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OGDEN RIVER FLOOD FORECASTING USING SNOW WATER EQUIVALENT LEVELS IN OGDEN RIVER BASIN

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1 Introduction

The use of Geographic Information Systems (GIS) analysis can be an invaluable aid to optimal reservoir operation. Most reservoirs are a part of a complex system that incorporates numerous factors that govern its creation, use, and operation. Reservoirs are built for two primary purposes: 1) Flood control, which is accomplished by manipulating the pool level in anticipation of expected high flows and 2) storing water, which is accomplished by controlling releases during each season to capture excess inflow volume. Additionally, reservoirs are subject to the demands of its customers. It needs to supply a yield or a reliable delivery to its customers during each important season of the year. Reservoir operators are tasked with the difficult job of balancing storage levels and releases with inflows and demands.

Figure 1. Pineview Reservoir from Utah Highway 39.

Optimization of these parameters can be achieved using systems analysis, however, this can still be a difficult process due to the unpredictable nature of reservoir inflows. Inflows can depend on many factors such as precipitation in the form of rainfall and snowfall, groundwater, and weather patterns. The largest inflows occur during seasonal runoffs during late spring and early summer, which is a function of the snowpack in the watershed.

Although predictions of flow rate into the reservoir during a runoff season are difficult, reservoir operators can benefit from forecasts of high and low runoff. These benefits can come in the form of controlling releases to avoid damage to both the dam structure and downstream property, as well as retaining the necessary storage to supply its yield over the year. The purpose of the present study is to use snowpack levels in the watershed surrounding the watershed to make these forecasts in order to reduce damage and retain storage. This work examines Pineview Reservoir east of Ogden, Utah and its surrounding watershed to make an in-depth analysis of the purposes mentioned above. Forecasts of Pineview Reservoir inflows and peak flow rates will be made by looking at snowpack levels in the Ogden River watershed.

2 Background

2.1 Pineview Reservoir & Ogden River Project

Pineview Reservoir is located on the Ogden River seven miles east of Ogden Weber County, Utah (USBR, 2009). It was built in Ogden Canyon by the United States Bureau of Reclamation in 1941 as part of the Ogden River Project, which also included the Ogden Canyon Conduit, the Ogden-Brigham Canal, the South Ogden Highline Canal and a gravity-fed culinary water source for the South Ogden Conservation District. It also provides reliable irrigation to over 25,000 acres of agricultural land in the Northern Wasatch Front.

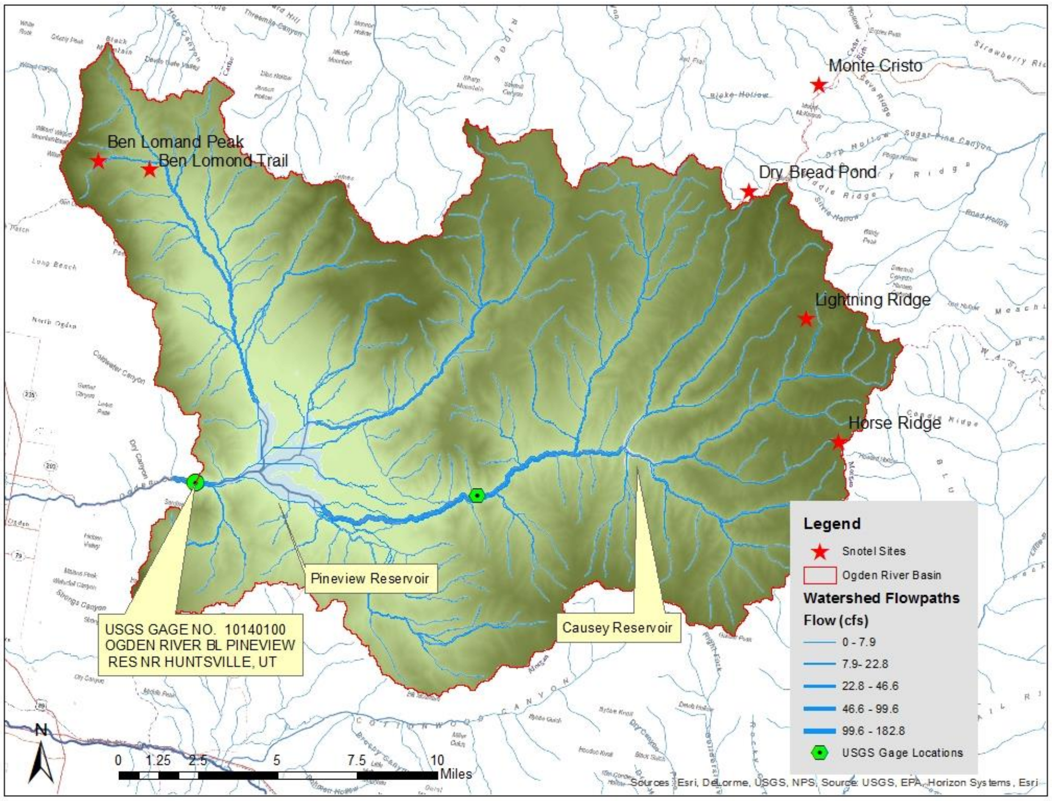

Figure 2. Ogden River Watershed. Preferred flowpaths are shown here that have been calculated using a digital elevation model of the watershed and spatial analysis in ArcGIS. Locations of SNOTEL sites are also shown.

Pineview Dam is located at the east end of Ogden Canyon. The town of Hunstsville is located near its banks and a number of major State Highways run over the dam as well as around the reservoir. It lies at the confluence of the North, Center, and South Forks of the Ogden River. Causey Reservoir, another significant impoundment, lies upstream of Pineview on the South Fork of the Ogden River to provide additional storage for users in the area. This report will not be concerned with the operations of Causey Reservoir and shall assume that inflows into Pineview Reservoir are independent of human influences.

Currently the dam has a height of 137 feet and enables the reservoir to have a capacity of 110,150 acre-feet. A 2,300 cubic foot per second capacity outlet works is located in a

Figure 3. Outlet works of Pineview Reservoir

tunnel in the right abutment. It consists of a 72 inch pipe which leads into the 75 inch Ogden Canyon Conduit, and a 60 inch pipe which discharges into the spillway stilling basin. From here, deliveries are made to the Ogden City filtration plant located downstream from the dam. Water from the dam is transported 4.7 miles through the Ogden Canyon Conduit, jointly owned by the Ogden River Water Users Association and Utah Power & Light Company, to the two canals for distribution (USBR, 2011). The Ogden-Brigham canal has a flow rate of approximately 120 cubic feet per second while the Highline canal flows at 35 cubic feet per second.

2.2 SNOTEL

SNOTEL (short for snow telemetry) is an automated system of snowpack and related climate sensors operated by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture in the western United States. Since the majority of precipitation in the west is stored as snow, data on snowpack provides critical information to decision makers and water managers. SNOTEL sites always measure snow water content, accumulated precipitation, and air temperature (NRCS, 2013), while some sites measure snow depth, soil moisture and temperature, wind speed, solar radiation, humidity, and atmospheric pressure in addition. These data are used to forecast yearly water supplies, predict floods, and for general climate research.

Figure 4. An arial view of Pineview Reservoir and Ogden Canyon.

2.3 SNODAS

SNODAS stands for Snow Data Assimilation System and is a product of the National Snow and Ice Data Center. (NSIDC, 2013) This is a modeling and data assimilation system that provides estimates of snow cover and associated parameters to support hydrologic modeling and analysis. The dataset provides a consistent framework to integrate snow data from satellite, airborne platforms, and ground stations with model estimates of snow cover (Carroll et al., 2001). Figure 7 contains a view of a set of SNODAS data within ArcMap.

3 METHOD

3.1 DEVELOPMENT

Although Pineview Reservoir was built primarily to supply additional water to downstream agricultural and municipal users, flood control is a significant purpose as well. The largest inflows occur in the late spring when accumulated snowpack melts and becomes runoff. Flows through the system reach their maximum during this time. If, however, reservoir operators lower pool levels to receive the additional runoff volume during this time, damages due to flooding downstream of the reservoir can be greatly mitigated. Forecasts of anticipated runoff discharges can be made my analysis of snow levels in the associated watershed. If outflows can be kept below "flood stage", or the level where the river begins to jump over its banks, then costs due to flood damages can be avoided.

Four different methods of calculating estimated snow volume in the watershed were used.

1. Using SWE values at one SNOTEL site
2. Using an average of SWE values across multiple SNOTEL sites
3. Using spatial analysis in ArcGIS to find a SWE depth based on elevation across the area.
4. Using SNODAS data to find an average SWE depth across the area.

Volume of snowpack water equivalent was estimated using the mean values of SWE depth on April 1 and multiplying by the watershed area calculated by the delineated watershed. These snowpack volumes are then compared to inflow volumes in Pineview Reservoir to determine which method is the most effective predictor of inflow volume. This was accomplished by calculating the root mean square error as explained by Helsel & Hirsch (1991).

3.2 DATA COLLECTION

3.2.1 Pineview Reservoir Operational Data

Reservoir operations data was collected from the US Bureau of Reclamation (USBR, 2013), which built and also operates the dam. Historical daily average values of storage (Acre-feet), inflows (cubic feet per second (cfs), outflows (cfs), and pool elevation (feet) were obtained for years 2008 to 2013. Additional inflow data dating back to 2003 was used in order to increase sample size to obtain larger sample sizes in data analysis. It is assumed that inflow data from the USBR represents total discharge into the reservoir from all sources including direct precipitation on the lake surface.

3.2.2 SNOTEL Data

Although there are numerous SNOTEL sites in Northern Utah, only 12 have been chosen to gather data from based on their proximity to the study area. Figure 2 shows the locations of six sites that are closest to the Ogden River Watershed. The other six sites were within a 60 mile radius of the watershed and data was collected from these sites to create a larger sample sizes. Values of snow water equivalent were recorded for years 2008-2013. Snow water equivalent measurements differ from snow depth measurements; it can be thought of as the depth of water that would theoretically result by melting the snowpack instantaneously. This gives a more accurate measurement of volume of water contained within the watershed's accumulated snowpack because it accounts for variability in snowpack density. The sites include: Ben Lomond Peak, Ben Lomond Trail, Bug Lake, Dry Bread Pond, Horse Ridge, Kilfoil Creek, Lightning Ridge, Little Bear, Lost Creek, Monte Cristo, Temple Fork, and Tony Grove RS (NRCS 2013). Since snowpack typically builds until temperatures start to rise in April, average daily values of SWE were obtained on April 1 of each year studied. Using a fixed date allowed for continuity and reliability in the data across different years of observation.

SNOTEL sites were also chosen based on the largest elevation ranges possible in order to achieve a stronger relationship between elevation and SWE. These relationships were used to generate linear relationships between the two parameters to allow for calculation of overall snow volume in ArcMap. Plots of SWE data versus SNOTEL site elevation is shown in Figure 5 along with the linear regression best fit line and associated equation for the year 2011. Although only one equation is shown in Figure 5, similar equations were obtained for each year's data for subsequent entry into ArcMap.

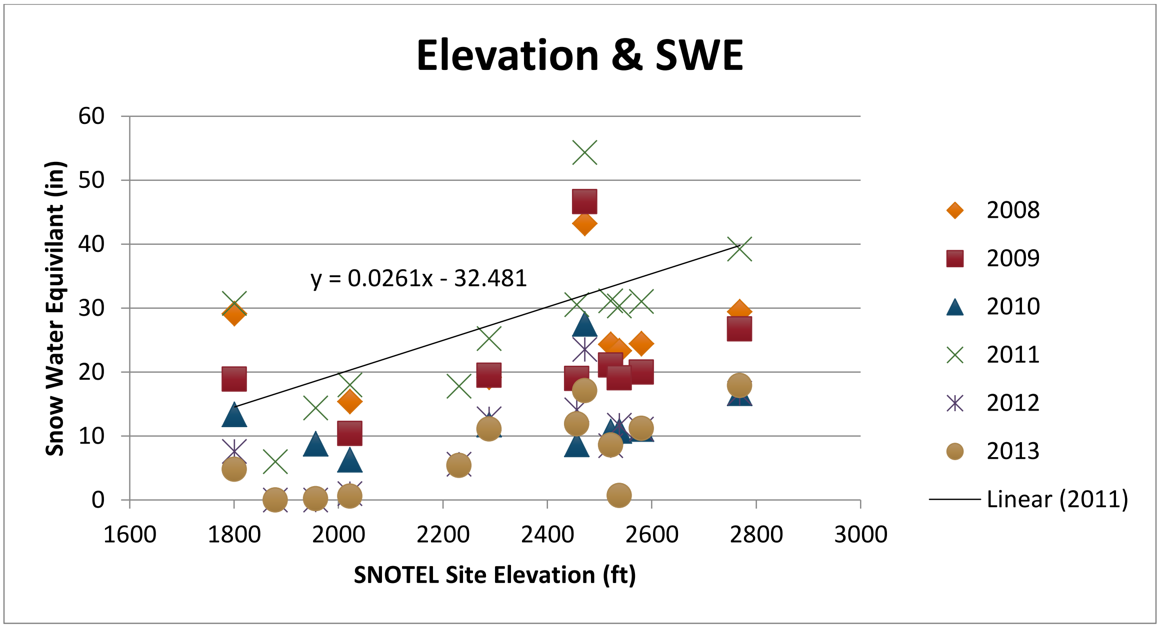

Figure 5. A plot of SNOTEL site elevation and measured SWE. A linear trendline and the cooresponding equation for year 2011 are shown.

Using ArcGIS, the Ogden River Watershed was delineated using the GIS landscape services server based on the longitude and latitude of of the USGS gage below Pineview Dam (USGS, 2013). This created a 203,217-acre area within the map that represented the entire watershed that drained to that point. The 30 meter National Elevation Dataset (NED30), which contains elevation data for the United States, was overlaid on top of this watershed area to create a raster digital elevation model (DEM). Raster refers to 30m by 30m gridded data for the watershed that contains elevation information in each grid cell. For each year, the equation relating SWE and elevation, as shown in Figure 5, was entered into the raster calculator in ArcMap to determine a mean snow depth across the watershed area. These values were then used to make forecasts of expected runoff for the season. SWE depth values across the area for 2011 are shown in Figure 6 where lighter shaded regions represent greater SWE depth levels.

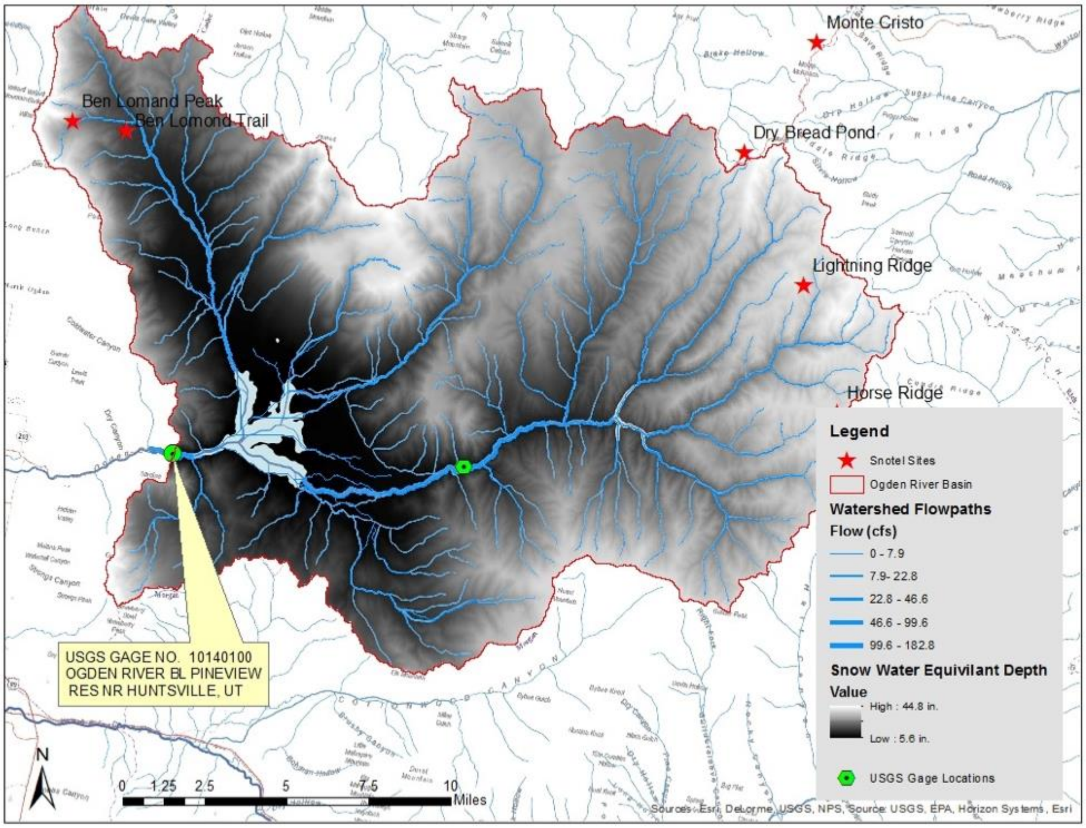

Figure 6. Snow water equivilant depths in the Ogden River watershed. Ligher shaded areas represent deeper SWE depths.

3.2.3 SNODAS Data

Estimates of snow water equivalent were obtained from the SNODAS online database for the western United States (NOHRSC, 2004). These raw data files had to be converted into TIF format to import into ArcMap as shown in Figure 7. Subsequently, the extract by mask tool was used extract the data over just the Ogden River watershed area. Using zonal statistics, a mean snow depth across the entire area was obtained for the April 1 data from 2008 to 2013.

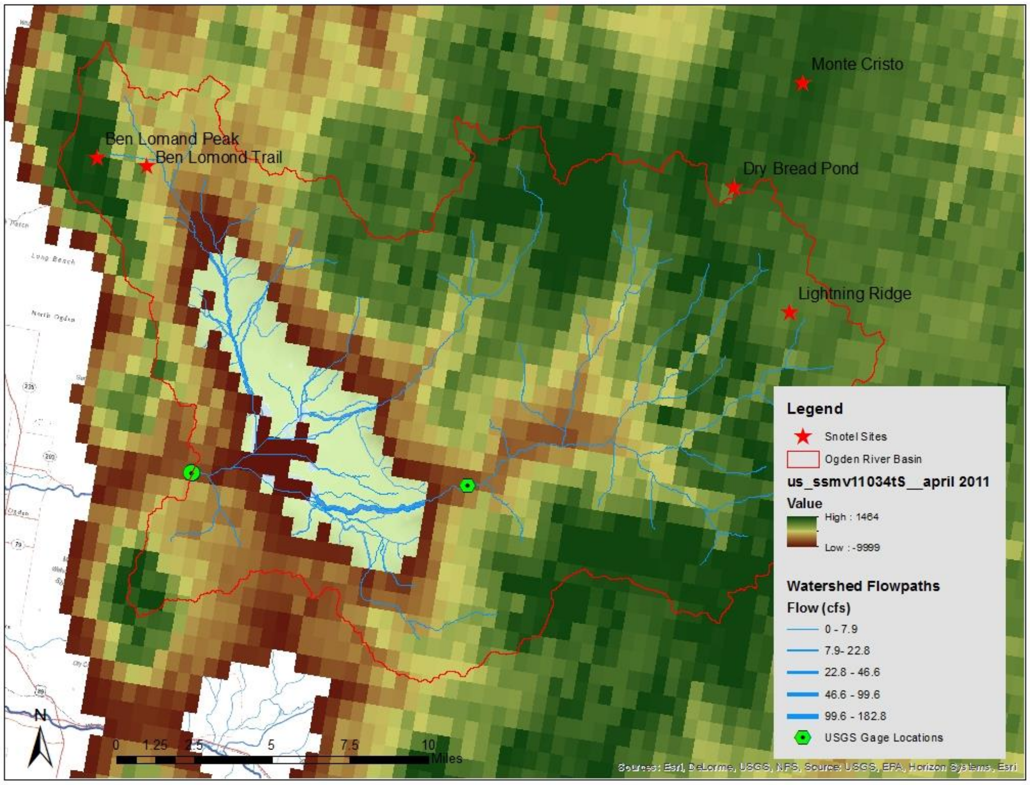

Figure 7. SNODAS raster dataset for April 2011 (us_...april 2011) overlayed on the Ogden River watershed (NOHRSC, 2004)

4 Results

Results from the methods described in the previous section are presented here. Figures 8-12 contain data that present the Pineview Reservoir inflow volume estimation results. An estimation of the total snow water equivalent volume was made using the four methods (one SNOTEL site, multiple SNOTEL sites, ArcMap spatial analysis, and SNODAS analysis). Figure 8 shows linear relationships between SWE volume and inflow volume using two separate SNOTEL sites and the SNOTEL average. Figure 9 shows linear relationships between SWE volume and peak inflow using the same two SNOTEL sites and the average. Simple estimations of inflow volume or peak inflow rates (plotted on the y-axis) can be made using these figures with known values of SWE on April 1 for a given season.

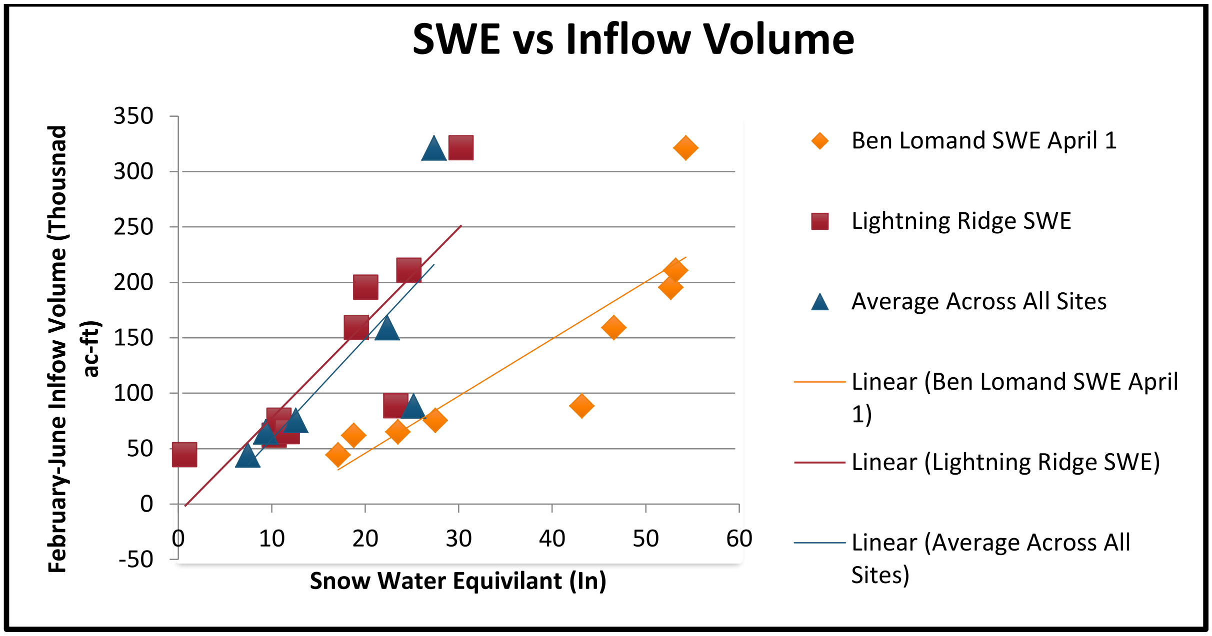

Figure 8. A plot of SWE vs. inflow volume.

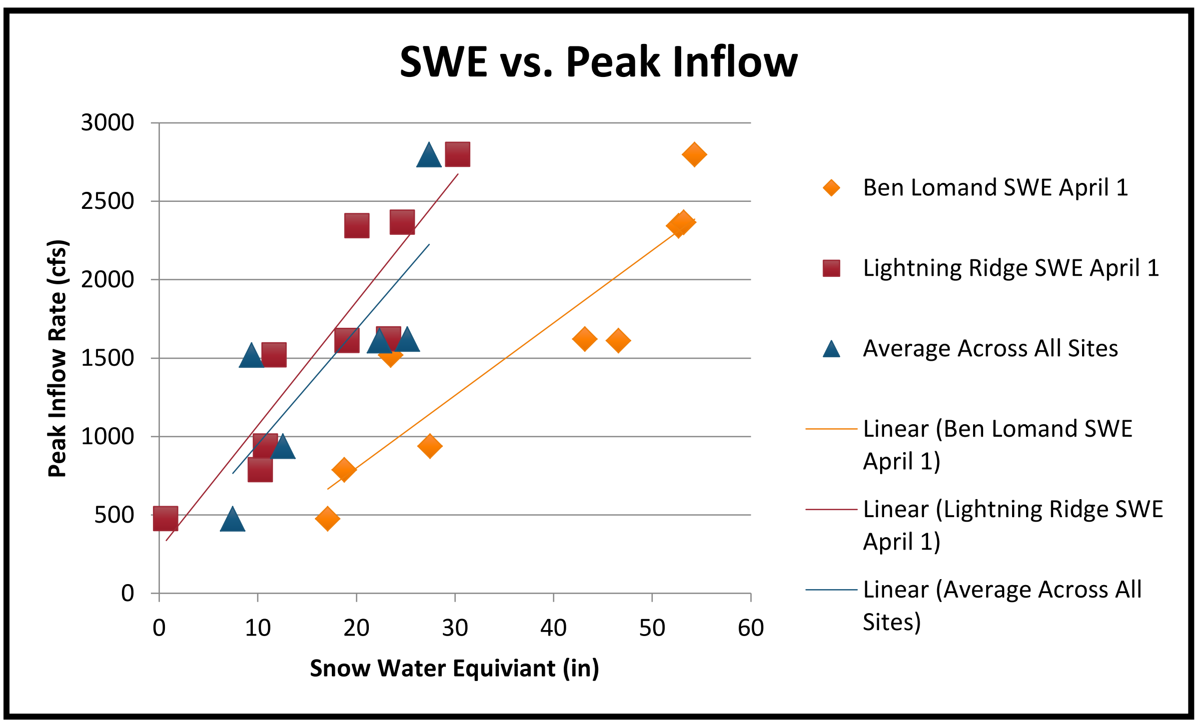

Figure 9. A plot of SWE data vs. Peak inflow rate.

Figure 10 contains results from the SNOTEL spatial analysis method and the SNODAS method. In this figure, total snowpack volume is directly compared with total inflow volume. Data for each of the four methods used to calculate snowpack volume are plotted against inflows measured the USBR (2013) into

Pineview Reservoir. Figure 11 plots volume of snowpack with peak inflow values. Each of these methods created a relationship to predict inflow based on known (or estimated) SWE depths.

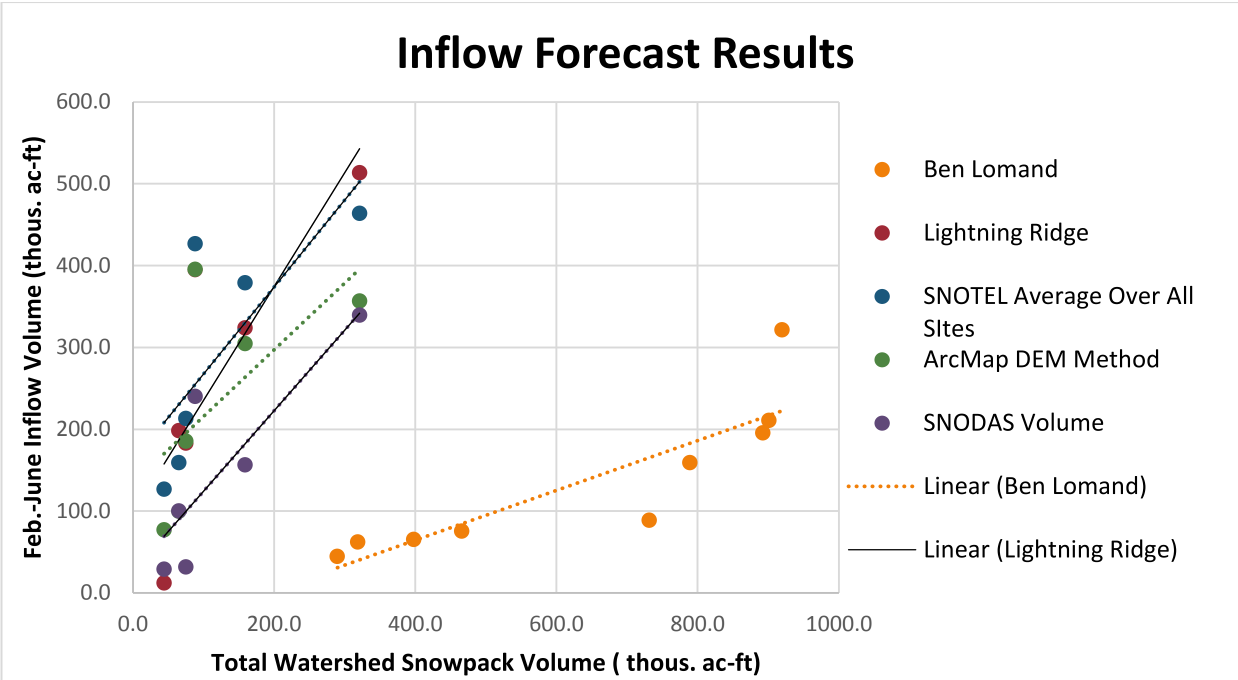

Figure 10. A plot of total snowpack volume vs. total inflow volume (February to June).

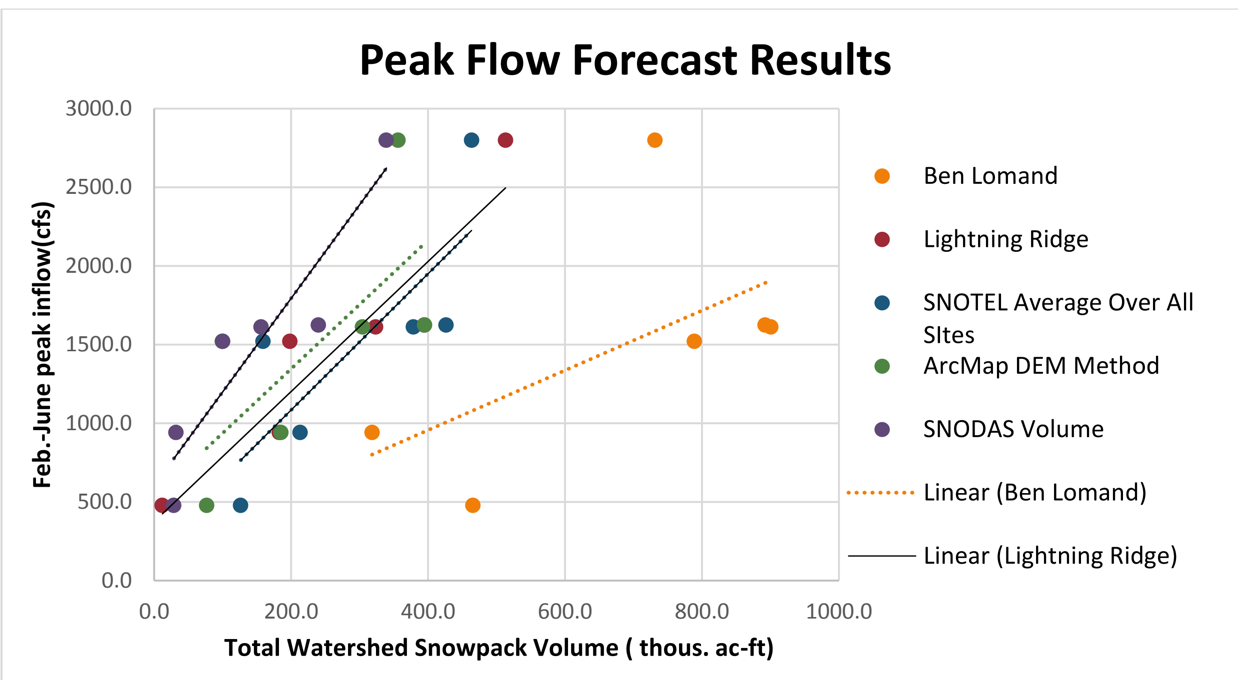

Figure 11. A plot of total snowpack volume vs. peak inflow (February to June).

Linear regression was used in both cases in Figures 10 and 11 to create best fit lines. A model performance analysis was performed for each of the four methods for both volume and peak flow. The root mean square error was calculated for each case and the results are found in Table 1.

Table 1. Model Performance Analysis.

	Root Mean Square Error (RMSE)	
Method	**Inflow Volume**	**Peak Flow**
One Site (Ben Lomond)	499	1041
One Site (Lightning Ridge	177	1348
SNOTEL Average Over All Sites	190	1347
ArcMap DEM	148	1408
SNODAS	67	1477

5 DISCUSSION

5.1 SOURCES OF ERROR

There are numerous places within the scope of this report where error could be introduced. Data from any of the sources could have errors in measurement, collection, and recording which could have affected the accuracy of the results. For example, the SNOTEL sites could have malfunctioned at any given point through the study period and given inaccurate snow depth readings. Similarly, error in collection of data from SNODAS or the Bureau of Reclamation could have affected the model. The spatial analysis of snowpack volume in ArcGIS also introduces error that does not perfectly represent reality. Estimated snowpack volumes based purely on elevation do not take into account other factors such as air temperature, solar radiation, shading, vegetation, land cover, and slope.

Also, assumptions made that the reservoir had no evaporation and infiltration losses or gains also could have been a source of error in the results. In a study with further scope and time, these parameters could be factored into the system and increased accuracy. Since the operations of Causey Reservoir were ignored, inflow values could have been affected by the storage of the reservoir.

5.2 MODEL RESULTS

The results contained in Figures 8-12 each show ways of predicting inflow volume or peak inflow based on SWE depths. According to the performance analysis (Table 1), the models with the lowest RMSE values were the most accurate methods. The results show that using the SNODAS data was the most accurate predictor of inflow volume because its RMSE value was least. Therefore in order to accurately plan reservoir operations to prepare for potential drought situations, the model using SNODAS data should be used.

Using data from the Ben Lomond site had the lowest RMSE value for predicting peak inflow. It appears, however, that this is not an accurate method of choosing the best predictor of peak flow because snowpack volume levels are significantly higher than any of the other presented methods. Figures 10 and 11 both clearly show that Ben Lomond data does not match the trend set by the other methods, including snowpack at the other single SNOTEL site. This is likely because the Ben Lomond Peak SNOTEL location is in an area that receives a disproportionally higher amount of snowfall. It is at a high elevation down from the ridge of the Wasatch Range that is on the downstream side of the predominate jet stream. Snowbasin Ski Area is located in a similar part of the mountain to take advantage of similar snowfall patterns. Therefore, the method with the next minimum RMSE was chosen: using the SNOTEL SWE average depth over all sites. To accurately predict potential flooding events and prepare reservoir operations accordingly, that method should be used.

6 Conclusion

Operations of Pineview Reservoir are complex and require detailed hydrologic modeling and analysis to effectively maintain the purposes of the reservoir. This project used the technology of ArcGIS to perform a part of that analysis to prevent flooding and drought conditions downstream of the reservoir. Snow water equivalent depths in the watershed were obtained from SNOTEL and SNODAS databases to create models that predicted both inflow volume and peak inflow rates. Four methods were chosen for this purpose: using one SNOTEL site, multiple SNOTEL site averages, spatial analysis in ArcGIS, and using raster data from SNODAS. Upon analysis of the effectiveness of these methods, SNODAS was chosen as the best predictor of inflow volume, and using SNOTEL SWE averages was chosen as the best predictor of peak inflow rates.

7 References

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