CEE 6440: GIS in Water Resources

Land Cover Analysis of Watersheds Of Impaired Waters in Utah

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1 BACKGROUND AND OBJECTIVE:

The U.S. Environmental Protection Agency gives the following definition of impaired waters: “These are waters for which technology-based regulations and other required controls are not stringent enough to meet the water quality standards set by states” [1]. In other words, they are waters that do not meet water quality standards, as dictated by state and federal guidelines.

A number of impaired water bodies exist in Utah. During the hot, dry summer of 2016, some impaired water bodies experienced extensive toxic algal blooms. The most notable of these was Utah Lake. Its water was declared unsafe by the Utah Department of Environmental Quality, and the entire lake was closed. Several communities and many agricultural users had to go without Utah Lake water for more than a week before it was declared safe for irrigation purposes.

While water bodies can be listed as impaired for a variety of reasons, one very common reason is nutrient pollution. Nutrients, mainly nitrogen and phosphorus, can contribute to algal blooms if their concentration is too high. Water bodies receive nutrients from many sources – wastewater treatment plant effluent, agricultural runoff, biological processes, and more.

The objective for this project was to analyze the land cover of the watersheds of selected impaired water bodies in Utah, then compared these watersheds with each other to see what relationships exist between land use and water impairment. Additionally, point sources of pollution were considered where applicable.

2 HYPOTHESIS:

Two major sources of nutrient pollution are agricultural runoff and wastewater treatment plant effluent. It was hypothesized that watersheds of impaired water bodies would most likely have a higher proportion of agricultural land than non-impaired water bodies. It was also hypothesized that a higher proportion of developed land would indicate a great likelihood for impairment, due to events such as direct runoff from land surfaces where fertilizers are applied, effluent from wastewater treatment plants, or chemical leaks and spills.

3 METHODOLOGY:

The watersheds of water bodies of three different classes were selected for this analysis. For each class, two impaired water bodies were selected, as well as two non-impaired water bodies to serve as controls. Only one control was selected for the large, low elevation class of water bodies, since there are not many such reservoirs in Utah. Efforts were made to select water bodies with similar characteristics and at similar elevations. Table 1 presents the water bodies analyzed in this study.

Table 1: Water Bodies for Analysis

Class of water body	Impaired water bodies	Non-Impaired water bodies
Large, low elevation	Utah Lake Cutler Reservoir	Yuba Reservoir
Large, mid-elevation	Scofield Reservoir Deer Creek Reservoir	Jordanelle Reservoir Strawberry Reservoir
Small, high-elevation	Tony Grove Lake Bridger Lake	Lake Mary Whitney Reservoir

Figures depicting each water body and its corresponding watershed are included in Appendix A.

The USGS National Land Cover Database (NLCD) was used to characterize land use [2]. Impaired water bodies were identified using the United States Environmental Protection Agency (EPA) Impaired Water dataset [3]. Point sources were identified using the U.S. EPA Point Pollution Sources dataset [4]. To analyze agricultural land use at a finer resolution than possible using the NLCD, a dataset produced by the state of Utah called Water Related Land Use was also used [5].

The ArcGIS ready-to-use Watershed tool was used to delineate each of these watersheds. As shown in the figure below, watersheds for this study encompass a wide range of sizes, elevations, and locations throughout Utah, as shown in Figure 1.

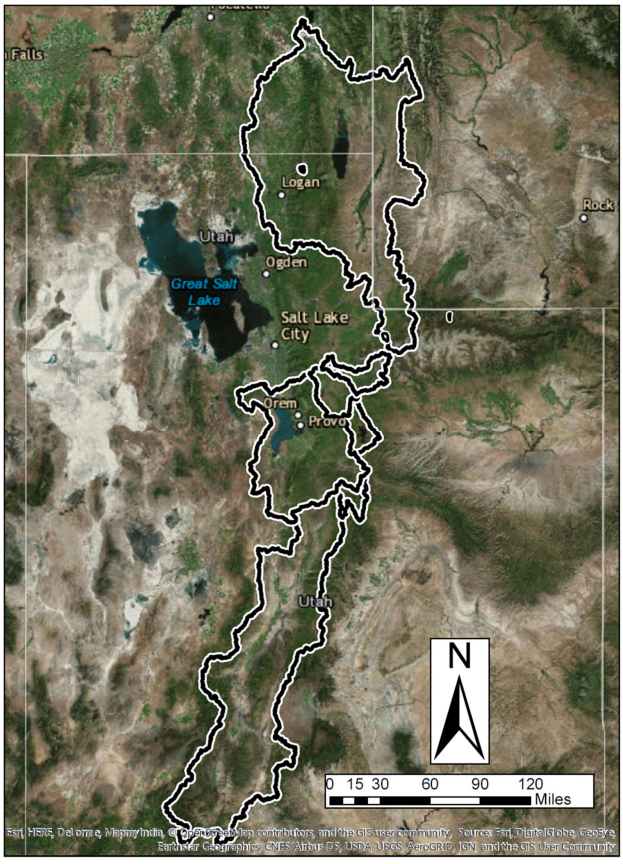

Figure 1: Watersheds for Analysis

After boundaries were delineated for each watershed, they were used to clip a raster from the NLCD, which was then reclassified according to the scheme in Table 2. At this point, the count of each raster type was brought into Microsoft Excel, the percent of each class in the watershed was computed, and these values were compared to that of other watersheds.

Table 2: Reclassification Scheme

NLCD Land Cover Class	New Class
Open Water	Water
Perennial Ice/Snow	
Woody Wetlands	
Emergent Herbaceous Wetlands	
Developed, Open Space	Developed
Developed, Low Intensity	
Developed, Medium Intensity	
Developed, High Intensity	
Grass and Shrub	Grass and Shrub
Shrub/Scrub	
Barren Land	
Deciduous Forest	Forest
Evergreen Forest	
Mixed Forest	
Pasture/Hay	Agriculture
Cultivated Crops	

Point sources of pollution were also considered. Only point sources defined by the EPA as major were considered for analysis.

4 RESULTS

Results of land cover analysis for each study watershed are presented in the following subsections.

4.1 Large, Low-Elevation Water Bodies

Figure 2 shows the results of the land cover analysis for the watersheds of large, warm water lakes and reservoirs analyzed.

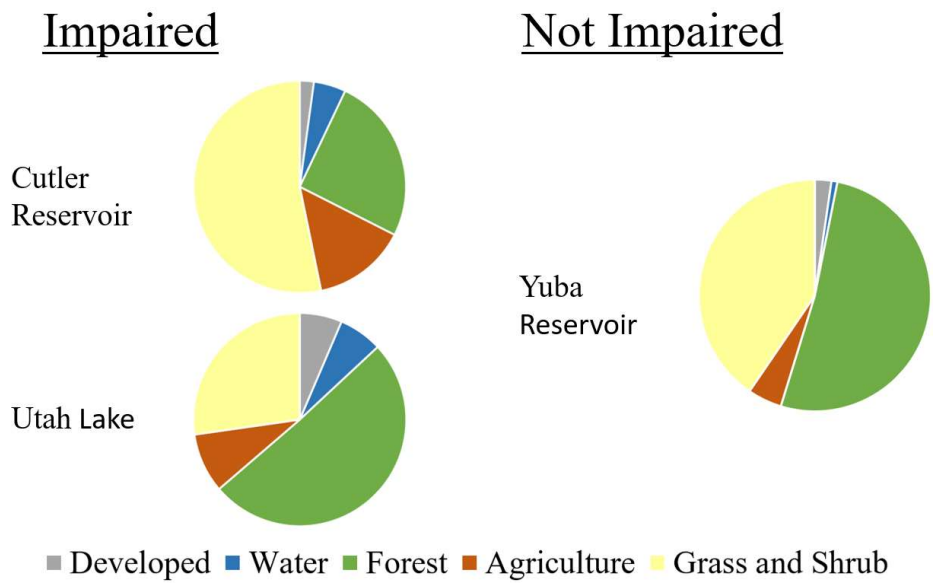

Figure 2: Land Cover of Selected Watersheds

Land cover data for each study watershed in this class is shown in Table 3.

Table 3: Land Cover of Study Watersheds

Watershed	% Developed	% Water	% Forest	% Agriculture	% Grass/Shrub
Cutler Reservoir	2.1	4.9	25.3	14.2	53.0
Utah Lake	6.4	6.6	50.2	9.0	27.0
Yuba Reservoir	2.3	0.82	51.0	4.7	40.0

Both impaired watersheds contained a significantly higher proportion of agricultural land than the control watershed. The Utah Lake watershed also contained a significantly higher proportion of developed land than the others. While there is uncertainty involved with this type of analysis, the watersheds analyzed in this class generally support the hypothesis that the proportion of agricultural and developed land in a watershed can contribute to impairment of water bodies.

Characteristics of each water body in this class were also investigated as possible reasons for differences in water quality. These are shown in Table 4.

Table 4: Characteristics of Study Water Bodies

Water Body	Maximum Depth (ft)	Average Depth (ft)	Watershed Size (mi^2)	Elevation (ft above MSL)
Cutler Reservoir	NA	6	6,289	4409
Utah Lake	14	9	2,780	4489
Yuba Reservoir	74	21.3	5,110	5100

Yuba reservoir is significantly deeper than average than the other two water bodies studied, which may also affect the temperature of the water and other biological processes related to water pollution. Its higher elevation may also enable it to remain cooler than the other lakes, despite being at a lower altitude.

4.2 Large, Mid-Elevation Water Bodies

Figure 3 summarizes the land cover of each study watershed in this class.

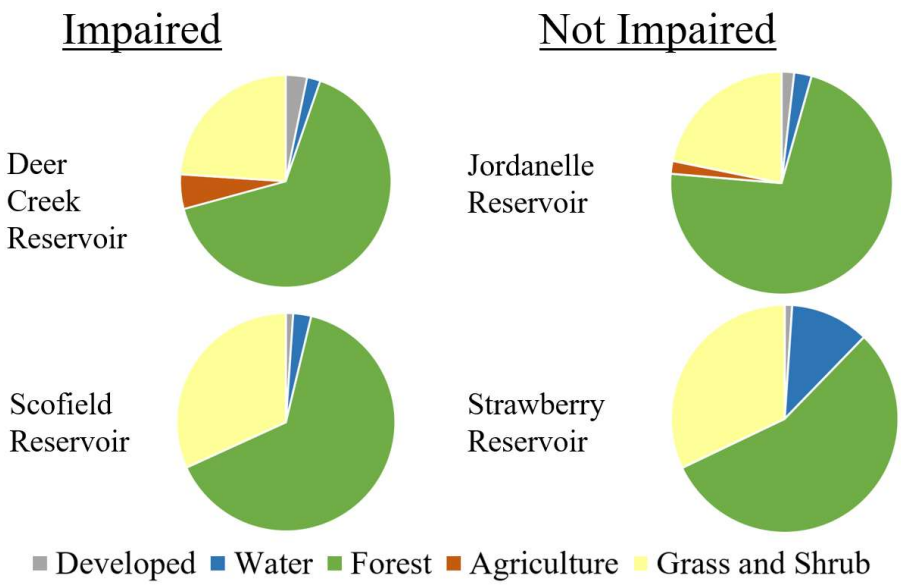

Figure 3: Land Cover of Large Mid-Elevation Reservoirs

Land cover data for each study watershed in this class is shown in Table 5.

Table 5: Land Cover of Study Watersheds

Watershed	% Developed	% Water	% Forest	% Agriculture	% Grass/Shrub
Deer Creek Reservoir	3.2	2.0	65.1	5.2	23.8
Jordanelle Reservoir	1.8	2.5	71.1	1.8	21.5
Scofield Reservoir	1.1	2.7	64.3	0	31.8
Strawberry Reservoir	1.1	11.2	55.6	0	32.1

One interesting comparison is that between Jordanelle and Deer Creek Reservoirs. Deer Creek reservoir is located downstream of Jordanelle Reservoir, meaning that the entire watershed of Jordanelle Reservoir is also within the watershed of Deer Creek Reservoir. A comparison of the two graphs shows a significant increase in both developed land and agricultural land between the Jordanelle and Deer Creek watersheds. Once again, this data appears to support the hypothesis that risk of water impairment increases as the proportion of agricultural and developed land in a watershed increases.

Scofield reservoir, on the other hand, has virtually no agricultural land in its watershed, and very little development, yet experiences nutrient impairment. This demonstrates that land cover and land use cannot be the only contributing factor to the impairment of a watershed.

Characteristics of each water body in this class are shown in Table 6.

Table 6: Characteristics of Study Water Bodies

Water Body	Maximum Depth (ft)	Average Depth (ft)	Watershed Size (mi^2)	Elevation (ft above MSL)
Deer Creek Reservoir	138	65	548	5417
Scofield Reservoir	66	26	155	7618
Jordanelle Reservoir	292	109	252	6165
Strawberry Reservoir	210	64	213	7612

The relatively shallow depth of Scofield reservoir may play a role in its vulnerability to algal blooms, especially during low water years. However, this analysis did not supply significant information to determine the source of pollutants in Scofield Reservoir.

4.3 Small, high-elevation Lakes

Figure 4 shows the land cover of the watersheds studied for water bodies in this class.

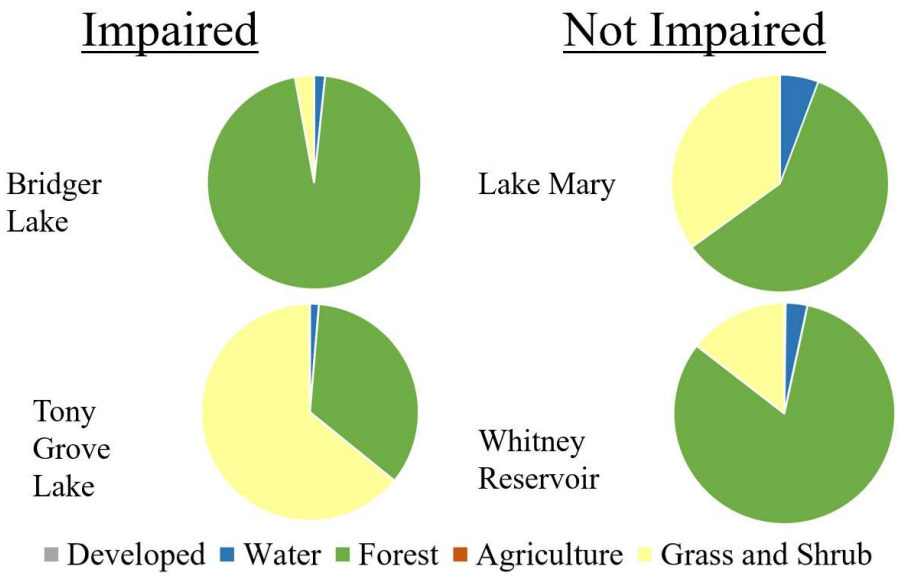

Figure 4: Land Cover of High-Elevation Study Lakes

Land cover data for each study watershed in this class is shown in Table 7.

Table 7: Land Cover of Study Watersheds

Watershed	% Developed	% Water	% Forest	% Agriculture	% Grass/Shrub
Bridger Lake	0	1.6	95.4	0	2.9
Tony Grove Lake	0	1.2	30.8	0	57.3
Lake Mary	0	5.2	53.9	0	31.8
Whitney Reservoir	0.2	3.1	79.7	0	14.1

None of these watersheds have a significant proportion of developed land or agricultural land. These watersheds don't reveal anything about the contribution of developed land and agricultural land to the impairment of watersheds. However, they do make it clear that there are factors besides land cover and land use that contribute to the impairment of a watershed.

Characteristics of each water body in this class are shown in Table 8.

Table 8: Characteristics of Study Water Bodies

Water Body	Maximum Depth (ft)	Average Depth (ft)	Watershed Size (mi^2)	Elevation (ft above MSL)
Bridger Lake	16	NA	1.90	9400
Tony Grove	36	13	2.08	8043
Lake Mary	72	NA	0.54	9500
Whitney	70	31	6.43	9260

The contrast between the depth of the impaired waters analyzed and the control water bodies is striking. It appears likely that shallow, high-elevation lakes are more prone to impairment than their deeper counterparts.

4.4 Point Sources

There were no major point sources of pollution present in any of the watersheds of the high-elevation lakes or large, mid-elevation reservoirs studied. Thus, a point source analysis was conducted only for the large, low-elevation lakes and reservoirs. The number of point sources in each watershed is summarized in Table 9, as well as the percent of the watershed that is developed.

Table 9: Point Sources vs Developed Land

Watershed	% Developed	Major Point Sources
Cutler Reservoir	2.13	3
Utah Lake	6.38	7
Yuba Reservoir	2.28	1

A plot was created to test whether the percent of the watershed that is developed can be used as a surrogate to predict about how many major point sources are present in a watershed. Figure 5 shows the correlation between these two parameters.

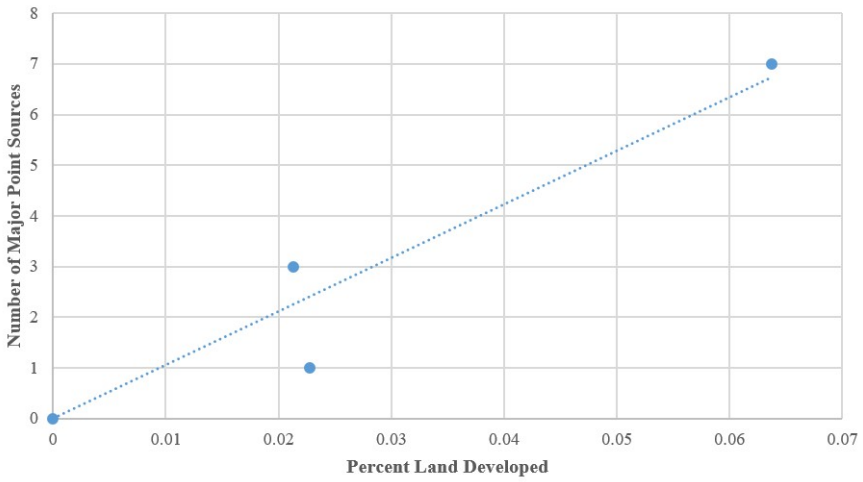

Figure 5. Developed Land vs. Number of Point Sources in Study Watersheds

These three data points appear to support the notion that there is some correlation between percent land developed and the number of major point sources in a watershed. While it is probably often true as a general rule, larger industrial operations in rural areas may give certain areas a disproportionate amount of major point sources. Considering these point sources directly is a better method than making assumptions based on land cover. This is especially true in a GIS application. The EPA search produced a CSV file as an output, which was very easy to load into ArcGIS Pro for analysis.

4.5 Water-related Land Use

The state of Utah produces a detailed GIS inventory of lands in Utah where water is used. This data set has detailed information on the use of each land, including the type of irrigation used on it, any crops grown on it, as well as its size and other metadata. It was used to evaluate the extent of agriculture in each watershed at a finer resolution than is possible using the NLCD. It was used to examine several qualitative characteristics of the largest watersheds studied, as shown in Figures 6 and 7.

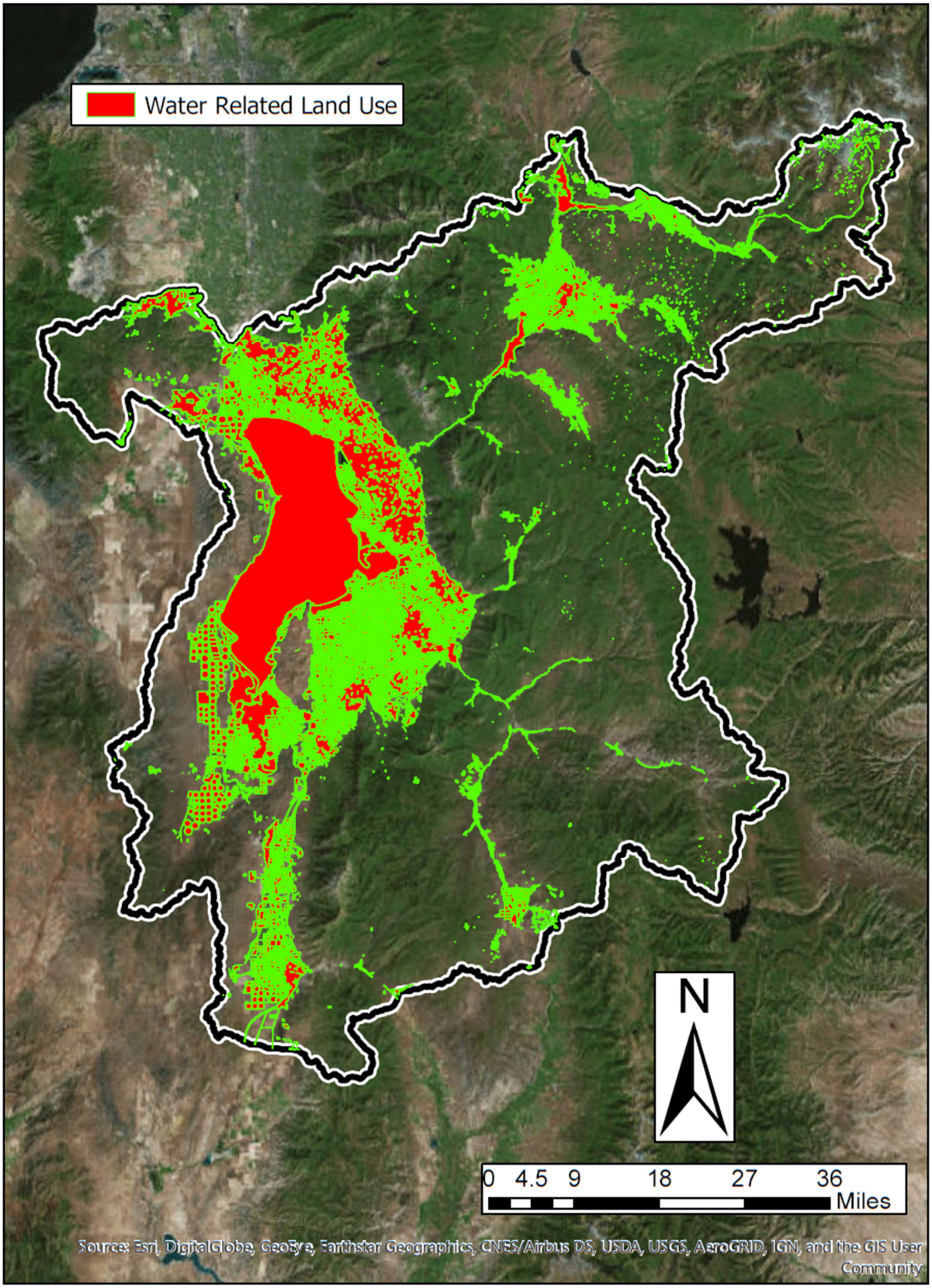

Figure 6: Water Related Land Use of the Utah Lake Watershed

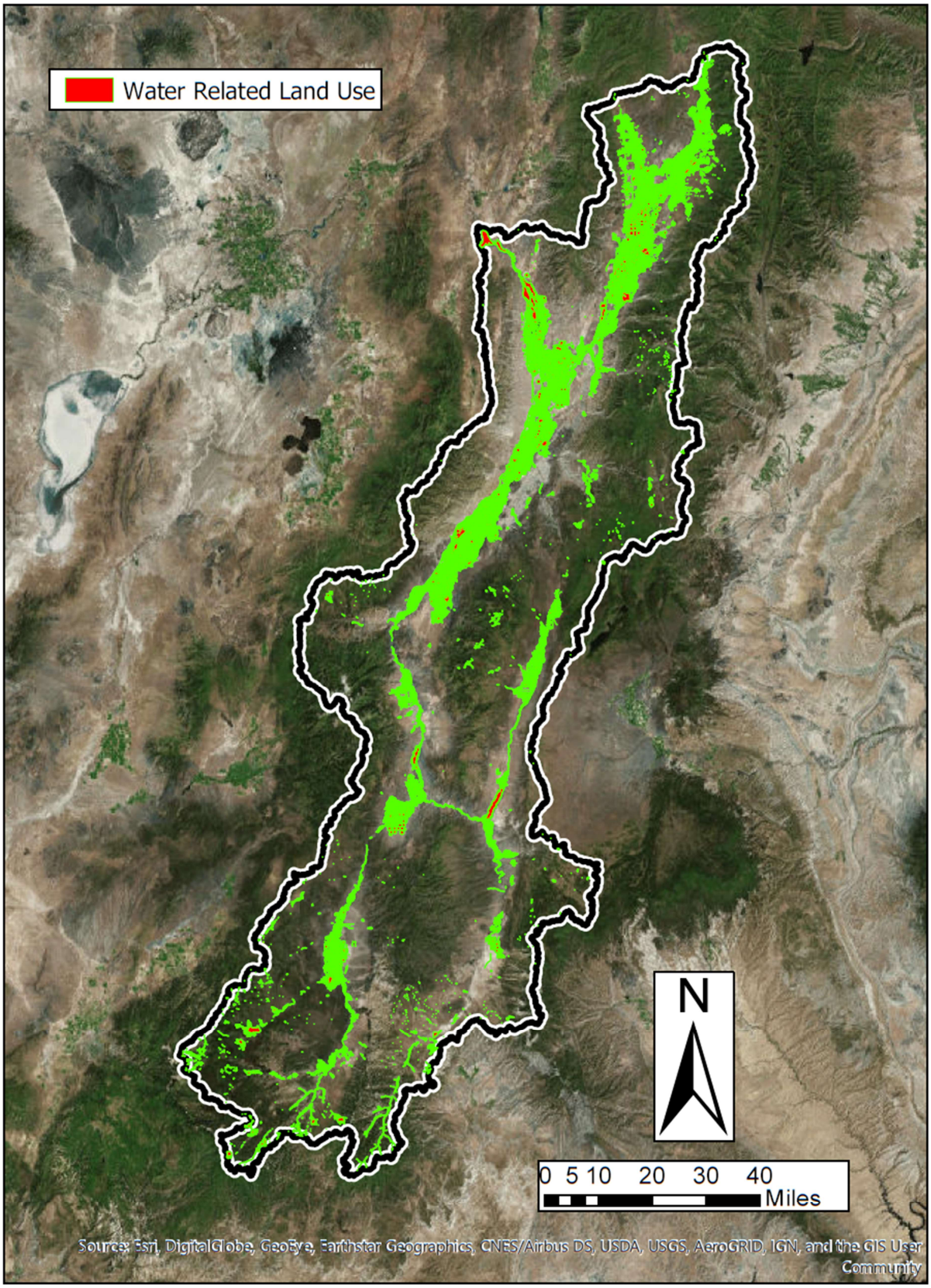

Figure 7: Water Related Land Use of the Yuba Reservoir Watershed

As shown, most agricultural water use in the Utah Lake watershed is in rather close proximity to Utah Lake (within approximately 10 miles). On the other hand, the agricultural water use in the Yuba Reservoir watershed is more evenly distributed throughout the watershed, with a significant portion more than 100 miles away from Yuba Reservoir itself. Since nutrients and other pollutants have more time to degrade or get intercepted when they travel long distances to reach a water body, this may play a role in the relatively good water quality of Yuba Reservoir. Cutler reservoir was not studied in this way because a significant portion of its watershed does not have this data available, since it is not in Utah. However, significant amounts of agriculture were present in the portion of its watershed within Cache County, Utah, within several miles of the reservoir.

This dataset also contains information on the way each specific parcel is used. Table 10 demonstrates the use of irrigated land in each watershed.

Table 10: Water Related Land Use of two Major Watersheds

Land Use	**Utah Lake Watershed**		**Yuba Reservoir Watershed**	
	Acres	**Proportion**	**Acres**	**Proportion**
Alfalfa	39544	7%	94033	16%
Beans	1	0%	0	0%
Berries	26	0%	0	0%
Corn	11059	2%	10417	2%
Fallow-Irrigated Land	759	0%	0	0%
Grain	8884	1%	6245	1%
Grass Hay	7661	1%	22218	4%
Grass Hay-subirrigated	658	0%	13363	2%
Idle-Irrigated Ag	0	0%	16502	3%
Idle-Irrigated Land	17728	3%	100	0%
Idle-Irrigated Pasture	10834	2%	5902	1%
Melon/Pumpkin/Squash	315	0%	15	0%
Oats	118	0%	80	0%
Onions	2.73	0%	0	0%
Open Water	93891	16%	16441	3%
Orchard	5565	1%	26	0%
Other Horiculture	576	0%	49	0%
Other Vegetables	143	0%	10	0%
Pasture	25327	4%	21687	4%
Pasture-subirrigated	12685	2%	20897	3%
Potatoes	25	0%	0	0%
Riparian	10233	2%	17030	3%
Safflower	84	0%	0	0%
Sewage Lagoon	441	0%	772	0%
Sorghum	20	0%	210	0%
Tomatoes	100	0%	0	0%
Turf Farms	214	0%	264	0%
Urban	320200	53%	142	0%
Urban Grass	6257	1%	1209	0%
Urban/Urban Idle	13984	2%	48853	8%
Wet Flats	13092	2%	0	0%

The most striking difference between the water related land use in these two watersheds is the proportion of irrigated land in urban settings. 56% of irrigated land in the Utah Lake watershed is in an urban setting, compared to just 8% in the Yuba Reservoir watershed. By comparison, the NLCD reports that 6.38% of the Utah Lake watershed is developed, and 2.13% of the Yuba Reservoir watershed is developed. This is a clear demonstration that land cover is not directly linked to water use, and further suggests that analyzing land cover is probably not the most accurate way to predict the effects of activities within a watershed on the quality of a water body.

5 CONCLUSIONS

While this analysis revealed several interesting characteristics about the watersheds of selected impaired and non-impaired waters in Utah, the limited nature of availability and the large amount of uncertainty associated with the topic in general made it difficult to carry out detailed quantitative analyses or draw firm conclusions. While this analysis made it clear that land cover is not the only factor contributing to impairment of a watershed, it did not provide any evidence to suggest that developed land and agricultural land do not contribute to watershed impairment. Accordingly, the hypothesis presented at the beginning of this report is plausible, though not all-encompassing.

Despite several quantitative limitations, this analysis still revealed important aspects about the application of GIS techniques to water resources. The use of GIS tools made this analysis relatively quick and straightforward. Classifying land cover and land use without the use of remote sensing and GIS would be very time consuming and/or extremely imprecise. However, classifying the land cover of a watershed with GIS required only four operations: (1) delineate the watershed, (2) clip NLCD data using the watershed boundary, (3) reclassify the NLCD data, and (4) tabulate and plot the data). GIS also provided a useful and convenient way to display and analyze EPA data on major point sources, and more specific data on water related land use in Utah.

While the techniques used in this project are not ideal for highly detailed scientific analysis, they are useful to quickly characterize data from a large amount of watersheds. For future analyses relating land and water quality, experimenters would be wise to use GIS to screen large amounts of data to determine which areas may be worth further study. Screening with GIS would allow for increased experimental efficiency and provide a good background information to such a project.

References

[1] "Program Overview: Impaired Waters and TMDLs," United States Environmental Protection Agency, 9 January 2017. [Online]. Available: https://www.epa.gov/tmdl/program-overview-impaired-waters-and-tmdls. [Accessed 19 September 2017].

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[3] "WATERS Geospatial Data Downloads," United States Environmental Protection Agency, 1 May 2015. [Online]. Available: https://www.epa.gov/waterdata/waters-geospatial-data-downloads#303dListedImpairedWaters. [Accessed 15 October 2017].

[4] "Discharge Monitoring Report (DMR) Pollutant Loading Tool," United States Environmental Protection Agency, 2017. [Online]. Available: https://cfpub.epa.gov/dmr/ez_search.cfm. [Accessed 30 November 2017].

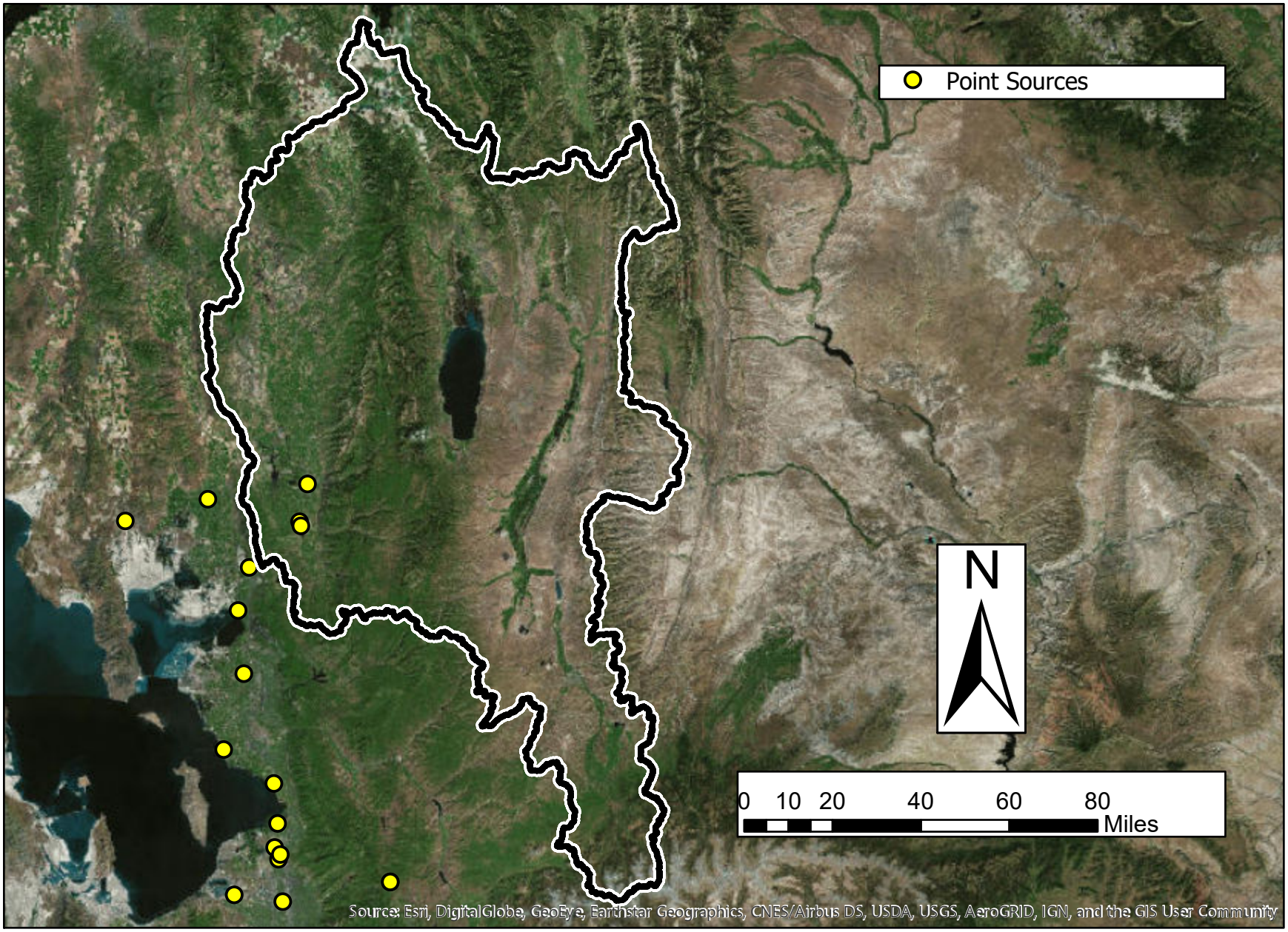
[5] "Water Related Land Use," Utah Automated Geographic Reference Center, 2017. [Online]. Available: https://gis.utah.gov/data/planning/water-related-land/. [Accessed 30 November 2017].

Appendix A: Watersheds Analyzed

Section 1: Large, Low-Elevation Water Bodies

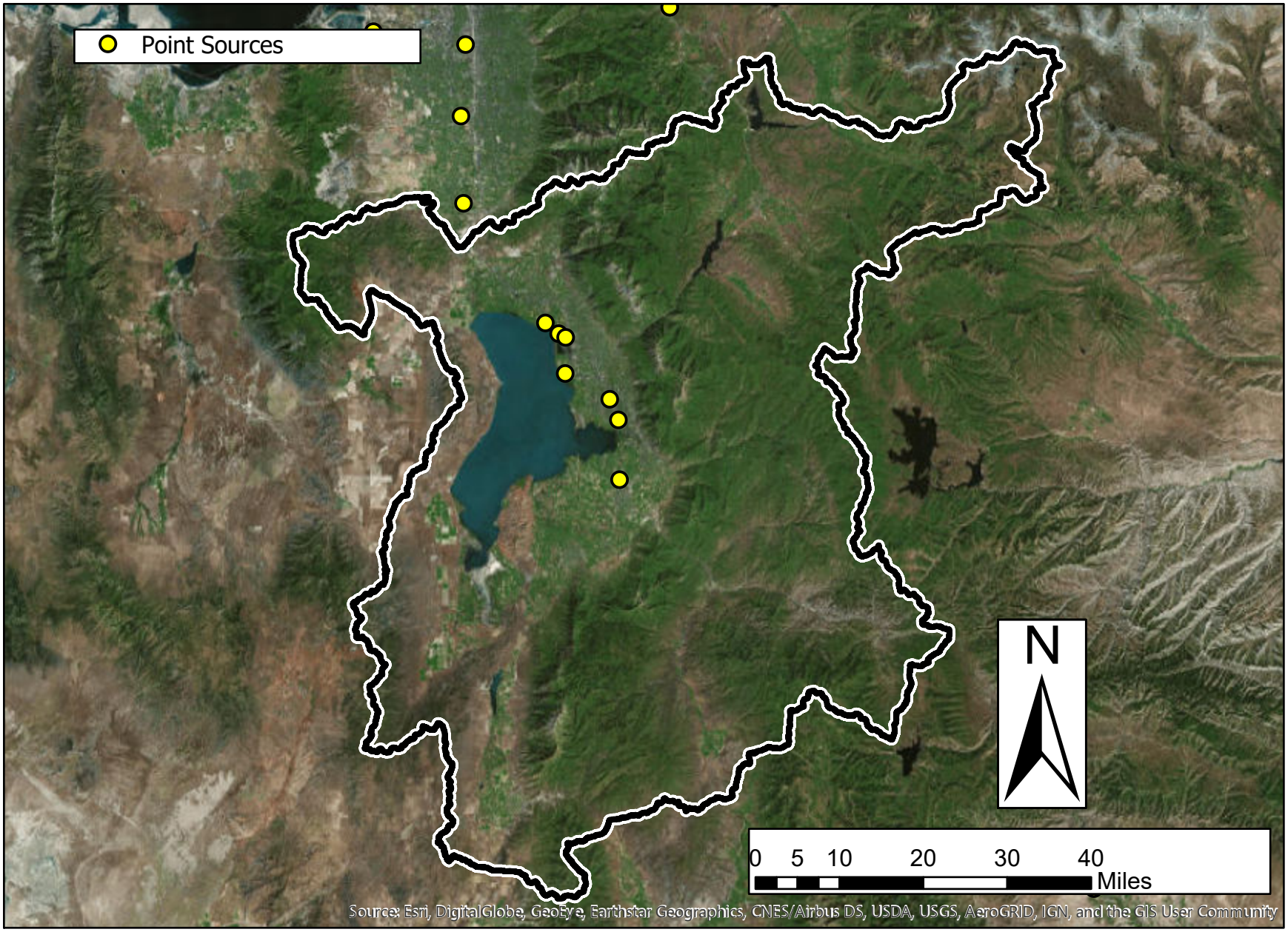
Watershed of Cutler Reservoir

Impaired Water Body



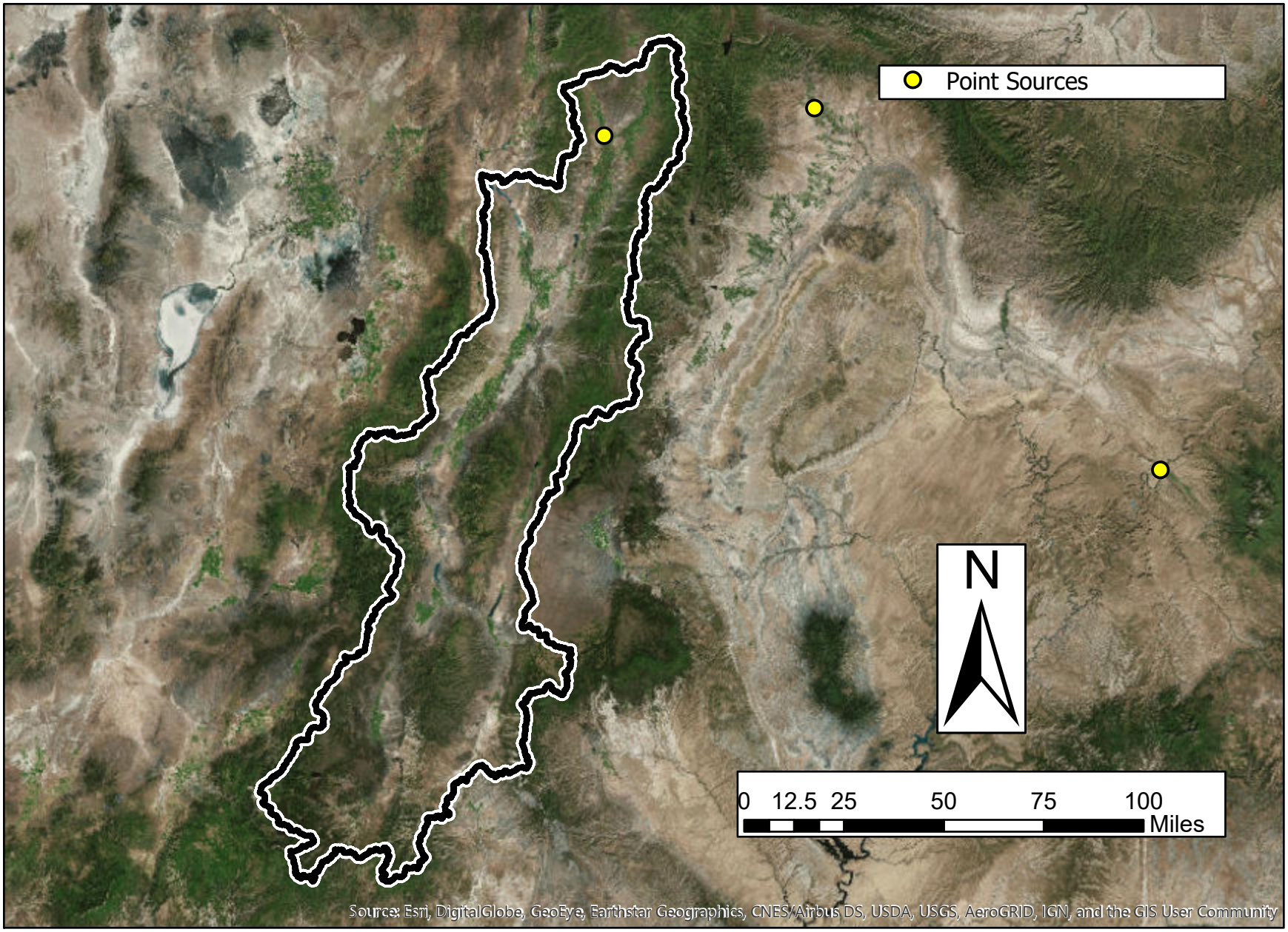
Watershed of Utah Lake

Impaired Water Body



Watershed of Yuba Reservoir

Control Water Body

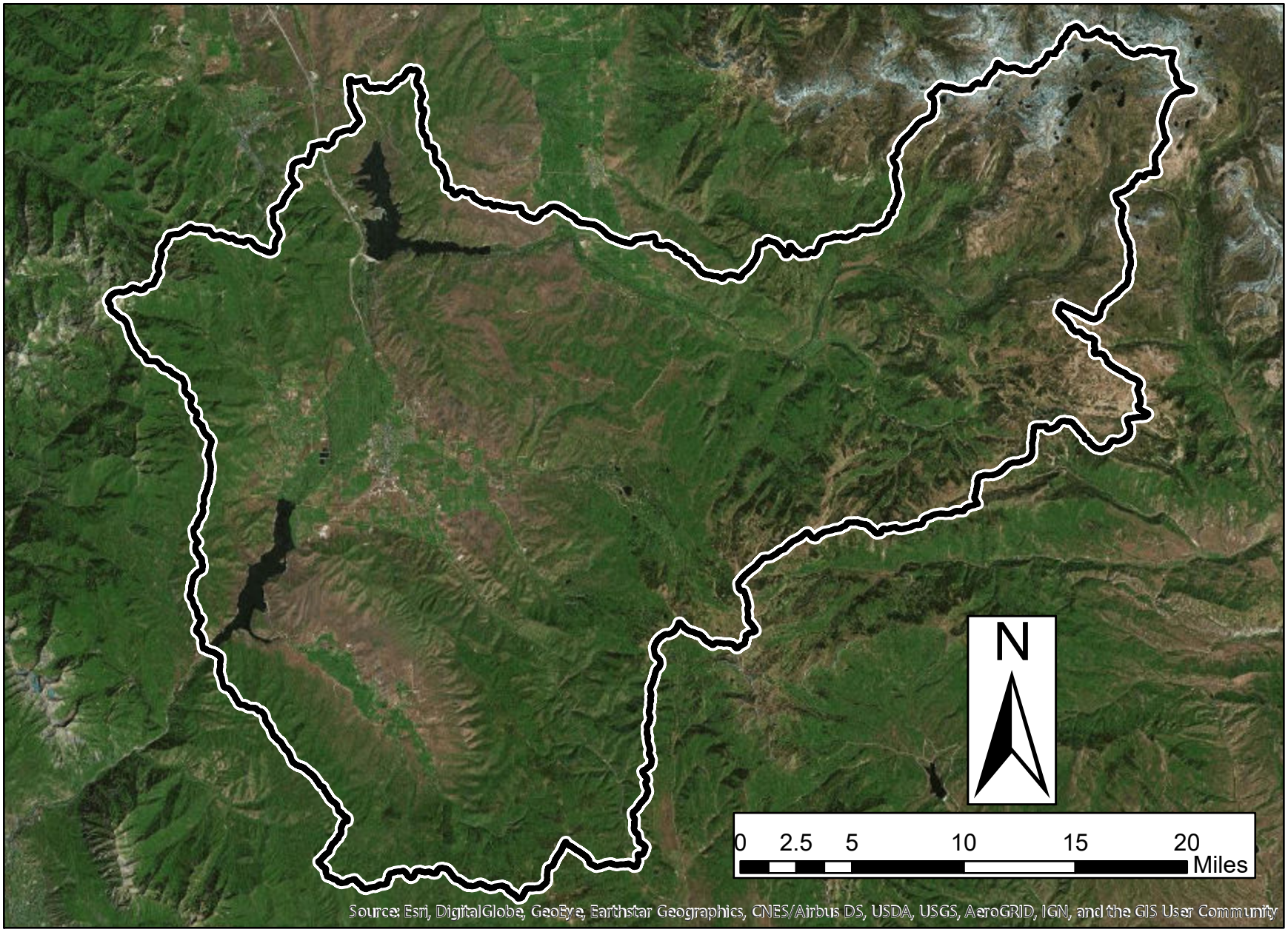


Appendix A: Watersheds Analyzed

Section 2: Large, Mid-Elevation Water Bodies

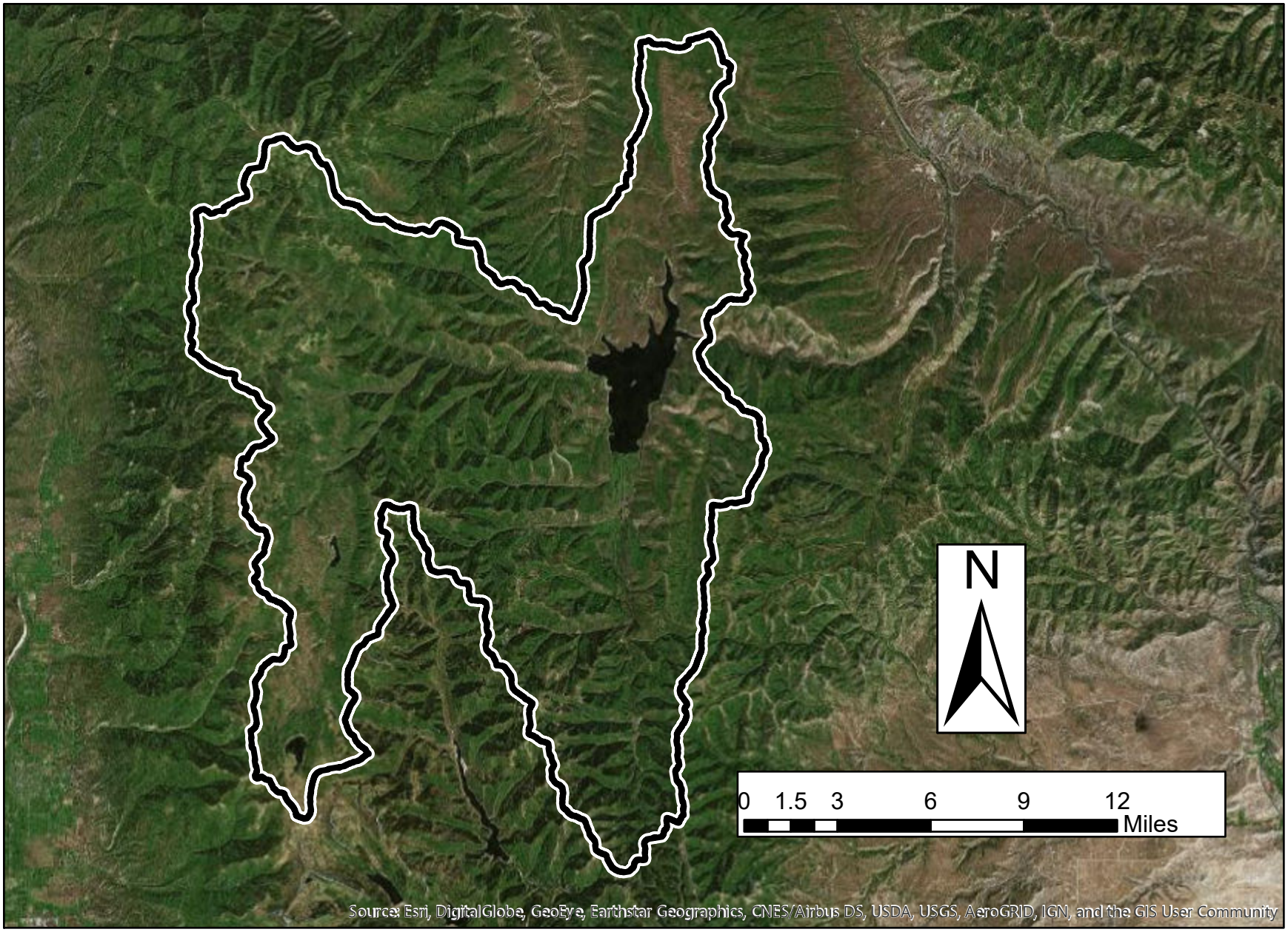
Watershed of Deer Creek Reservoir

Impaired Water Body



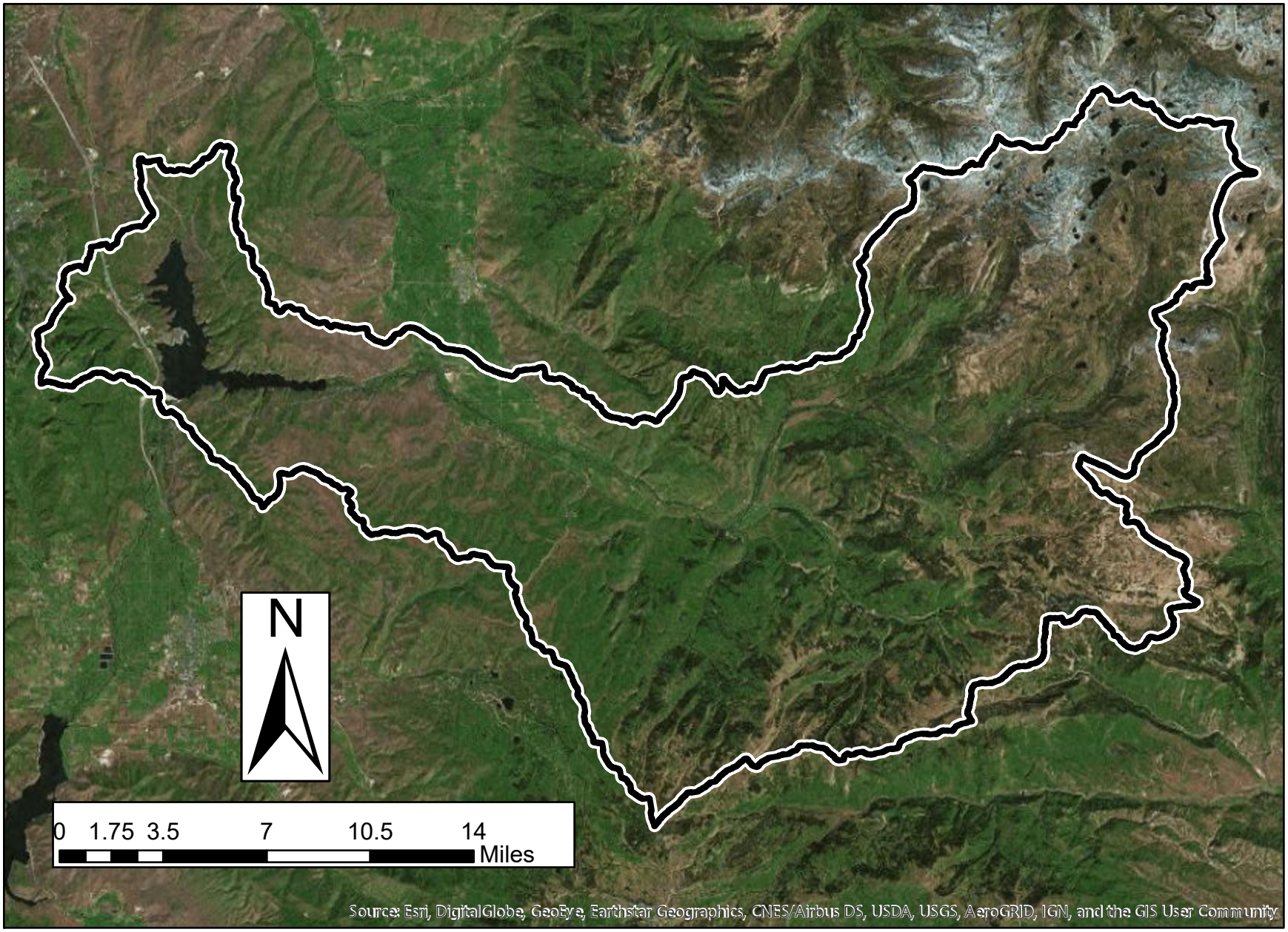
Watershed of Scofield Reservoir

Impaired Water Body



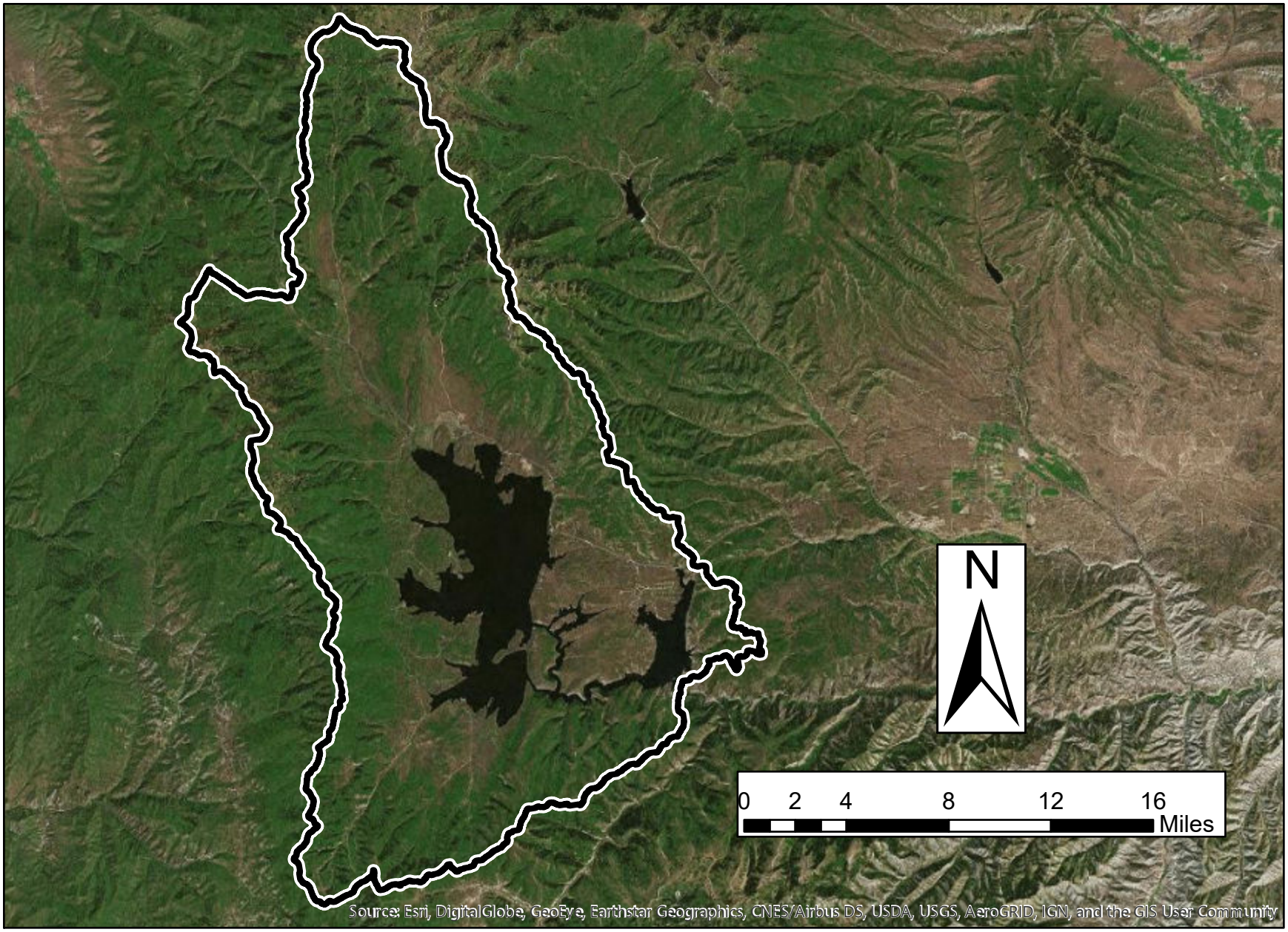
Watershed of Jordanelle Reservoir

Control Water Body



Watershed of Strawberry Reservoir

Control Water Body

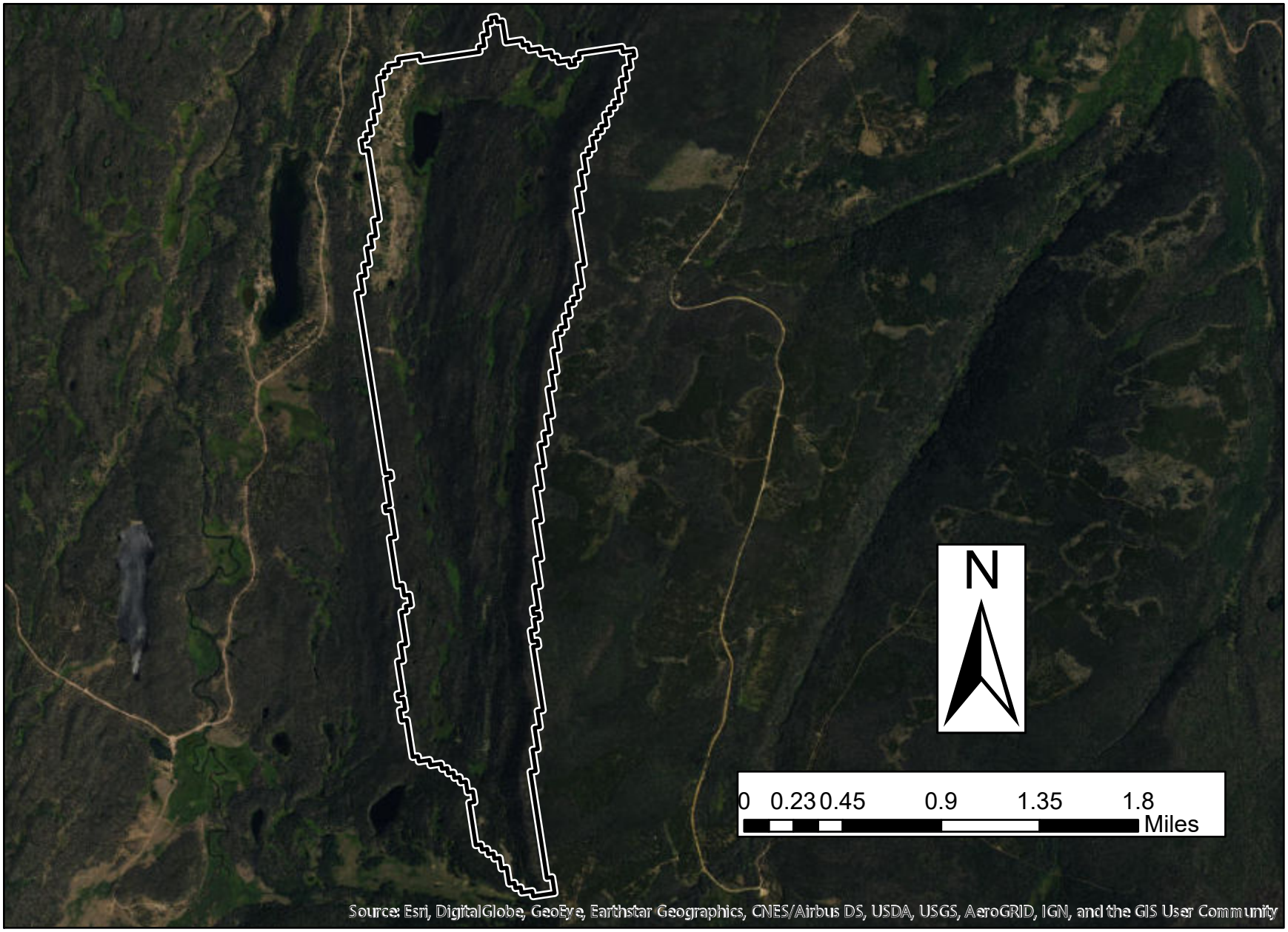


Appendix A: Watersheds Analyzed

Section 3: Small, High-Elevation Water Bodies

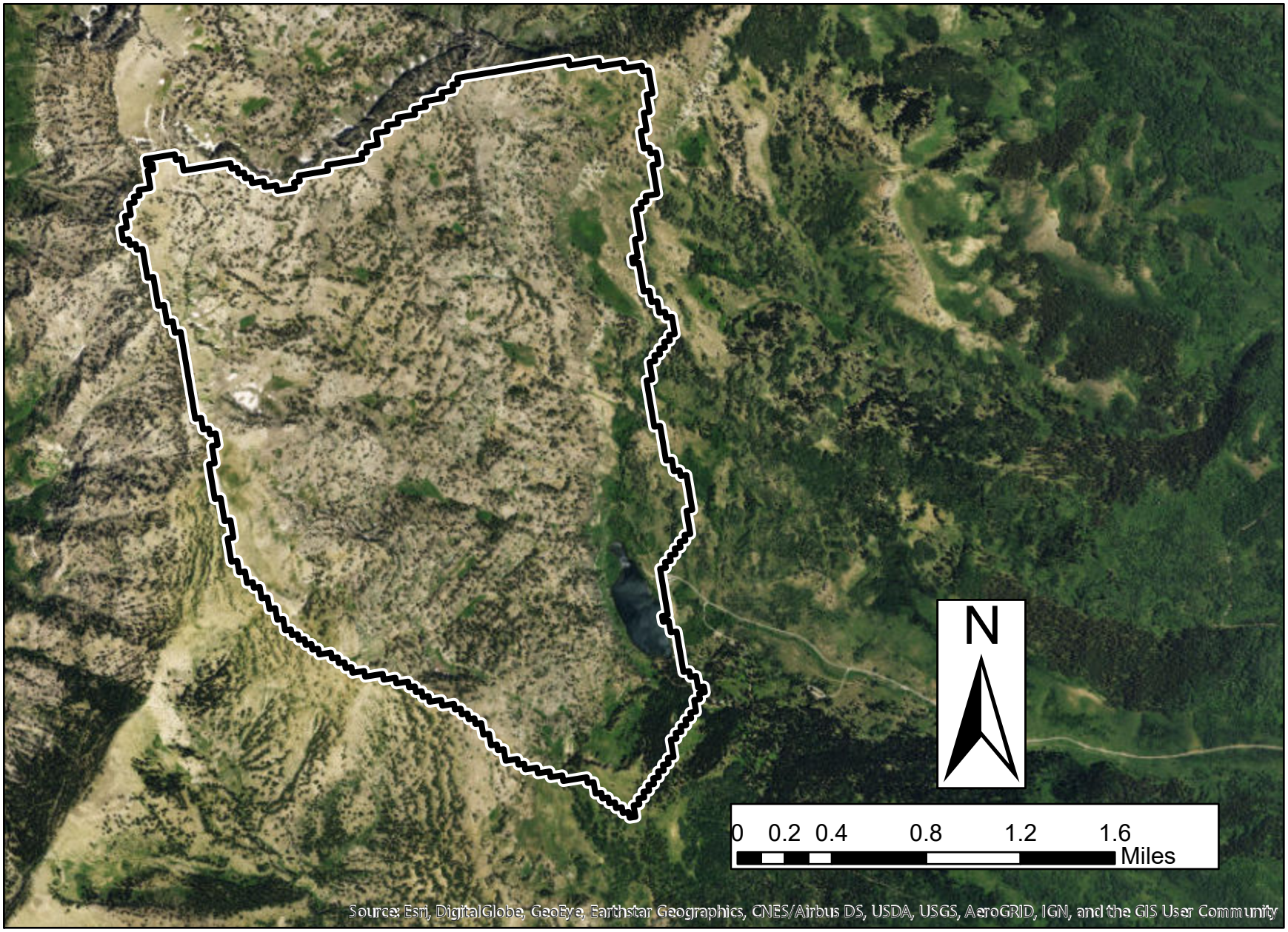
Watershed of Bridger Lake

Impaired Water Body



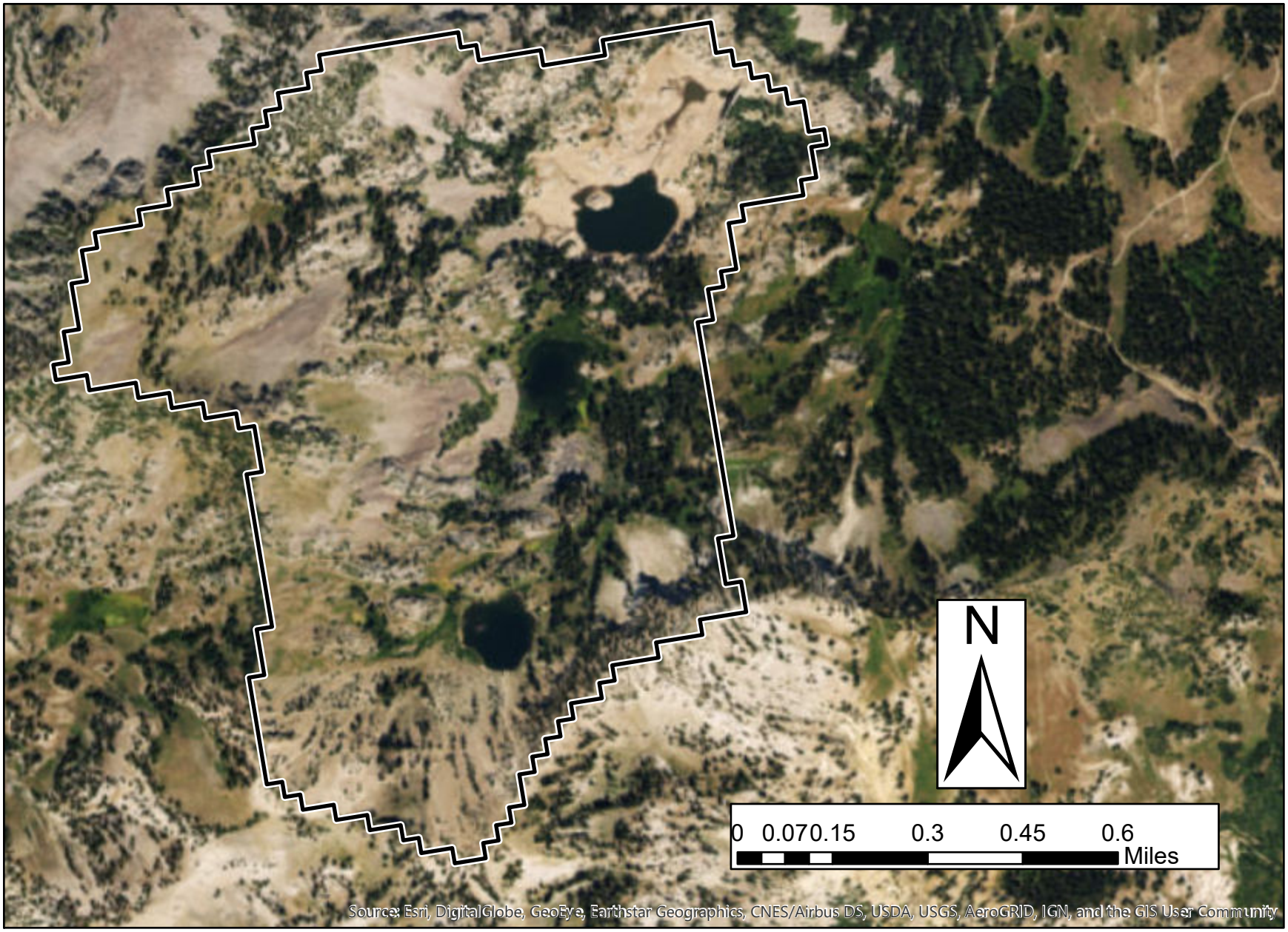
Watershed of Tony Grove Lake

Impaired Water Body



Watershed of Lake Mary

Control Water Body



Watershed of Whitney Reservoir

Control Water Body