# INCREASING STORAGE CAPACITY OF WOODRUFF CREEK RESERVOIR

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A GIS Approach

Tyler Stuart (A00361762)

CEE 6440 - GIS In Water Resources

## Table of Contents



## Table of Figures



## List of Tables

# INTRODUCTION

An increase in storage for the Woodruff Creek Watershed is desired, and has been investigated. It is desired to be able to run approximately 100 cubic feet per second (cfs) of water for about 80 days rather than the current 20 days. The first thing that needed to be done was to see how much water was available on an average year. Due to the GIS approach that was taken, PRISM precipitation data and USGS Stream flow data were used to find runoff ratio for a 16 year time period (due to only available stream flow data) and was then multiplied by a 30 year precipitation average for the basin in order to see if the watershed produces enough water to meet the desired demand on an average year. A stage-storage relationship for the additional storage was then created to determine the required increase in dam height to accommodate the corresponding storage requirement.

# BACKGROUND

Woodruff Creek Reservoir was built in 1970 and is located about 8 miles south west of Woodruff, Utah. The reservoir which currently has a storage capacity of 3,400 acre-feet stores runoff water from the Monte Cristo Range for agriculture purposes during the summer months (UDEQ). The 3400 acre-ft of storage is enough to supply the downstream users with approximately 20 days of water, at a flow between 70 and 100 cfs after high volumes of early water spill from the reservoir during undesirable times. An Example of the current stream flow from the reservoir is indicated by the blue line in Figure 1, while the “Ideal” (desired) stream flow is noted by the red line.

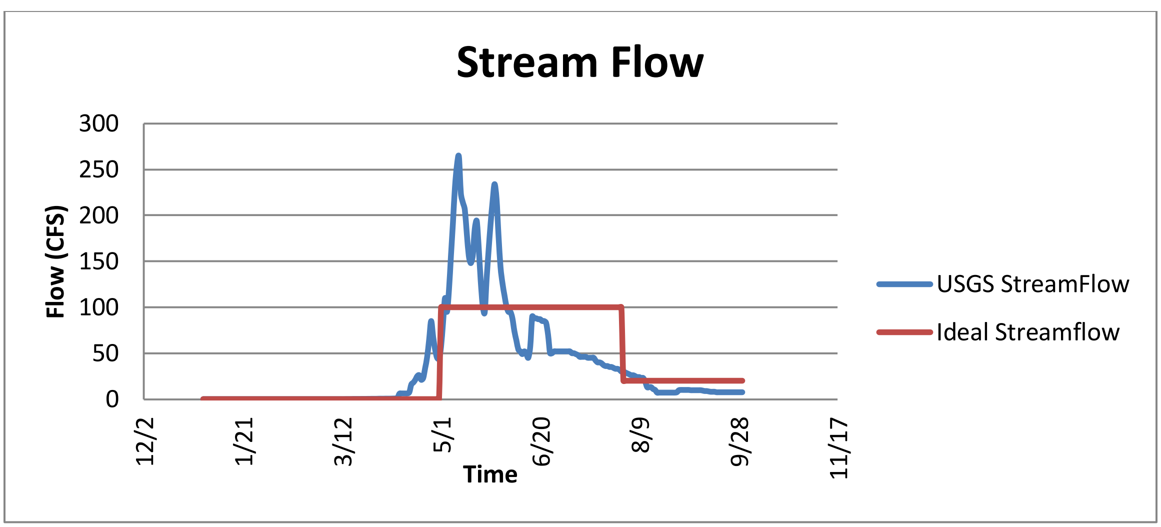



**FIGURE 1 EXAMPLE OF CURRENT STREAM FLOW DISPLAYED WITH DESIRED STREAM FLOW**

When the reservoir was built, the allotted storage was about 6,000 acre-ft between itself and the neighboring reservoir Birch Creek Reservoir which had a capacity of about 2,000 acre-ft. In the

1980's, an additional storage of about 8,000 acre-ft was permitted for the watershed which consisted of the two reservoirs. Birch creek reservoir only reaches capacity once every 15 years, where Woodruff Creek reservoir has spilled every year since it was built (Stuart, Bill). Therefore, any extra storage would need to come from Woodruff Creek watershed. There have been many propositions on how to accommodate the extra storage which include the construction of new dams below the current dams, or increasing the capacity of the current Woodruff Creek Reservoir. The problem that is encountered with constructing new reservoirs is that the priority to store the water is lower than other downstream priorities, but the current reservoir would still maintain its high priority, allowing all allotted available water to be stored first.

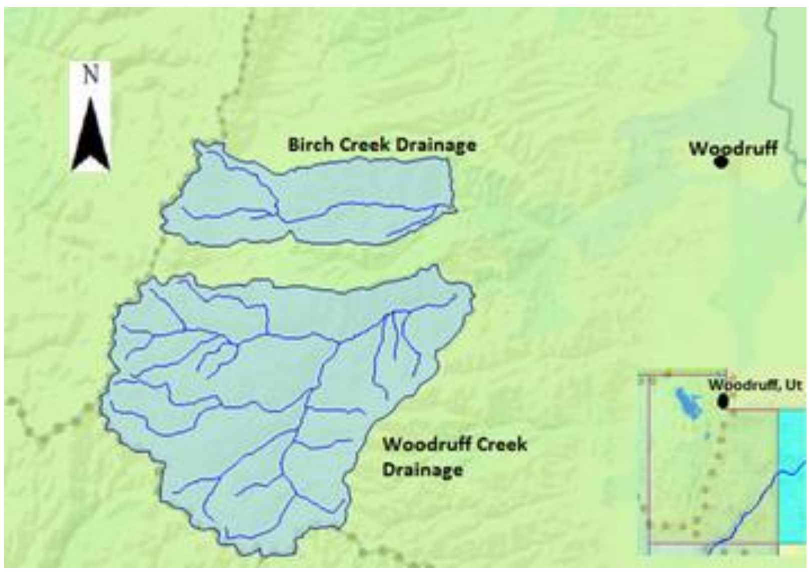



**FIGURE 2 WATERSHEDS AND RESERVOIRS CONTRIBUTING TO WOODRUFF IRRIGATION**

## TOTAL VOLUME OF RUNOFF

The first thing that was desired was to find the total average volume of runoff for the watershed to first see if the watershed produced enough runoff to justify increasing the capacity of the reservoir and to see if there was enough runoff to provide the desired 100 cfs for 80 days. This was done by finding first finding the Area of the watershed, second multiplying the area by the 30-year average precipitation data for a total volume, and third applying a runoff ratio to the equation for a runoff volume. The average values were used in this procedure solely to understand the nature of the watershed. In later phases of design, dry years should be given the most consideration.

## Area of Watershed

The first thing that was done was to delineate the watershed above the Woodruff Creek Reservoir using Arc-Map. By doing this, the area of the watershed was able to be found. The coordinates of the dam were converted into decimal degrees, and placed into an excel file. Then, from ArcMap, this file was added to the working map as the location of the dam. The Watershed tool in the Spatial Analysis toolbox was then used to delineate the Woodruff Creek Watershed from the dam location. This delineation can be seen in Figure 2. Opening the attribute table for the newly created watershed, it was found that the watershed consisted of 140.9 square kilometers which is approximately 54.4 square miles or 34,816 acres.

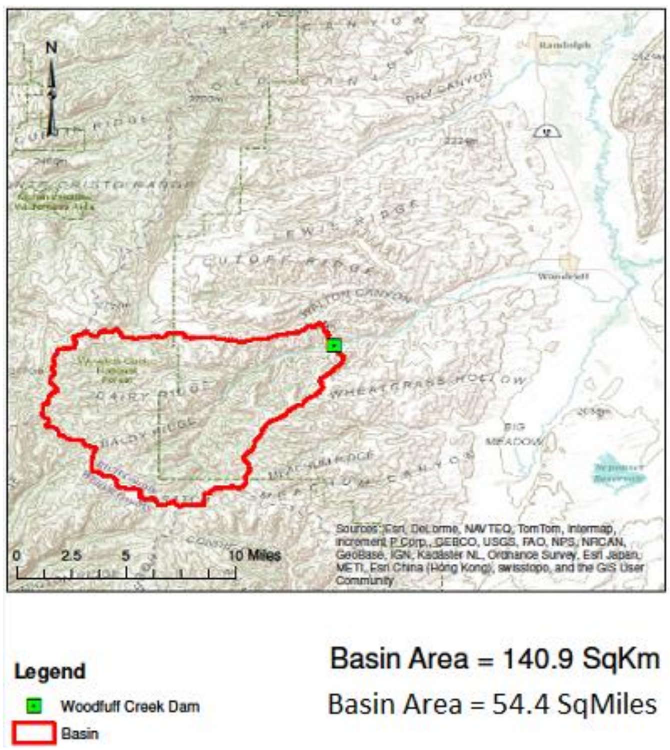



**FIGURE 3 DELINEATED WATERSHED**

## PRISM 30-Year Average Precipitation

Using data from the PRISM Climate Group, the 30 year average precipitation values for the entire conterminous United States was downloaded and added to ArcMap (Appendix A). The data was in raster form with precipitation values in cells of 800 meters.

Once the data had been imported into ArcMap, the Spatial Analysis tool "Extract by Mask" was used to extract all the precipitation data for the Woodruff Creek Basin (Figure 3). The basin specific statistics where then put into a table and the 30-year average annual precipitation value was found to be 850.83 mm which is approximately 2.69 ft of water over our entire basin.

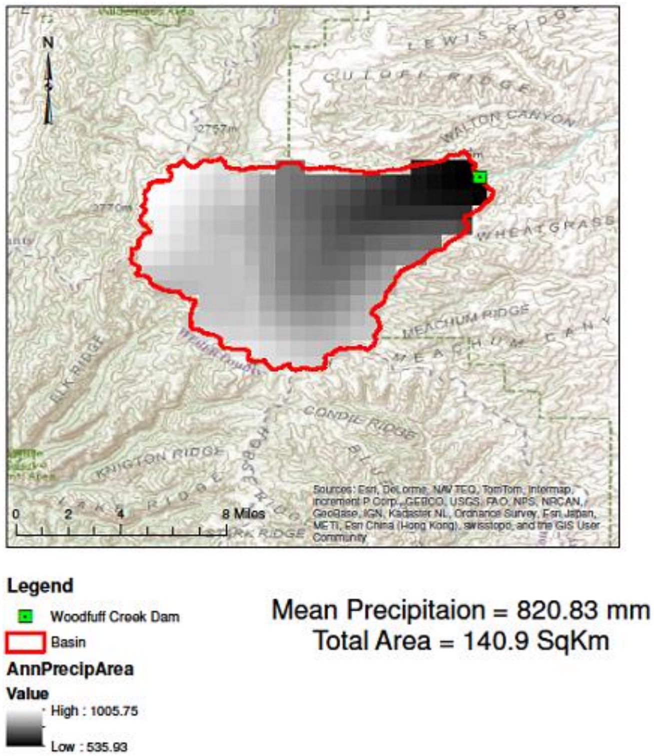



**FIGURE 4 30 YEAR AVERAGE PRECIPITAION FOR BASIN FROM PRISM**

This amount of precipitation amounts to 93,700 acre-ft of water across our entire basin, however this is not the amount of water that will be stored. The water that will be stored will be the total precipitation minus evaporation, groundwater, etc. losses. Because of lack of data about infiltration, evaporation, etc., for the basin is available, a runoff ratio will be found to determine how much of the precipitation ends up in the reservoir.

## Runoff Ratio

The available stream flow data for the reservoir was only for 1970 to 1986 (USGS). The dataset is quite small for the magnitude of the problem that is faced, therefore, for the 16 year dataset (16 water years 1971-1986) and corresponding precipitation data a runoff ratio is calculated for each year and then an average runoff ratio is found. This runoff ratio will be used with the 30 year average to give a better estimate of the average precipitation over the watershed. The Runoff Ratio is described in Eq. 1.

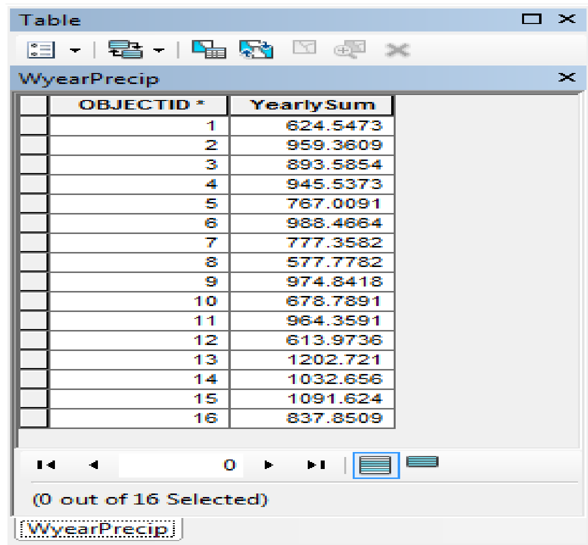
$$Annual\ Runoff\ Ratio = \frac{Annual\ Runoff\ Volume}{Annual\ Precipitaion\ Volume}$$

$$Eq. 1$$

**PRISM Annual Yearly Precipitation (1970-1986)**

As can be seen by Equation 1, the runoff ratio is based off of two components. The first, runoff volume, has already been obtained through USGS, the second, Annual Precipitation Volume, needed to be found. From the PRISM climate group, the same group that provided the 30-year average, the annual data for each desired year was downloaded. During this process, a cause for concern was discovered. The date range for the current problem is in Utah Water Years. A Utah Water Year is from October 1 to September 30. Most Agricultural water rights in Utah are from May 1 to September 30, so storage is obtained between October 1 and April 30. Because of the nature of the seasons the storage is generally depleted by October 1, hence a consistent starting point for a new water year. This is especially the case for Woodruff Creek Reservoir, therefore, the desired time period is the Utah Water Year. The problem that was discovered was that the PRISM dataset was from January to December. Therefore the problem arose of correlating the data with each other for appropriate comparisons. This would require going through 16 years' worth of monthly data and grouping them in the desired time frame. Quite a tedious job if someone were to do it by hand. Therefore, a python code was scripted to automatically manage the data. The following list summarizes the algorithm of the code, and the code itself can be found in Appendix ##.

- All files were placed in the same working folder
- Python sorted through the files and grouped them according to water year
- Shape file of basin was input
- Zone Statistics for the shape (basin) was calculated for each water year
- Table was created to contain ObjectID (the year), and the yearly sum
    - Yearly Sum is the sum of the monthly averages which is the yearly average (Figure 4)



Table

WyearPrecip

| OBJECTID * | YearlySum |
|---|---|
| 1 | 624.5473 |
| 2 | 959.3609 |
| 3 | 893.5854 |
| 4 | 945.5373 |
| 5 | 767.0091 |
| 6 | 988.4664 |
| 7 | 777.3582 |
| 8 | 577.7782 |
| 9 | 974.8418 |
| 10 | 678.7891 |
| 11 | 964.3591 |
| 12 | 613.9736 |
| 13 | 1202.721 |
| 14 | 1032.656 |
| 15 | 1091.624 |
| 16 | 837.8509 |

(0 out of 16 Selected)

WyearPrecip

**FIGURE 5 OUTPUT TABLE PRODUCE BY PYTHON SCRIPT**

## Runoff Ratio Results

Now that the USGS stream flow data has been found, and the PRISM precipitation data has been organized to correspond with the stream flow data, both data sets were put into a table in excel to calculate the runoff ratios for each year and find the average over the 16 years (Table 1). PRISM precipitation data was in millimeters; therefore some conversions also take place in the table for comparison purposes.

**TABLE 1 CALCULATIONS OF RUNOFF AVERAGE RUNOFF RATIO FOR A 16 YEAR TIME PERIOD**

| Start Date | End Date | Water Year | USGS Total Runoff (Acre-ft) | Precipitation (mm) | Precipitation (ft) | Precip Volume (Acre-ft) | Runoff/ PrecipVolume |
|---|---|---|---|---|---|---|---|
| Oct-70 | Sep-71 | 1971 | 31791.00 | 959.36 | 3.15 | 109583.95 | 0.29 |
| Oct-71 | Sep-72 | 1972 | 29683.16 | 893.59 | 2.93 | 102070.68 | 0.29 |
| Oct-72 | Sep-73 | 1973 | 16597.11 | 945.54 | 3.10 | 108004.93 | 0.15 |
| Oct-73 | Sep-74 | 1974 | 20585.42 | 767.01 | 2.52 | 87612.37 | 0.23 |
| Oct-74 | Sep-75 | 1975 | 19861.91 | 988.47 | 3.24 | 112908.55 | 0.18 |
| Oct-75 | Sep-76 | 1976 | 14997.44 | 777.36 | 2.55 | 88794.50 | 0.17 |
| Oct-76 | Sep-77 | 1977 | 3670.30 | 577.78 | 1.90 | 65997.29 | 0.06 |
| Oct-77 | Sep-78 | 1978 | 16211.53 | 974.84 | 3.20 | 111352.27 | 0.15 |
| Oct-78 | Sep-79 | 1979 | 17627.69 | 678.79 | 2.23 | 77535.35 | 0.23 |
| Oct-79 | Sep-80 | 1980 | 27012.81 | 964.36 | 3.16 | 110154.87 | 0.25 |
| Oct-80 | Sep-81 | 1981 | 6500.06 | 613.97 | 2.01 | 70131.75 | 0.09 |
| Oct-81 | Sep-82 | 1982 | 25412.21 | 1202.72 | 3.95 | 137381.99 | 0.18 |
| Oct-82 | Sep-83 | 1983 | 34952.69 | 1032.66 | 3.39 | 117956.10 | 0.30 |
| Oct-83 | Sep-84 | 1984 | 34257.37 | 1091.62 | 3.58 | 124691.79 | 0.27 |
| Oct-84 | Sep-85 | 1985 | 25797.99 | 837.85 | 2.75 | 95704.35 | 0.27 |
| Oct-85 | Sep-86 | 1986 | 41448.17 | 1178.47 | 3.87 | 134611.90 | 0.31 |
| | | | | | | | |
| | | | | | | Average= | 0.21 |

### Average Annual Runoff

With the basin area defined, the 30 year average precipitation found, and the runoff ratio determined, all the components for the average annual runoff are ready. Equation 2 shows the calculation of the said runoff.

$$Average\ Annual\ Runoff = Basin\ Area\ (acres) \times 30yearAvg.(mm) \times \frac{1\ ft}{304.8\ mm} \times runoff\ Ratio$$

$$Eq. 2$$

$$Average\ Annual\ Runoff = 34{,}816\ acres\ \times 820.83\ mm \times \frac{1\ ft}{304.8\ mm} \times 0.21 = 20{,}008\ acre\ ft$$

The total volume of runoff during an average year is about 20,000 acre ft. The question that was asked earlier was whether there was enough runoff on an average year to even justify increasing the storage capacity of the reservoir. The irrigation company was allotted 8,000 acre ft in addition to the 4,100 acre-ft of storage that is currently stored in the reservoir. Therefore, it can safely be stated that yes, there is easily 12,000 acre ft of runoff that can be stored.

One more comparison that is important is to see is if the available water is greater than or equal to the demands of Woodruff Irrigation Company. As mentioned earlier, they request that at least 100 cfs be delivered for 80 days. For comparison purposes, 100 cfs for 80 days will be converted into a total volume with units of acre ft. Equation 3 shows the conversion.

$$100\frac{ft^3}{sec} \times \frac{86{,}400\ sec}{day} \times \frac{1\ acre}{43{,}560ft^2} \times 80\ days = 15{,}0868\ acre\ ft$$

$$Eq. 3$$

The demand requested by Woodruff Irrigation Compnay can be satisfied by the available water. There is more than enough on the average year to supply this demand, however, storage alone will not suffice. Therefore it is important to know that in order to obtain the requested flows; inflows to the reservoir will need to be considered especially in the later months of the irrigation season. The late runoff from the watershed is where the additional storage comes from.

## STAGE STORAGE RELATIONSHIP

Now that it has been determined that there is sufficient runoff to meet the demands of the water right, it is important to find out if the reservoir is a good candidate for increasing the size. A good candidate would show exponential growth in storage as the dam height increased. A stage storage relationship will be found using ArcMap to check effectiveness of increasing the dam height. Figure 6 is a diagram of the current storage and how the volume will change with each incremental increase.


**FIGURE 6 INITIAL STOARGE AND ELEVATION. ILLUSTRATION OF STAGE STORAGE**

The required data to accomplish a stage storage relationship is the National Elevation Data Set (NED) which was downloaded as a 10 meter raster set. This was the best available data for the area given. To get more accurate results, a smaller raster would be best, but this is the best that was available. Once the data had been downloaded for the region, the "Extract by Making" tool was used to isolate the data just in the watershed and the new raster was named "BasinBaseElevation. This was done so that "Raster Calculator" could be used to determine the relationship.

Raster Calculator was used to create 20 new raster sets that differentiated between cells in the "BasinBaseElevation" Raster that were above a specified elevation and the ones below the elevation (Figure 8). The elevations were on increments of 1 ft. Since the Elevation Dataset is measured in meters, conversions from meters to ft were necessary for formulation of the equation.

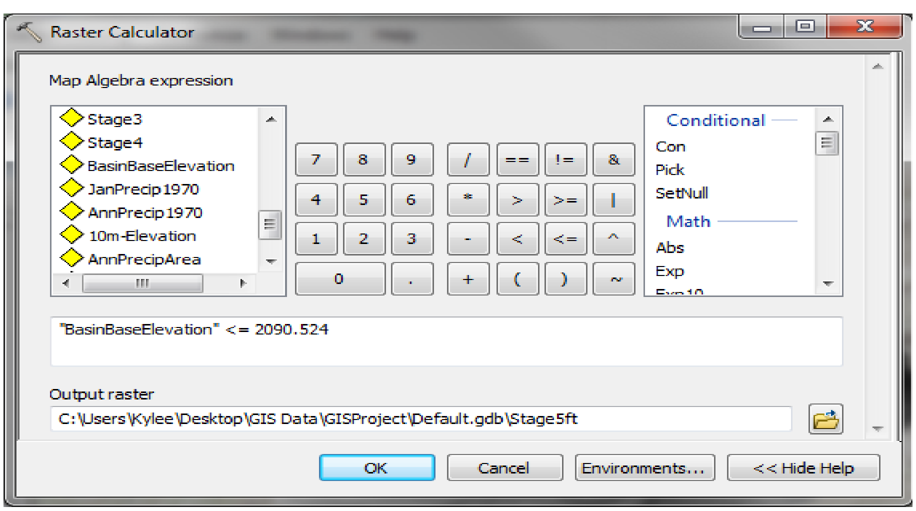
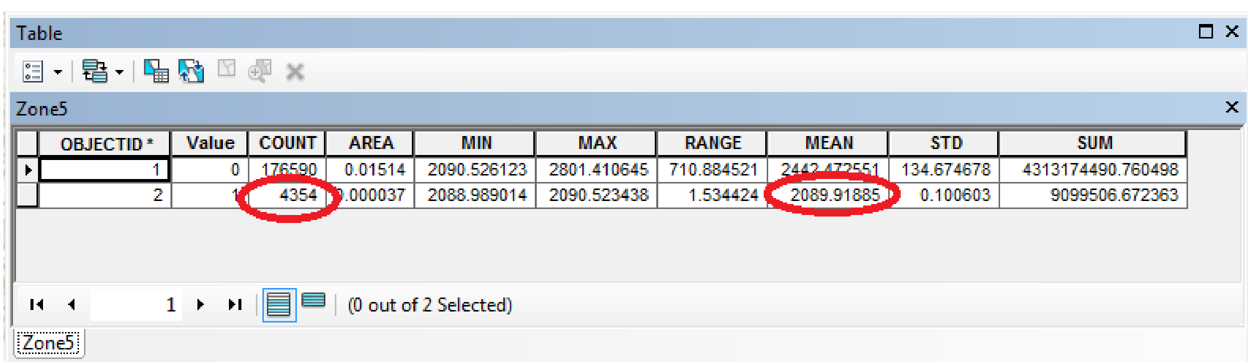



**FIGURE 7 INTERFACE OF RASTER CALCULATOR. THIS CALCULATION WAS FOR 5 FT INCREASE**


FIGURE 8 OUTPUT RASTER FROM RASTER CALCULATOR BLUE IS RESERVOIR GREEN IS WATERSHED

After the raster sets had been created for the different levels of the reservoir, the next step was to find the statistics for each raster that was created. This was done using the Zone Stats As Table Tool. Figure 9 shows the results of the table, for the 5 foot increase, and the values of interest are circled in red.



Table

Zone5

| OBJECTID * | Value | COUNT | AREA | MIN | MAX | RANGE | MEAN | STD | SUM |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 176590 | 0.01514 | 2090.526123 | 2801.410645 | 710.884521 | 2442.472551 | 134.674678 | 4313174490.760498 |
| 2 | 1 | 4354 | 0.000037 | 2088.989014 | 2090.523438 | 1.534424 | 2089.91885 | 0.100603 | 9099506.672363 |

1 (0 out of 2 Selected)

Zone5

FIGURE 9 ZONAL STATISTICS FOR THE RASTERS PRODUCED FROM RASTER CALUCLUATOR

The calculator only produced 2 scenarios, everything above, and everything below, identified by OBJECTID. The first value that was of interest was the count column for all the values below the elevation. This is revealing how many 10 meter square raster cells are located below the elevation that was stated in the Raster Calculator. The second red circle indicates the average elevation of the cells below the specified elevation. With these values, the increase in volume for the new elevation can be found using Equation 4.

$$Additional\ Volume = (New\ Elevation - Mean\ Elevation\ below) \times Number\ of\ Cells \times Cell\ Area$$

$$Eq. 4$$

The new elevation is the elevation of the dam. The reason that the mean elevation is subtracted, is because the average elevation below the new datum would simulate entire elevation of the cells below the new datum, in turn giving the thickness dimension of the incremental water storage.

As mentioned, the previous procedure was done for each foot of increase up to 20 feet. The results are shown in Table 2.

**TABLE 2 STAGE STORAGE RELATIONSHIP FOR ONE FOOT TOO 30 FEET INCREASE**

| ft Raised | Elevation (ft) | Elevation (m) | Number of Cells Below | Average Elevation | Additional Volume (m^3) | Additional Volume (Acre-ft) | New Volume of Reservoir (Acre-ft) |
|---|---|---|---|---|---|---|---|
| 4 | 6857.675 | 2090.219 | 4204 | 2089.90 | 134192 | 109 | 3510 |
| 5 | 6858.675 | 2090.524 | 4354 | 2089.92 | 262982 | 213 | 3614 |
| 6 | 6859.675 | 2090.829 | 4459 | 2089.94 | 398099 | 323 | 3724 |
| 7 | 6860.675 | 2091.134 | 4583 | 2089.97 | 535569 | 434 | 3835 |
| 8 | 6861.675 | 2091.438 | 4692 | 2090.00 | 677243 | 549 | 3950 |
| 9 | 6862.675 | 2091.743 | 4821 | 2090.04 | 822077 | 666 | 4067 |
| 10 | 6863.675 | 2092.048 | 4935 | 2090.08 | 970714 | 787 | 4188 |
| 11 | 6864.675 | 2092.353 | 5031 | 2090.12 | 1122819 | 910 | 4311 |
| 12 | 6865.675 | 2092.658 | 5142 | 2090.17 | 1277581 | 1036 | 4437 |
| 13 | 6866.675 | 2092.962 | 5238 | 2090.22 | 1435945 | 1164 | 4565 |
| 14 | 6867.675 | 2093.267 | 5344 | 2090.28 | 1596894 | 1295 | 4696 |
| 15 | 6868.675 | 2093.572 | 5436 | 2090.33 | 1761264 | 1428 | 4829 |
| 16 | 6869.675 | 2093.877 | 5540 | 2090.40 | 1928917 | 1564 | 4965 |
| 17 | 6870.675 | 2094.182 | 5636 | 2090.46 | 2099184 | 1702 | 5103 |
| 18 | 6871.675 | 2094.486 | 5741 | 2090.53 | 2272517 | 1842 | 5243 |
| 19 | 6872.675 | 2094.791 | 5857 | 2090.61 | 2448929 | 1985 | 5386 |
| 20 | 6873.675 | 2095.096 | 5981 | 2090.70 | 2629247 | 2132 | 5533 |
| 25 | 6878.675 | 2096.62 | 6657 | 2091.225 | 3591437 | 2912 | 6313 |
| 30 | 6883.675 | 2098.144 | 7260 | 2091.74 | 4652309 | 3772 | 7173 |

From analyzing the statistics calculated in the Stage Storage table, it can be noticed that this reservoir is not very efficient with topology. Ideally, when the dam is raised, the top half of the storage increases much more rapidly per unit of increase. This pattern occurs with this reservoir, however it does not occur as rapidly as would be desired. It takes an entire 20 feet to gain an additional 2100 acre-ft of storage. When you start discussing raising a dam a significant amount, then costs and logic is lost. Therefore, increasing the size of the dam would likely be infeasible given the conditions encountered with the stage storage relationship.

Work beyond this point might include finding a location for another reservoir below the current one if a study found that the loss of priority would be of minimal significance. Another route might be to run an optimization model for the system. An optimization model would include the following:

- Objective function is to Minimize the Capacity
- The main decision variable would be the reservoir size, but others might be found during model formulation such as spills.
- Constraints would be the agricultural demands and the maximum capacity
- Inflow data would need to be processed from the USGS data

An optimization model would be of great significance because it would basically minimize the size of the reservoir by taking into account inflows throughout the entire seasons. An optimization model will not be used in this study, but should be done in future work.

## CONCLUSION

Woodruff Creek Reservoir has been analyzed to find out if the contributing watershed produces enough runoff to accommodate new storage water rights. Not only if it produces enough water to satisfy the storage right but also the desired agricultural demands for Woodruff Irrigation Company. It was found that the watershed produces enough water for both interests. Therefore, a stage-storage relationship was found for every foot of increase in the reservoir from 4 ft up to 30 ft. This was done to see if the reservoir was capable of being increased to the desired capacities. It turns out that due to the topology of the surrounding area that little extra storage is gained as the dam height is increased. Therefore, it was concluded that at this point an optimization model should be ran for future work to find the smallest reservoir size that can produce the desired agricultural demands.

# BIBLIOGRAPHY

"PRISM Climate Group, Oregon State U." PRISM Climate Group, Oregon State U. N.p., n.d. Web. 04 Nov. 2013

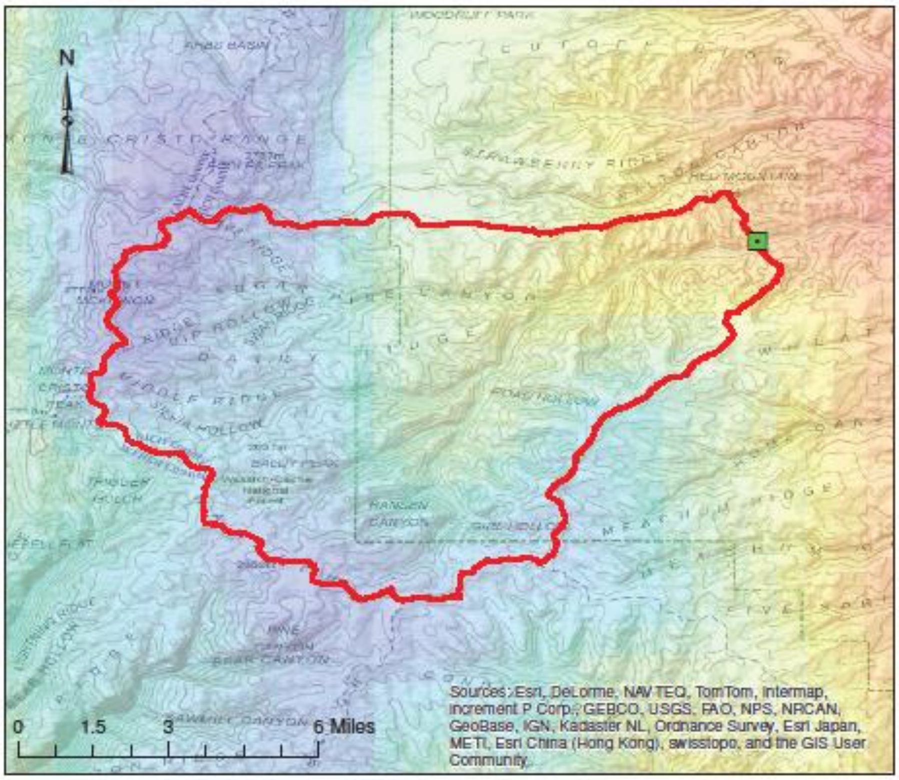
Stuart, Bill. Woodruff Irrigation Board. personal communication. November4, 2013.

UDEQ (Utah Department of Environmental Quality). "Woodruff Creek Reservoir." http://www.waterquality.utah.gov/watersheds/lakes/WOODRUFF.pdf. November 1, 2013.

# APPENDICES

## Appendix A- PRISM 30-Year average precipitions for the conterminous United States

### Woodruff Creek Annual Precipition (PRISM)




**Legend**

Woodfuff Creek Dam

Basin

**Annual Precipitation (mm)**

High : 1023.76

Low : 447.35

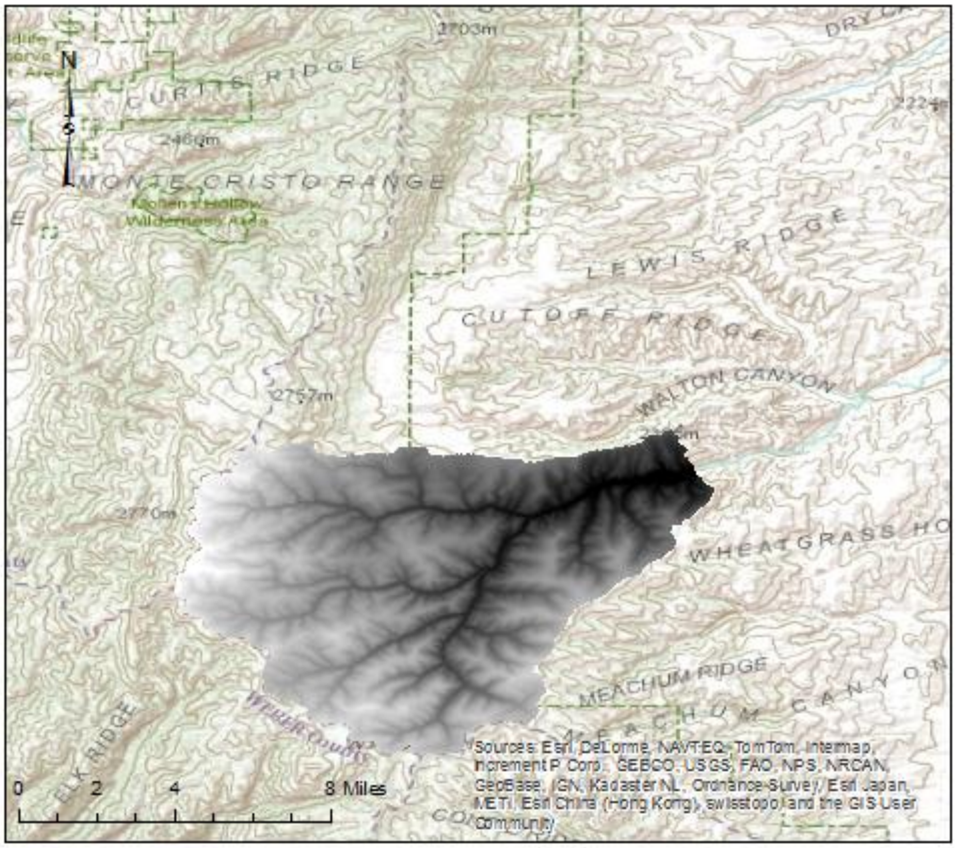
# Appendix B- Python Script for organizing PRISM annual data into Utah Water Year data.

```
# Python modules used
import sys
import arcpy, datetime, os, shutil
from arcpy import env
from arcpy.sa import *
# Check out the ArcGIS Spatial Analyst extension for using the zonal statistics function
arcpy.CheckOutExtension("spatial")
# Use the current working directory as the folder to work in
Folder= r"C:\Users\Kylee\Desktop\GIS Data\GISProject" # Or use os.getcwd()
env.workspace = Folder
# Geodatabase and file paths
gdbname="Prism.gdb"   # geodatabase
outtable="WyearPrecip"                 # table where zonal statistics will be saved
zoneshape=r"C:\Users\Kylee\Desktop\GIS Data\GISProject\Basin.shp" # Watershed feature class /shape
WorkFolder = Folder+os.sep+"PrismPrecip"  # This is the folder to store the precipitation rasters (.asc)
TempFolder = Folder+os.sep+"temp"  # This is the folder where temporary tables are written
if not os.path.isdir(TempFolder):
    os.makedirs(TempFolder)                #create temp folder if it doesn't exist
tabnamefull=gdbname+os.sep+outtable              # full name of the output table
field1="Year"
field2="YearlySum"
field3="YearlyMean"
arcpy.CreateTable_management(gdbname, outtable,"","")   #  Create Table
arcpy.AddField_management(tabnamefull, field1, "DATE","","","","","")  #  Add date field
arcpy.AddField_management(tabnamefull, field2,"FLOAT","","","","","")  #  Add yearly sum value field
arcpy.AddField_management(tabnamefull, field3,"FLOAT","","","","","")  #  Add yearly mean value field
rows = arcpy.InsertCursor(tabnamefull,"")
VarFiles=os.listdir(WorkFolder)
startYear = 1970
endYear = 1986
totalYear = endYear - startYear
wyearlySum = [0] * (totalYear+1)          # array to hold (water)yearly sum of monthly precipitations
for theFile in VarFiles:
    if theFile.endswith(".asc"):  # Only ASC files
        yearString = theFile[-14:-10]
        monthString = theFile[-10:-8]
                #print theFile + " " + yearString + " " + monthString
        yearV = int(yearString)           #convert them to integer
        monthV = int(monthString)
        if monthV < 10:
            j = yearV - startYear
        else:
            j = yearV + 1 - startYear
        if 0 <= j <= totalYear:
                        # do for j  = 0 to totalyear
            zonetable=TempFolder + os.sep + "table"+ yearString + monthString   # to keep unique name
            fullFile=WorkFolder+os.sep+theFile
            outZSaT = ZonalStatisticsAsTable(zoneshape, "Id", fullFile,zonetable, "", "MEAN")
            tableRow = arcpy.UpdateCursor(zonetable)
# zone table only has one row.  Extract its mean
            for linerow in tableRow:
                meanValue = linerow.MEAN
                print yearString+ " " + monthString + " " + str(meanValue)
                wyearlySum[j] = wyearlySum[j] + meanValue
```

```
#copy values to table
for i in range(0,totalYear):
    line = rows.newRow()
    line.setValue(field1,startYear)
    line.setValue(field2,wyearlySum[i])
    yearlyMean = wyearlySum[i]/12
    line.setValue(field3,yearlyMean)
    rows.insertRow(line)
# Clean up
del line
del rows
del linerow
del tableRow
# redo last zonal statistics.  Append "t" to name to make it different.  This seems necessary to delete the locks
outZSaT = ZonalStatisticsAsTable(zoneshape, "Id", fullFile,
                                      zonetable+"t", "", "MEAN")
try:
    if os.path.isdir(TempFolder):  # Remove temporary folder
        shutil.rmtree(TempFolder)
except:
    print "Unable to delete temporary folder: "+TempFolder
print "Done"
```

# Appendix C- National Elevation Dataset Isolated to the watershed

National Elevation Dataset for Watershed




**Legend**

**BasinBaseElevation**

**Value**

High : 2801.41

Low : 2088.99

10 Meter NED
Elevations measured in Meters