Forecasting Spring Runoff Volumes for Jordanelle Reservoir

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Abstract

This project evaluates if there is a relationship between maximum snow water equivalent values (swe) and spring runoff volumes for the Provo River watershed. The project discusses data acquisition from various sources. The analysis performed used data from water years 1981 to 2016. Due to incomplete data sets, the data was forecasted backwards to fill in missing records. Various methods were used to determine maximum swe values over the watershed. The Thiessen polygon method was used. The area is mountainous, and there is a reasonable relationship between elevation and swe values. A linear regression based on swe values and elevation was determined for each snow year to find the maximum swe value for the watershed. A direct comparison was also performed between maximum swe values for individual stations and inflow volume. Data from the National Operational Hydrologic Remote Sensing Center (NOHRSC) gave swe values much higher than other methods and was therefore not used in any analysis.

Inflow volumes into Jordanelle Reservoir were determined using two methods. The first method used data provided by the United States Geological Survey (USGS). An analysis of stream flow determined the bulk of the inflows from snowmelt occur between April 1st to July 31st of each year. The Colorado Basin River Forecasting Center (CBRFC) provided the second set of inflow volumes. Both sources of inflow volumes were used to create a relationship between maximum swe values and inflow volumes. Precipitation data was also analyzed to establish the effect it has on runoff volumes. An analysis was also performed on the sensitivity of maximum swe values and temperature over the watershed.

The results of this project show there is a relationship between maximum swe values in the watershed and inflow volumes into Jordanelle Reservoir. The best linear regression occurs when comparing the average maximum swe values to the inflow volume provided by the CBRFC. This information is valuable to reservoir managers to help ensure the reservoir has capacity to store spring runoff volumes.

Table of Contents

List of Tables

List of Figures

List of Equations

Introduction

Snow provides much of Utah's water. A brochure produced by the Utah Division of Water Resources states that 58% of Utah's water comes during the winter (UDWR, 2017). Snow produces much of the spring and summer runoff in Utah. Reservoirs are used throughout the state to store water from snowmelt for use the rest of the year. In order to accomplish this, reservoir planning is critical. Estimating the volume of inflow into each reservoir from snowmelt is essential to maximizing the capacity of every reservoir and storing water for droughts.

Jordanelle Reservoir is located in Utah on the border of Summit and Wasatch counties. This reservoir receives water from the Provo River watershed. The watershed is 229 square miles with a mean basin elevation of 8654 feet. Jordanelle Reservoir helps provide culinary water to Wasatch, Utah, and Salt Lake counties (UDNR, 2017). Due to increasing population projections in these counties, water provided by Jordanelle Reservoir is becoming more important for water supply.

Estimating the inflow to Jordanelle Reservoir from snowmelt can help ensure the reservoir is used to its fullest capacity. Establishing a relationship between swe and inflow volume will help with reservoir planning and ensuring the reservoir can store the inflow volume each spring.

Objective

The overall aim of this project is to establish a relationship between maximum snow water equivalent (swe) values in the Provo River watershed and inflow volumes to Jordanelle Reservoir. Maximum swe values were determined for the watershed using data from the National Resource Conservation Service (NRCS) SNOTEL sites. Inflow volumes were determined from USGS streamflow data and posted inflow volumes by the Colorado Basin River Forecasting Center (CBRFC). A linear regression was used to determine which method would best estimate inflow volume to Jordanelle Reservoir.

Methods

For every method examined, a relationship between swe and inflow volume was created. The swe values for comparison were determined four different ways: using Thiessen polygons, determining a swe vs. elevation relationship, doing a direct comparison of maximum values, and using snow depth data from the National Operational Hydrologic Remote Sensing Center (NOHRSC). Inflow volumes were obtained by using stream flow data provided by the USGS and accumulated inflow volume data provided by the CBRFC.

Defining the Area of Interest

The first step of the project was to delineate the watershed for Jordanelle Reservoir. The watershed was delineated by first importing the stream gage to ArcGIS Pro using the make xy event layer tool and exporting the point to a feature dataset. The stream gage location was found on the USGS website. The wastershed tool in the ready-to-use toolbox was used to delineate the watershed, using the stream gage as the input point. The elevation ArcGIS server was used to load a DEM for the country. The extract by mask tool was used to obtain the DEM for the watershed. The DEM statistics show the mean basin elevation is 8654 feet.

SNOTEL stations were chosen by looking for stations close to the watershed on the NRCS webpage (NRCS, 2017). Eight nearby stations were chosen to be used in this analysis. Only one of these stations is within the watershed boundary. The other seven are near the watershed. The stations were imported into ArcGIS Pro using the make xy event layer tool and then exported to a feature dataset. Figure 1 shows the watershed boundary with the SNOTEL stations and USGS stream gage.

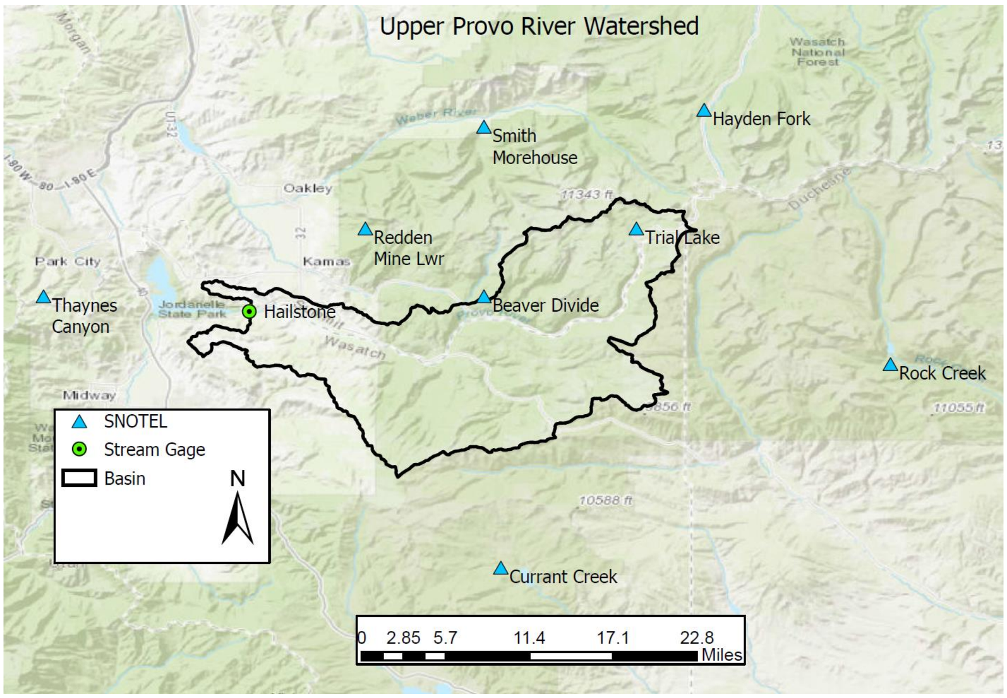

Figure 1. Area of Interest

Data for the eight SNOTEL sites was downloaded from water years 1981 to 2016 (NRCS, 2017). The maximum swe value was found for every year at each station. Most of the stations provided data from water years 1981 to 2016. However, two stations did not provide data back to 1981. The Thaynes Canyon station started collecting data in 1989 and the Redden Mine Lower station did not start collecting data until 2012. Maximum swe values were forecasted back to 1981 for these two stations using a process outlined by Ibrahim Mohammed (2006) in a thesis titled "Modeling the Great Salt Lake."

Determining SWE Values

Four different methods were used to determine the maximum swe values to compare with inflow volume. These methods and the processes involved are outlined in this section.

Thiessen Polygon Method

The Thiessen polygon method was the first method used. The Thiessen polygon and intersect tools in ArcGIS Pro were used to divide the watershed into Thiessen polygons (Figure 2).

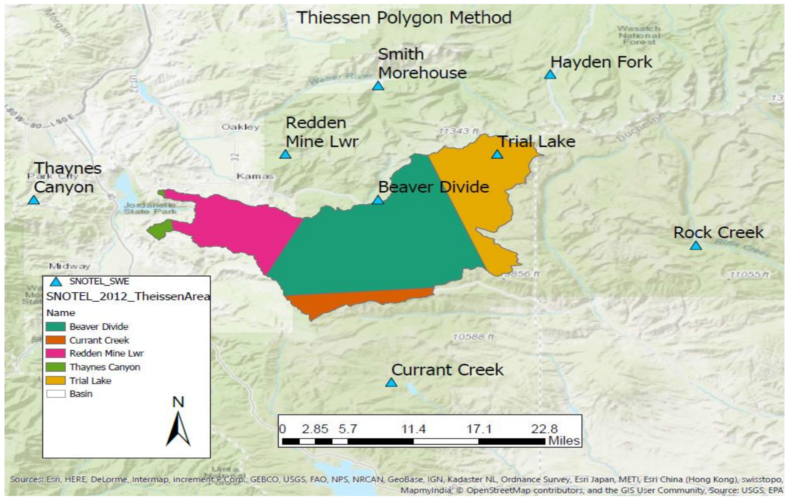

Figure 2. Thiessen Polygon Method

After exporting the areas of the Thiessen polygons, swe values were computed for the entire watershed in Excel using the equation below, where A is the total area of the basin, A_j is the area of a single polygon, and P_j is the maximum swe value at the nearest station for the polygon. This computation was repeated for each water year from 1981 to 2016.

$$Avg.SWE = \frac{1}{A} * \sum_{j=1}^{j} A_j P_j$$

Equation 1. Thiessen Polygon

SWE vs. Elevation Relationship

The next method used to compute basin maximum swe values involved creating an elevation-swe relationship. Maximum swe values vs. elevation was plotted to find a relationship for each year from 1981 to 2016. A linear regression fit the data and gave good correlation factors. Figure 3 is the plot for 1981. The maximum basin swe value was calculated using the equation for the linear regression on each plot and the average basin elevation of 8654 feet.

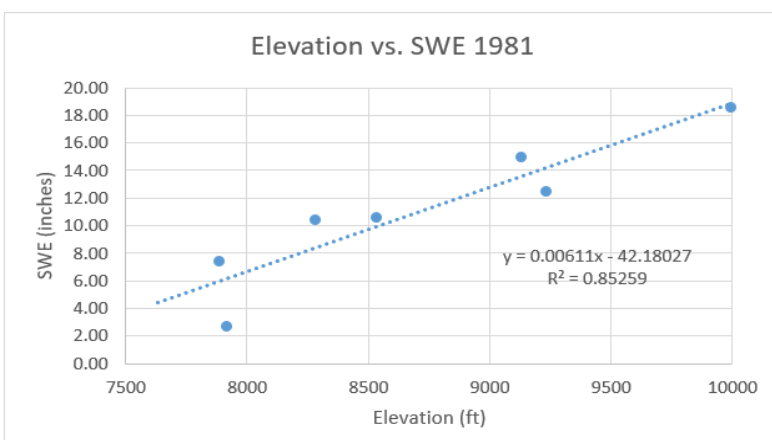

Figure 3. Elevation vs. SWE Relationship 1981

NOHRSC Data

The final way maximum swe values were computed for the watershed was using data from NOHRSC (NOHRSC, 2017). They provided an accumulated snow depth raster for the country. ArcGIS Pro was used to extract by mask the raster cells that covered the watershed. From this new raster, the average maximum snow depth (inches) of the area was found. A snow density analysis for the SNOTEL stations was then performed. Snow density is calculated by using the equation below, where swe and snow depth are for the same time period.

$$Density = \frac{swe}{snow\ depth}$$

Equation 2. Snow Density

This returns the percentage of the snow pack that is water. Table 1 below shows a summary of the results and final average snow density for the area of interest.

Table 1. Snow Density Analysis

	Beaver Divide	Currant Creek	Hayden Fork	Redden Lower	Rock Creek	Smith Morehouse	Thaynes Canyon	Trial Lake
Minimum	0.03	0.05	0.02	0.10	0.03	0.01	0.03	0.003
Maximum	0.60	0.62	0.70	0.70	0.60	0.96	0.60	0.95
Average	0.24	0.26	0.27	0.30	0.23	0.27	0.29	0.30
STD	0.084	0.082	0.079	0.090	0.073	0.113	0.091	0.119

Average snow density	0.27

The average snow density of 0.27 was multiplied by the average maximum snow depth from the NOHRSC raster. This method returned maximum swe values more than 4 times greater than the maximum swe values computed using other methods. Due to the high values, this data was not used for any analysis. The large values may be explained due to the raster product being accumulated depth for the entire water year.

Direct Comparison of SWE Values

The direct comparison method involved calculating which SNOTEL stations had high correlation factors when compared to inflow volume. The maximum swe value for each station was averaged every year to determine if this improved the correlation factor.

Determining Inflow Volumes

Determining inflow volumes was done by using USGS streamflow and CBRFC data. Both inflow volumes were used to establish a linear regression between maximum swe values to see which inflow volume data would yield the best results. The USGS inflow volume is generally larger than the CBRFC data. However, some years did return similar inflow volumes.

USGS Streamflow Data

Daily streamflow data from water years 1981 to 2016 was gathered from the USGS (USGS, 2017). The data was imported into Excel and a pivot table was used to make a plot of the mean of monthly streamflows (Figure 4).

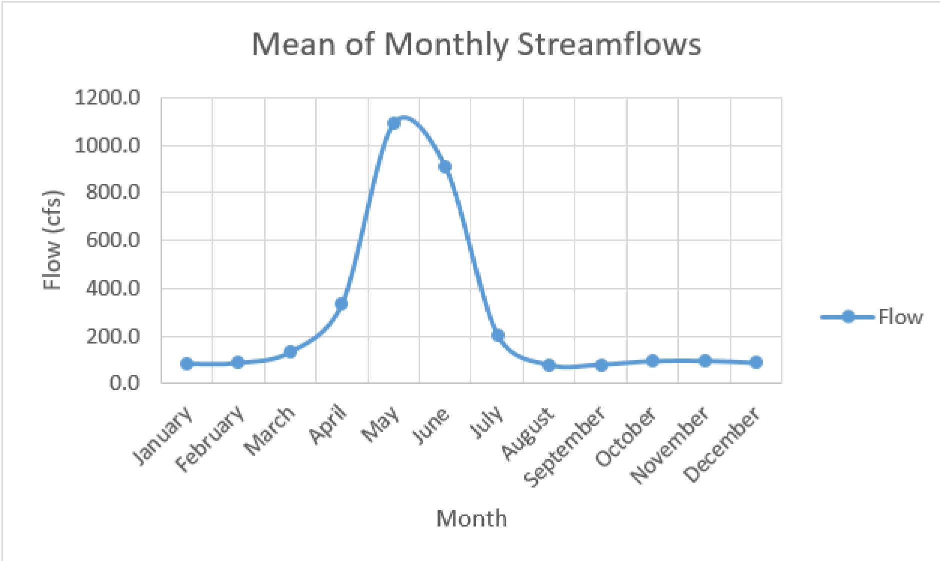

Figure 4. Mean of Monthly Streamflows

The bulk of the inflow to Jordanelle Reservoir occurs from April 1st to July 31st. Most of the snowmelt from the watershed enters the reservoir during this time period. Consequently, data was used from April through July to determine inflow volumes to Jordanelle Reservoir for each year.

CBRFC Data
The CBRFC posts an accumulated inflow volume to Jordanelle Reservoir from April 1st to July 31st on their website (CBRFC, 2017). Inflow volume from water years 1981 to 2016 was gathered for analysis.

Precipitation Analysis
Precipitation data was gathered from all eight SNOTEL stations for water years 1981 to 2016. At each station, the accumulated precipitation depth for April through July for each year was calculated. An elevation vs. precipitation analysis was performed to determine the basin average precipitation for each year from April to July. This basin average precipitation was added to the average maximum swe values for each year. This calculated value of swe plus basin average precipitation was compared to the inflow volume to see if better correlation factors would exist.

Temperature Analysis
The final task performed was a sensitivity analysis on maximum swe values and temperature. Yearly average temperature data was gathered from PRISM from 1981 to 2016 (PRISM, 2017). ArcGIS Pro was used to extract by mask the raster cells over the watershed. The raster statistics were analyzed to obtain the average watershed temperature for each year. A plot of temperature vs. maximum swe values was created to determine a relationship between the two variables. If higher temperatures lead to lower swe values, the increased temperatures associated with climate change may be a concern for future snowpack in the watershed.

Results

The inflow volumes provided by the CBRFC produced better correlation factors when plotted against swe values. Because of this, only the plots of swe vs. CBRFC inflow volume are shown. Plots of swe vs. USGS inflow volume are included in the appendix for each of the methods used. All plots show swe in units of inches and inflow volume in units of thousand acre-feet.

SWE vs. Inflow Volume Relationships

The results from performing Thiessen polygon calculations are shown in Figure 5.

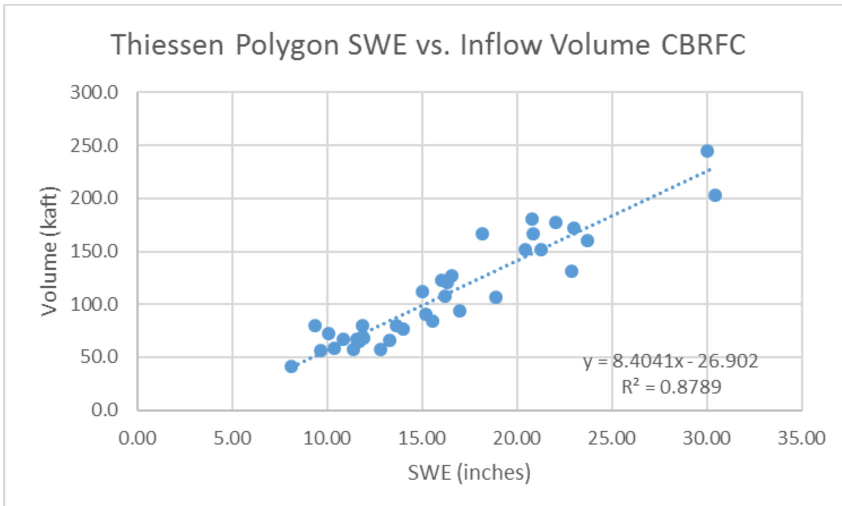

Figure 5. Thiessen Polygon SWE vs. CBRFC Inflow Volume

The results from using the elevation vs. swe relationship are shown in Figure 6.

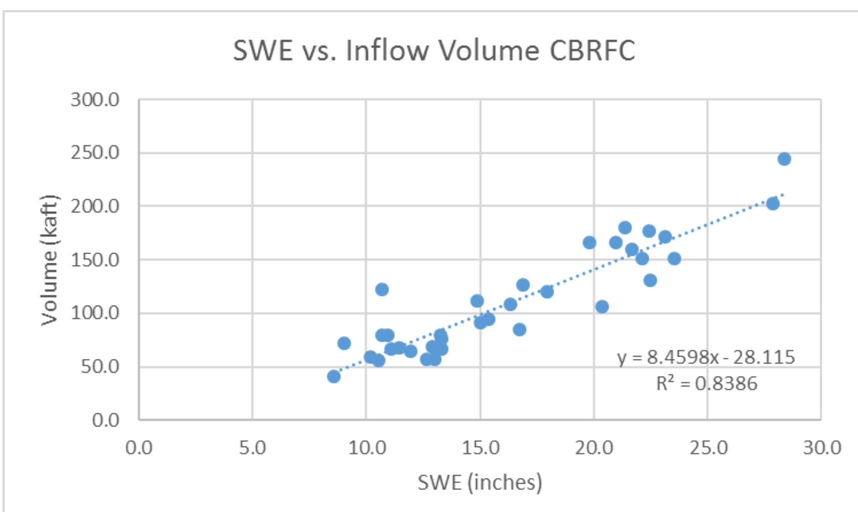

Figure 6. Elevation Relationship SWE vs. CBRFC Inflow Volume

The final method used was a direct comparison of average maximum swe values and inflow volume (Figure 7).

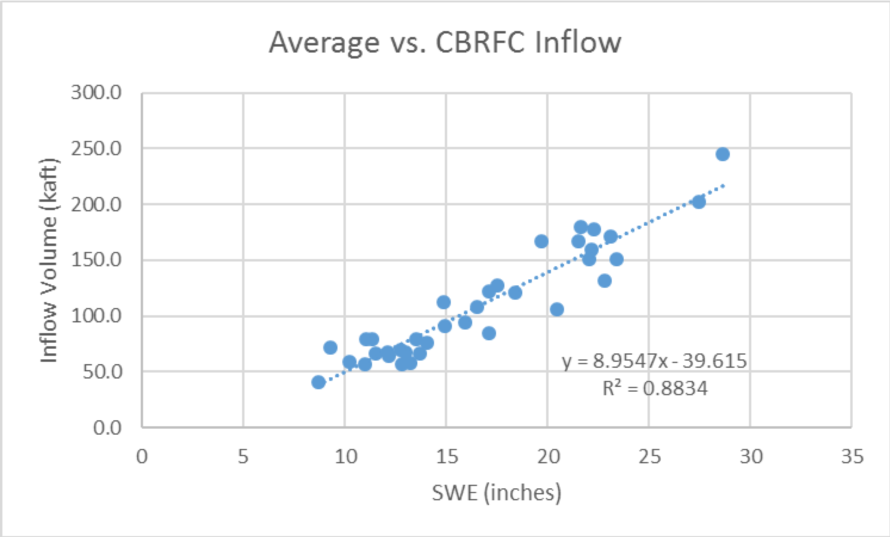

Figure 7. Average SWE vs. CBRFC Inflow Volume

Plotting the average maximum swe value vs. the CBRFC inflow volume produced the best linear regression. Some individual stations had good correlation factors, but the best result came from using the average maximum swe values. The equation from this linear regression was used to estimate the inflow volume from 1981 to 2016 (Figure 8).

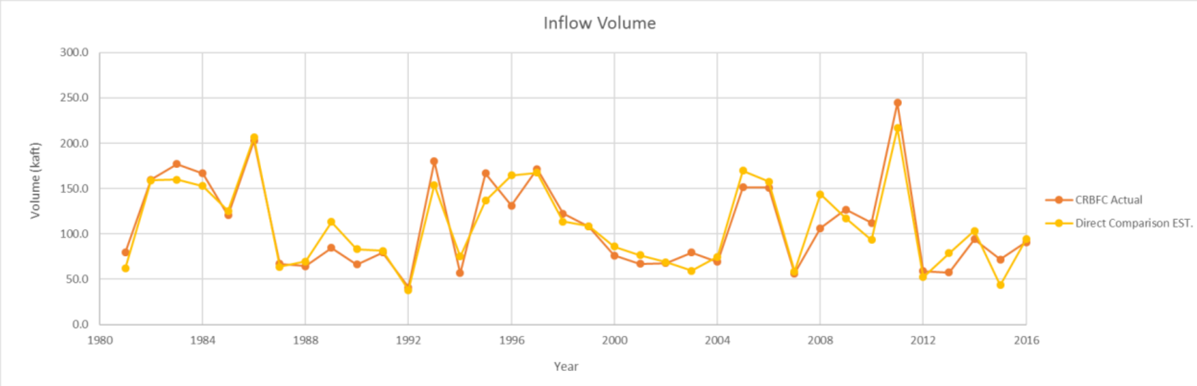

Figure 8. Estimated Inflow Volume vs. Actual Inflow Volume

The orange line is the actual inflow volume and the yellow line is the estimated inflow volume.

Precipitation Added to SWE Relationships

Figure 9 shows the linear regression after adding precipitation from the months of April to July of each year to the maximum swe value of each year. The average maximum swe values from all stations were used in this analysis.

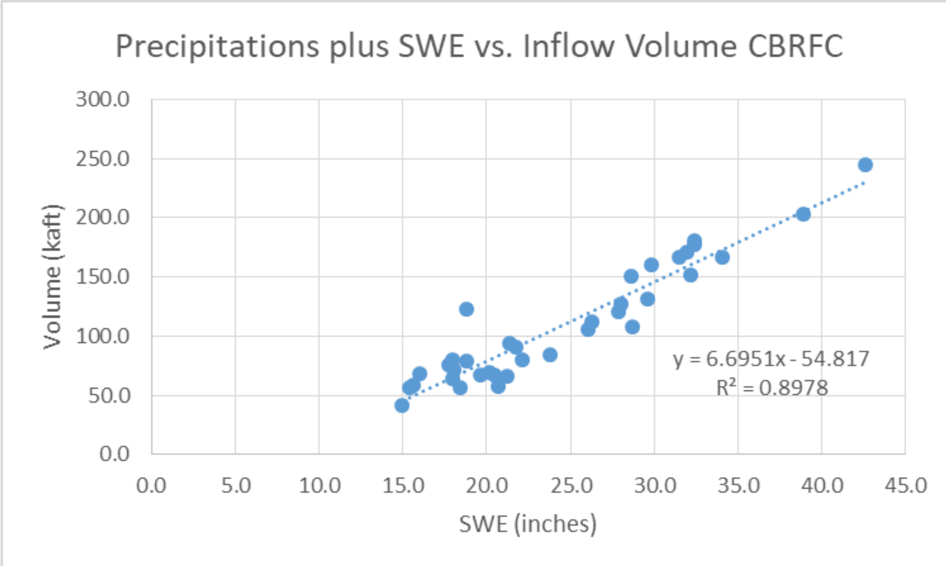

Figure 9. Precipitation plus SWE vs. Inflow Volume

Temperature Results

The final portion of the project looked at the sensitivity of the maximum swe values for the basin and the average temperature of the basin. The average maximum swe value from all stations was used in this analysis. The results are shown in Figure 10.

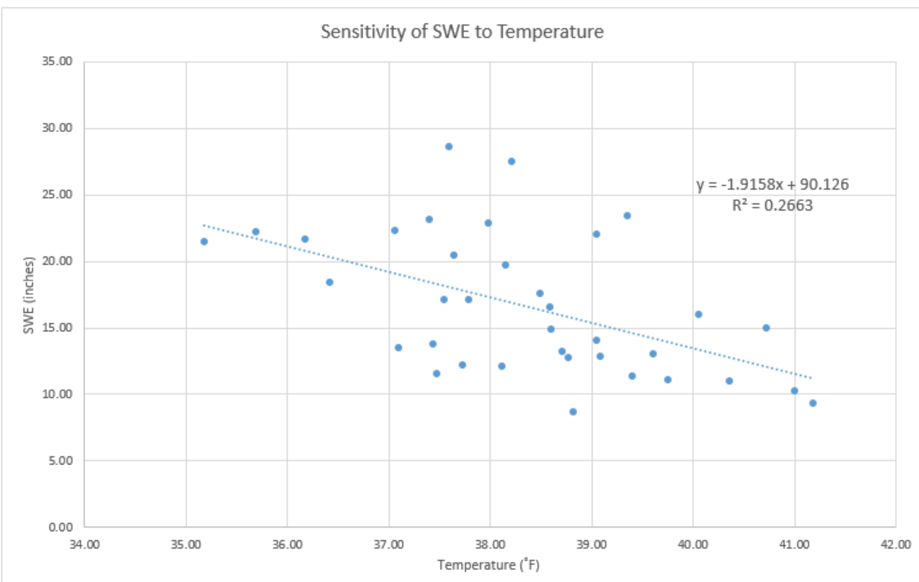

Figure 10. Sensitivity of SWE to Temperature

Discussion

Table 2 summarizes the different methods used to compare maximum swe values to inflow volume.

Table 2. Correlation Factor Summary

Method	CBRFC Inflow	USGS Inflow
Thiessen Polygons	0.8789	0.7062
Elevation vs. SWE relationship	0.8386	0.7165
Averaging Maximum Values	0.8834	0.7559

The high correlation factor for using Thiessen polygons to compute maximum swe was surprising. The Thiessen polygon method does not take elevation into account, and there is a wide range of elevations across the Provo River watershed. This method may have performed well for this watershed because of the SNOTEL station elevations. Area weighting the elevations of the five SNOTEL stations used in the Thiessen polygon method yields an elevation of 8709 feet. Only 55 feet higher than the mean basin elevation.

There is a reasonable relationship between maximum swe values calculated using the elevation relationship and inflow volume into Jordanelle Reservoir. Surprisingly, the Thiessen polygon method returned a higher correlation factor when compared to the CBRFC inflow volume.

Figure 8 shows the inflow volume to Jordanelle Reservoir can be reasonably estimated using the linear regression shown in Figure 7. This is valuable to reservoir managers to ensure the reservoir has capacity for spring runoff.

Figure 9 shows that improved correlation factors exist when adding cumulative precipitation from the months of April through July to maximum swe values. However, this is not a practical approach for estimating inflow volume to Jordanelle Reservoir during the spring. Precipitation for the months of April through July are not known when the snow pack reaches a maximum value. Although this approach was an interesting analysis, it was decided this linear regression would not be used to forecast inflow volumes.

There is a general trend that higher temperatures will lead to smaller maximum swe values (Figure 10). However, the correlation factor for this trend is very small. This type of analysis is limited because mean annual temperature data was used. It may be better to use mean temperature during the time snow is accumulating to determine if there is a relationship between temperature and maximum swe values.

Conclusion

The results of this project show there is a relationship between maximum swe values and inflow volumes into Jordanelle Reservoir. The best linear regression occurs when doing a direct comparison of average swe values to CBRFC inflow volume. This knowledge is valuable to reservoir managers. The relationship established can help estimate how much water Jordanelle

Reservoir will receive once the snow in the watershed starts to melt. This will help reservoir managers to know how to adjust the firm yield of the reservoir to ensure there is enough room in the reservoir to store runoff and maximize reservoir capacity. The limitation for this approach is that inflow volume can only be estimated for the current year by looking for the maximum swe values for each SNOTEL station. There is no way to use this method to look beyond the current year.

The Thiessen polygon method produced good results for this watershed when using the nearest SNOTEL stations. This may be due to the area weighted elevation of the SNOTEL stations being close to the mean elevation of the basin. Using an elevation vs. swe relationship also returned a good correlation factor. However, this method produced the lowest correlation factor of the three methods.

NOHRSC data could have been very useful for this project. If there was more time, it would have been interesting to explore different periods of annual snow accumulation to see if different dates show higher correlation factors. The data used was season accumulated snow depth, which may have produced the discrepancies in large swe values.

Adding basin average precipitation to maximum swe improved correlation factors. However, this is not a practical approach to estimating inflow volumes to Jordanelle Reservoir because precipitation for future months is not known.

For the data acquired, there was little relationship between maximum swe values and mean basin temperature. Another possible future analysis is a projection regarding the effect of climate change on inflow volumes. Increased temperature could lead to a change in inflow volume from snowmelt.

Limited data availability was a constraint on this project. Only one SNOTEL station was in the watershed boundaries. This type of analysis could be improved if there were more SNOTEL stations strategically placed around the watershed.

References

Colorado Basin River Forecast Center. “PVHU1 Water Supply Forecasts.” Web. 1 Oct. 2017 <https://www.cbrfc.noaa.gov/rmap/wsup/point.php?id=PVHU1>

Mohammed, Ibrahim N. “Modeling the Great Sal Lake.” Web. 27 Oct. 2017 <http://hydrology.usu.edu/dtarb/ibrahim_thesis.pdf> (2006).

National Operational Hydrologic Remote Sensing Center. “National Snowfall Analysis.” Web. 18 Nov. 2017 <https://www.nohrsc.noaa.gov/snowfall_v2/>

PRISM Climate Group, Oregon State University. Web. 21 Nov. 2017 <http://www.prism.oregonstate.edu>

National Resource Conservation Service. “Snow Telemetry and Snow Course Data Products.” 23 Oct. 2017 <https://www.wcc.nrcs.usda.gov/snow>

USGS. “USGS 10155000 Provo River Near Hailstone, UT.” Web. 1 Oct. 2017 <https://waterdata.usgs.gov/usa/nwis/uv?10155000>

Utah Division of Natural Resources. “Jordanelle State Park.” Web. 7 Dec. 2017 <https://stateparks.utah.gov/parks/jordanelle/>

Utah Division of Water Resources. “Utah's Water Supply.” Web. 27 Nov. 2017 <https://water.utah.gov/brochures/uws_broc.htm>

Appendix:

Table 3. Maximum Snow Water Equivalent Values at Each SNOTEL Station

Snow Water Equivilant (inches)								
Elevation (ft)	7915	9992	8280	9230	8532	9130	7886	7631
Water Year	Currant Creek	Trial Lake	Beaver Divide	Thanynes Canyon	Redden Mine Lwr	Hayden Fork	Rock Creek	Smith and Morehouse
1981	2.7	18.6	10.4	12.5	10.6	15	7.4	13.6
1982	14.3	39.8	17.6	28.3	24.0	25.3	9.1	19.1
1983	19.8	35	16.1	28.0	23.8	23.3	13.9	18.3
1984	17.8	38.4	12.8	27.3	23.1	22.3	9.7	20.5
1985	17.5	27.3	10.6	21.9	18.6	20	12.2	19.3
1986	19.3	56	20	37.7	31.9	19.6	16.6	18.6
1987	5	19.4	9	13.2	11.2	15.6	7	11.8
1988	7.8	19.5	8.6	14.2	12.0	15.3	8.2	11.9
1989	12.7	29.2	8.7	25.5	18.7	18.2	7.7	15.9
1990	9.3	18.4	11	21.0	14.7	12.9	7.9	14.5
1991	6.7	22.5	10.1	21.0	14.8	12.6	8.2	12
1992	6.6	10.3	6.7	16.0	9.7	6.4	5.4	8.4
1993	16.4	32.3	15.1	33.3	23.9	18.7	13.6	19.7
1994	9	16	8.7	22.5	13.8	14.6	6.5	11.4
1995	12.3	34.5	10	35.4	22.7	21	7.9	13.8
1996	13.4	36.6	17.1	34.7	25.0	23.9	11.3	20.4
1997	15	38.4	16.3	33.1	25.3	20.2	17.8	18.9
1998	8.4	25.3	11.8	30.6	18.7	16	10.4	15.8
1999	6.8	28.8	10.8	29.2	18.6	16.1	7.8	14.2
2000	6.5	22	11	20.3	14.7	14.7	9.5	13.6
2001	6.1	18.4	6.7	27.6	14.5	12.5	8.3	9.8
2002	4.1	17	10.2	20.1	12.6	13.3	5.6	13.9
2003	4.9	15.3	6.6	18.3	11.1	15.3	7.2	9.7
2004	11.7	17.2	8.7	19.9	14.1	11.1	8.8	10.5
2005	12.9	35.1	12.7	45.2	26.0	19.8	17.4	17.9
2006	14.4	34.2	15.1	35.7	24.4	23.1	12.3	17
2007	6.8	15.5	6.8	17.3	11.4	11.5	6.3	12.2
2008	15.6	25.1	15.3	33.7	22.0	22.4	11.6	18
2009	8.6	28.5	11.3	28.6	18.9	19.3	7.2	17.9
2010	8.9	20.7	12.6	24.9	16.5	14.2	8.9	12.1
2011	15.7	51.6	21.4	41.2	31.9	30.9	12.8	23.6
2012	6.2	16.7	7.7	15.5	11.3	11.1	4.6	8.9
2013	7.1	22.9	9	23.1	12.1	14.1	6.2	11.2
2014	8.7	27.7	13.4	21.1	16	18.1	6.4	16.2
2015	5.8	15.4	8.3	12.7	9.7	8	4.9	9.5
2016	6.8	23.4	11.9	21.2	16.8	15.8	11.9	11.7

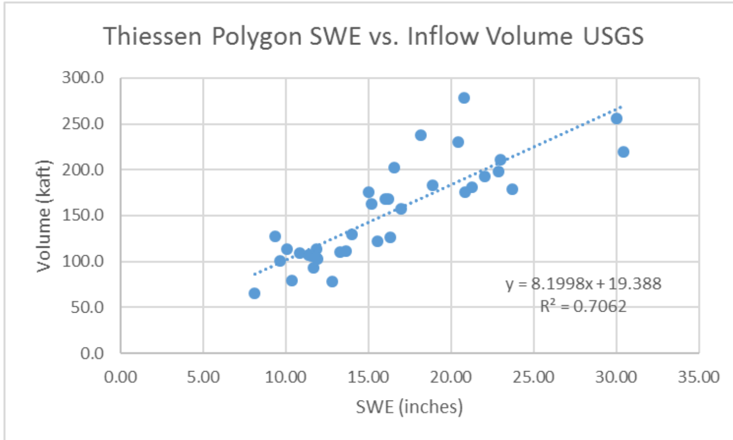

Figure 11. Thiessen Polygon SWE vs. USGS Inflow Volume

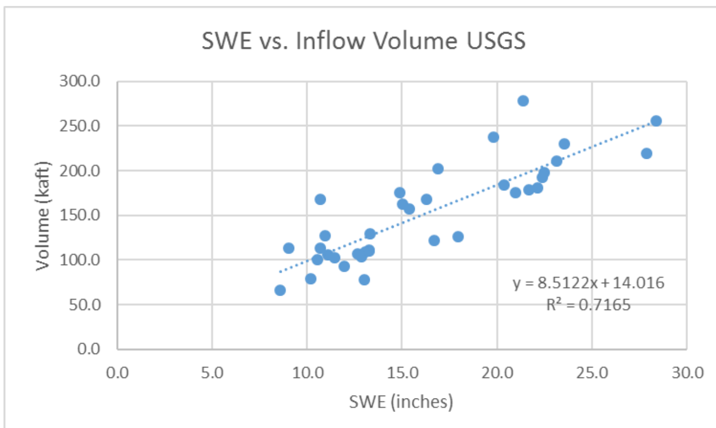

Figure 12. Elevation Relationship SWE vs. USGS Inflow Volume

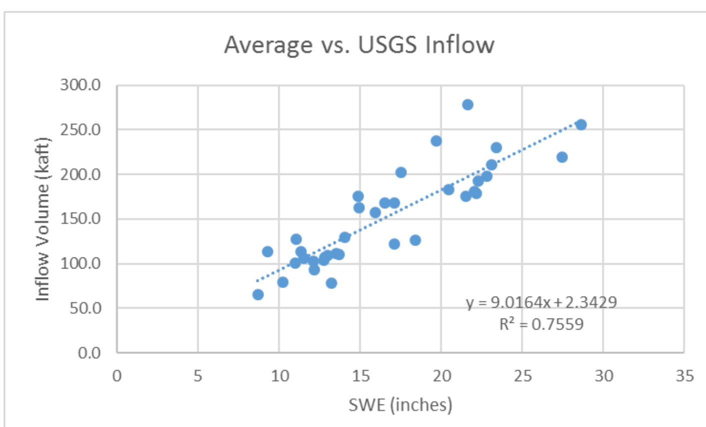

Figure 13. Averaging SWE vs. USGS Inflow Volume