GIS as a Tool for Visualizing Changes in Water Quality through a Watershed

Jared Richens

CEE 6440 Term Project

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## Introduction

The Little Bear River (LBR) drains the southern portion of Cache Valley, located south of Logan, Utah as seen in Figure 1.

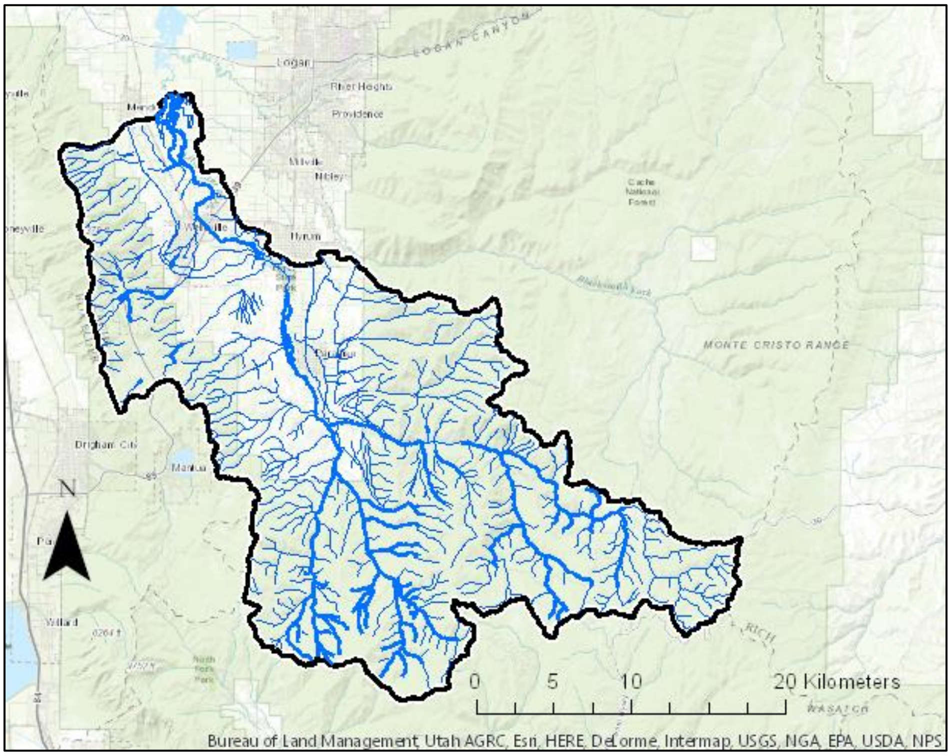


*Figure 1. Location of the Little Bear River Watershed with respect to Logan, Utah.*

The LBR drainage encompasses 182,000 acres (UDEQ, 2000). The headwaters of the LBR include an East and South Fork which flow through mostly undeveloped forest land with only 2% of the land use above the confluence of the East and South Forks classified as agricultural. Below the confluence, 40% of the land use is classified as agricultural (UDEQ, 2000). The East Fork drains National Forest land and is stored in Porcupine Reservoir which is regulated primarily as an irrigation reservoir (UDEQ, 2000).

The LBR has beneficial use designations of 2B, 3A, 3D, and 4 but is listed as impaired for high phosphorous and turbidity (UDEQ, 2000). As the LBR flows to its ultimate destination in Cutler Reservoir, it passes through both irrigated and non-irrigated cropland along with the Trout of Paradise Sportsman's Club before entering Hyrum Reservoir, located in Hyrum, Utah (UDEQ, 2000).

While Hyrum Reservoir is managed as an irrigation reservoir, the construction of Hyrum State Park resulted in beneficial use classifications of 2A, 2B, 3A, and 4 for which it is listed as impaired for high phosphorous and low dissolved oxygen (DO) levels (UDEQ, 2002). Below Hyrum Reservoir, summer flows in the LBR are primarily irrigation return flows; however, during spring runoff high flows can be experienced (UDEQ, 2000).

In an effort to improve the water quality, the United States Environmental Protection Agency (U.S. EPA), established the TMDL program to classify and protect water bodies based upon their beneficial uses (Copeland, 2012). In the event a water body does not meet those water quality criteria, it is listed as impaired, and steps taken to rectify the issues.

A major contribution to the impairment of water quality within the LBR is assumed to result from non-point sources such as agricultural runoff and current agricultural practices (UDEQ, 2000). For example, in certain areas within the watershed, cattle are allowed to water directly in the stream, thus trampling riparian vegetation and increasing erosion. One approach to mitigating the effect of non-point sources is to implement best management practices (BMPs) which are designed to change behaviors by increasing stakeholder interest. Unfortunately, it can be difficult to effectively communicate the need for behavioral changes to reverse the deteriorating trend in water quality to stakeholders.

The Utah Department of Environmental Quality (UDEQ) has determined a phosphorous target of 0.05 mg/L in the LBR (UDEQ, 2000). Algal blooms frequently occur within Hyrum Reservoir and it is assumed that, as phosphorous is the limiting nutrient in the system, by limiting phosphorous these algal blooms and the large amounts of benthic algae in the bottom of the watershed can be eliminated. For this project, other water quality constituents of concern such as total nitrogen concentrations will also be considered to determine whether analyses are effective on more than one water quality constituent of concern.

## Objectives

The objective of this project is to establish the use of GIS as a tool for visualizing water quality data collected within a watershed. In addition to visualizing data, the feasibility of using GIS as a way to improve communication between water managers and stakeholders concerning their practices which may be contributing to deteriorating water quality within a watershed, will also be evaluated. In order to accomplish this, GIS will be used to visually display water quality data for phosphorous and nitrogen through the LBR watershed and to collect and organize other information such as the percent agricultural land use draining to each water quality monitoring station along the LBR. Collected data will then be processed and analyzed for trends which may help explain the causes of water quality impairment.

## Materials and Methods

Information on water quality along the Little Bear River was first collected from the National Water Quality Monitoring Council (NWQMC), a collective effort by the United States Geological Survey (USGS) and the U.S. EPA. An ongoing research project at the Utah Water Research Laboratory (UWRL) has also been collecting data of interest. The data from the UWRL would have been preferable for use in this project; however, at the outset of this project no data was available and a website which had been used to allow public data access was no longer being maintained due to budget constraints.

After water quality data was collected, it was sorted based on water quality constituent, sampling time, and sampling location, and converted to a .csv file to allow it to be added to an ArcGIS Pro map. Extensive amounts of data was available and significant time was spend in processing the data into a useable format. However, no information on data quality was provided along with reported values.

All data used represents one sampling event conducted by the UDEQ in June, 2015 for total dissolved phosphorous (TDP) and total nitrogen (TN). These two water quality constituents were selected based on their importance as limiting nutrients in the natural environment, but also to limit the scope of this project to what is achievable. Limited experience using GIS has resulted in the scope of this project changing with time.

Extraneous data points were clipped from the map using the clip tool in the 'Geoprocessing' tab of ArcGIS Pro and data was displayed along the watershed based on water quality constituent. The symbology for the phosphorous data was set using graduated colors and creating manual intervals spaced from 0 – 0.05 mg/L and an additional interval for any result over 0.05 mg/L. This graduation was determined using the UDEQ target concentration of 0.05 mg/L phosphorous. The symbology for nitrogen was set in a similar manner; however, without an instream water quality guideline provided by the UDEQ the graduation is arbitrarily set at 'Natural Jenks' and analysis is only meant to determine trends in nitrogen concentration and possible influences from non-point sources.

Following the processing of water quality data, information on flow lines within the watershed were retrieved. Because of the highly developed nature of the watershed, flow lines were obtained from the High Resolution National Hydrography Dataset rather than using an elevation raster to delineate flow accumulation areas in order for canals and other man made water bodies to be shown on the map in their proper location. However, with the vast amount of development within this watershed, the map quickly became excessively cluttered and as a result only natural flow lines were displayed in the final maps presented here. An example of both the symbology described previously and the flowlines within the LBR watershed can be found in Figure 2 below.

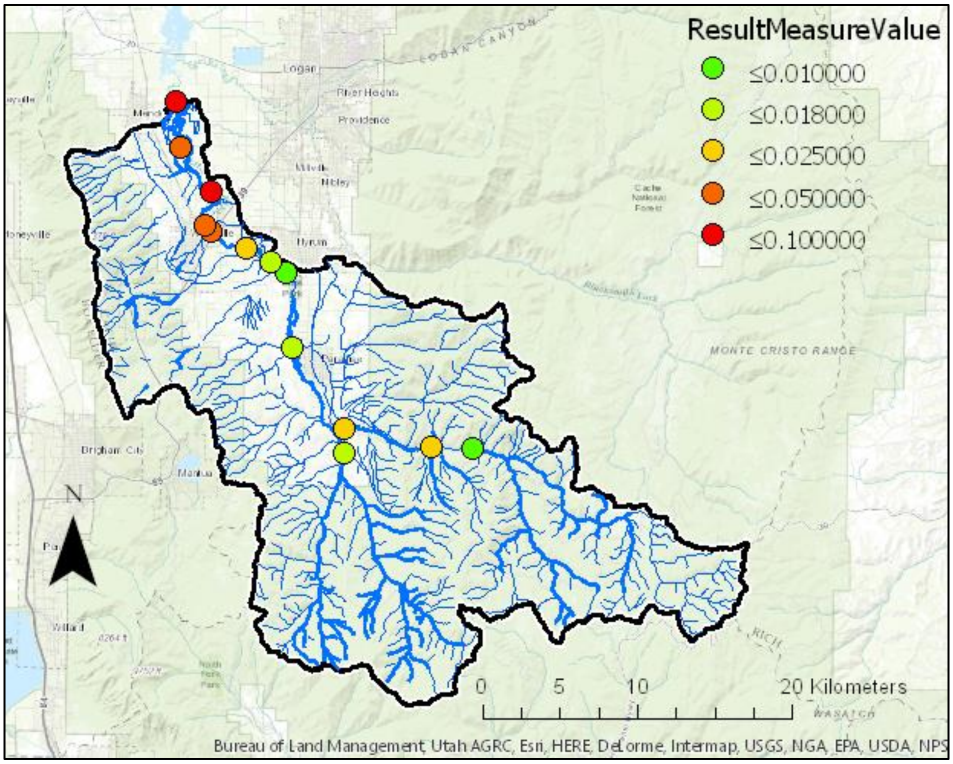


*Figure 2. Phosphorous Symbology with result value in units of mg P/L*

The Utah Automated Geographic Reference Center provided data on sub-watersheds and water-related land use within the LBR basin. The locations of Utah Pollutant Discharge Elimination System (UPDES) point source dischargers within the basin was gathered from the Bear River Commission, and land cover information was obtained from the National Land Cover Database (NLCD). Through use of the 'Extract by Mask' and 'Clip' features available in the 'Geoprocessing' tab of ArcGIS Pro, all collected information was able to be organized for only the area of interest. The only UPDES point sources in the LBR watershed that are identified by the Bear River Commission are the Wellsville Sewer Treatment Lagoons. These sewer lagoons discharge to Wellsville Creek which is a tributary to the lower Little Bear River. Because nutrient data was used from June 2015, and the Wellsville Sewer Treatment Lagoons only discharge in the fall of each year when their discharge permit allows for higher levels of nutrients, they were left off of the maps in this project but discussed here because it is of importance to note.

Data analysis was conducted using the location information from each water quality monitoring station that was common among all water quality constituents considered as part of the project. First, water quality data was plotted against total upstream drainage area at each monitoring point to determine if an increasing trend existed between increased water quality impairment and the amount of contributing area from the watershed. Following this, drainage areas to each monitoring station were delineated using the 'Watersheds' tool within ArcGIS Pro. The resulting drainage areas based on water quality monitoring locations can be seen below.

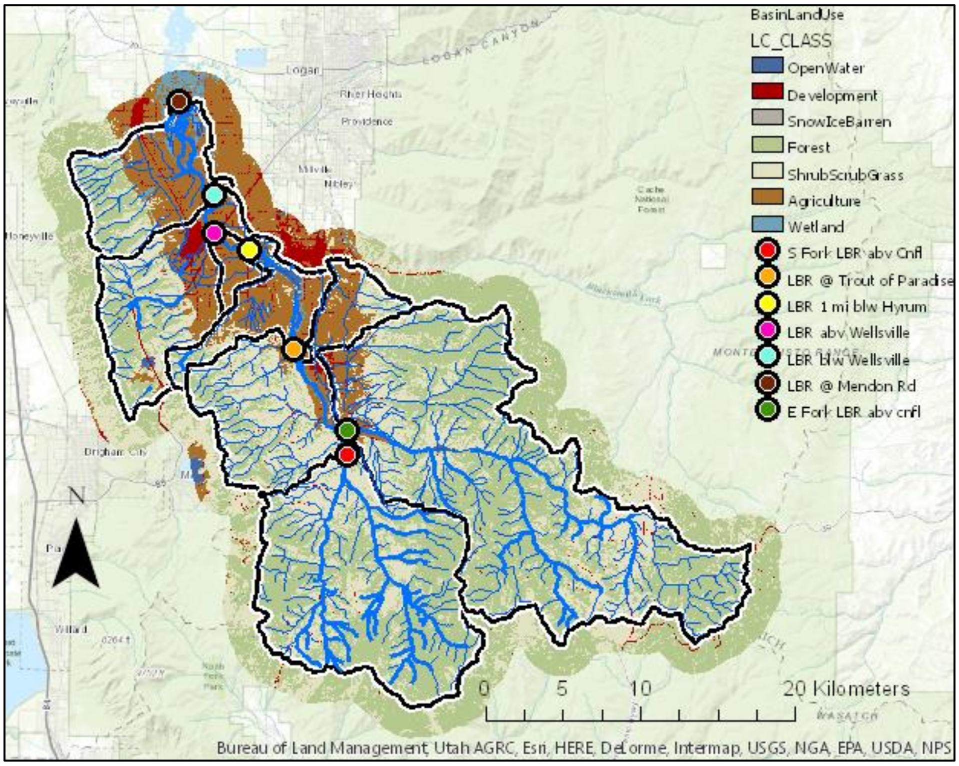


*Figure 3. LBR water quality monitoring locations and their drainage areas*

These drainage areas were then used to extract land cover data within the drainage area using the 'Extract by Mask' tool and the land cover raster for each drainage area was then analyzed to determine the percent agricultural land use within each drainage area. Because the NLCD provides land use in a raster format, the number of cells multiplied by the cell size can be used to determine an approximate area for a given land use. After dividing the area designated as agricultural use by the total area within each drainage, the resulting percent agricultural area was plotted against water constituents of concern to determine if a correlation between increasing agricultural use and increased water quality impairment existed. An example calculation is provided in Appendix A.

## Results and Discussion

After adding and displaying nutrient data to the ArcGIS map, it quickly became clear that increased nutrient concentrations were being measured on the LBR as it flows down the watershed as was seen in Figures 2 above. Additional maps illustrating this trend with land use data visible are available in Appendix B, and the combination indicate GIS is an effective tool at displaying water quality data. When a gradient is applied to the nutrient data as in Figure 2, and the maps in Appendix B, it is easily understood that there are increasing levels of nutrients in the LBR; however, In order to provide an additional interpretation normalized by contributing area, nutrient data was plotted against total contributing area at each of the monitoring locations identified in Figure 3. The resulting plots for TDP and TN are found below.

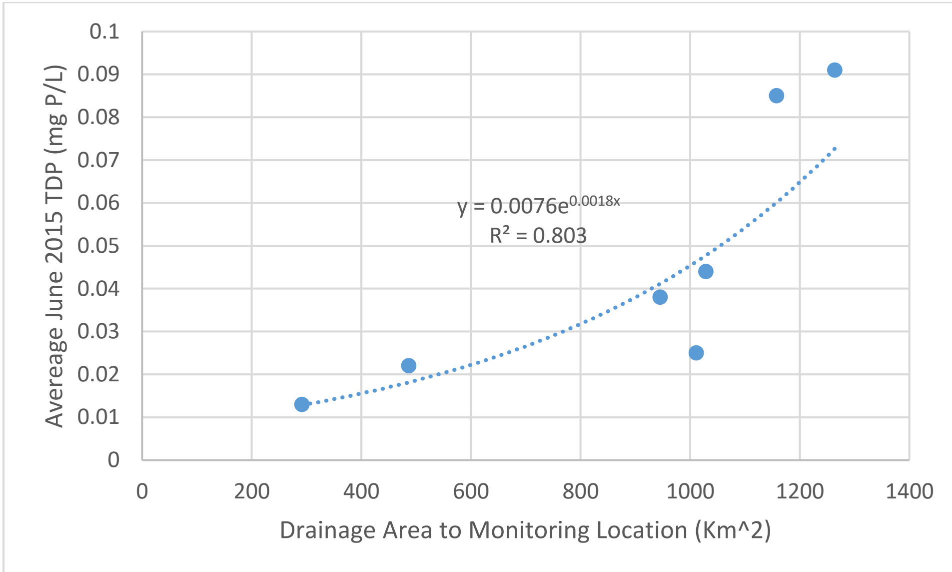


*Figure 4. Drainage Area vs. June 2015 TDP (mg/L)*

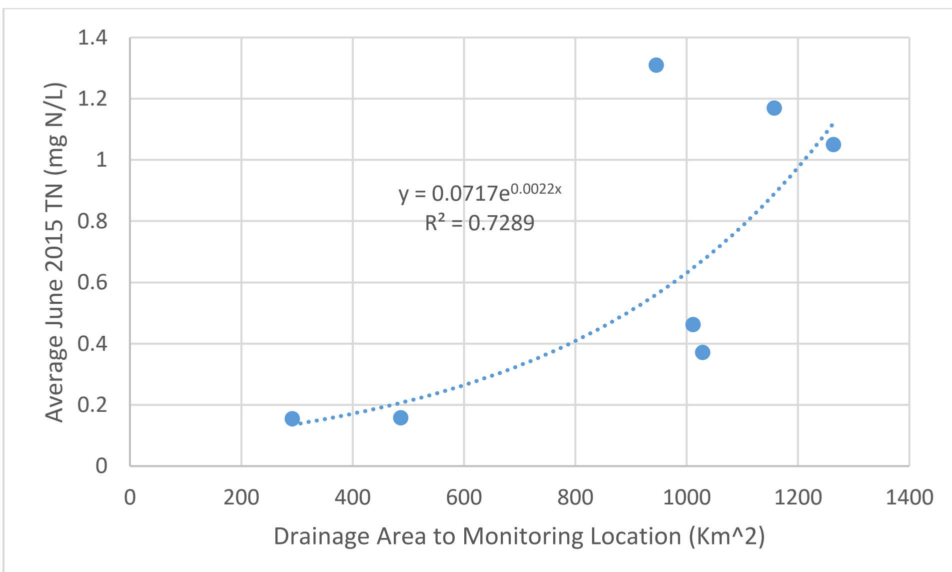


*Figure 5. Drainage Area vs. June 2015 TN (mg/L)*

An apparent exponential trend between drainage area and TDP exists with the only exception occurring at the 4th water quality monitoring location not far downstream of Hyrum Reservoir. Lakes are often considered a sink for nutrients within a watershed and this, coupled with the fact that the majority of flow below Hyrum Reservoir consists of groundwater recharge and irrigation return flows because the majority of natural flows are diverted into an irrigation system, are assumed to create the lower than expected value (UDEQ, 2000).

A similar trend between drainage area and TN concentration also exists but the data is less correlated with the highest values occurring upstream of Hyrum Reservoir at the Trout of Paradise monitoring location. Trout of Paradise diverts a large portion of the flow from the LBR into their Fisherman's club and returns it on the downstream side of their operation. Trout of Paradise is considered a point source along the LBR in the LBR TMDL but it was not identified by the Bear River Commission. It is possible that the Trout of Paradise sportsmen's club is a major contributor to nitrogen contamination within the watershed; however, it could also be possible that an analysis error occurred. Because no information on data quality was provided, this cannot be determined from the available information.

Overall there is a definite trend of increasing nutrients with increasing contributing area. However, this trend is expected to occur naturally within watersheds similar to the LBR watershed as alpine headwaters with little primary production receive increased allochthonous contributions from runoff and riparian vegetation. In turn, these allochthonous inputs increase primary production in the lower reaches of the watershed. Because of this, a correlation between agricultural land use and increased nutrient concentrations was also considered. The resulting trends are found below.

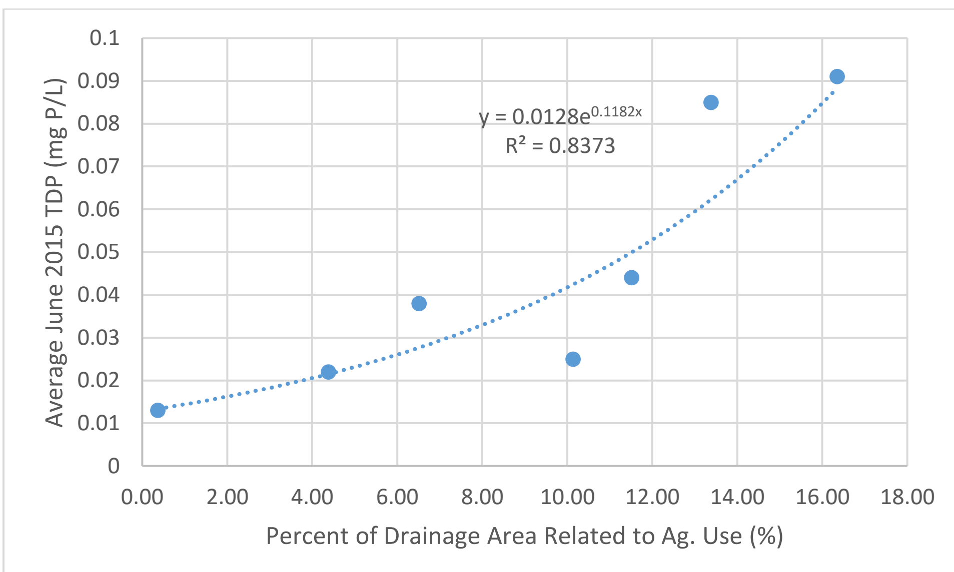


*Figure 6. Percent Ag Use vs. June 2015 TDP (mg P/L)*

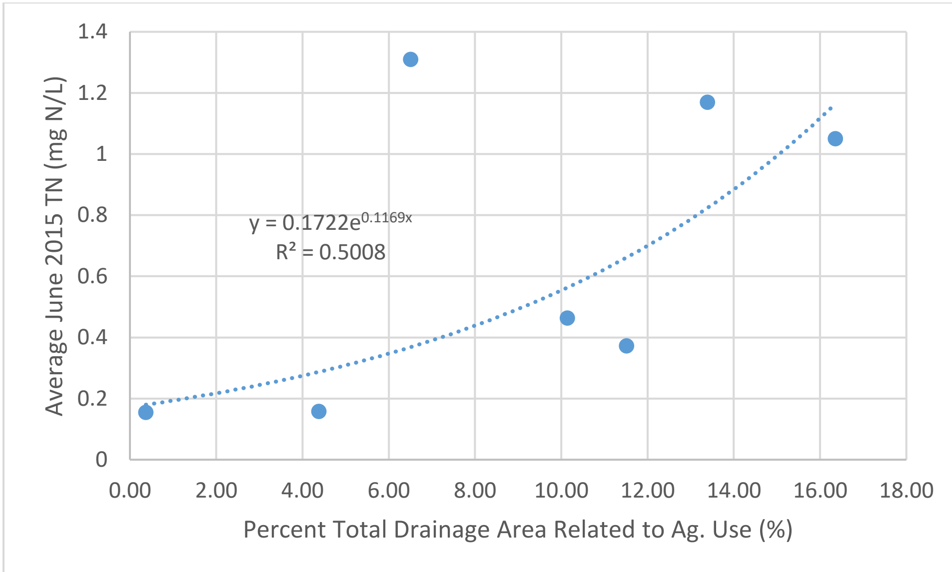


*Figure 7. Percent Ag. Use vs. TN (mg N/L)*

The increased correlation between percent of contributing area related to agricultural use and the increase in dissolved phosphorous over the correlation between total contributing area and increase in phosphorous (Figure 4 vs. Figure 6) is a compelling argument that agricultural practices are contributing phosphorous to the watershed because an increased correlation between agricultural land use and TDP would suggest that agricultural land use is more significant to TDP levels in the LBR than contributing area. However, based on personal experience in the watershed it is not practical that every agricultural user is contributing to deteriorating water quality. Rather it would be more practical that the actions of a few stakeholders cause the greatest impacts to water quality within the watershed.

However, based on the same logic, the lower correlation between agricultural land use and total nitrogen suggest that agricultural use is less significant than total contributing area to total nitrogen concentrations. This could provide support for the idea that the Trout of Paradise Sportsmen's Club is the significant contributor to nitrogen levels within the LBR watershed but a lack of data prevents a definitive conclusion from being made at this time.

## Summary and Conclusions

While correlation is not necessarily causation, Figure 6 does provide a compelling argument for water managers to use in an attempt to improve stakeholder's behaviors to better protect water quality. When used in conjunction with Figure 4, the increase in correlation between plots shows that agricultural land use is more significant than natural processes to the phosphorous concentrations in the LBR. Additional data points representing the same snapshot in time at each location would strengthen the argument.

What has been proved, is that GIS is an effective tool at visualizing changes in water quality through a watershed, and that because of its potent geographical analysis tools, GIS could be used as a way to improve communications between water managers and stakeholders by presenting water quality data in a more understandable way. The robust analysis tools of ArcGIS Pro also provides for data to be correlated with a possible cause in an attempt to determine which influences may be most significant to water quality impairment.

## References

Copeland, C., (2012). Clean Water Act and Pollutant Total Maximum Daily Loads (TMDLs). Congressional Research Service, 7-5700. <www.crs.gov>

Utah Department of Environmental Quality (UDEQ), Division of Water Quality, TMDL Section (2000). *Little Bear River Watershed TMDL.* Salt Lake City, UT <http://www.deq.utah.gov/ProgramsServices/programs/water/watersheds/approvedtmdls.htm> (September 13, 2016).

Utah Department of Environmental Quality (UDEQ), Division of Water Quality, TMDL Section (2002). *Hyrum Reservoir TMDL.* Salt Lake City, UT <http://www.deq.utah.gov/ProgramsServices/programs/water/watersheds/approvedtmdls.htm> (September 13, 2016).

# Appendix A – Example Calculations

Areas and Percent of total areas were calculated based on the following equations:

$$Total\ NLCD\ Cell\ Count * NLCD\ Cell\ Area = Total\ Area$$

$$\frac{Total\ Agriculture\ Area\ in\ Drainage}{Total\ Area\ in\ Drainage} * 100\% = \%\ Ag$$

| Drainage | Total Cell Count | Cell Area (m^2) | Total Area (Km^2) | Ag Area (Km^2) | % Ag | Avg. TDP (mg P/L) | Avg. TN (mg N/L) |
|---|---|---|---|---|---|---|---|
| SF | 323992 | 900 | 292 | 1.08 | 0.37 | 0.013 | 0.155 |
| EF | 540406 | 900 | 486 | 21.29 | 4.38 | 0.022 | 0.158 |
| TF | 1050244 | 900 | 945 | 61.55 | 6.51 | 0.038 | 1.31 |
| BlHrym | 1123694 | 900 | 1011 | 102.55 | 10.14 | 0.025 | 0.463 |
| AbvW | 1143005 | 900 | 1029 | 118.44 | 11.51 | 0.044 | 0.372 |
| BlW | 1286130 | 900 | 1158 | 154.94 | 13.39 | 0.085 | 1.17 |
| Mendon | 1404372 | 900 | 1264 | 206.69 | 16.35 | 0.091 | 1.05 |

Average concentrations were found using June 2015 Data retrieved from NWQMC as described above.

# Appendix B – Additional Maps

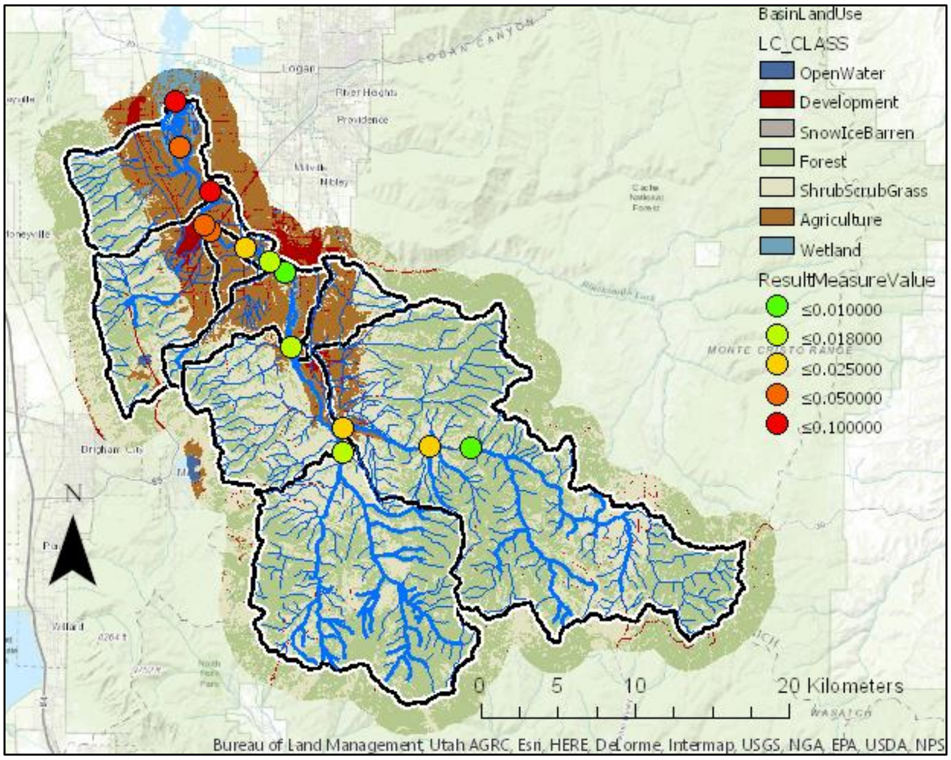


*Figure 8. Average June 2015 TDP at locations along LBR 'Result Measure' in mg P/L*

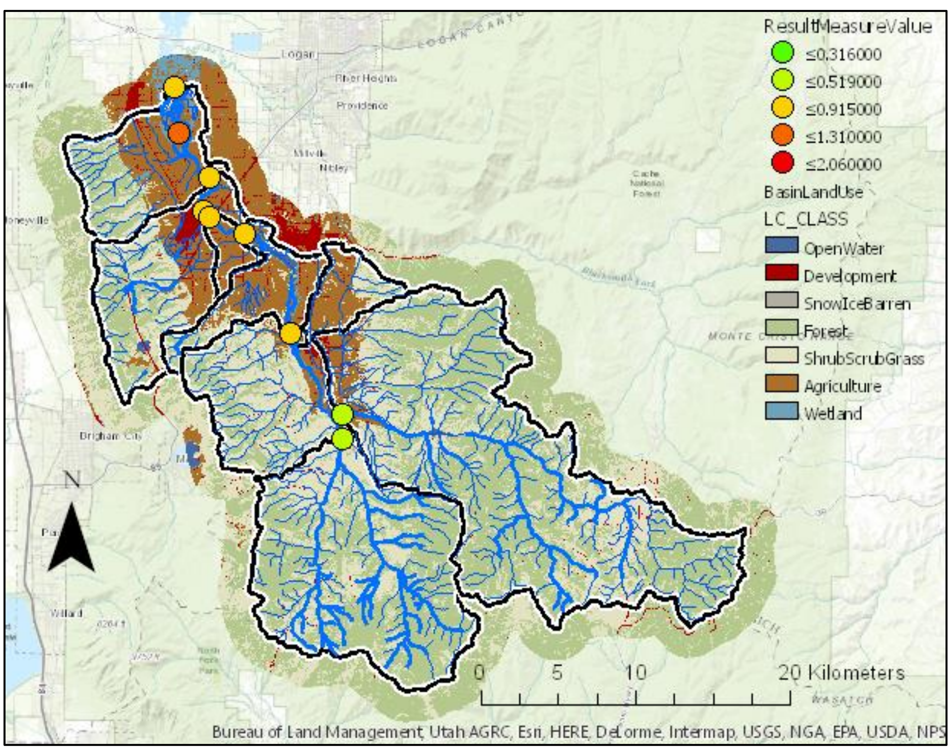


*Figure 9. Average June 2015 TN at locations along LBR 'Result Measure' in mg N/L*