Nathan Wright

Hyrum Reservoir and How it Applies to Flood Control

CEE 6440 GIS Water Resources

Term Project

Introduction

Hyrum reservoir is located a few miles south of Logan, Utah. It was completed in 1935 in order to help farmers with irrigation and flood control. Previously the farmers had been using a 9 mile stretch of canals that took water out of the Little Bear River to irrigate their farms. The purpose of this report is to evaluate Hyrum Reservoir and its impact on flood control. This will be accomplished by completing the following 5 steps.

1.) Delineate the Watershed that drains into Hyrum Reservoir
2.) Gather the stream flows that flow into Hyrum Reservoir
3.) Gather local Snow Water Equivalents (SWE) interpolate SWE values over the watershed
4.) Calculate the percent of SWE that is runoff
5.) Evaluate Hyrum Reservoir's flood control ability

In order to better understand where Hyrum Reservoir is located, a map was created using ArcMap. This was done by locating Hyrum Reservoir in Google Earth and then using the georeferencing toolbar in ArcMap to properly reference the Google Earth image. To properly reference the figure, a road intersection was selected on the Google Earth figure, and then the same intersection was selected on the ArcMap base map. This was repeated several times until the map was properly oriented. The resulting map can be seen in Figure 1 on the following page.

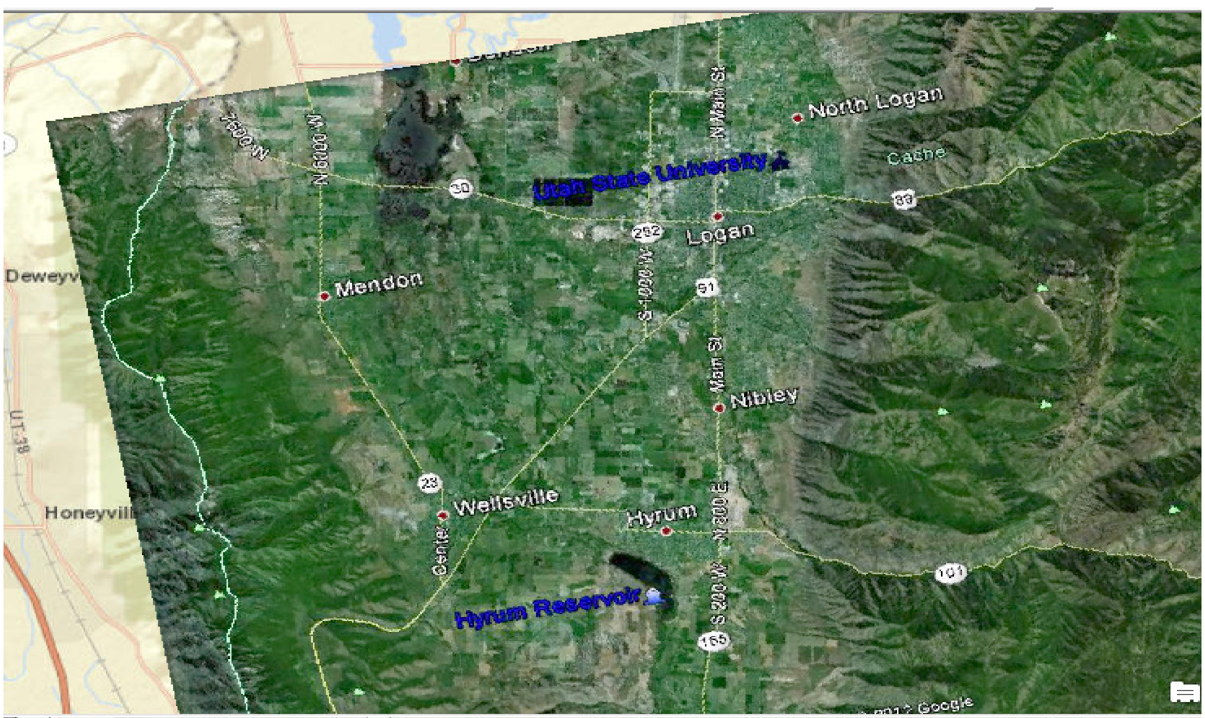

Figure 1: Location Map

Watershed Delineation

To properly analyze the ability of Hyrum Reservoir to help with flood control, the watershed must be known. In order to calculate the watershed, several different functions in ArcMap were used. The first step was to find a Digital Elevation Model (DEM). The USGS Earth Explorer interactive map was used to find a DEM for the area near Hyrum Reservoir. The DEM was clipped to make it easier to work with, but it was larger than the anticipated watershed area to ensure that the entire watershed would be contained. It was originally thought that DEM had 30 meter grid spacing, but it was later determined that the grid spacing was 30 arc second spacing or roughly 1 km spacing. This may lead to a lack of accuracy over the process.

The following steps were used in delineating the watershed. First, the Fill tool was used to fill all of the pits in the DEM. Once the pits were filled, the Flow Direction tool was used to establish a grid that calculated the direction water would flow from each cell. The Flow Accumulation tool took the flow direction output and summed all the cells to show where water accumulates as it flows downhill from grid to grid. The watershed was then established by creating a shapefile at the inlet to Hyrum Reservoir and using the Watershed tool in GIS. The final output shows the delineated watershed for Hyrum Reservoir. The Raster Calculator tool was then used to show all cells which had a flow accumulation value greater than 25. The Stream Link tool was then used to give each segment in the stream a specific value.

The watershed was then broken into catchments for the watershed. The raster data was also converted to a polygon feature by using the Raster to Polygon tool. This was important because the geometry of each polygon could then be calculated, giving the contributing area of the watershed. The stream links were also converted to features using the Stream to Feature tool. The Strahler Stream Order method was used in GIS to show smaller tributaries flowing into larger ones. Figure2 on the following page shows the watershed for Hyrum Reservoir with its subcatchments and the stream orders that drain into the reservoir.

Once the watershed was properly delineated, the Raster to Polygon conversion tool was used to change the data from a raster format to a polygon. This was important for calculating the area of the watershed, which was done by creating a new field in the attribute table. The area was then calculated using the Calculate Geometry function in the Attribute Table. The total area of the watershed was calculated to be 312.7 square miles.

In order to easily delineate watersheds in the future, a Model Builder was created in GIS. This was done by creating a new Toolbox and then adding a model within the toolbox. Within the model, a DEM and shape file were inserted as inputs for certain tools. Tools were then inserted which used the input data and created outputs. The model builder then took the outputs from these tools and used them as inputs for other tools. The final network of this model builder can be seen in Appendix A.

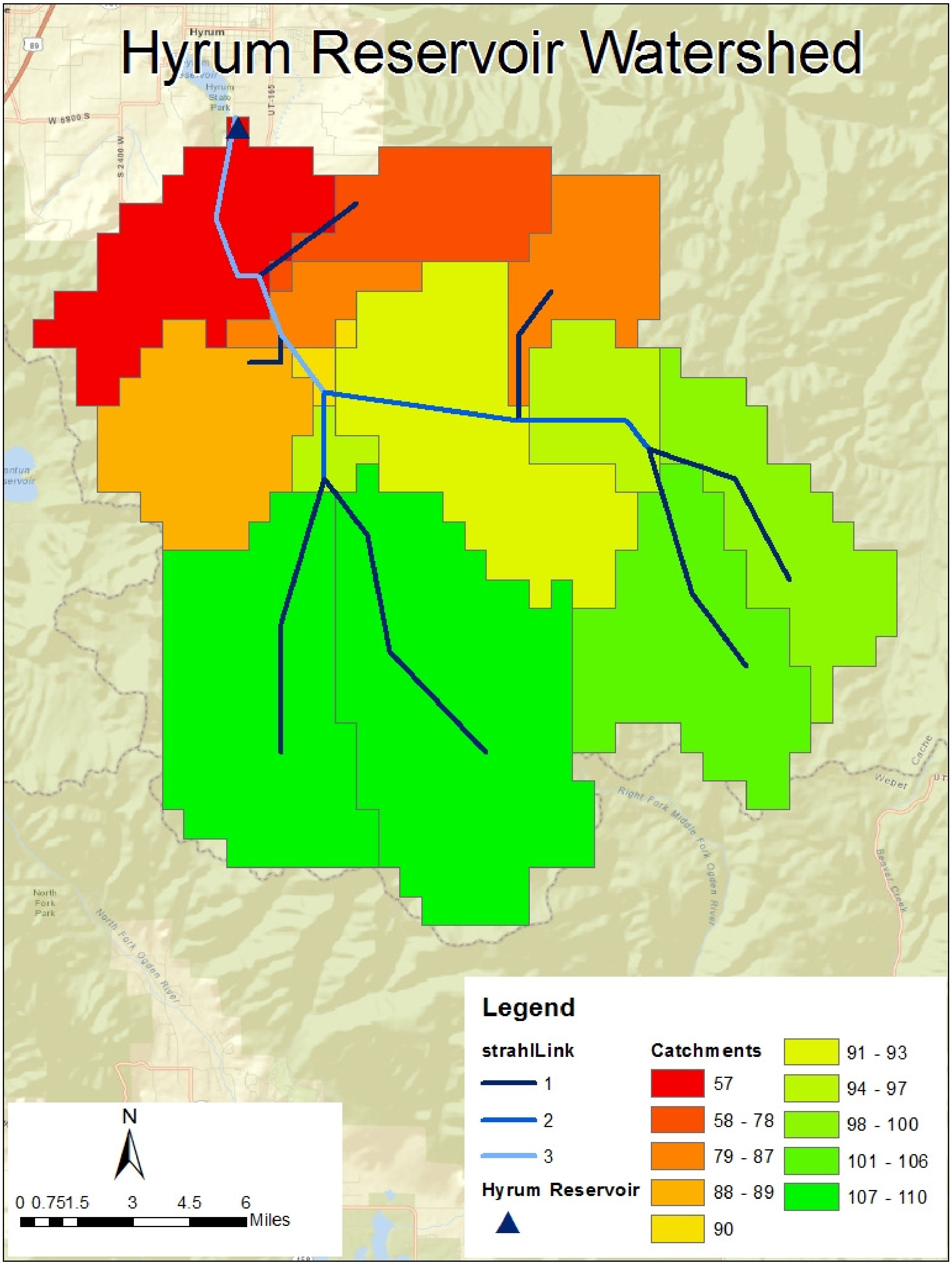

Figure 2: Hyrum Reservoir Watershed with Strahler Stream Orders

Stream Flows

In order to understand the ability of Hyrum Reservoir to help with flood prevention, the maximum flow in the river must be known. The USGS has thousands of stream gages located throughout the United States. In order to find the stream gages that were within my watershed, a KMZ file of Utah was downloaded from the USGS website and converted to a feature class in GIS using the KMZ to Layer tool. A map showing stream gages located in the watershed can be seen in Appendix B.

One important assumption to note is that the flows read at the Little Bear River at Paradise, Utah gage are the flows assumed to enter Hyrum Reservoir. Data for this site was collected starting in the year 2000 and going to the present year of 2012. This data was imported into Excel, and the total flow from March 1 to July 31 was calculated. This time frame was chosen to capture the entire peak of the runoff season. The maximum volume of stream flow was 114,169 acre-ft in 2011. The daily flow rates can be seen in Figure 3 starting with the year 2000. Observation of Figure 3 shows that although the largest volume of water occurred in 2011, the maximum peak in flow occurred in 2005. As it is unclear which of these two years has the highest risk of flooding, both years will be analyzed in evaluating Hyrum Reservoir as a flood control device.

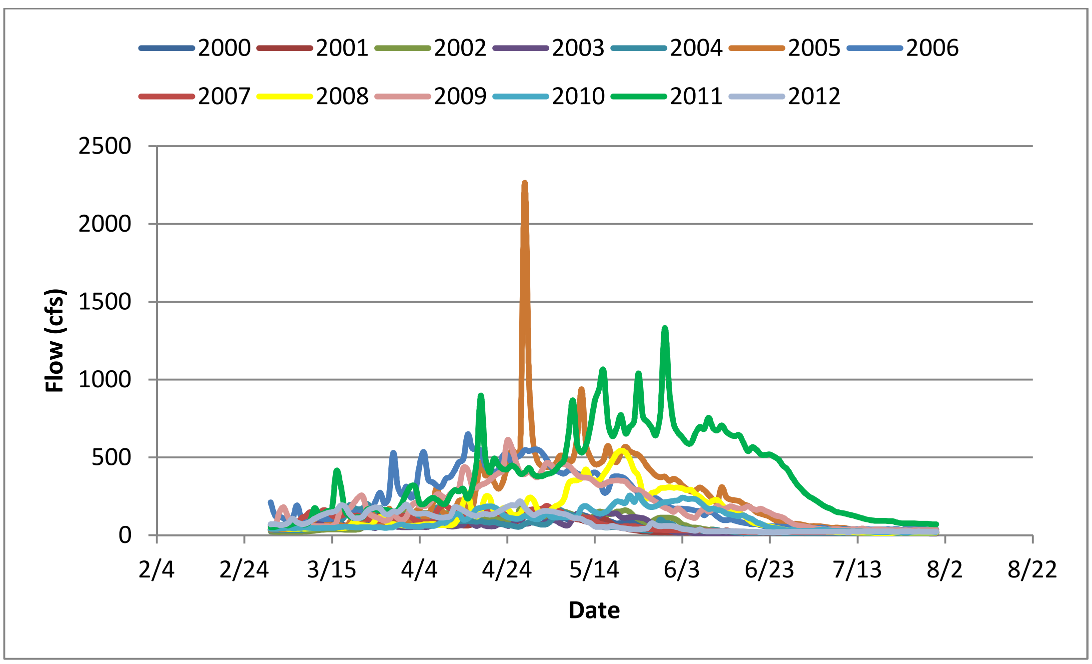

Figure 3: Stream Flow Data for the Little Bear River at Paradise, Utah Gage

Snotel Sites

Snotel data was found using the NRCS website. Six different snotel sites were chosen in the area of the Hyrum Reservoir Watershed. These sites were chosen to maximize the range of elevations so that the Snow Water Equivalent (SWE) values could be interpolated according to the elevation. This was done by taking the data for a single day and performing linear regression to create an equation. In doing this, it was found that the site to the southwest had much higher SWE values although it had the minimum elevation. It is supposed that this site was on the opposite side of the mountain and for this reason received much more snow than the other sites. A graph of the SWE data for 2010 shows the point with the lowest elevation as having the highest SWE value. This snotel site was therefore not included in any of the analysis performed.

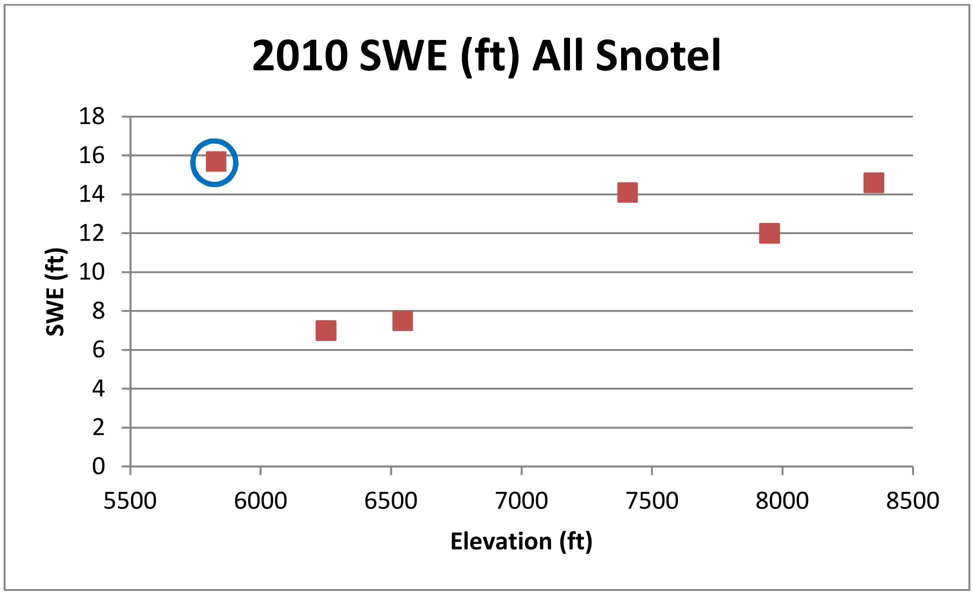

Figure 4: Outlying Snotel Site

Linear regression was performed for three separate years in the time frame considered from 2000-2012. Those are the years having the least, middle, and maximum SWE values. The years selected were 2003, 2010, and 2011. It can be seen in Figure 5 that SWE values vary a great deal from year to year as well as from site to site. This leads me to believe that calculating SWE values is much more complicated than presented here. This method of calculating SWE is a rough estimate to get a general idea of how it affects the runoff. SWE values are dependent on such things as temperature, density of the snow, drifting, weather patterns, slope, etc. For the purpose of this report, only elevation was considered in calculating SWE values. Figure 5 shows the linear regressions performed for all three years. The graphs on the left represent the use of all five snotel sites, whereas the graphs on the right removed the single most outlying point for each set of data.

It was decided to use the set of data that included the outlying point as it is a more complete data set. The equations shown in the graph were then used to calculate the SWE value at the mean elevation of 7300 feet which will be referred to as SWE_r. The equation used was $SWE = SWE_r + x*(z-zr)$, where x is the slope of the linear regression for each day, z is the elevation of a given point, and zr is the average elevation of 7300 ft. Entering the equations calculated through the linear regression into the Raster Calculator tool and using the DEM data, the SWE values were interpolated across the entire watershed. A figure for each year with its accompanying SWE values can be seen in Appendix C. It should be noted that due to the nature of the equations, negative values were calculated. As SWE values will never be negative, all values less than zero were assumed to be zero.

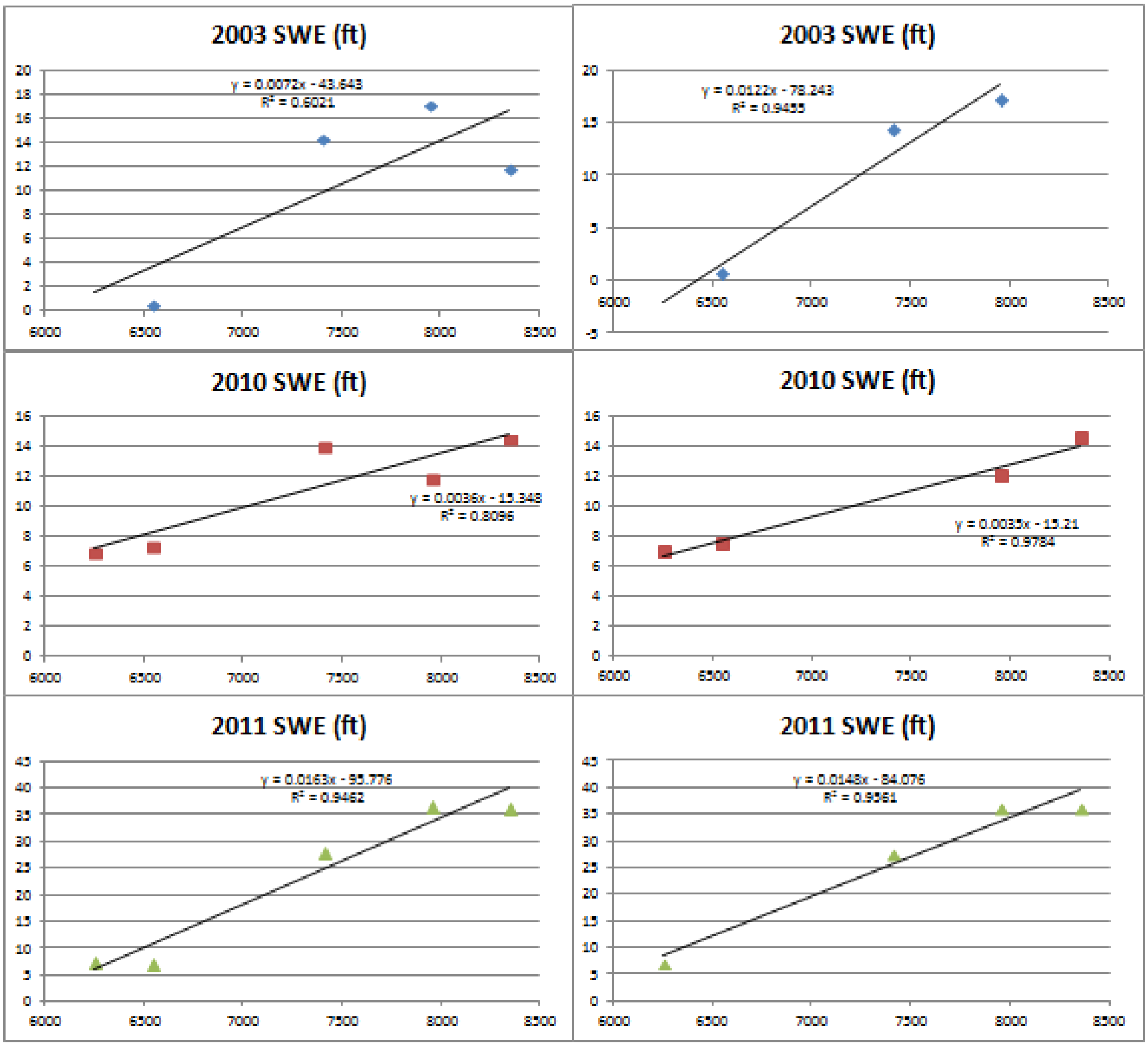

Figure 5: Linear Regression of SWE Data used to Calculate SWE as a function of Elevation

<u>SWE Runoff versus Stream Flow</u>

Floods in the Hyrum Watershed are typically caused from snowmelt. The ratio of the total runoff that is attributed to Snow Water Equivalents can be calculated using the following Equation. It is important to note that this method neglects all other forms of precipitation that is not part of the snow pack.

$$Snowmelt\ Runoff\ Ratio = \frac{Stream\ Flow * time}{Average\ SWE * Area} \tag{1}$$

The average SWE data were collected from the properties table in GIS for each of the SWE datasets. The area that had SWE values greater than zero was then calculated for each of the three years. The Raster Calculator tool was used to calculate all SWE values greater than zero, and then the raster data was converted to a polygon. The geometry of the polygon was then calculated, and the area was found in acres. The results of these calculations can be found in Table 1.

The stream flow data for each day was converted from a flow rate to a volume by multiplying the flow by the time. These volumes were summed over the time period of March 1 to July 31. Equation 1 was then used to calculate the ratio of the snowmelt that actually makes it into the river. The results of this data can be found in Table 1 below.

	SWE (ft)	Area (Ac)	Volume (Ac*ft)	Flow Rates (cfs)	Volume (Ac*ft)	SWE Ratio
2011	9.80	138222	1354985	7604.8	114168.595	0.0842582
2010	7.97	200149	1594991	14590	28938.84298	0.0181436
2003	0.67	4835341	3244514	57560	15083.90083	0.004649

Table 1: Ratio of SWE in the form of Stream Flow

The results show that during a wet year more water makes it into the river than during a dry year. One reason for this may be that the ground will become saturated sooner allowing for more water to runoff into the streams rather than infiltrate. The ratio is, however, lower than I would have expected it to be. Some possible reasons for this may be due to infiltration over the watershed or irrigation upstream of the Little Bear River at Providence, Utah gage.

<u>Hyrum Reservoir</u>

In the past 12 years two major flow events have occurred in the watershed draining into Hyrum Reservoir. In order to evaluate Hyrum Reservoirs ability to help with flood control, the Little Bear River at Paradise, Utah gage was used to calculate inflows.

The next step was to develop a storage-elevation curve. The data used to develop this curve was found on the United States Bureau of Reclamation's (USBR) website. The streambed as it enters the reservoir has an elevation of 4590 feet while the maximum water level in the reservoir is 4672 feet. The other values were found from a water resources report done by the USBR. The stage-storage curve can be seen in Figure 6 below.

Elevation (ft)	Storage (AF)
4590	0
4649.62	5524
4651.43	6137
4655	7399
4659.55	9126
4661.2	9785
4672	18685

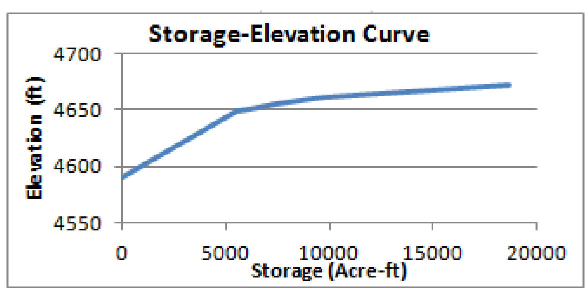

Figure 6: Storage-Elevation Curve and Table

Hyrum Reservoir releases water through an outlet works as well as a spillway. The outlet works are located at an elevation of 4666 feet and has a capacity of 300 cfs. The spillway has a maximum capacity of 6000 cfs at an elevation of 4672 feet. With the use of these two structures, reservoir releases flow to users downstream. In the case of a flood, both features will be used at capacity to release water. This means that the reservoir will fill until it reaches the elevation of the outlet works; then it will release up to 300 cfs, yet keeping the minimum elevation at the low-level outlet works. As the reservoir continues to fill, it will reach the spillway elevation at which it will release up to 6000 cfs more giving a maximum release of 6300 cfs. A set of if-then statements were used in developing an excel spreadsheet that routed the stream flows through the reservoir. These if-then statements can be seen in Table 2 below.

If	Then
Initial Storage < Storage at Outlet Works	Ending Storage = Initial Storage + Inflow
Initial Storage >= Storage at Outlet Works < Storage at Spillway	Ending Storage = Initial Storage + Inflow - Outflow (Maximum of 300 cfs)
Initial Storage >= Storage at Spillway	Ending Storage = Initial Storage + Inflow - Outflow (Maximum of 6300 cfs)

Table 2: If-then statements used to calculate the reservoir storage

For the purpose of this report, it is assumed that the reservoir begins at an elevation of 4666 feet or at the outlet works. Using the excel spreadsheet, Figure 7 shows how Hyrum reservoir was able to handle each flood event. The 2005 event had a maximum flow of 1253 cfs, while the maximum flow in 2011 was 1330 cfs. In 2005 the maximum inflow was 2260 cfs, while the maximum outflow was only 1253 cfs. However, in 2011 the maximum inflow and outflow were both 1330 cfs. Figure 8 shows that in both years there was a long period of time where the storage remained constant as the inflows exceeded the capacity of the outlet works, and the excess was released over the spillway. This shows that Hyrum Reservoir has a relatively small effect on flood control over the watershed.

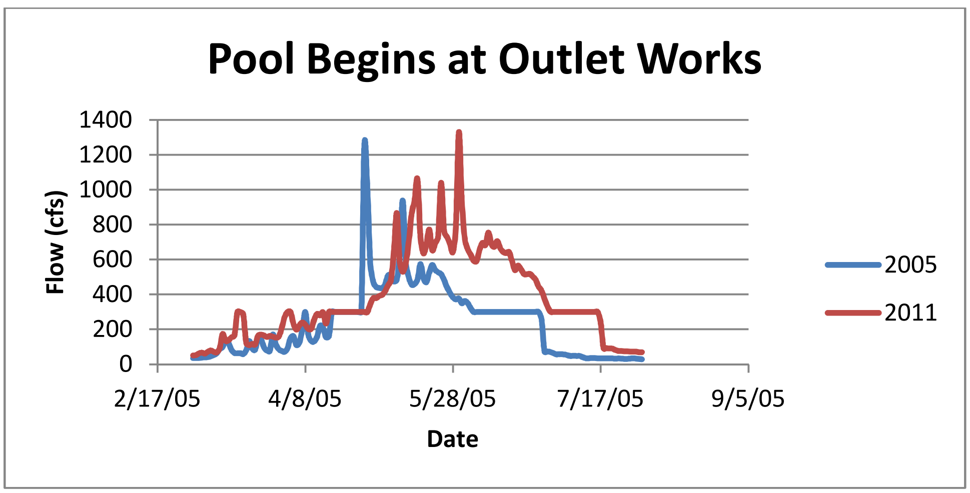

Figure 7: Flow versus Time Graph

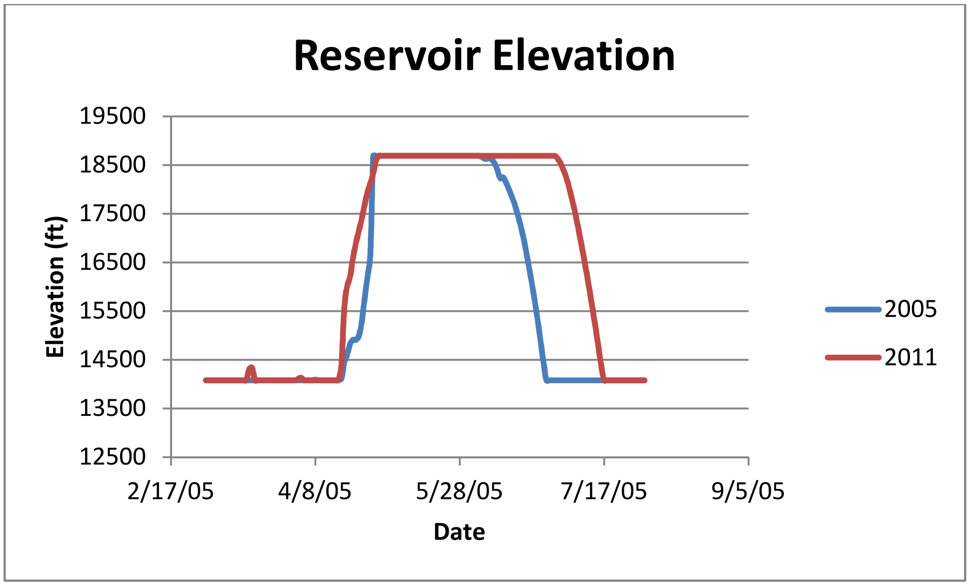

Figure 8: Reservoir Elevation versus Time Graph

Conclusion

The watershed was delineated for the Hyrum Reservoir. It was however determined that the DEM lacked precision. A more accurate DEM such as a 10 meter or 30 meter DEM would be recommended for future studies. Data from a stream gage just upstream of Hyrum Reservoir was gathered and it was seen that 2005 and 2011 posed the biggest risk of flooding. Snow Water Equivalent Data was collected and used to estimate SWE values, as a function of elevation, over the entire watershed.

A ratio of the Stream Flow versus SWE data was calculated and found to be greater in years having higher SWE values. This is as expected as the ground would become saturated and allow for more runoff. The ratios were however lower than expected. Possible reasons for this may have been due to infiltration or irrigation.

Stream flow data was routed through the reservoir to investigate the ability of the reservoir to help with flood control. The worst case for flooding occurred in 2011 when the inflow and outflow both were 1330 cfs. This shows that Hyrum Reservoir is not a major factor in preventing major floods.

Appendix A: Model Builder

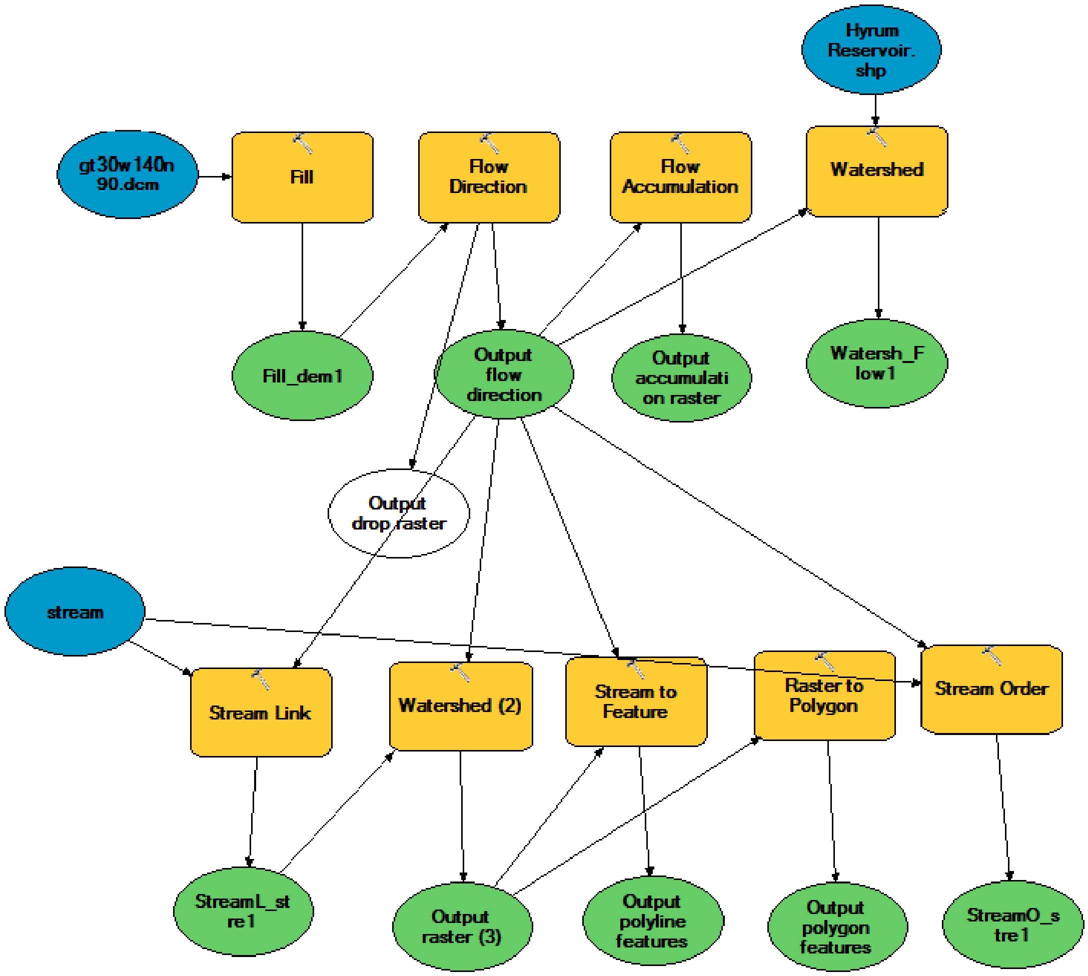

Figure A-1: Model Builder Diagram

Appendix B: Stream Gage Map

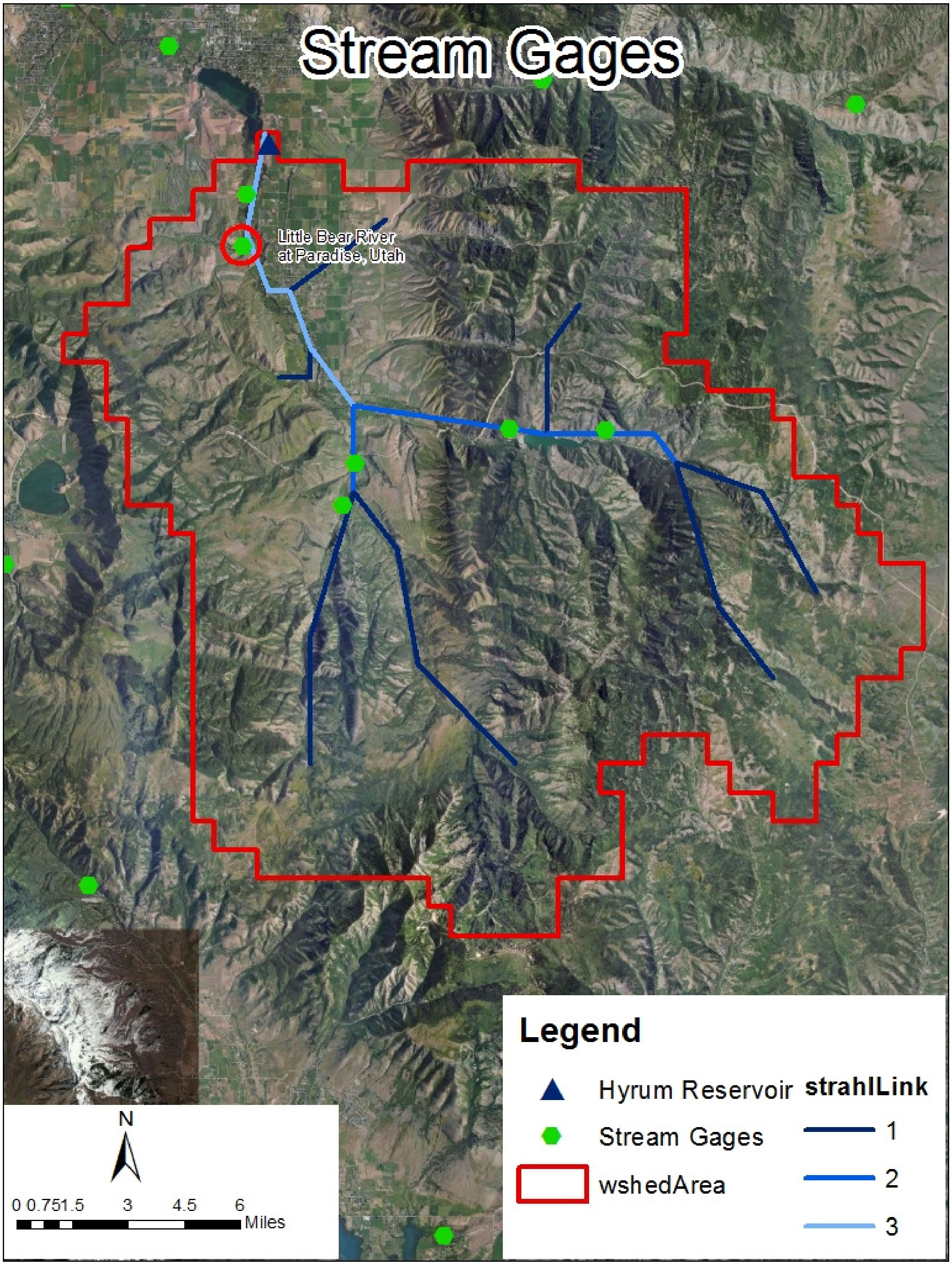

Figure B-1: Stream Gages near Hyrum Reservoir

Appendix C: Snow Water Equivalent Interpolations

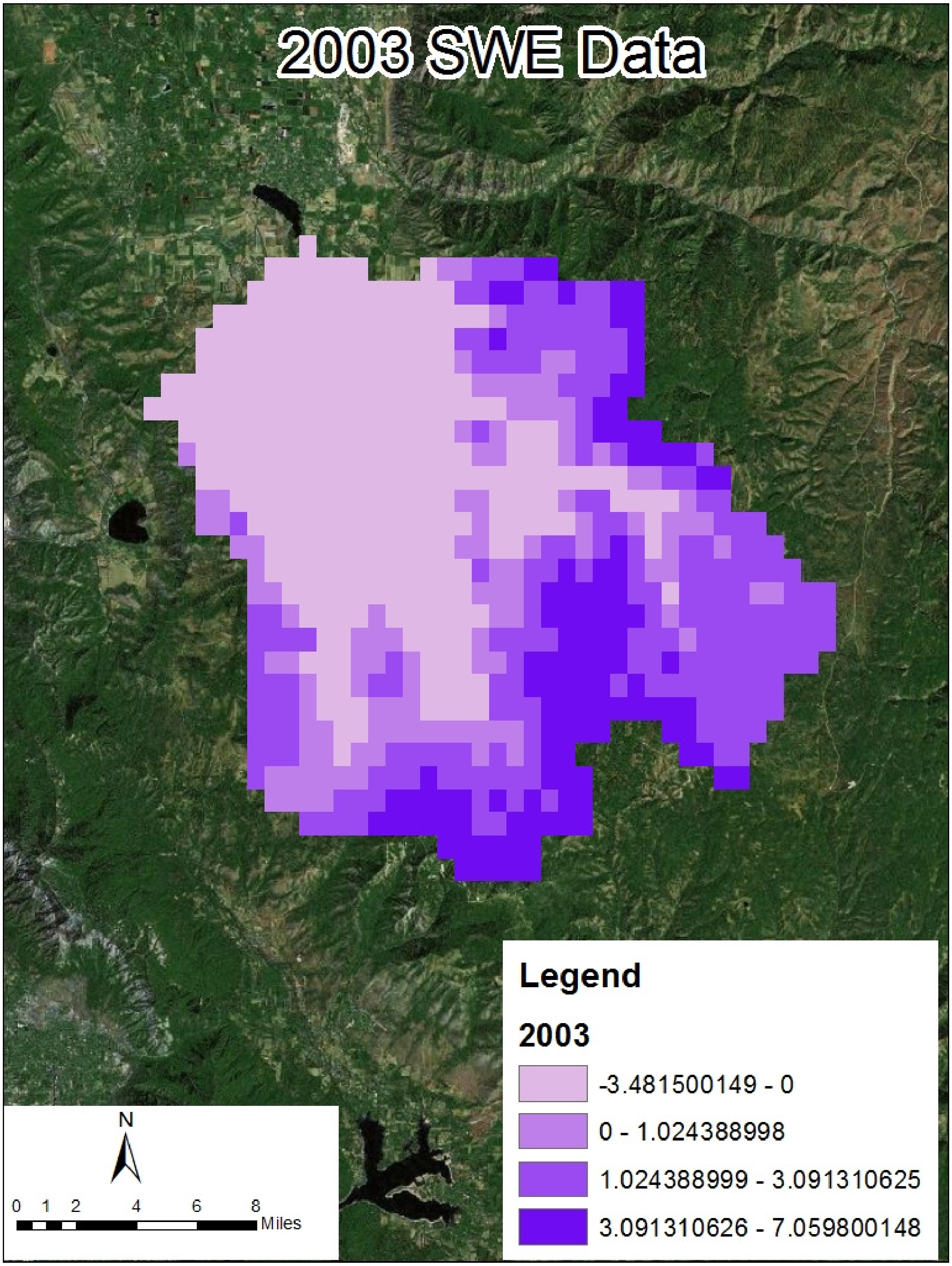

Figure C-1: 2003 SWE Data

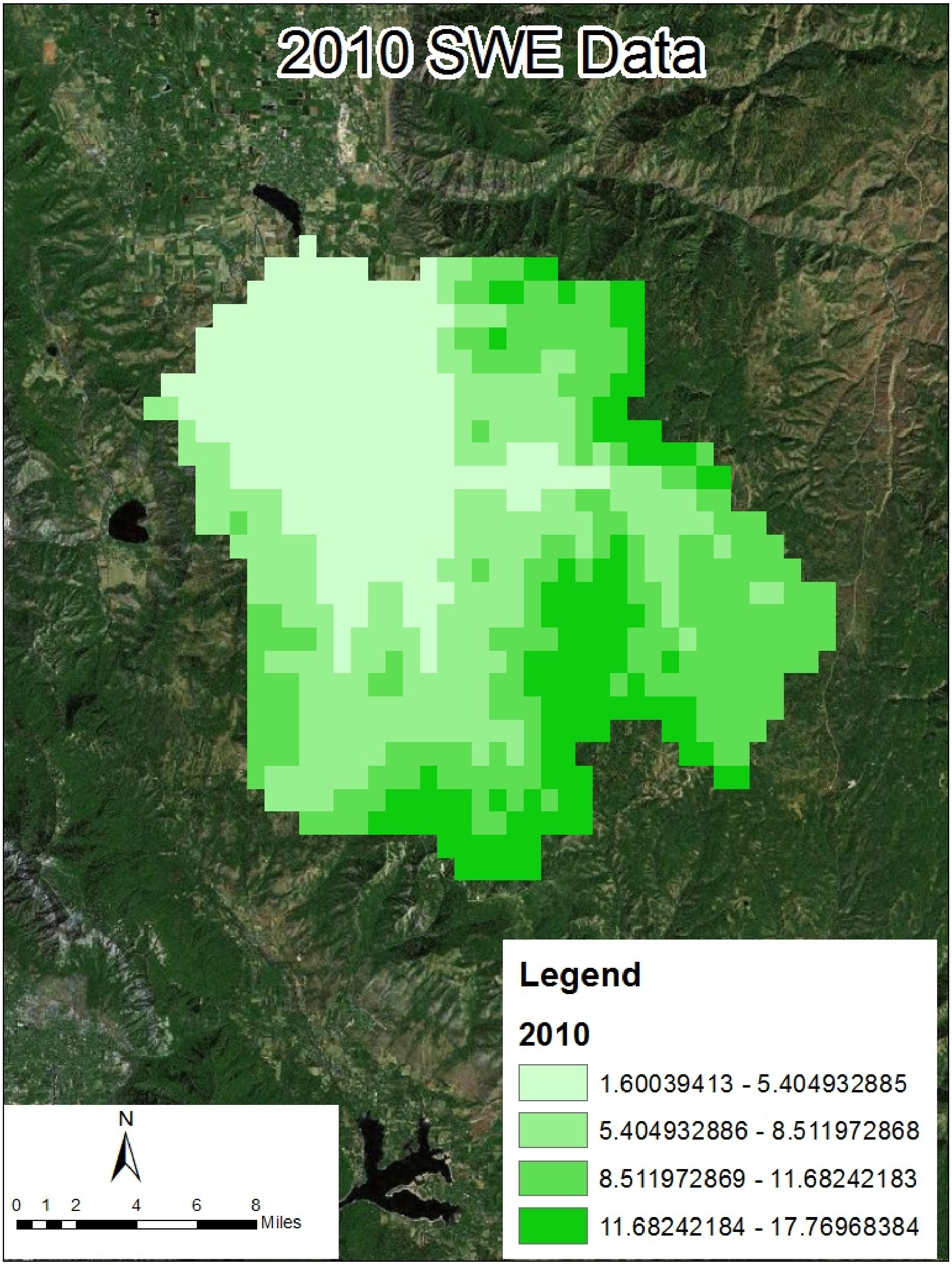

Figure C-2: 2010 SWE Data

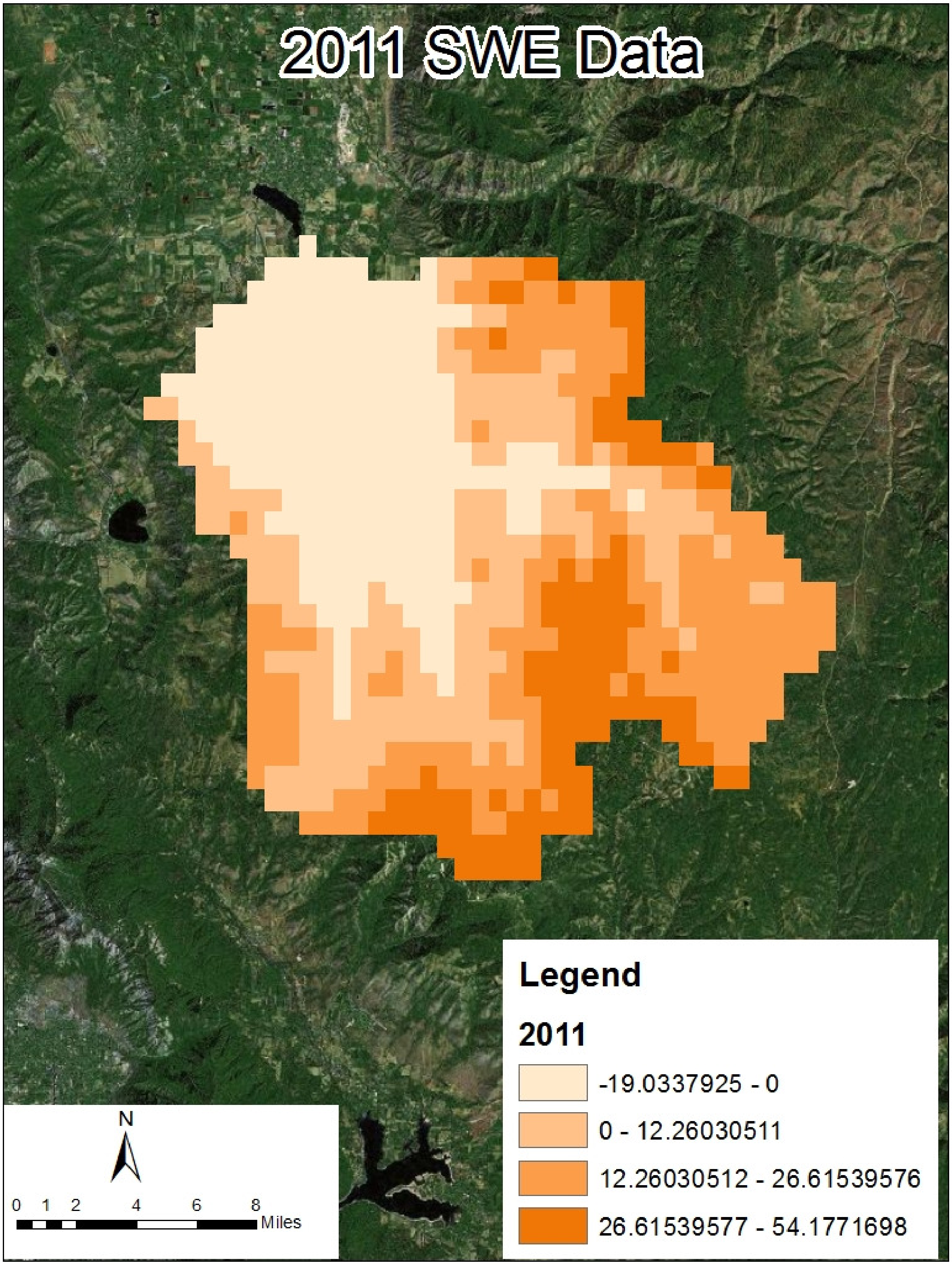

Figure C-3: 2011 SWE Data