Flow Prediction on the Yampa River

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Introduction

The Yampa River is said to be one of the last 'wild rivers' in the West because it only has a few small diversion structures. There is no way to control the spring runoff from the Yampa River Basin. During the spring months of a heavily precipitated winter, the high water levels that flow out of the Yampa River Basin pose a large threat upon land owners downstream. Downstream of the confluence of the Green and Yampa Rivers has a great risk of flooding during the high water years. Therefore, the focus of this term project is to explore the historical data from the Yampa River Basin to be able to predict the peak flow in the Yampa River. This will allow land owners downstream to prepare for the high water that may be coming their way and to take necessary measures to prevent property and facility damage due to flooding activity.

Description

The Yampa River is located in the North-West corner of the state of Colorado (Figure 1). It flows into the Green River on Dinosaur National Monument land near the Utah-Colorado border. After the Yampa flows into the Green River, the Green River flows along the East side of the state of Utah before eventually flowing into the Colorado River in Canyonlands National Park near Moab, UT.

Figure 1

Location of the Yampa River

The Yampa River Basin consists of about 8,260 square miles. The majority of the basin is located in Colorado while a lesser portion spans into Wyoming (Figure 2).

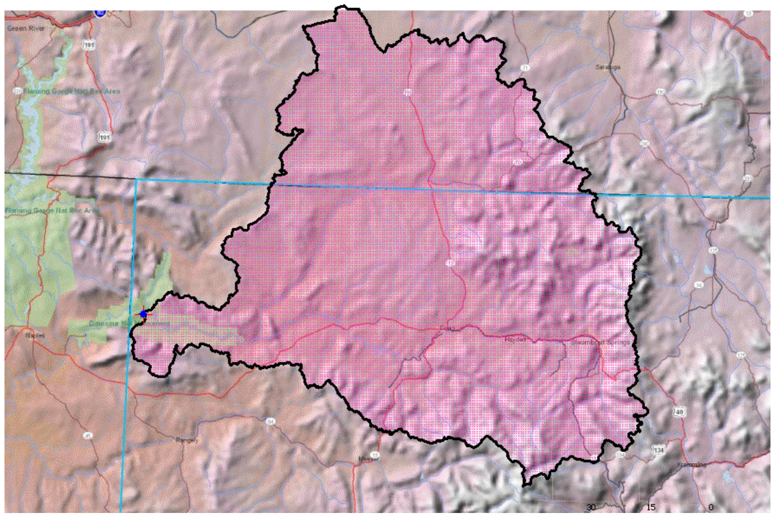


Figure 2
Yampa River Basin (StreamStats)
(USGS 2012a)

Objectives

The main objective of this project is to analyze historical data in order to be able to predict the peak flow that will be expected in any given year for the Yampa River. ArcMap and Excel will be the main programs used in this project. The following tasks will need to be completed in order to reach the main objective:

- Study area defined in ArcMap
- Digital Elevation Model (DEM) data found and mapped in ArcMap
- SNOTEL site locations and data found and analyzed in ArcMap
- Determine max Snow Water Equivalent (SWE) for each historical year for each SNOTEL site
- Find a linear relationship relating elevation to max SWE for each SNOTEL site
- Stream Gage data collected for the outlet of the Yampa River Basin
- Determine annual peak flow for the Yampa River near the outlet of the basin
- Interpolate max SWE across the basin for each year

- Determine the mean SWE (from max values) across the area of the basin that is above the average snow line (determined from the relationship of elevation and max SWE)
- Determine SWE vs. Peak Flow Relationship to predict future peak flows

Methods

The Yampa River Basin boundary was determined using USGS's streamstats tool for Colorado (USGS 2012a). This boundary was downloaded from streamstats as a shapefile and then added into ArcMap along with major rivers in the basin (Figure 3). Many different clip and extract tools (depending on what layer needed to be edited) were used in order to cut large quantities of data to within the basin boundary as can be seen in Figure 3 with the major US Rivers.

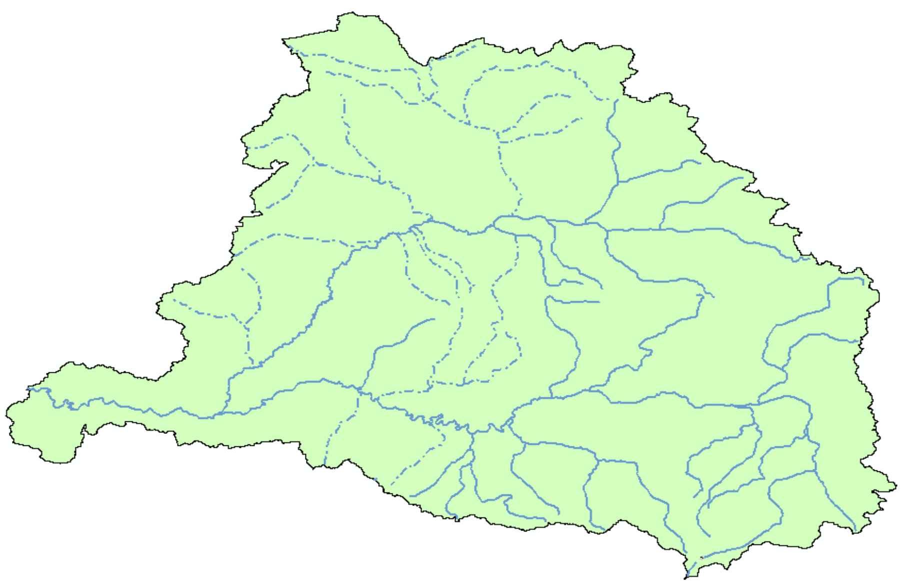


Figure 3

Yampa River Basin Shapefile (ArcMap)

The Yampa River Basin is split into four HUC8 subwatersheds and is depicted in Map 1 in Appendix A. The four subwatersheds include the Upper Yampa, the Lower Yampa, the Little Snake, and the Muddy. The boundaries for these subwatersheds were found using the National Map Viewer (USGS 2012b).

Digital Elevation Model (DEM) data was found from the USGS's National Map Viewer (USGS 2012b). This data came in 12 different datasets and was compiled together in ArcMap using the mosaic tool in the data management section of the toolbox. The result is shown in Map 2 of Appendix A.

SNOTEL data for the Yampa River Basin and surrounding areas was found using HydroDesktop (CUAHSI HydroDesktop 2012). A total of 28 SNOTEL sites were analyzed; nine of which were within the Yampa River Basin. Daily SWE historical data from 1984 to 2012 was gathered from each of the SNOTEL sites in order to find the max SWE for each site for each year. Table 1 shows the data for the nine sites within the basin. However, the data for all 28 sites was added to the SNOTEL layer in ArcMap to use for interpolating the SWE over the basin. This was done by adding a field for each year to the attribute table and manually entering the max SWE for the given site and year. The nine SNOTEL sites within the Yampa River Basin were further analyzed to find an average elevation for the snow line throughout the basin. The elevation for each site was found by using Extract Values to Points tool in ArcMap; values were taken from the DEM layer.

Table 1

Max Yearly Snow Water Equivalent (SWE)

	Location								
Elevation (m)	2902	2780	2423	2267	2792	2969	2681	2692	2267
Year	RABBIT EARS	LITTLE SNAKE RIVER	SANDSTONE RS	BATTLE MOUNTAIN	ELK RIVER	LOST DOG	DRY LAKE	CROSHO	WHISKEY PARK
	SWE (inches)								
1984					26.8				
1985					21.1		25.3		
1986			17.6	11.9	23.6		26		
1987	18.1		10.1	7.5	13.3		14.2	9.2	18.6
1988	26.4		13.9	9.7	20.8		25.8	15.5	35.1
1989	27.3		13.1	13	19.8		22.1	11.7	31.4
1990	24.6		11.6	9.4	22.3		23.9	12.3	24.5
1991	31.5		13.7	11.7	18		22.2	10.9	27.7
1992	23.8		10.7	9.6	13.6		15.7	9	19.6
1993	39		17.7	14.2	23.5		30	16.7	35
1994	23.7		13.4	9.3	16.7		17	12.7	25.2
1995	39.5		14.2	10.6	22.6		23.6	13.3	34.7
1996	42.6		18	11.4	23.1		29.6	20.3	38.9
1997	47.2		20	17.6	30.2		27.6	14.5	46.5
1998	32.9		15.1	13.2	18.8		20.9	11.4	31.6
1999	29		15.3	13.1	17.9	24	18.3	9.7	32.9
2000	32		14.7	12.4	19.7	24.3	24.1	13	25.1
2001	23.1		13.4	10.8	17.6	22.1	19.2	11.1	26.8
2002	17.2		8.8	11.6	15.2	18.4	18.8	9.3	20.2
2003	32.3		14.4	13.1	19.1	24.9	22.4	15.2	31.9
2004	21.6		10.6	14.1	17	20.6	19	11.7	25.2
2005	23.4	24.5	14.1	13.6	22.5	25.3	21.4	9.8	28.4
2006	38	36.2	16.9	14.3	21.5	29.3	24.7	16.3	42.9
2007	22.7	19.1	10.3	9.1	16.8	21.2	18.7	9.1	21.4
2008	38	31.9	20.4	18.5	29.8	31.3	28.7	19.4	39.7
2009	32.8	34.8	21.9	18.9	24	31.8	24.9	15.6	35.6
2010	19.2	29.1	16.2	12.6	20.8	25	19.4	11.6	29.9
2011	51.6	41.3	23.3	15.2	30.8	45.5	37.6	19.1	44.3
2012	15.2	19.8	11.1	11.2	14.8	16.6	14.7	9.8	20.7

The max SWE at each site was plotted vs. the elevation for each year. The years 1984 and 1985 were not considered due to the lack of SNOTEL data during these years. A linear line of best fit was adapted to each of the graphs. The equation that fit each line was used to find the elevation where the SWE equaled zero for the year. Over the 27 year period, the minimum elevation found was 1841 m while the maximum was 2256 m. The average snow line elevation was calculated to be 2116 m. An example of this procedure is shown in Figure 4 for the year 2011. This will be used in ArcMap to analyze the interpolated SWE values over the area in the basin that is above the elevation 2116 m. The Whiskey Park SNOTEL site had smaller SWE values at higher elevations and as a result skewed the data significantly. Therefore, the Whiskey Park data was removed from all the plots to give a more correct fitting to the lines. The Whiskey Park data also was not used in the ArcMap analysis of the project.

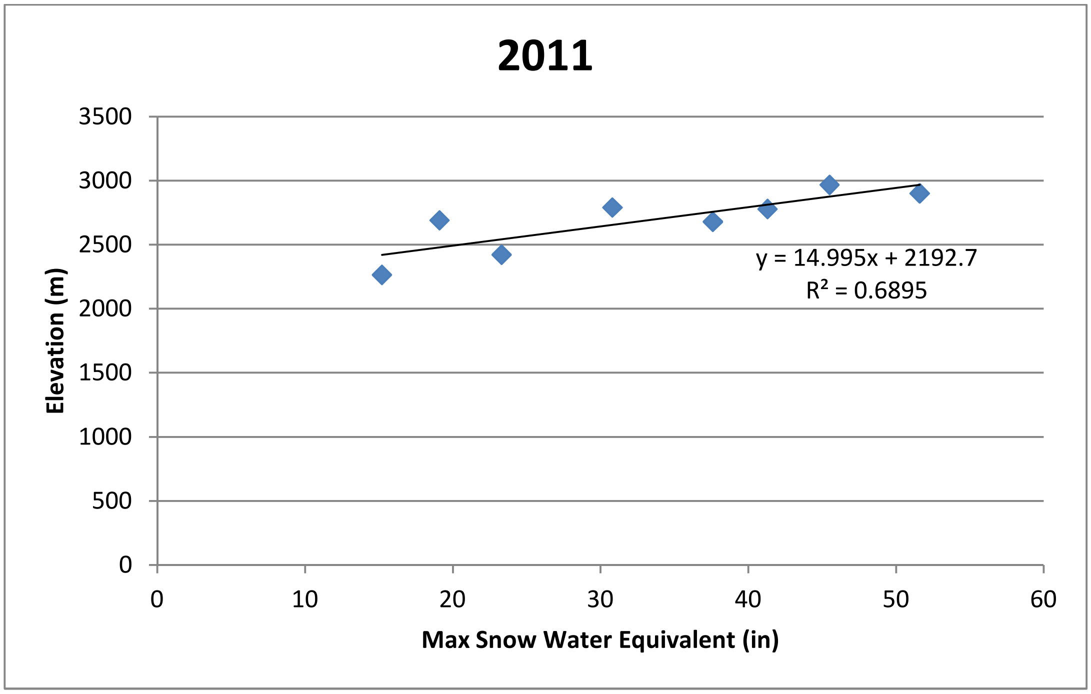


Figure 4

2011 SWE vs. Elevation

Map 3 of Appendix A shows the 27 SNOTEL sites after removing Whiskey Park from the data. Very few sites close to the study area were found north of the basin and therefore may cause uncertainty in the analysis. It is clear after comparing Map 2 and Map 3 in Appendix A that the SNOTEL sites are found at higher elevations in the area.

Stream gage data at DeerLodge Park on the Yampa was examined to determine the annual peak flow. DeerLodge Park is located shortly upstream the Yampa from the confluence of the Green River. The gage is the closest gage to the end of the Yampa River Basin before it flows into the Green River. The data was gathered from The National Weather Service's Colorado Basin River Forecast Center (USGS 2012c).

In ArcMap the Raster Calculator tool was used to create a layer that showed the part of the Yampa River Basin that had an elevation higher than the average snow line which was found to be 2116 m in our SWE vs. elevation analysis. This area is depicted in Map 4 of Appendix A. Map 5 also found in Appendix A shows this higher elevation divided into the four HUC8 subwatersheds. The layer shown in Map 5 was created using the Extract by Mask tool in spatial analyst to divide the raster set defined by the area above 2116 m elevation into the four separate HUC8 subwatersheds.

The max snow water equivalent for each year of the 27 SNOTEL sites was added into ArcMap in the attribute table of the SNOTEL layer using the editor toolbar. Once this data was added to the layer in ArcMap, interpolation of the snow water equivalent across the basin was performed. The Spline Interpolation tool from the Spatial Analyst toolbox was used to perform the snow water equivalent interpolation. This was calculated for each year, from 1984 to 2012. Year 2012 was first interpolated and can be seen in Map 6 of Appendix A. After the interpolation was completed, the Zonal Statistics as Table tool was used to export the statistics from the interpolated SWE layer into an excel file to find the mean SWE across the basin. The map layer that only contained the area above the 2116 m elevation was used as the zone, therefore the mean SWE would only take into consideration the area above the snow line. Otherwise the interpolated SWE in the areas below 2116 m would be considered and this would create inaccuracies in the mean SWE value due to the fact that those areas were assigned negative SWE values in the interpolation.

In order to speed up the process of using the spline tool to interpolate the SWE over the basin for each year and exporting the data to an excel file with the zonal statistics as table tool, a tool was created using Model Builder to perform all these steps at once. The input to the spline tool was set to be the feature class that contains the max snow water equivalent data with the option to change the year field. The output for this tool is the input to the Zonal Statistics as Table tool with zones being the entire basin, the HUC8 divided basin, and the area above 2116 m elevation. The later is the only one needed for the analysis however the other two were created to view the difference in mean SWE when the negative SWE values were included. The model builder outline for this new tool can be seen in Figure 5.

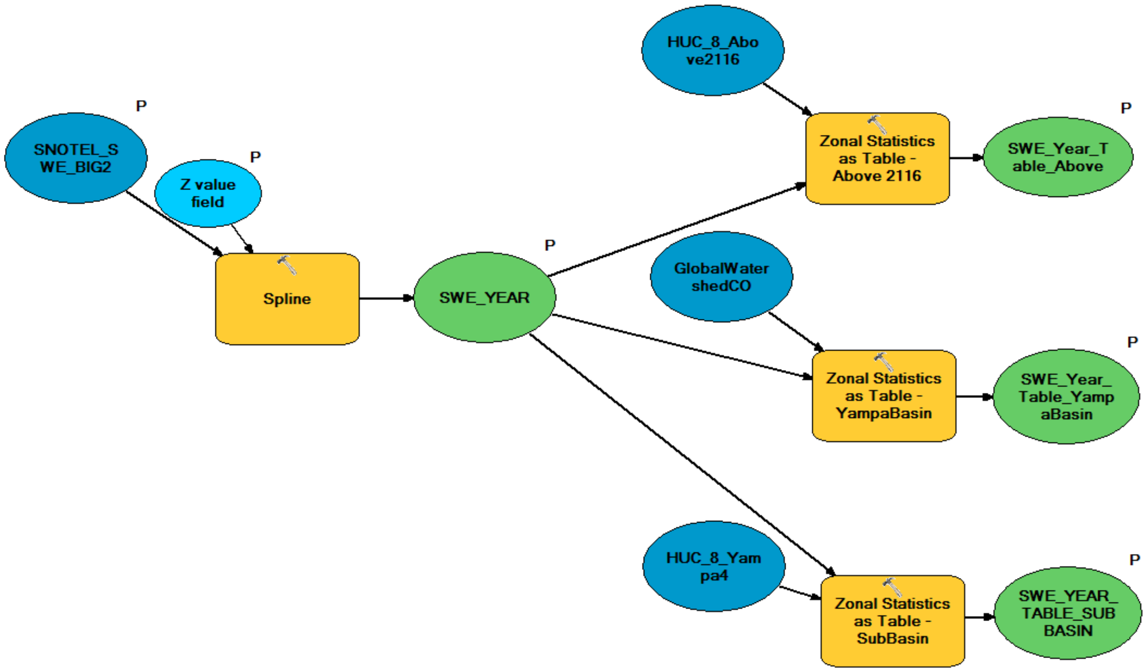


Figure 5

Model Builder Outline View of Custom Tool

The custom tool depicted above in Figure 5 was used to interpolate SWE and export the results to Excel for the remaining years of the study. The maps (Maps 7-32) for these years can be found in Appendix A. Maps of the 1984 and 1985 SWE interpolations were not included in the maps in Appendix A due to lack of SNOTEL data for those years at some of the sites.

Results and Discussion

The mean snow water equivalent over the area of the Yampa River Basin that is above 2116 m in elevation was compiled in Excel from the output data that was exported when the model builder was run for each year. Table 2 shows the corresponding max SWE values that would result if the entire Yampa River Basin area above the elevation of 2116 m had the same SWE. Also shown in Table 2 is the Peak Flow for the Yampa River for each year.

Table 2

Max SWE & Peak Flow

Year	Max Yearly Value	
	SWE (in)	Q (cfs)
1985	11.55	18500
1986	2.30	16900
1987	7.08	7990
1988	9.63	14500
1989	11.81	6150
1990	9.37	9960
1991	10.45	9910
1992	10.82	7120
1993	15.15	16400
1994	9.43	7670
1997	18.95	20400
1998	14.16	14100
1999	10.73	14300
2000	10.04	11700
2001	10.04	9760
2002	11.71	3810
2003	12.91	16200
2004	12.52	7290
2005	11.51	15600
2006	12.36	14400
2007	9.87	8400
2008	18.38	22300
2009	15.45	16300
2010	10.84	17400
2011	14.35	27400

In order to predict future peak stream flows for the Yampa River, the interpolated max snow water equivalent across the basin will be plotted in relation to the peak stream flow. With this relationship established the peak flow in future years in the Yampa River can be predicted once the max SWE across the basin has been determined. This relationship has been plotted and is presented in Figure 6 below.

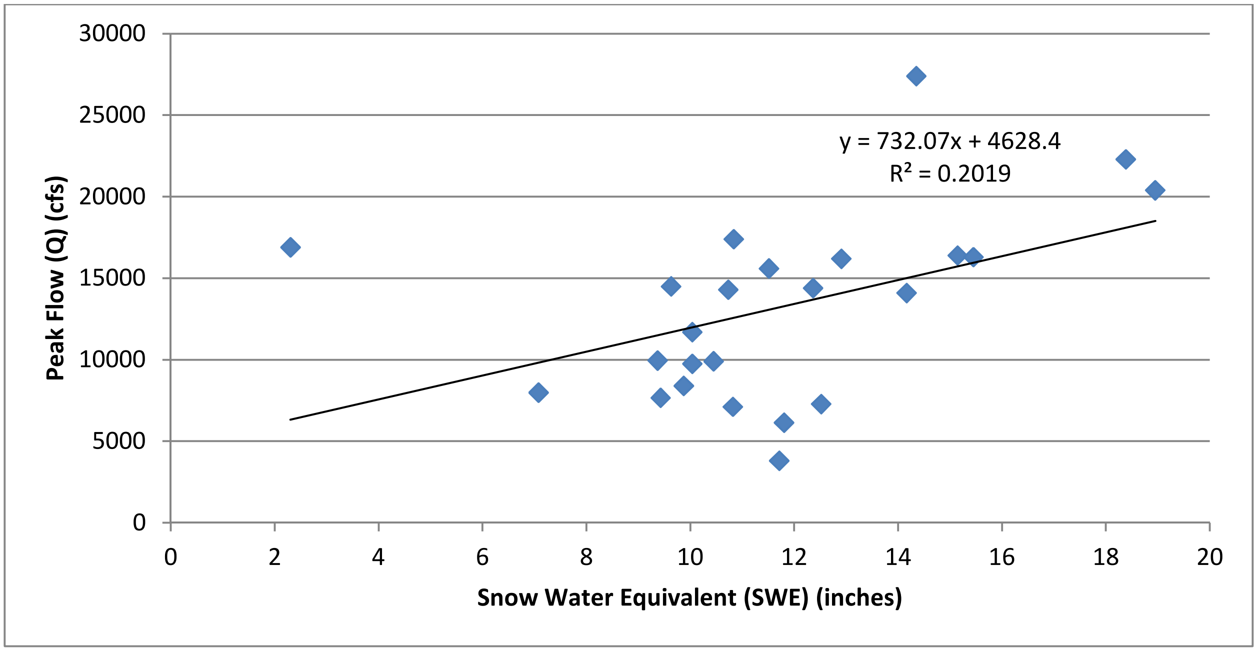


Figure 6

Yampa River Basin Interpolated SWE vs. Yampa River Peak Flow

As can be noted from the graph, the equation from the linear trendline for this historical data can be used to estimate the peak flow for the Yampa River in the future. The first step would be to gather the max SWE for the year at each of the SNOTEL sites. Add this data into the SNOTEL layer in ArcMap and then run the custom tool built in Model Builder that was discussed previously. Open the exported data file and plug the resulting SWE for the basin into the equation found in Figure 6.

It is noted that the R^2 value for the linear trendline is low. The peak flow prediction method outlined in this report does not appear to be the best method for predicting the peak flow in the Yampa River. However, this project did not take into account many factors that contribute to determining the peak flow due to SWE. Some of those factors include: storm patterns, snow drifting due to wind, land cover (vegetation), slope of land, direction of slope (whether it is facing the sun or not), and climate (melting rate). There are other factors that were assumed in this project that may not be entirely accurate. One of which is assuming the snow line to be 2116 m high in elevation. Also, due to the distance between SNOTEL sites, the interpolation of the SWE data across the basin has plenty of room for inaccuracies. However, even with all of the uncertainties, this project still provides a way to estimate the peak flow from the Yampa River.

There are many other methods and data that could improve the reliability of this project to predict the peak flow for the Yampa River, however, they lay outside the timeframe of this project. It would be interesting to see improvements made to this study by analyzing different data and methods. Data to calculate runoff ratios from SWE on the Yampa River Basin was calculated but will not be presented in this report.

Conclusion

In conclusion, the method presented in this report of interpolating max SWE over the Yampa River Basin does not appear to be the most reliable method for predicting peak flow in the Yampa River. Many outside factors that were not considered in the analysis of the project could increase the reliability of this method. That being said, an estimate of the peak flow for the Yampa River can still be calculated with this method. This will in turn give downstream land owners an idea of what peak flows could be expected and help them to prepare for any flooding conditions that may come their way.

References

CUAHSI HydroDesktop (2012). HydroDesktop 1.5.10 Experimental Release. <http://hydrodesktop.codeplex.com/releases/view/96967> (November 29, 2012)

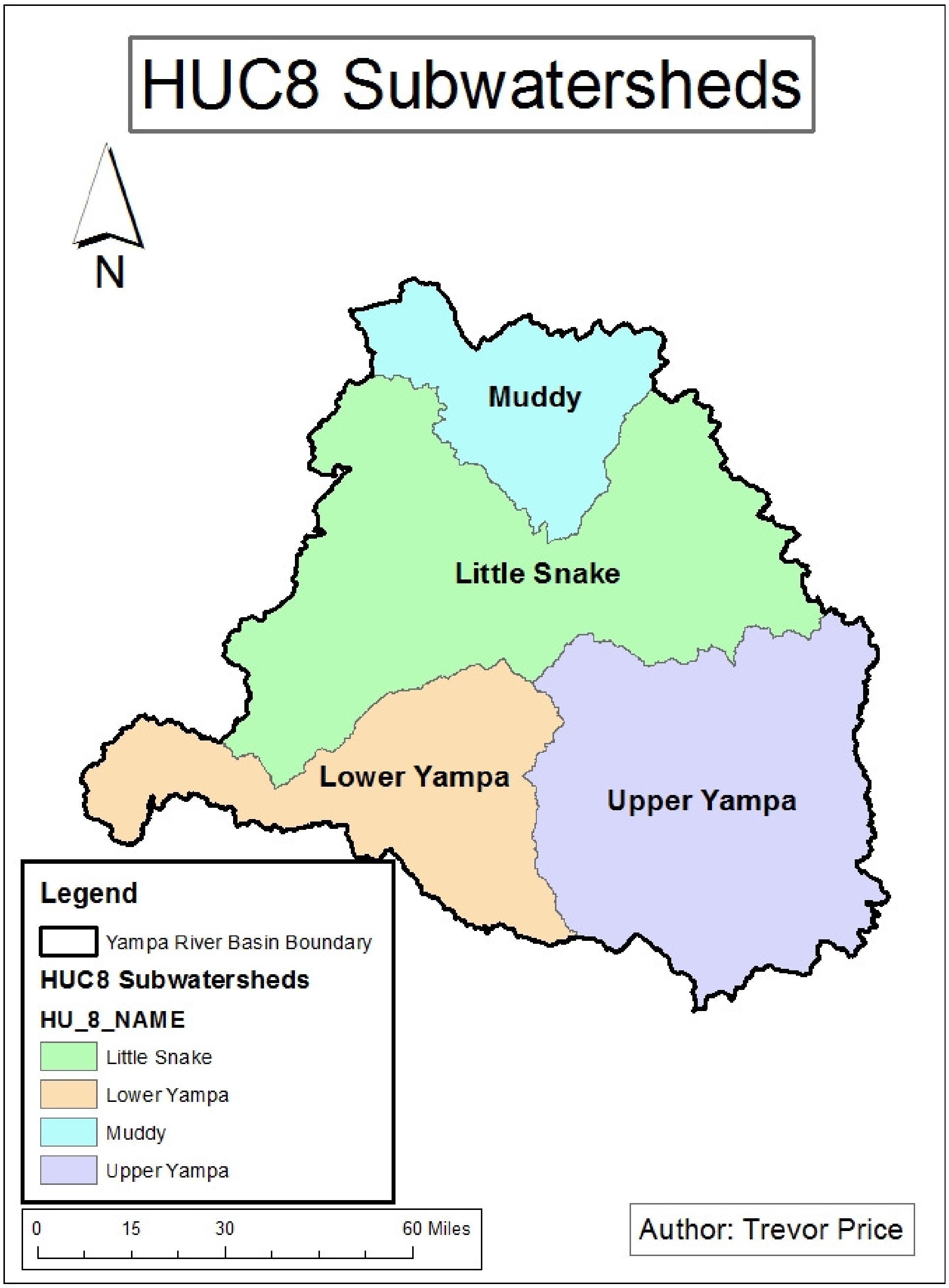
USGS. (2012a). Streamstats Colorado. <streamstats.usgs.gov/colorado.html> (October 25, 2012)

USGS. (2012b). The National Map NHD. <http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd> (November 10, 2012)

USGS. (2012c). National Weather Service: Colorado Basin River Forecast Center. <http://www.cbrfc.noaa.gov/> (November 25, 2012)

APPENDIX A - Maps

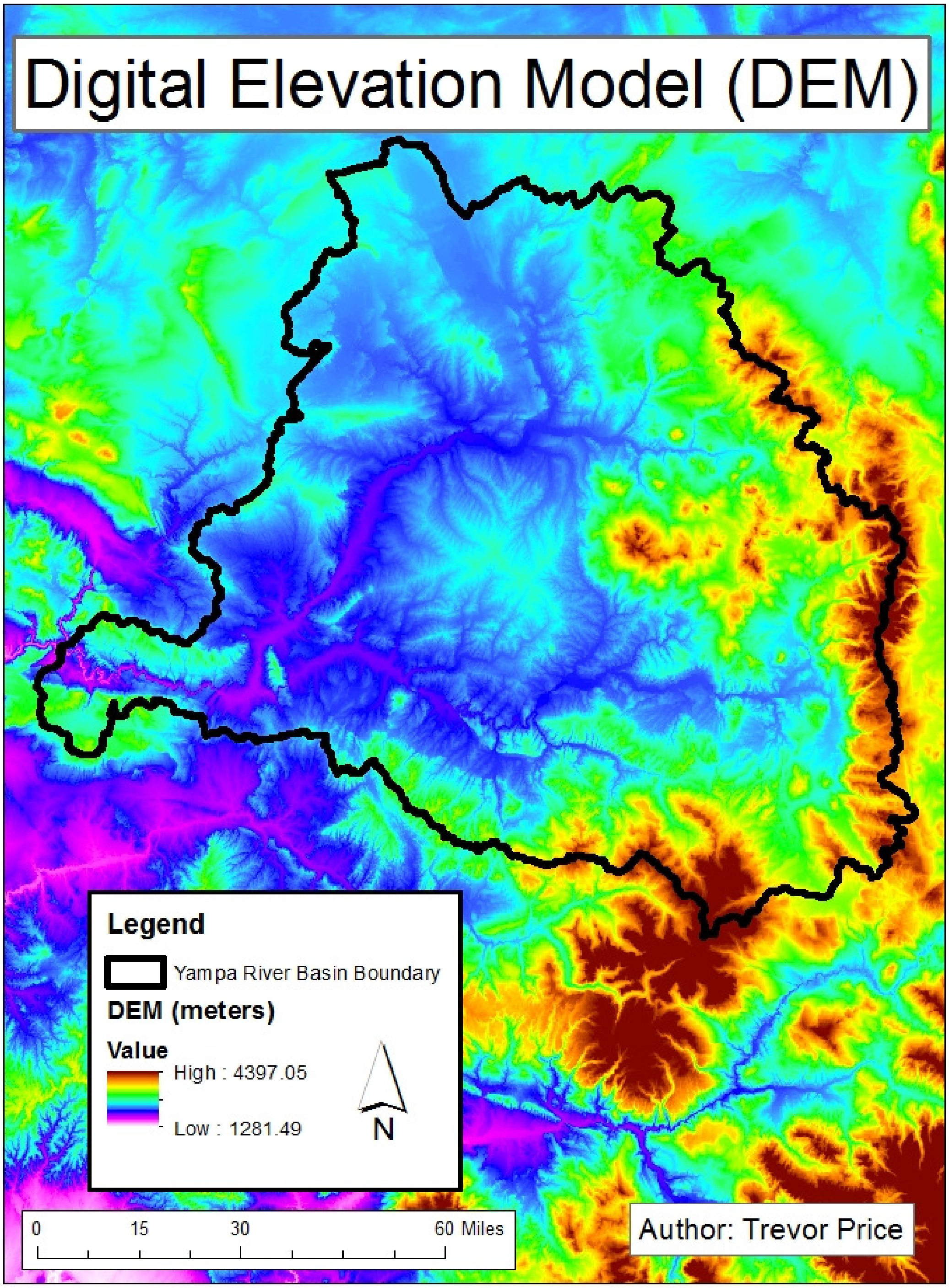
Map 1 shows the Digital HUC8 Subwatersheds within the Yampa River Basin. The Upper Yampa is 2619 square miles, the Lower Yampa is 1571 square miles, the Little Snake is 3062 square miles, and the Muddy is 1007 square miles.



Map 1

Digital Elevation Model (DEM) (ArcMap)

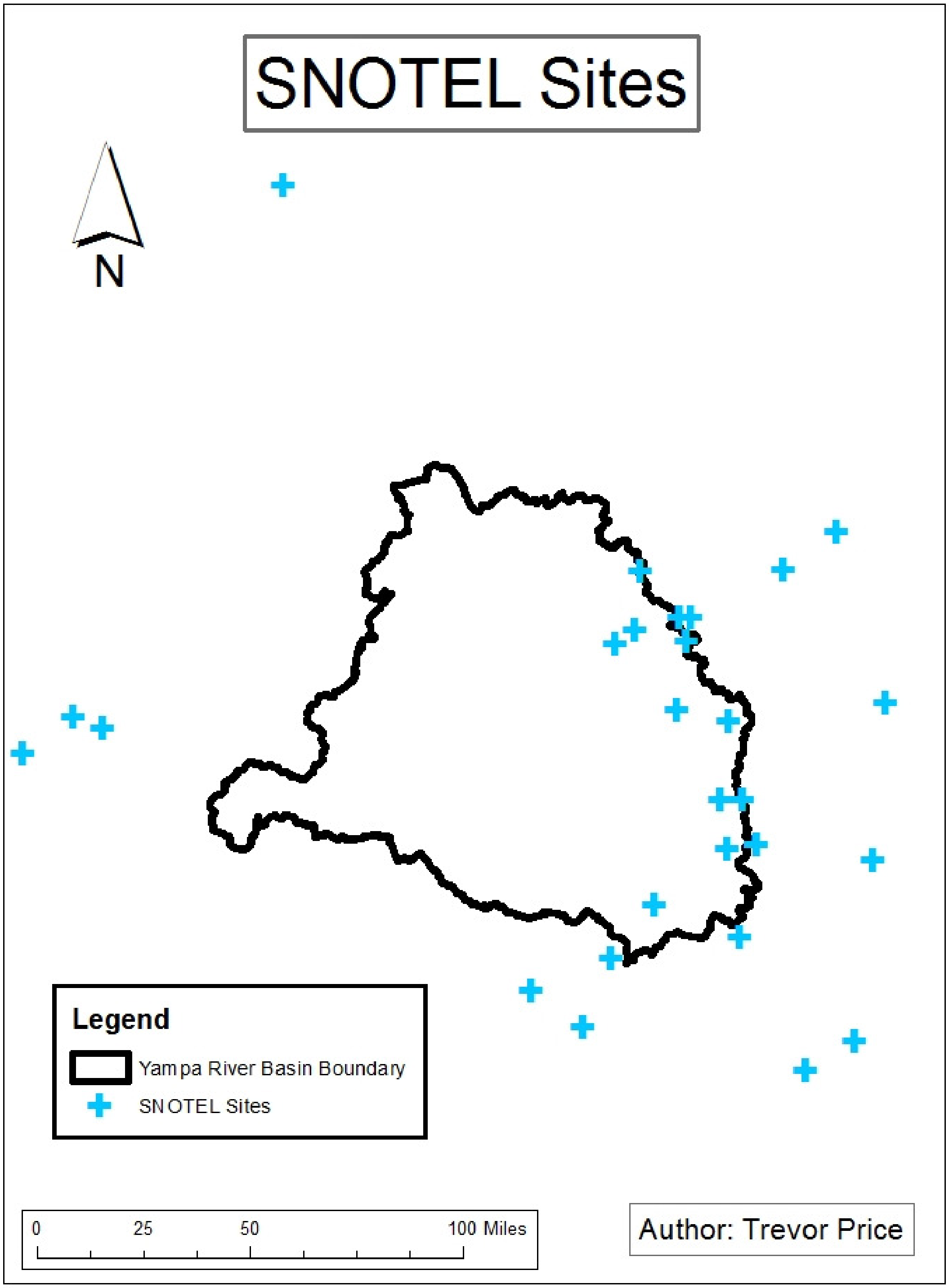
Map 2 shows the Digital Elevation Model (DEM) surrounding the Yampa River Basin.



Map 2

Digital Elevation Model (DEM) (ArcMap)

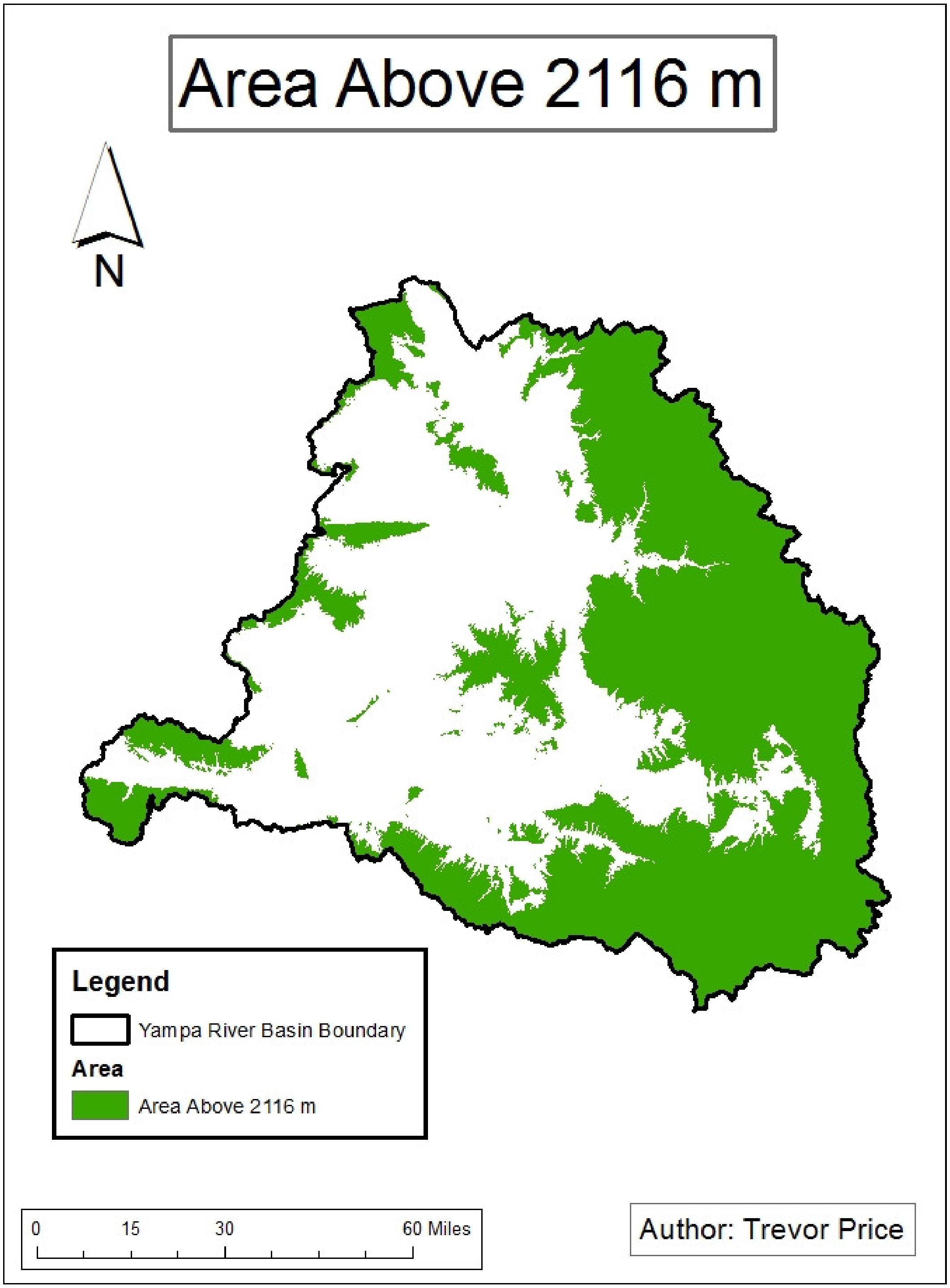
Twenty-seven SNOTEL sites within and surrounding the Yampa River Basin are depicted in Map 3.



Map 3

SNOTEL Site Locations (ArcMap)

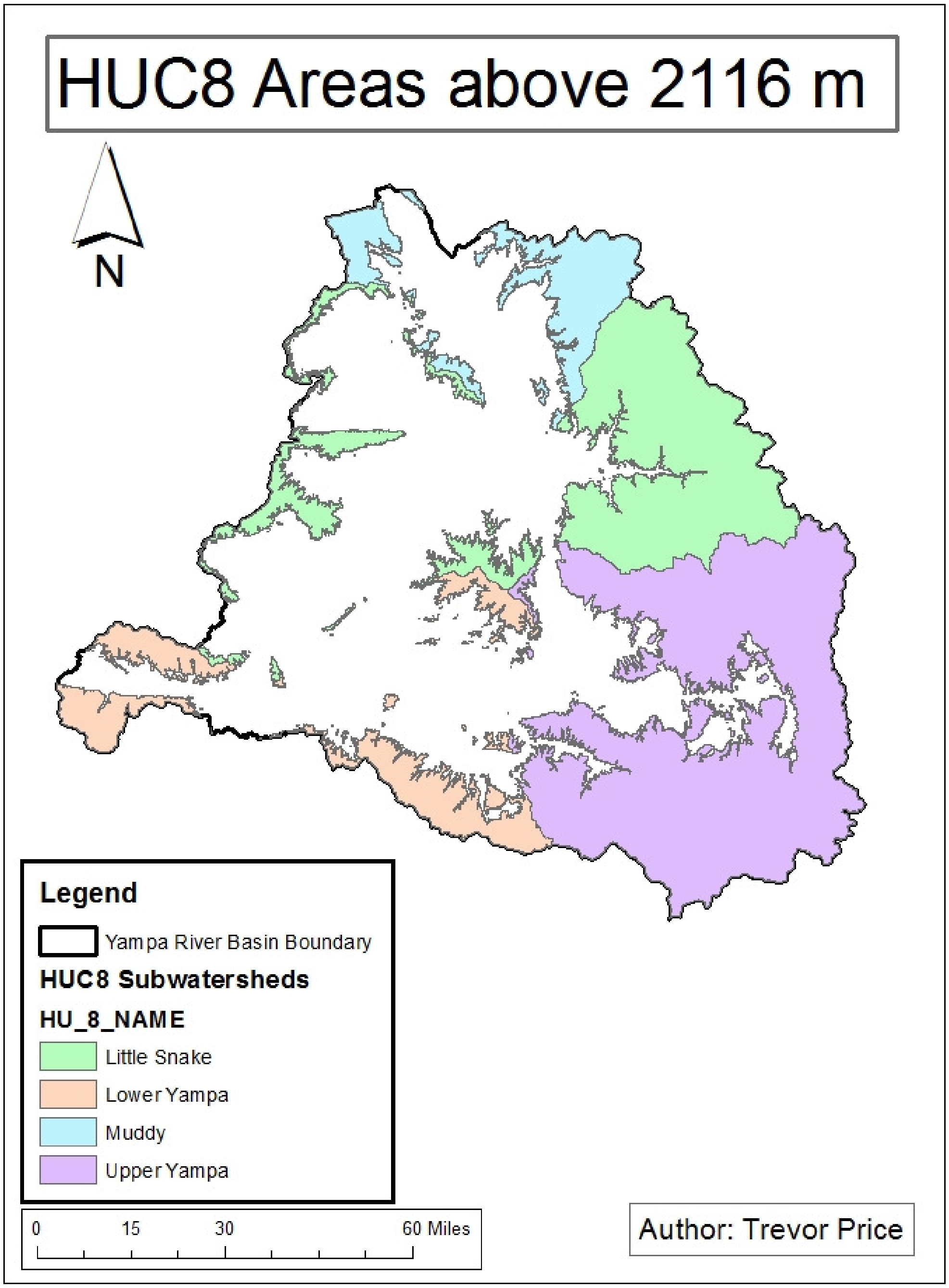
Map 4 is the area in the Yampa River Basin that is above the average snow level of 2116 m. This was created using the raster calculator in the spatial analyst toolbox.



Map 4

Area above 2116 m (ArcMap)

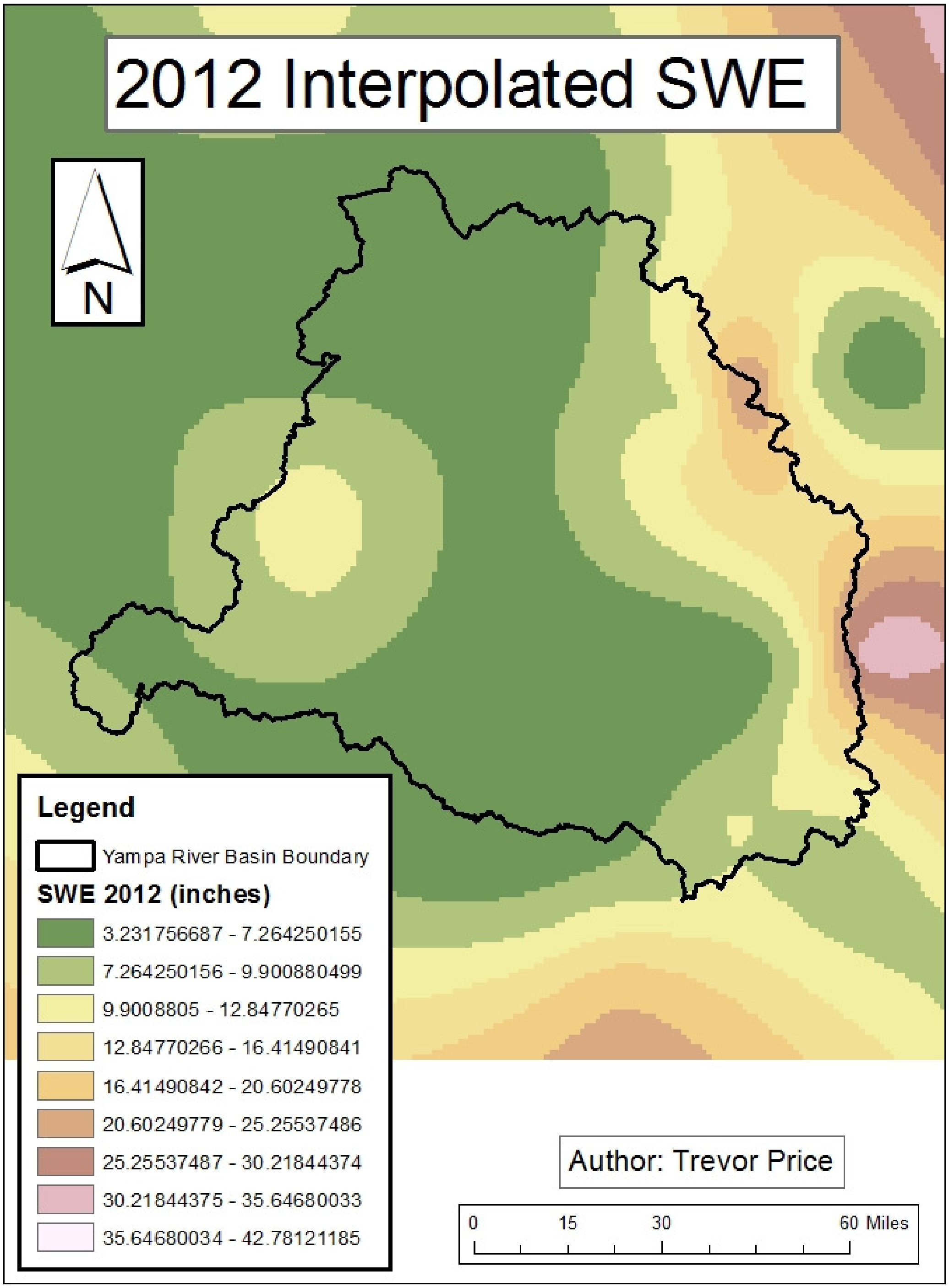
Map 5 is the area in each of the HUC8 subwatersheds that is above the average snow level of 2116 m. The area in the Upper Yampa that is above 2116 m is 1988 square miles, the area in the Lower Yampa is 500 square miles, the area in the Little Snake is 1271 square miles, and the area in the Muddy is 408 square miles.



Map 5

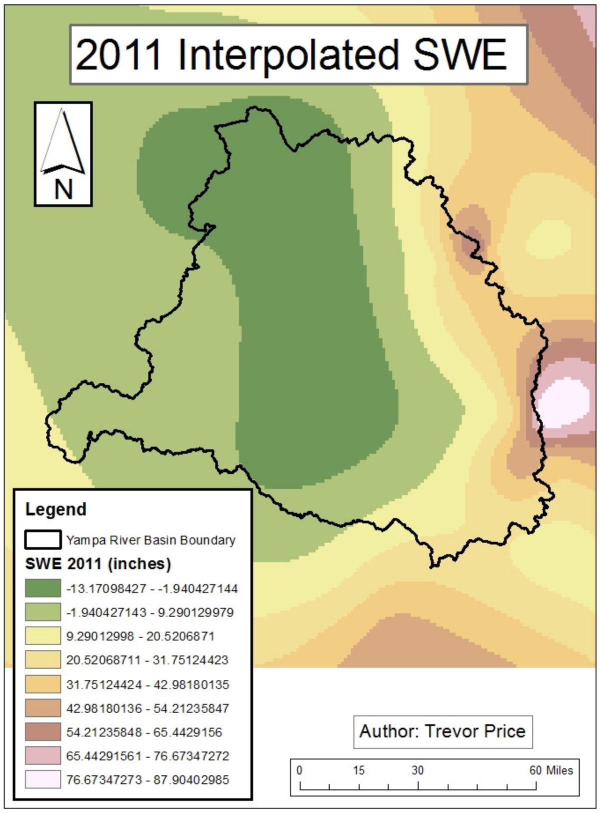
HUC8 Area above 2116 m (ArcMap)

Map 6 shows the interpolated snow water equivalent layer across the Yampa River Basin. The spline interpolation technique was used to perform this task.



Map 6

2012 Interpolated SWE layer (ArcMap)



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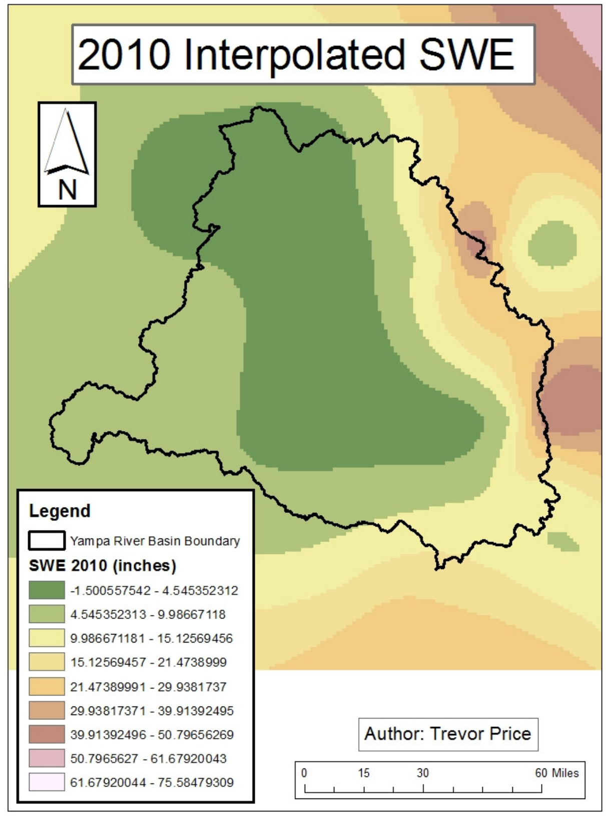

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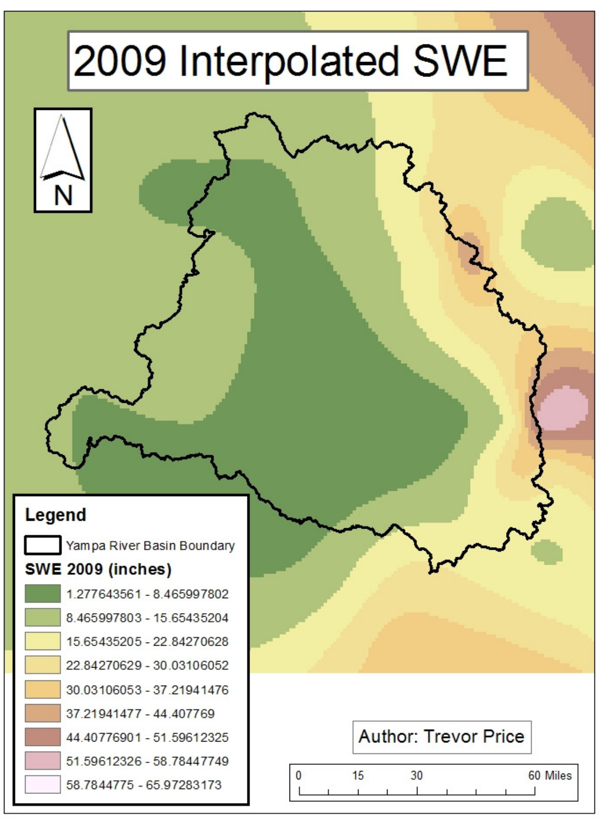

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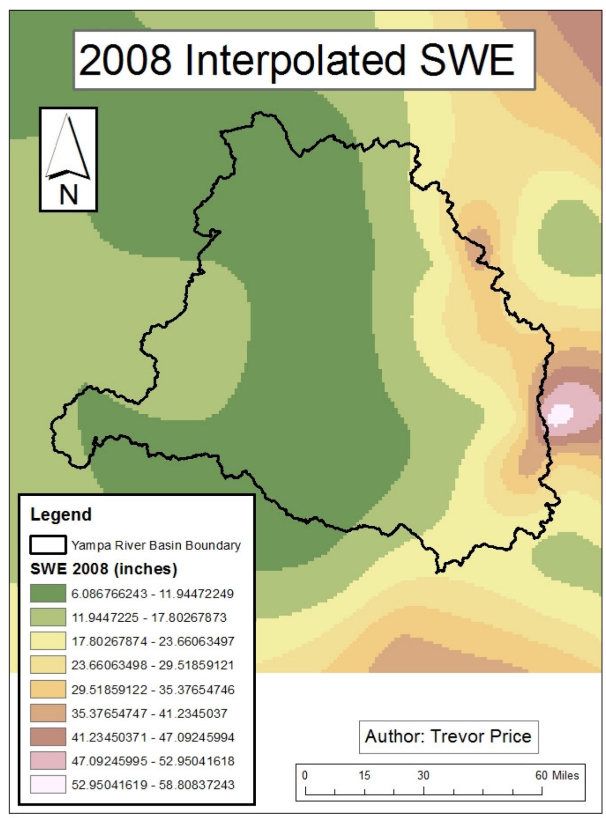

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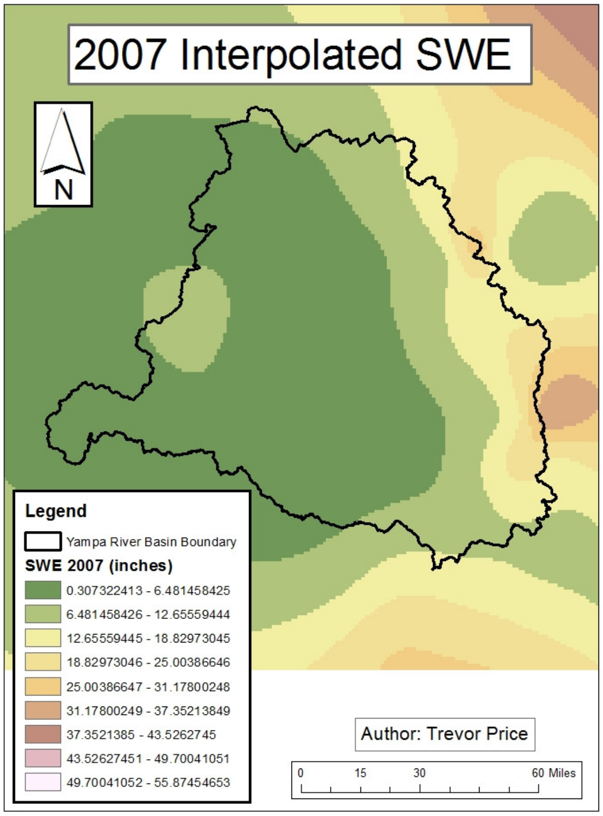

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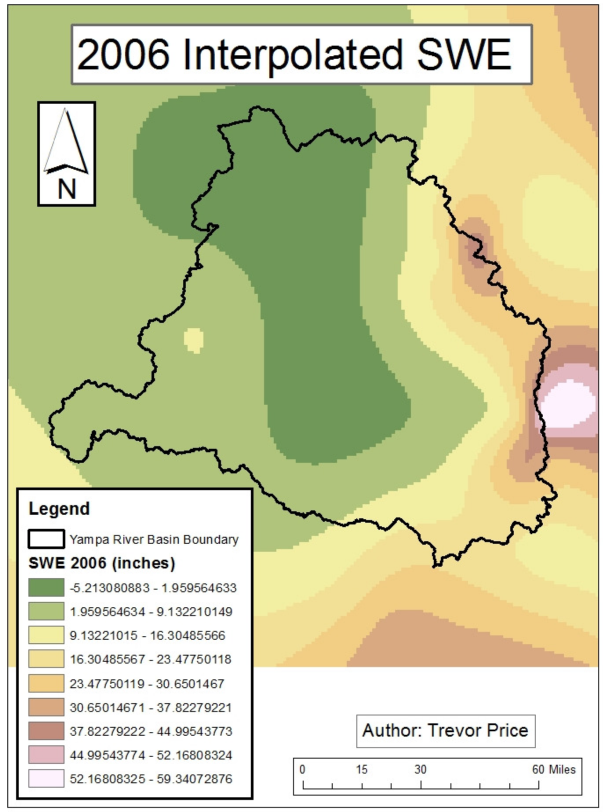

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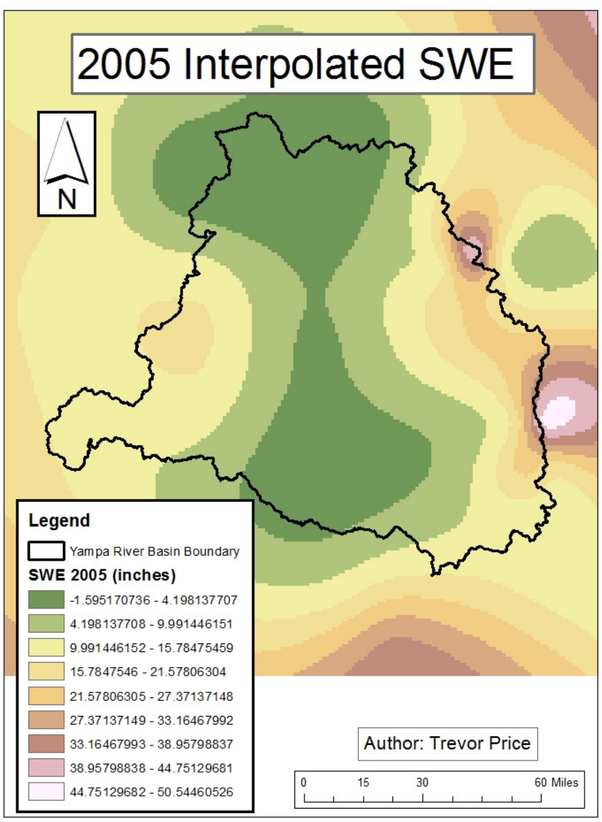

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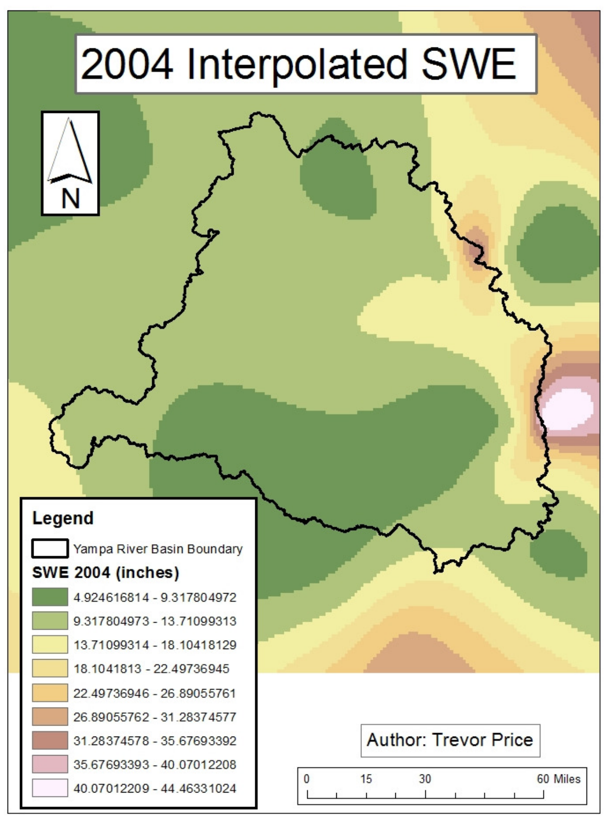

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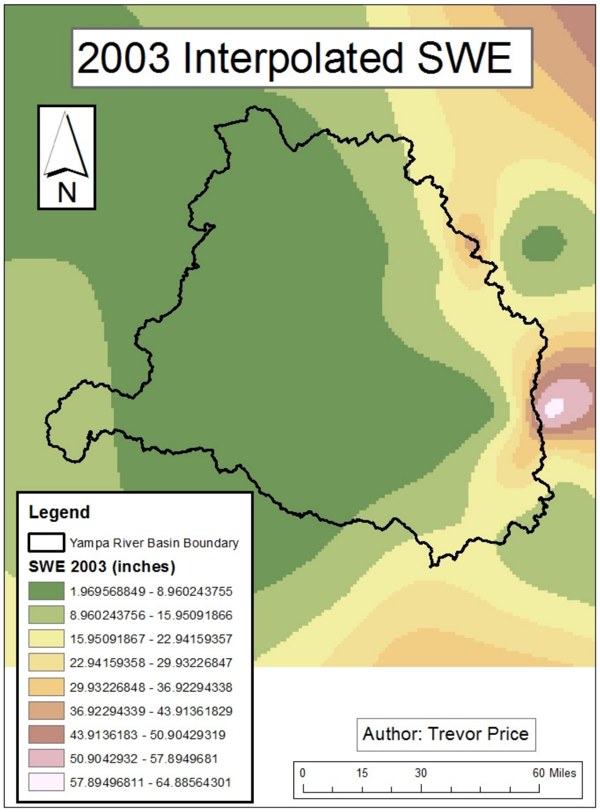

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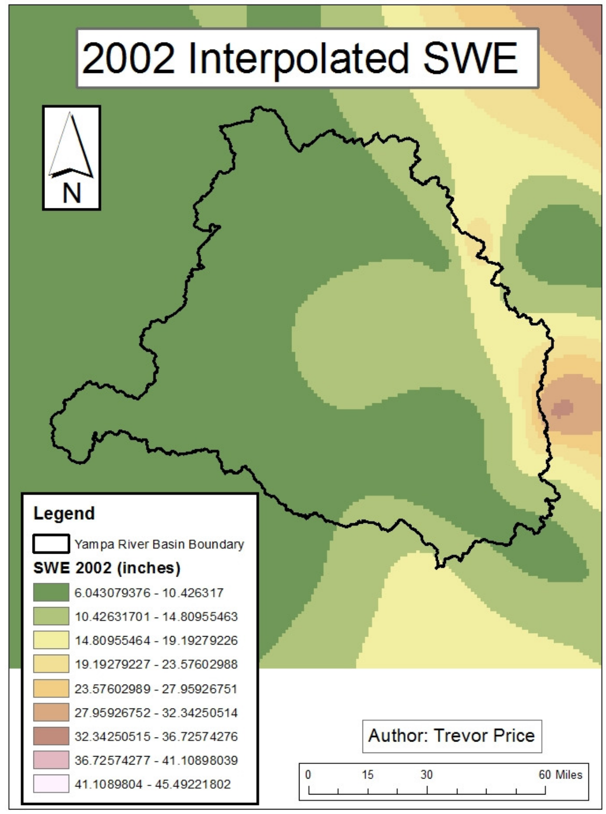

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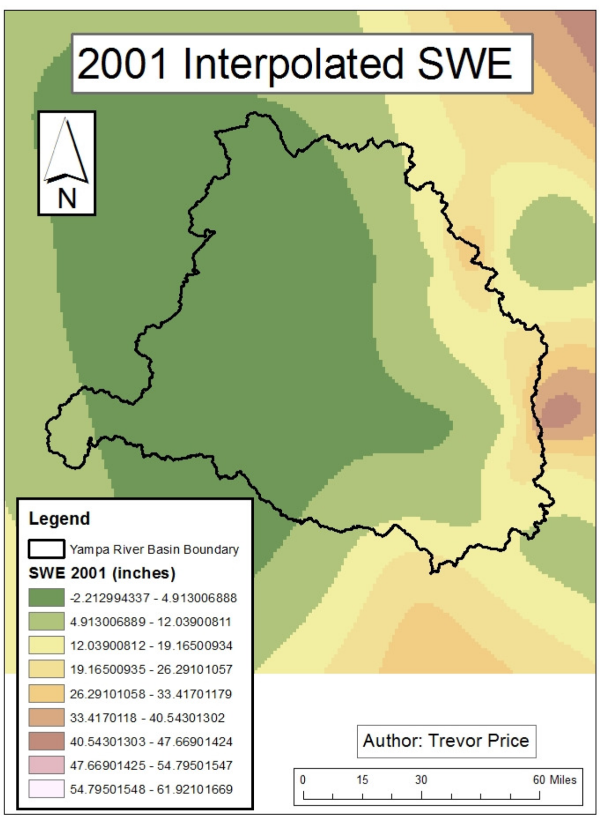

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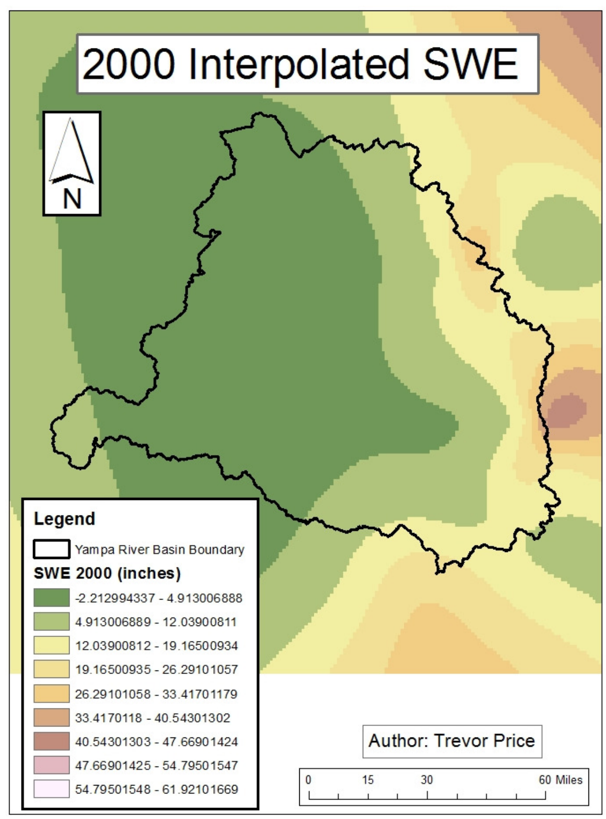

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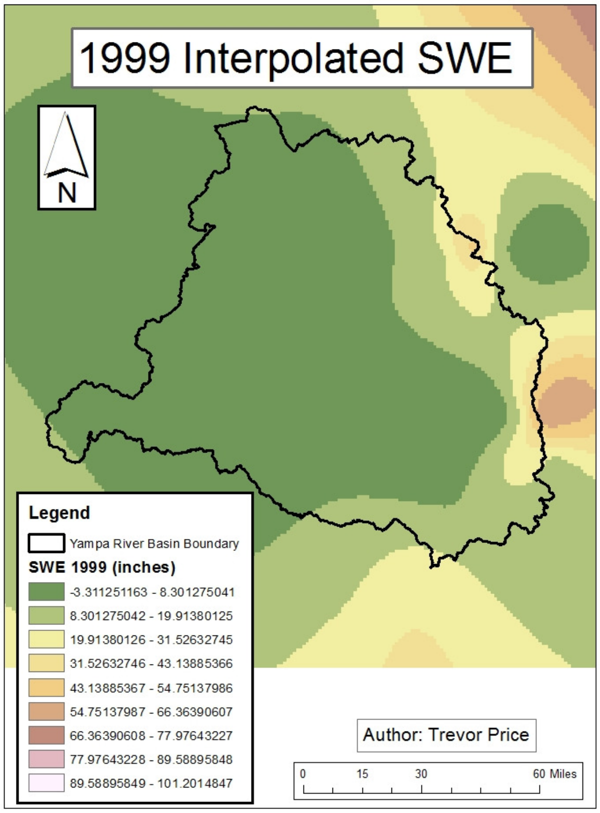

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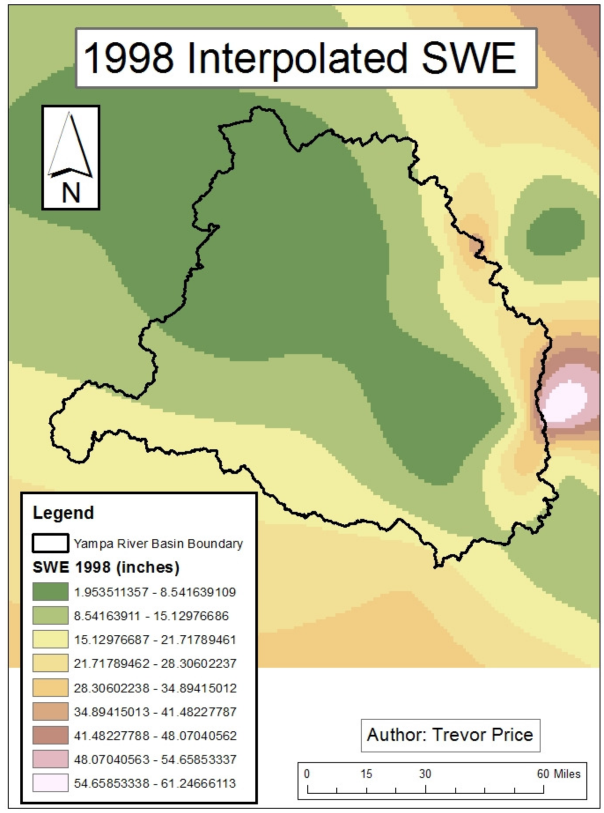

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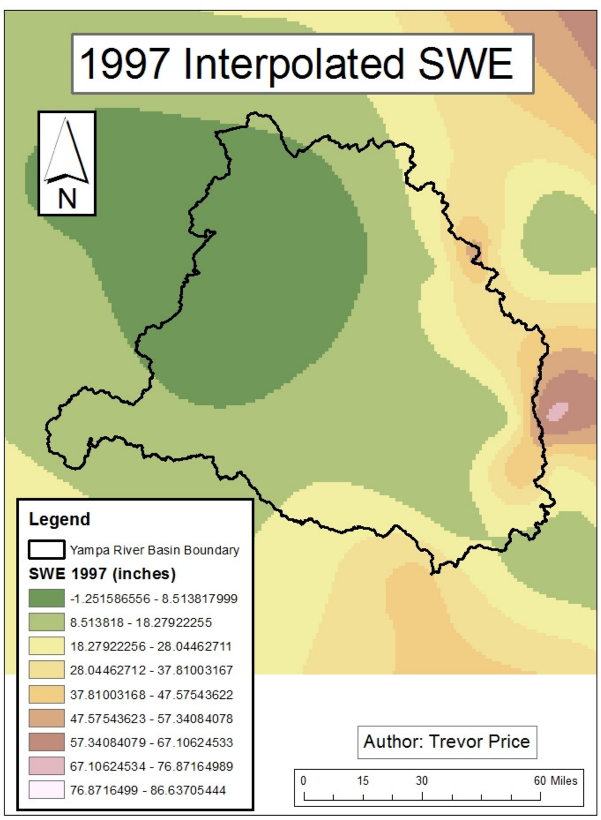

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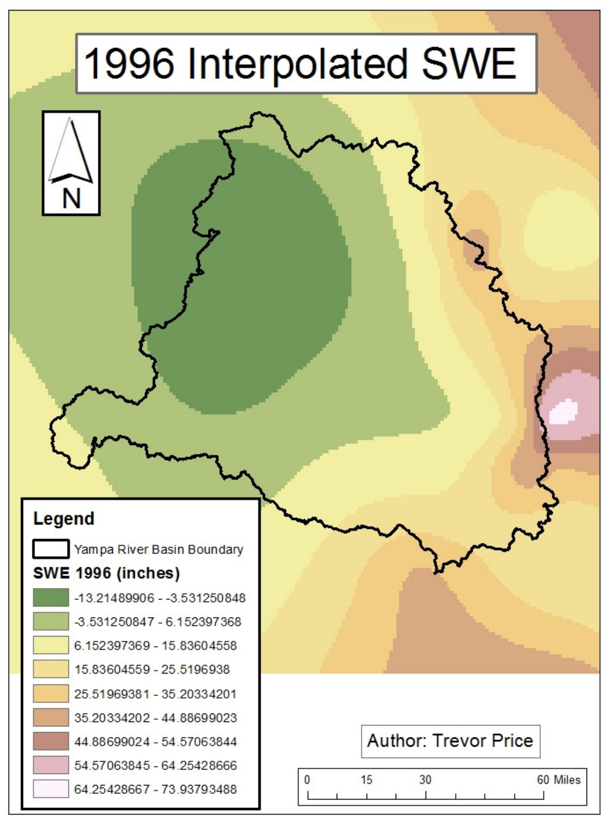

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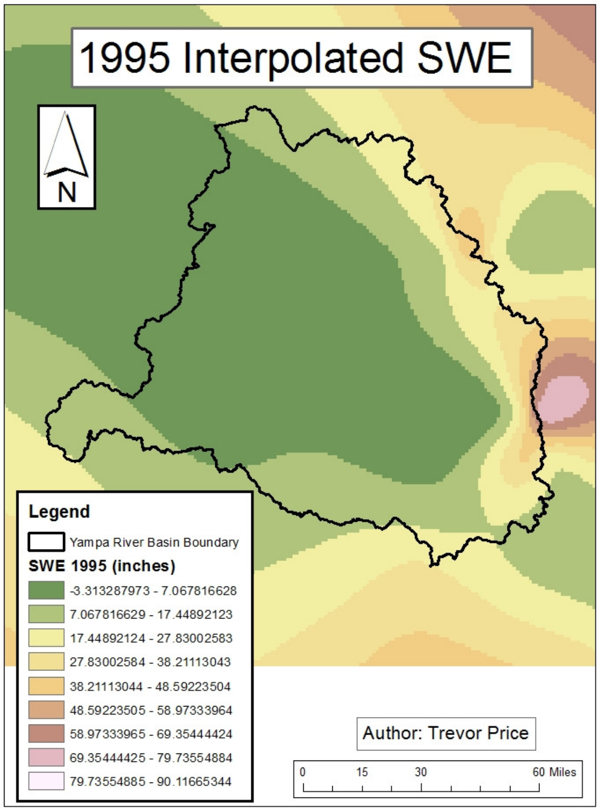

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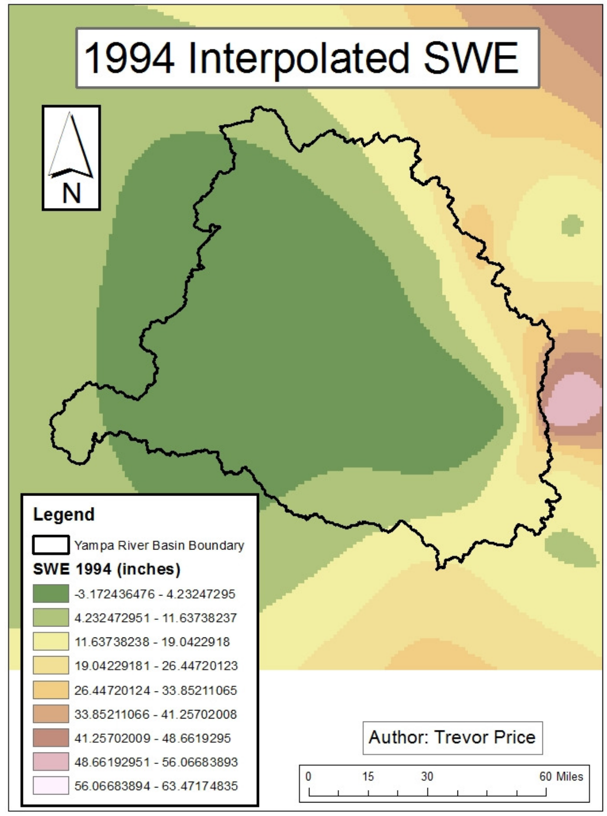

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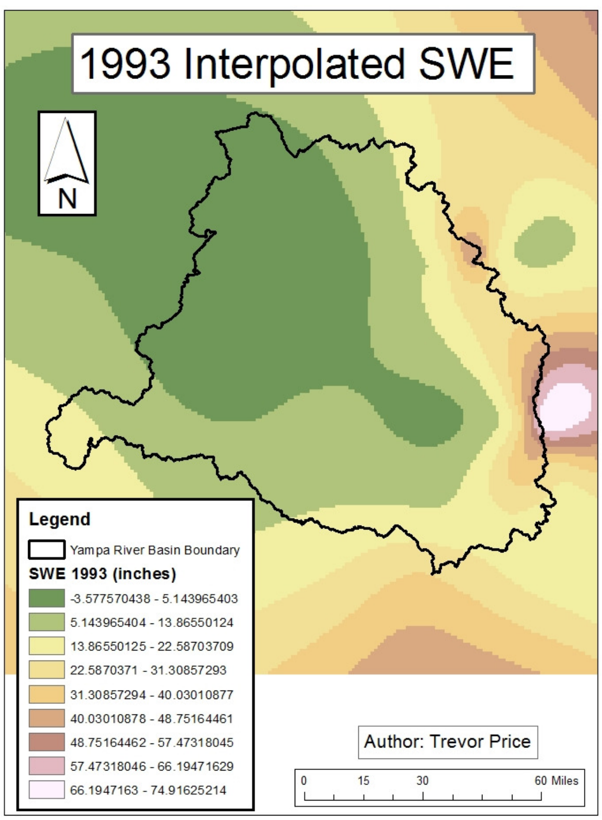

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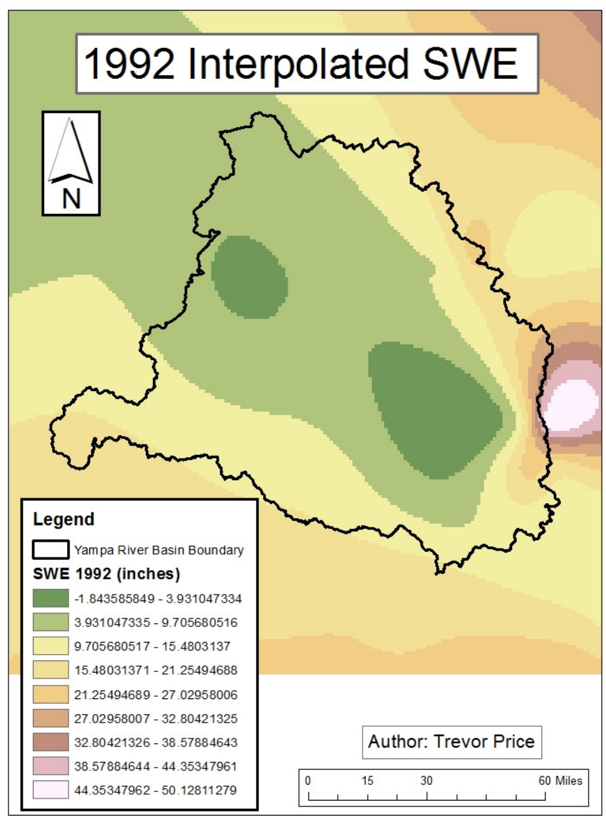

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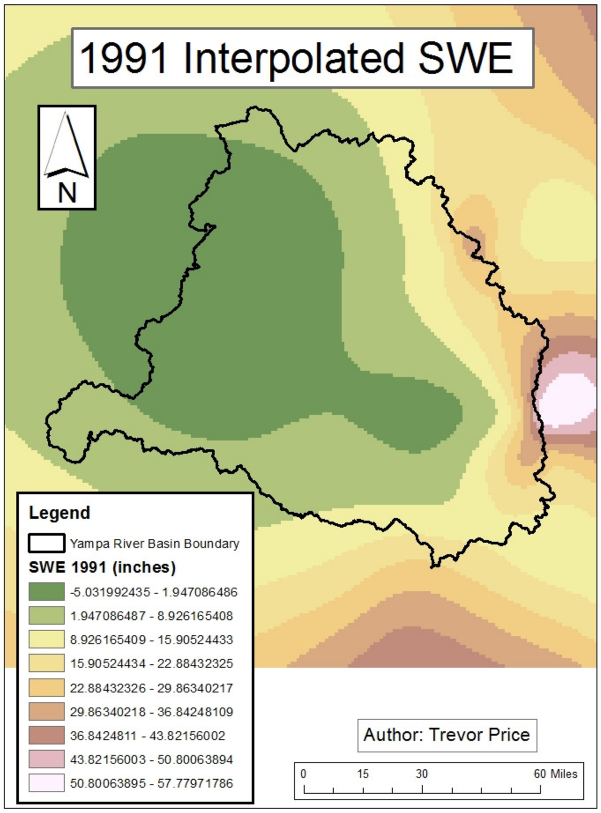
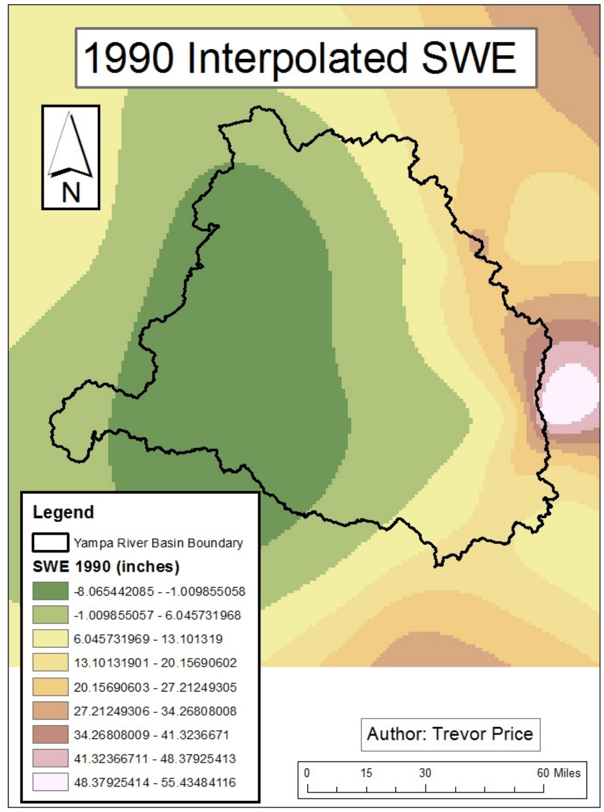
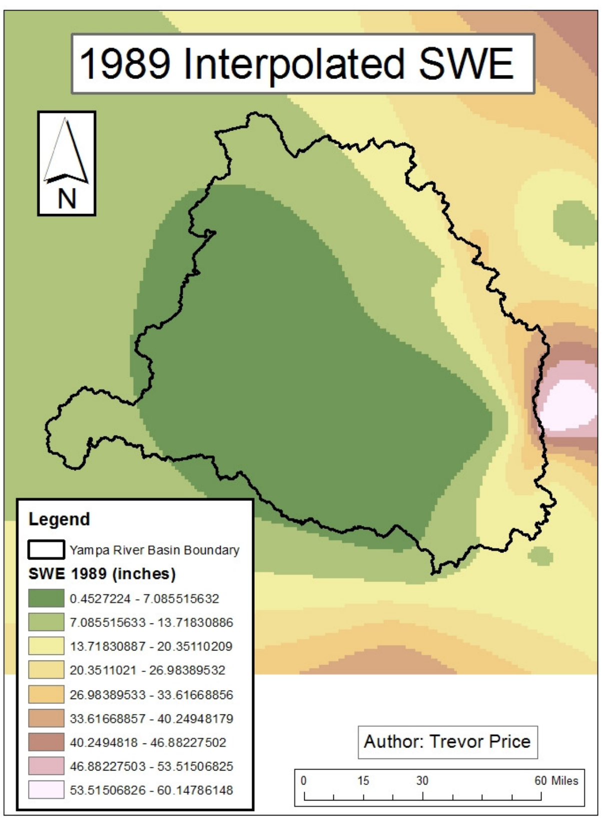


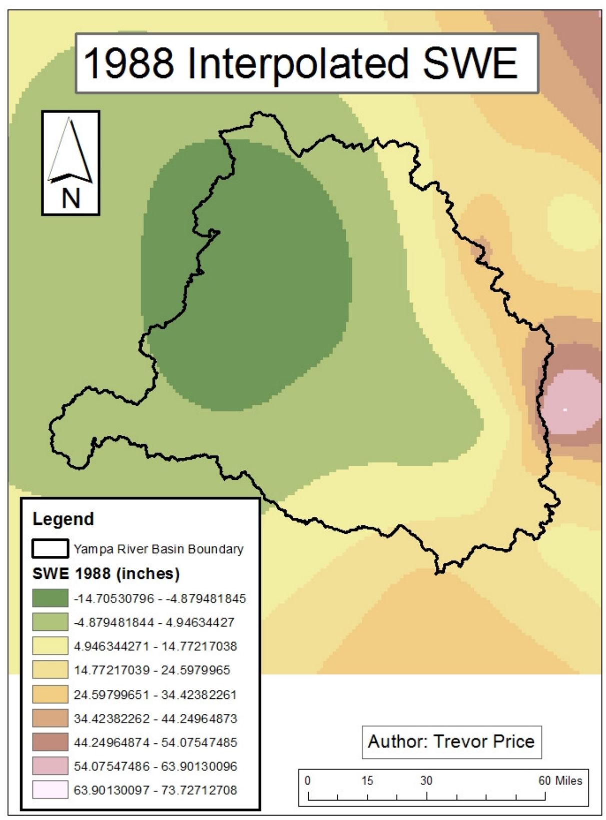
Map 27



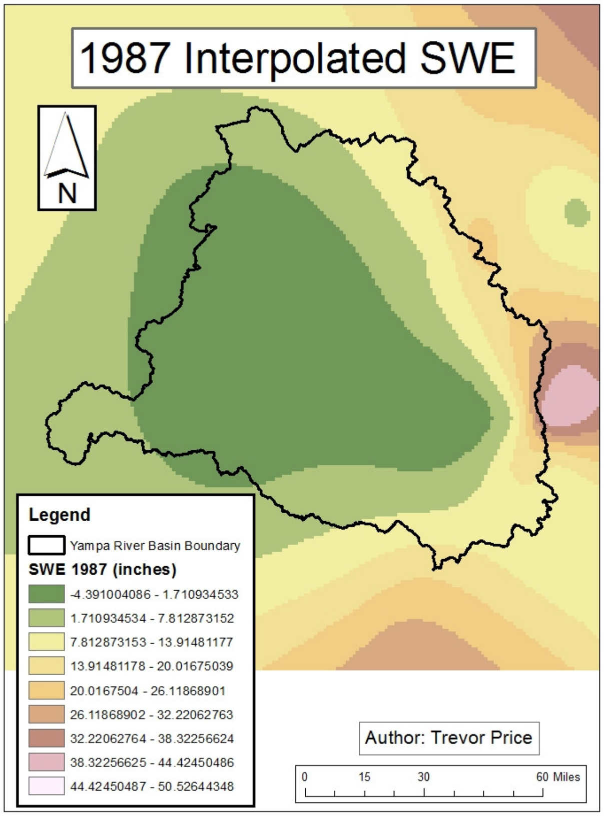
Map 28



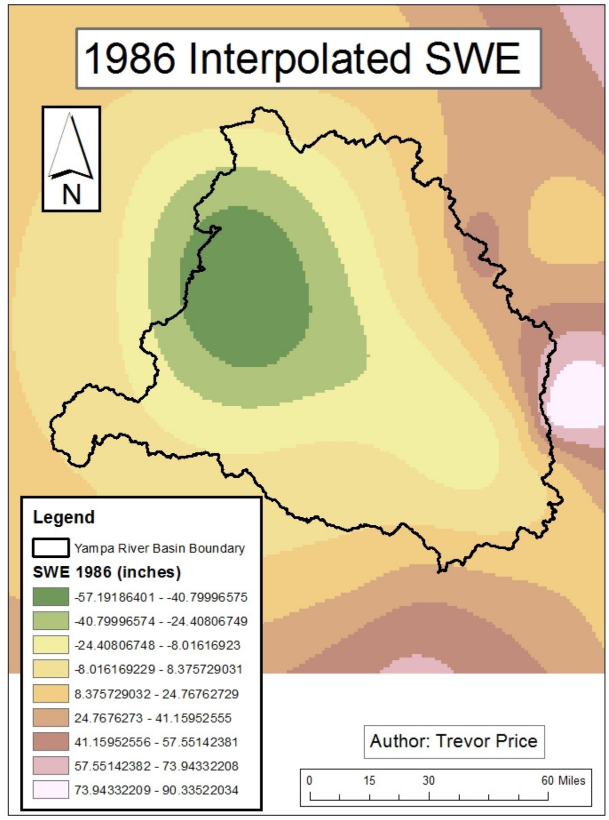
Map 29



Map 30


1987 Interpolated SWE
N
Legend
Yampa River Basin Boundary
SWE 1987 (inches)
-4.391004086 - 1.710934533
1.710934534 - 7.812873152
7.812873153 - 13.91481177
13.91481178 - 20.01675039
20.0167504 - 26.11868901
26.11868902 - 32.22062763
32.22062764 - 38.32256624
38.32256625 - 44.42450486
44.42450487 - 50.52644348
Author: Trevor Price
0
15
30
60 Miles

Map 31


1986 Interpolated SWE
N
Legend
Yampa River Basin Boundary
SWE 1986 (inches)
-57.19186401 - -40.79996575
-40.79996574 - -24.40806749
-24.40806748 - -8.01616923
-8.016169229 - 8.375729031
8.375729032 - 24.76762729
24.7676273 - 41.15952555
41.15952556 - 57.55142381
57.55142382 - 73.94332208
73.94332209 - 90.33522034
Author: Trevor Price
0
15
30
60 Miles

Map 32