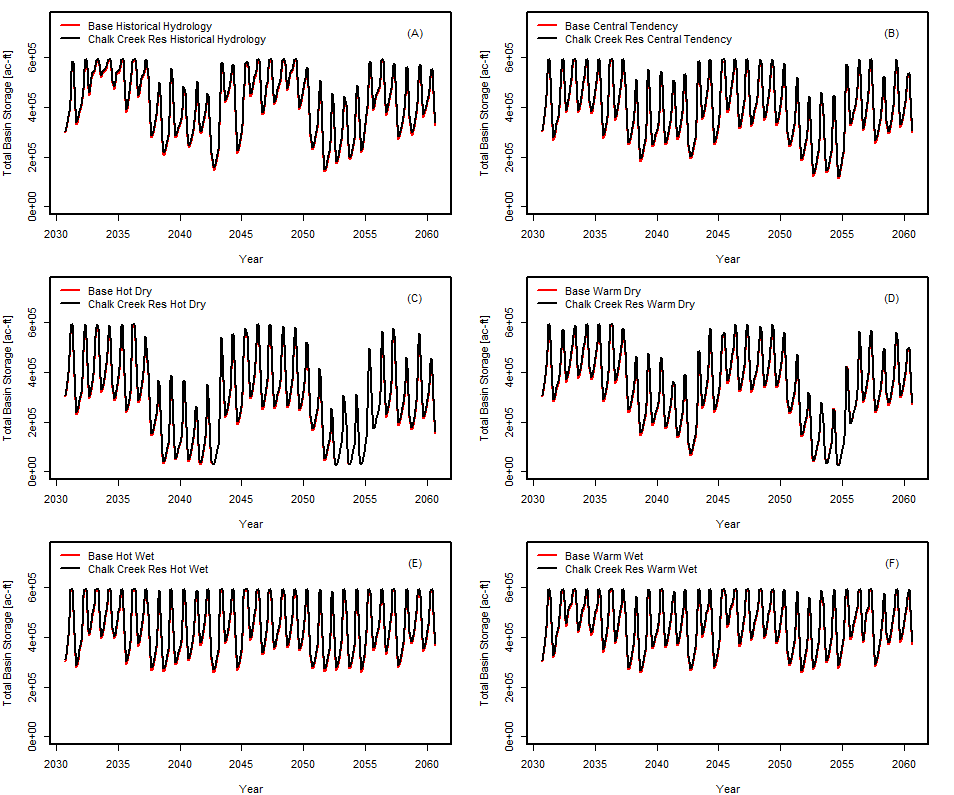


Figure 19 - Total Basin Storage including Chalk Creek Reservoir for the Historical Hydrology and the 5 Climate Change Scenarios

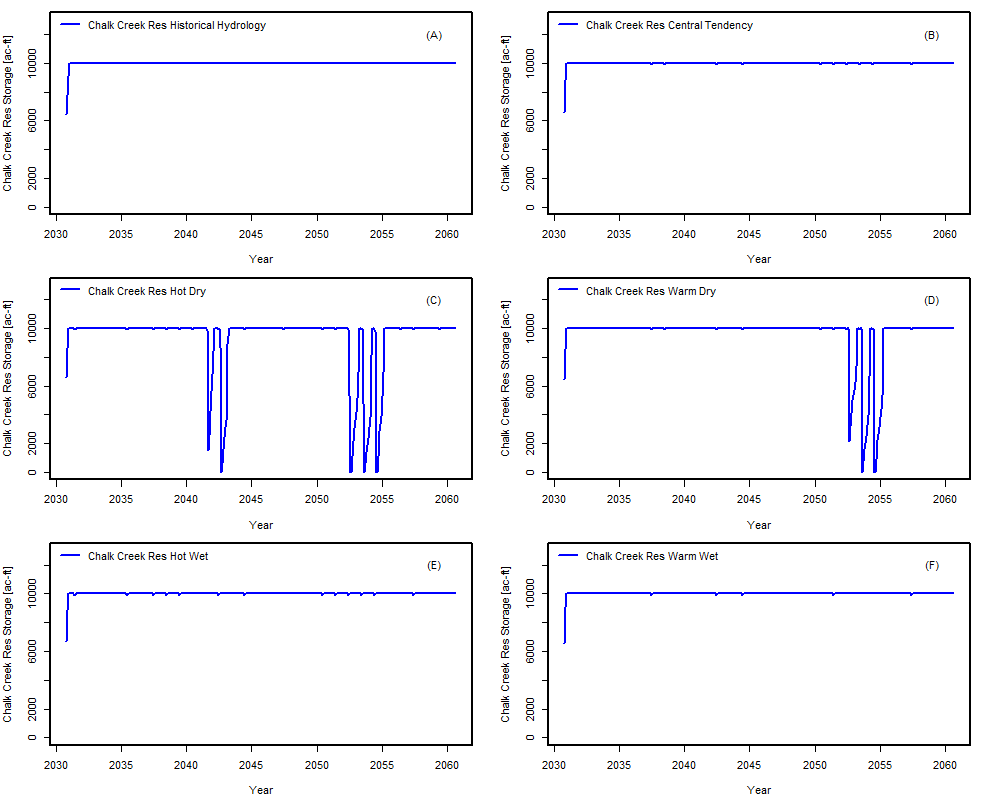


Figure 20 - Gravel Pit Reservoir Storage for the Historical Hydrology and the 5 Climate Change Scenarios

### Expanded ASR

Figures 21 and 22 show a total basin storage comparison and average ASR storage for historical hydrologic conditions and 5 climate change scenarios respectively. Figure 21 gives a comparison between the base case and ASR scenario. As one would expect, including ASR increases total basin storage. However, Figure 22 shows that ASR storage is only used during the hot-dry and warm-dry climate change scenarios.

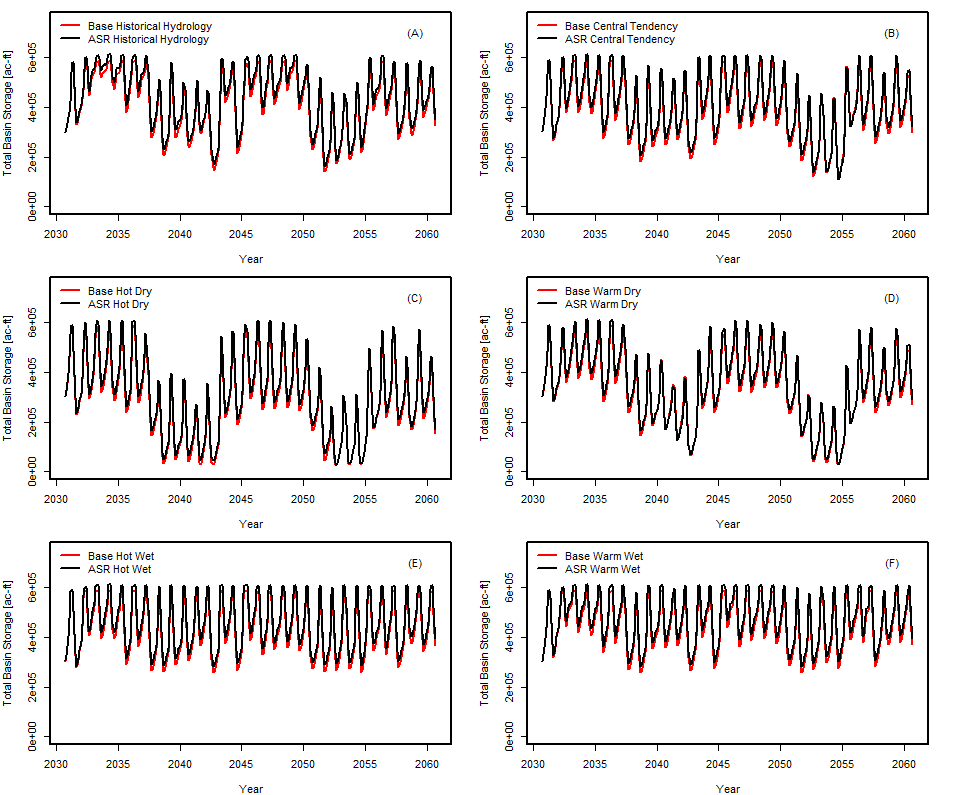


Figure 21 - Total Basin Storage including Aquifer Storage for the Historical Hydrology and the 5 Climate Change Scenarios

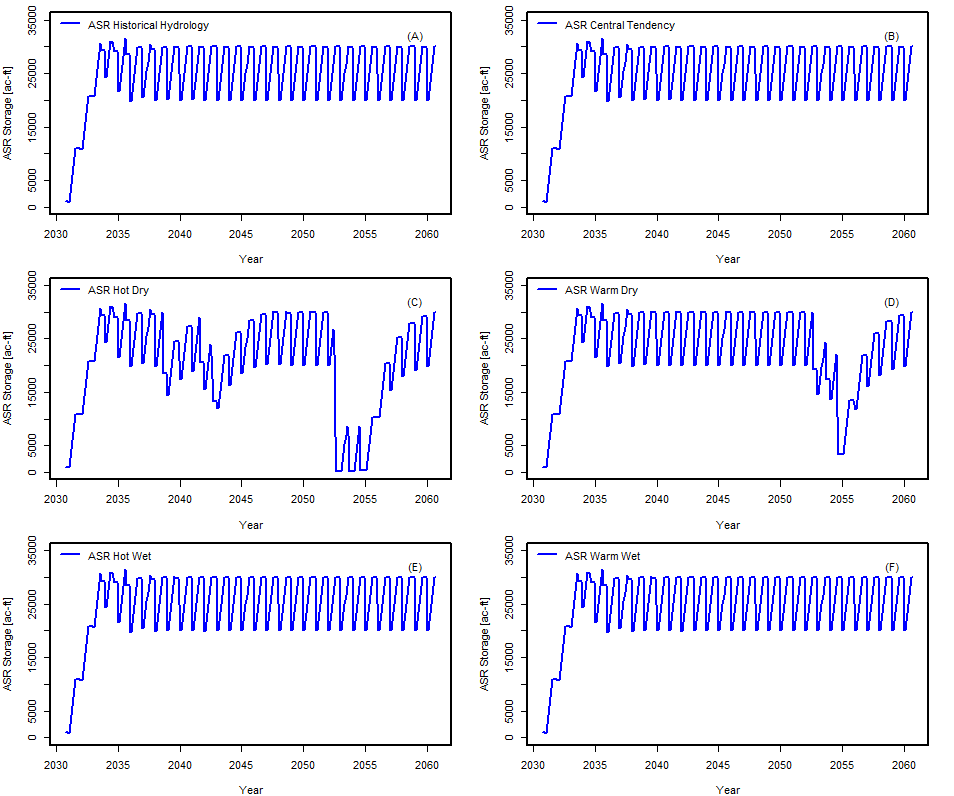


Figure 22 - Average ASR Storage for Historical Hydrogic Conditions and 5 Climate Change Scenarios

### Wastewater Reuse

Figure 23 shows a total basin storage comparison between the base case and wastewater reuse for historical hydrologic conditions and 5 climate change scenarios. It is apparent that the greatest benefit from implementing wastewater reuse is obtained during moderate to severe drought conditions. This is likely due to the fact that wastewater reuse is only implemented for the Gateway Canal service area and diversion shortages, even under normal demand conditions, only occur during moderate to severe drought conditions.

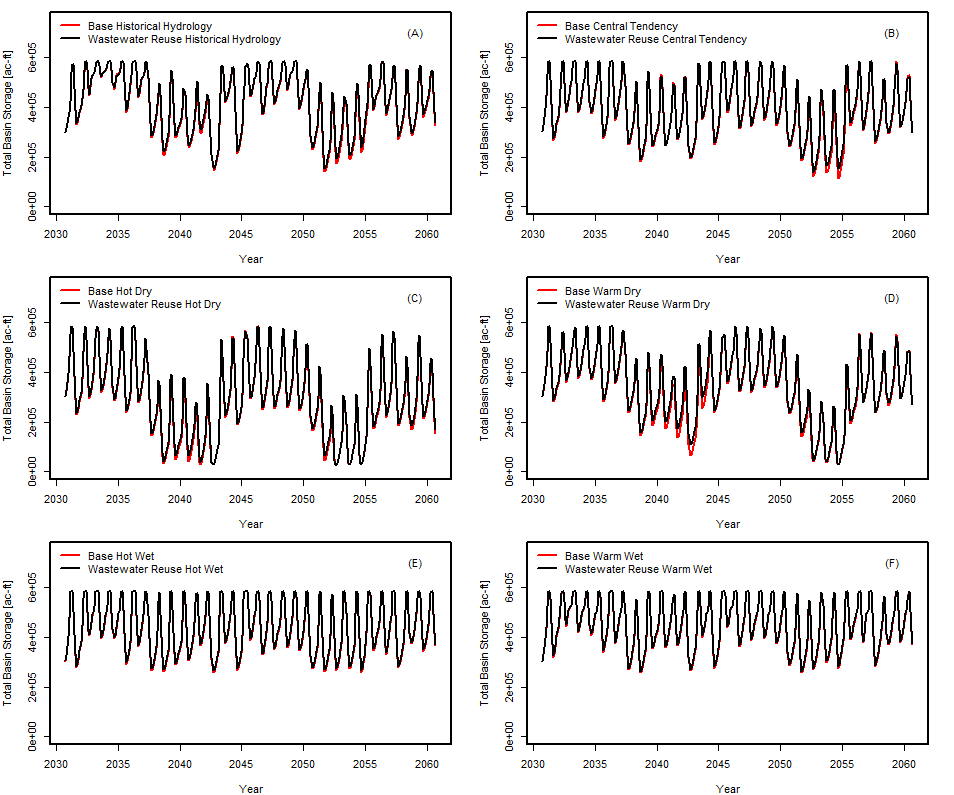


Figure 23 - Total Basin Storage Considering Wastewater Reuse for the Historical Hydrology and the 5 Climate Change Scenarios

## Drought Response

### Demand Management

Figure 24 shows a total basin storage comparison between the base case and the demand management scenario for historical hydrologic conditions and 5 climate change scenarios. It is apparent from the figure that the greatest benefit from the demand management scenario can be observed during moderate to severe droughts. This is a function of how the demand management scenario is implemented in the model. This scenario used predefined storage and runoff thresholds which triggered demand reductions for moderate and severe droughts.

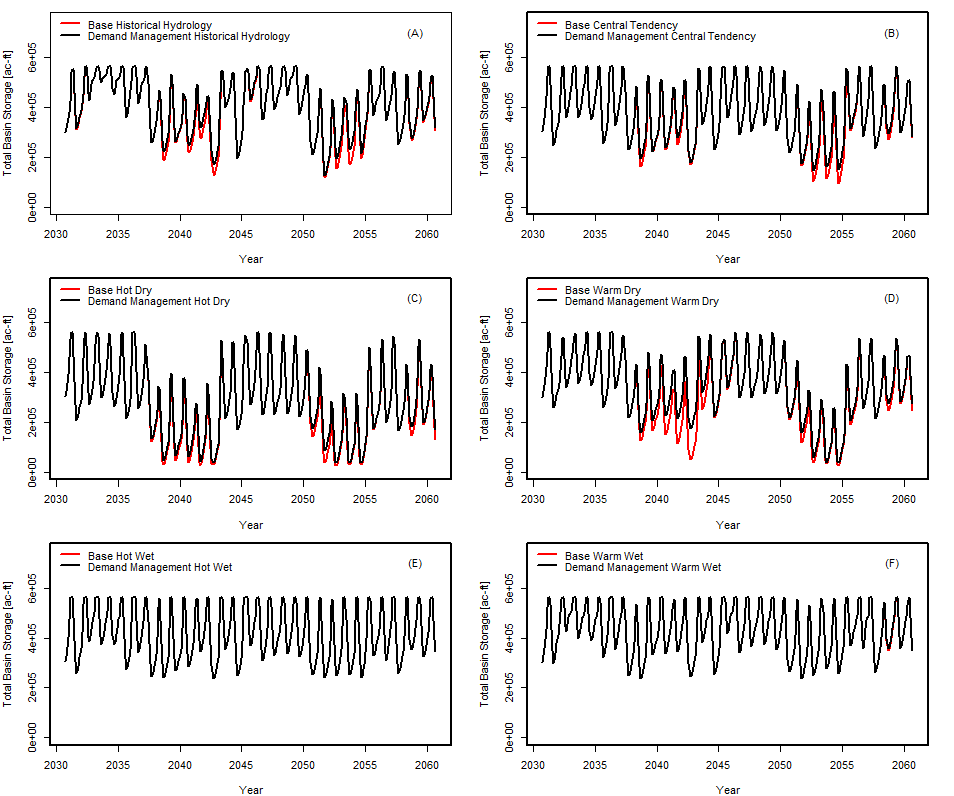


Figure 24 - Total Basin Storage implementing Demand Management Reductions for the Historical Hydrology and the 5 Climate Change Scenarios

### Fallowing Program

Figure 25 shows a total basin storage comparison between the base case and the crop fallowing scenario for historical hydrologic conditions and 5 climate change scenarios. This scenario behaved similar to the demand management scenario, with less effect on the moderate droughts. This is due to the fact that the fallowing program was implemented during severe to extreme droughts, according to the demand triggers given in Table 12.

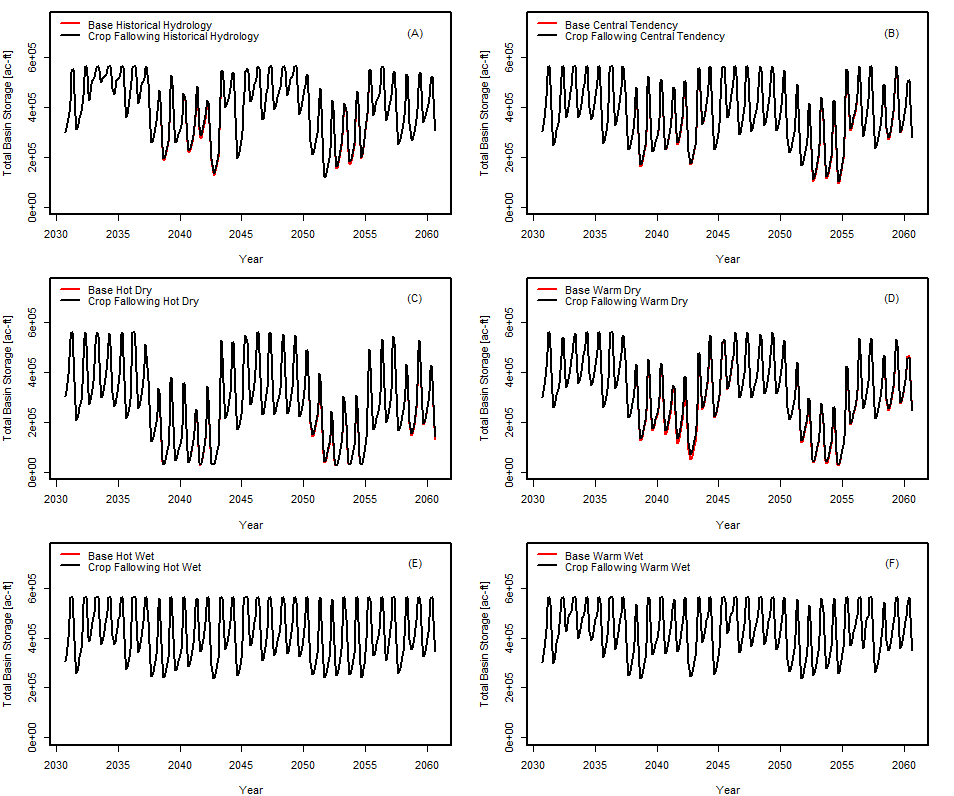


Figure 25 - Total Basin Storage Considering Crop Fallowing Programs for the Historical Hydrology and the 5 Climate Change Scenarios

## Additional Scenarios

### Increased Demand

Figure 26 shows a total basin storage comparison between the base case and the population growth demand increase scenario for historical hydrologic conditions and 5 climate change scenarios. According to the figure, there are noticeable differences between the base case and the population growth scenarios in each climate change scenario. The most noticeable differences are in the historical hydrology, central tendency, and warm-dry climate change scenarios. Differences would be more noticeable in the hot-dry scenario, but total basin storage appears to approach minimum capacity.

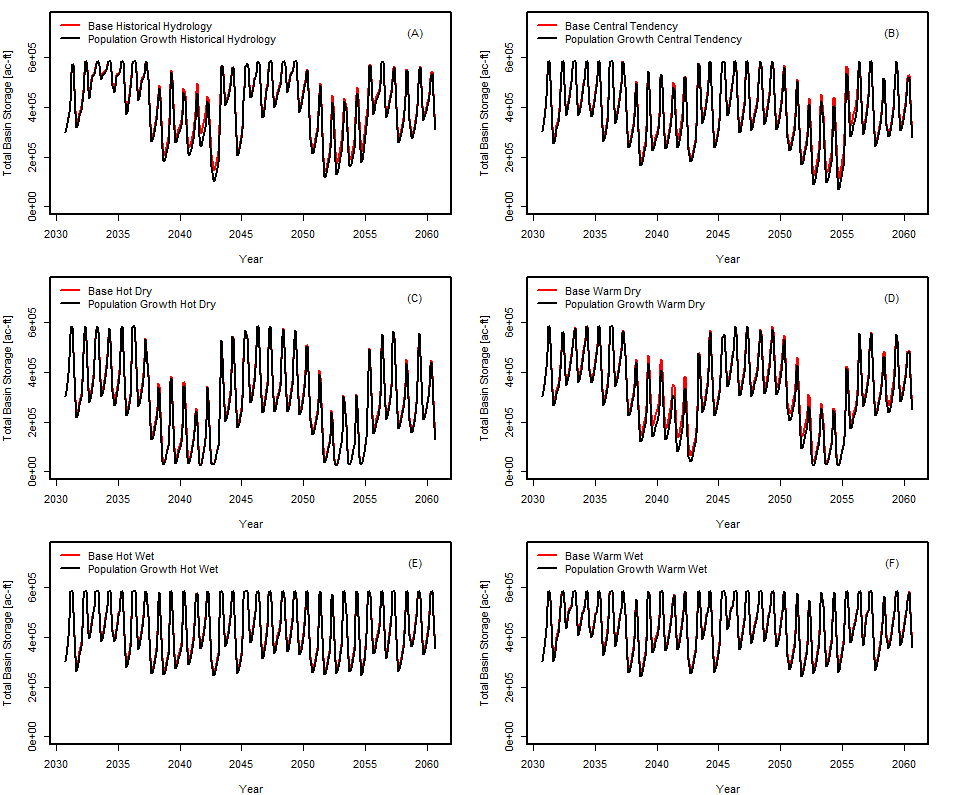


Figure 26 - Total Basin Storage Considering Demand Increases from Population Growth for the Historical Hydrology and the 5 Climate Change Scenarios

# Summary

## Observations on Inflow Scenarios

The experience of developing and running these scenarios for the model have highlighted a number of points that should be mentioned. The two versions of input data (i.e. climate change, and paleo flows) should be considered different in their value and use.

The paleo records simulated through the model gives stakeholders an extensive window to the past, albeit a hazy one. Nonetheless, these records provide a way to *observe the frequency, severity, and duration of actual droughts from the past*. While the hydrological inputs may give some indication of this, having monthly data modeled in the system gives a clearer understanding of the impacts of inflows.

While some of the drought response actions evaluated through the paleo version of the model are informative, on the whole this approach loses its context when the action is modeled for the entire nearly 600 year period. It may be of greater benefit to evaluate certain sections of the paleo record, however this would present a house keeping challenge with the model that would need to be addressed first.

Climate change scenarios developed from the CMIP5, on the other hand, are at a scale that is simple to comprehend the meaning of response actions. Any change in operation is observable in the results and can be digested easily. There is a great deal of uncertainty, however, with the predictions of the climate change models these inflows were developed from. The consequence being stakeholders have a large range of possibilities to plan for. Ultimately, these inflows provide a way to model potential climate changes which would otherwise not be possible.

## Observations on Action Scenarios

Each of the action responses have their benefits and drawbacks. Drought mitigation scenarios such as the Gravel Pit, Chalk Creek, and ASR scenarios increase the district’s ability to store water during drought years. These scenarios appear to only supplement water deliveries during extreme drought conditions (e.g., 1630s, hot-dry, and warm-dry scenarios), however there are basin benefits during drought years. These reservoirs are modeled as “last resort” reservoirs that are called on last in line. In actuality, they offer additional storage that WBWCD can use to lessen the impact all drought years.

The wastewater reuse and crop fallowing scenarios appear to increase total basin storage during moderate drought years. However, during extreme drought years, the water saved from implementing these programs is depleted. The demand management scenario offers a demand reduction that accounts for the severity of the drought. This being the case, the demand management scenario appears to be the most adequate scenario for mitigating the effects of extreme drought events.

## Model Limitations

Results from model runs are best viewed in terms of total basin storage. Reservoirs are not perfectly modeled, and there are likely variations in how the system would truly be operated given certain conditions. There still may be some benefit in isolating a certain reservoir or groups of reservoirs, but the results should be considered to have higher variability than a total basin storage assessment.

Inflows and demands are skewed by the imperfect approach in accounting for uses in the model. Most of the system uses diversions to calculate inflows without considering return flows, and there are certainly return flows at some of these locations. However, most of the largest diversions are lower in the basin where the return flow is not a factor. There is a possibility that attempting to improve these numbers would not produce very different results from the current flawed process. Reservoir storage, which is the recommended way of inspecting results, would almost certainly not change.

While there is not guarantee that doing any consumptive use analysis for the service areas will dramatically affect the model results, it would be ideal to have this aspect of the model more accurately reflect what is truly happening on the ground. So it is recommended to include in future simulations an improvement to this facet of the model.

# Appendix