

# Lake Powell: Preliminary data analysis

*Tammy Lee*

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## Project description

Long term effects of dams and reservoirs on water quality remain poorly understood. Lake Powell is a reservoir on the Colorado River that resulted from the Glen Canyon Dam. Glen Canyon Dam construction began on February 11, 1959 and finished on September 13, 1963. Amazingly, several sites were monitored for various environmental parameters (e.g. physical, nutrient, sediment) since 1928 by several different government agencies. This long-term publicly available data set has yet to be fully analyzed. The purpose of this report is to provide preliminary results examining parameters continuously monitored across all sites, and determine if there are any significant differences among sites for each parameter before and after dam construction. Data collected and organized for this report will be used for future analyses examining the influences of dam construction and other potential environmental effects on water quality and biogeochemical processes.

## Methods

### Site descriptions

The five sites used for this project include:

- Colorado River at Cisco (Cisco)
- San Juan at Bluff (Bluff)
- Green River at Green River (Green)
- Colorado River at Lees Ferry (Lees)
- Colorado River at Colorado River, near Grand Canyon (Colorado)

Cisco, Green, and Bluff represent boundary conditions for Lake Powell and are the three major tributaries to Lake Powell (Green and Colorado merge before entering Lake Powell but these sites have long term monitoring data available). Lees is approximately 25 km below the dam and measures reservoir outflow. Colorado is a site within Grand Canyon and provides an approximation of any biogeochemical processing that might be occurring within the river itself.

### Data collection and analysis

Data are publicly available and can be download through NWIS (<https://nwis.waterdata.usgs.gov/usa/nwis/qwdata>) for each of the five sites. Environmental parameters monitored continuously across all sites for at least 10 years prior to dam construction were selected. Additional criteria used to select the initial 936 parameters as well as data cleaning steps can be found at <https://github.com/tam8to/Lake-Powell>.

Among group comparisons for five specific parameters were assessed using Kruskal-Wallis for pre- and post-dam construction (total of ten comparisons). Parameters included were nitrate as nitrogen, calcium, magnesium, bicarbonate, and pH.

## Summary

A total of 33 parameters were initially examined across all five sites. Many paraments tended to exhibit strongly observable cyclical patterns prior to dam construction. Post-dam construction there appeared to be a lag response with an attenuated, less distinct cyclical pattern.

Table 1: Table 1. Code and description of parameters used in this analysis. Codes with a "c" designation were combined.

Parameter	Group	Description
p00028	Information	Agency analyzing sample, code
p82398	Information	Sampling method, code
p00935	Inorganics, Major, Metals	Potassium, water, filtered, milligrams per liter
p00915	Inorganics, Major, Metals	Calcium, water, filtered, milligrams per liter
p00925	Inorganics, Major, Metals	Magnesium, water, filtered, milligrams per liter
p00930	Inorganics, Major, Metals	Sodium, water, filtered, milligrams per liter
p00940	Inorganics, Major, Non-metals	Chloride, water, filtered, milligrams per liter
p00945	Inorganics, Major, Non-metals	Sulfate, water, filtered, milligrams per liter
p00955	Inorganics, Major, Non-metals	Silica, water, filtered, milligrams per liter as SiO <sub>2</sub>
p00410c	Inorganics, Major, Non-metals	Acid neutralizing capacity, water, unfiltered, fixed endpoint (pH 4.5) titration, laboratory, milligrams per liter as calcium carbonate
p00191	Inorganics, Major, Non-metals	Hydrogen ion, water, unfiltered, calculated, milligrams per liter
p00440c	Inorganics, Major, Non-metals	Bicarbonate, water, unfiltered, fixed endpoint (pH 4.5) titration, field, milligrams per liter
p00405	Inorganics, Major, Non-metals	Carbon dioxide, water, unfiltered, milligrams per liter
p01046	Inorganics, Minor, Metals	Iron, water, filtered, micrograms per liter
p71851	Nutrient	Nitrate, water, filtered, milligrams per liter as nitrate
p71887	Nutrient	Total nitrogen [nitrate + nitrite + ammonia + organic-N], water, unfiltered, milligrams per liter as nitrate
p00613c	Nutrient	Nitrate, water, filtered, milligrams per liter as nitrogen
p00660	Nutrient	Orthophosphate, water, filtered, milligrams per liter as PO <sub>4</sub>
p00671	Nutrient	Orthophosphate, water, filtered, milligrams per liter as phosphorus
p70507	Nutrient	Orthophosphate, water, unfiltered, milligrams per liter as phosphorus
p00010	Physical	Temperature, water, degrees Celsius
p00060c	Physical	Discharge, cubic feet per second
p00095	Physical	Specific conductance, water, unfiltered, microsiemens per centimeter at 25 degrees Celsius
p00900	Physical	Hardness, water, milligrams per liter as calcium carbonate
p00902c	Physical	Noncarbonate hardness, water, unfiltered, field, milligrams per liter as calcium carbonate
p00400c	Physical	pH, water, unfiltered, field, standard units
p80154	Sediment	Suspended sediment concentration, milligrams per liter

Of the 33 parameters, five were further examined for among group comparisons pre- and post-dam construction. For the most part nitrate concentrations were different across all sites pre- and post-dam construction. Magnesium and bicarbonate concentrations went from heterogenous across all sites pre-dam construction to more homogenous across most sites post-dam construction. Calcium concentrations went from some sites being similar to more sites being similar. pH was the only parameter that went from more similar across sites to more different across sites post-dam construction.

## Future directions

Although these preliminary results suggest parameter changes across sites might be due to dam construction, further analyses must be conducted and additional parameters investigated to fully attribute differences to dam construction. In addition, two of the stations are located below Lake Powell, and any changes upstream may be due to other factors not included in this preliminary analysis. The preliminary analyses of this project serve to provide a first pass of available data and help make future decisions about parameters and analyses on which to for this long-term data set. Current next steps include time-series analysis.

## Results

There were approximately 967 different parameters measured for Bluff, Colorado, Green, Lees, and Cisco combined. Of those 967, 33 were of interest based on availability of data across all sites. These 33 parameters were further cleaned to a total of 27 usable parameters (several parameters were combined with other parameters because measurement methods were changed at some point during the monitoring period). Table 1 provides the parameter code, the group it belongs to, and description.

### Inorganic, Major, Metals

Four parameters fall under the *Inorganics, Major, Metals* group. Figure 1 shows measurements taken for each parameter across all sites. The shaded region represents dam construction period. For each of the parameters up through the construction of the Glen Canyon dam there is a cyclical pattern of concentration levels across all sites. Post-dam construction, that pattern attenuates across all sites.

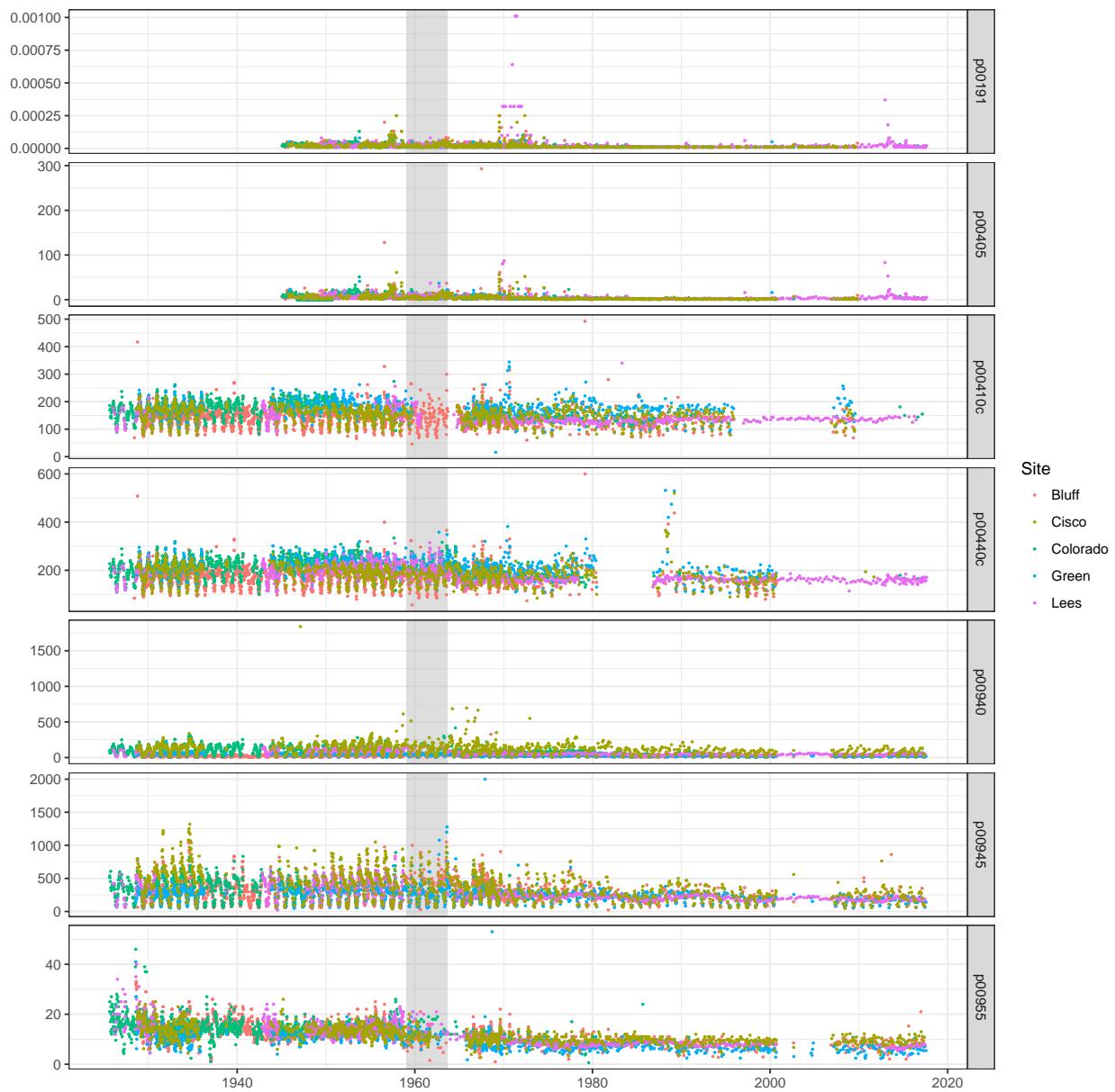
Fig 1. Parameter group: Inorganics, Major, Metals



### Inorganic, Major, Non-metals

Seven parameters fall under the *Inorganics, Major, Non-metals* group. Figure 2 shows measurements taken for each parameter across all sites. Several of the parameters have an observable cyclical periodicity as observed with the *Inorganics, Major, Metals* group prior to dam construction. Post-dam construction that pattern attenuates over time.

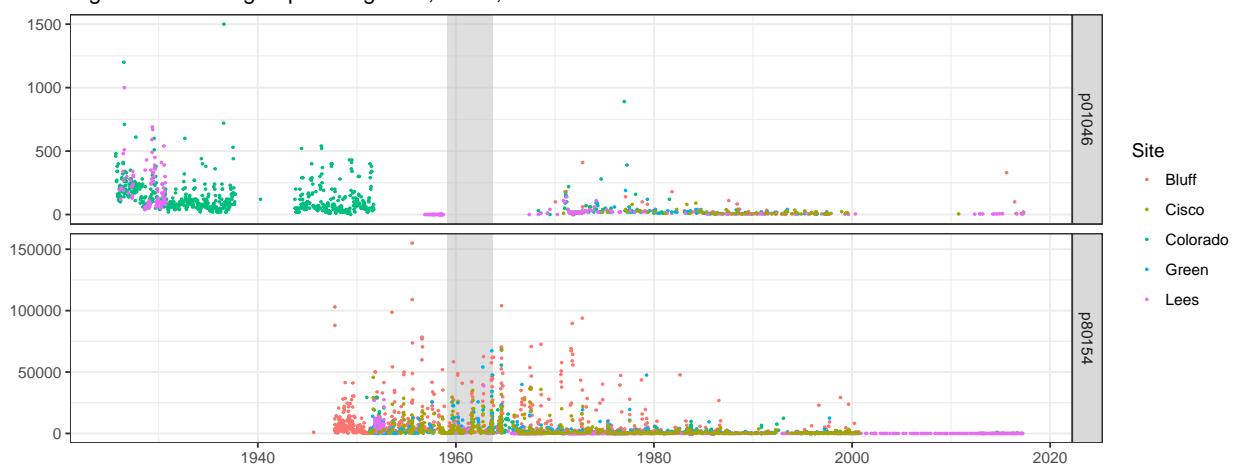
Fig 2. Parameter group: Inorganics, Major, Non-metals



### Inorganic, Minor, Metals & Sediment

One parameter falls under each of the *Inorganics, Minor, Metals* and *Sediment* groups. Data seems to be incomplete for Iron concentration (p01046) across all sites, and range of values for suspended sediment concentration (p80145) varies across sites (Fig. 3).

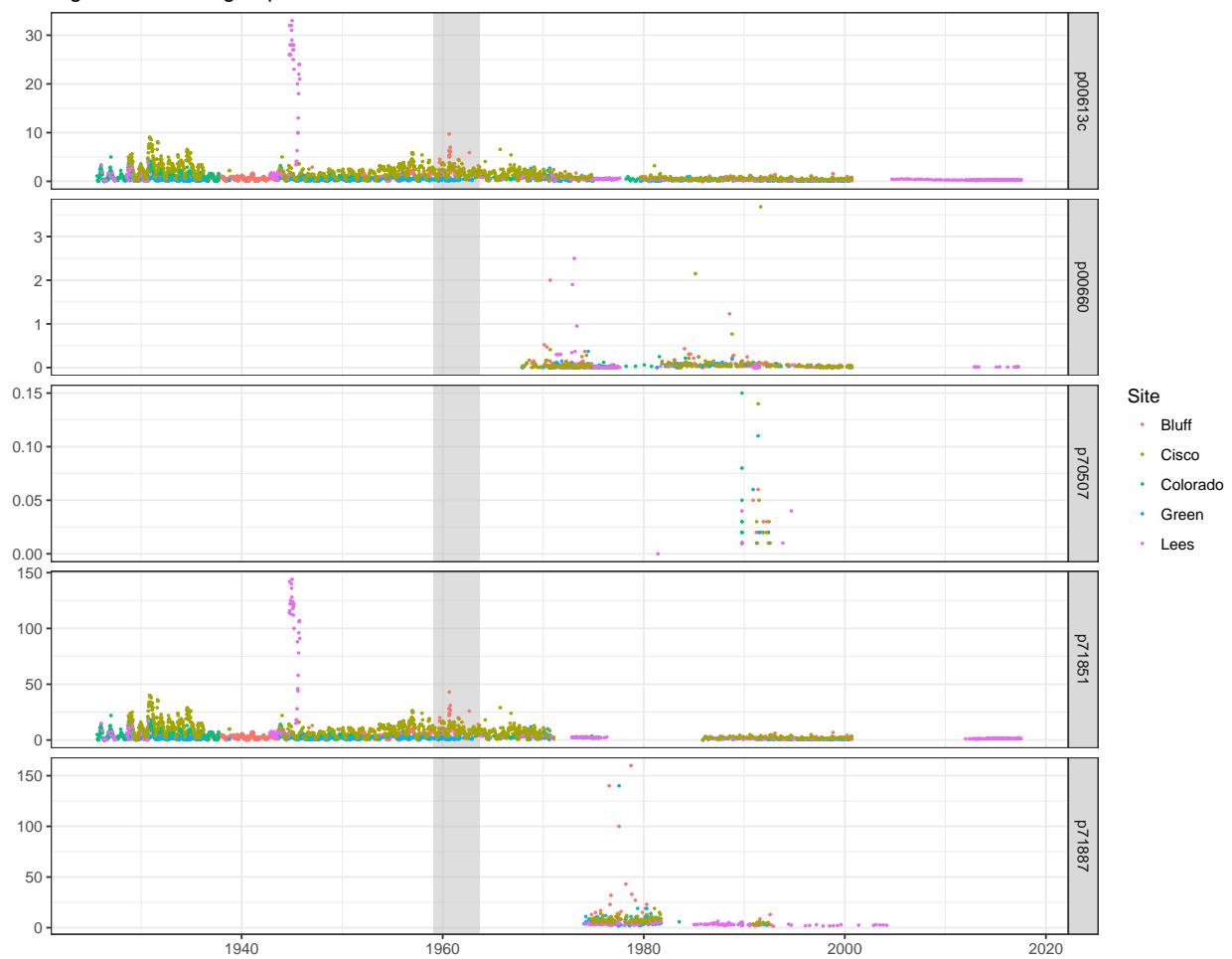
Fig 3. Parameter groups: Inorganics, Minor, Metals & Sediment



## Nutrient

Five parameters fall under the *Nutrient* group. Although data are continuous for nitrate as nitrogen and nitrate as nitrate (two different methods for measuring nitrate), other parameters are included because these water quality variables are of interest for further analyses (Fig 4).

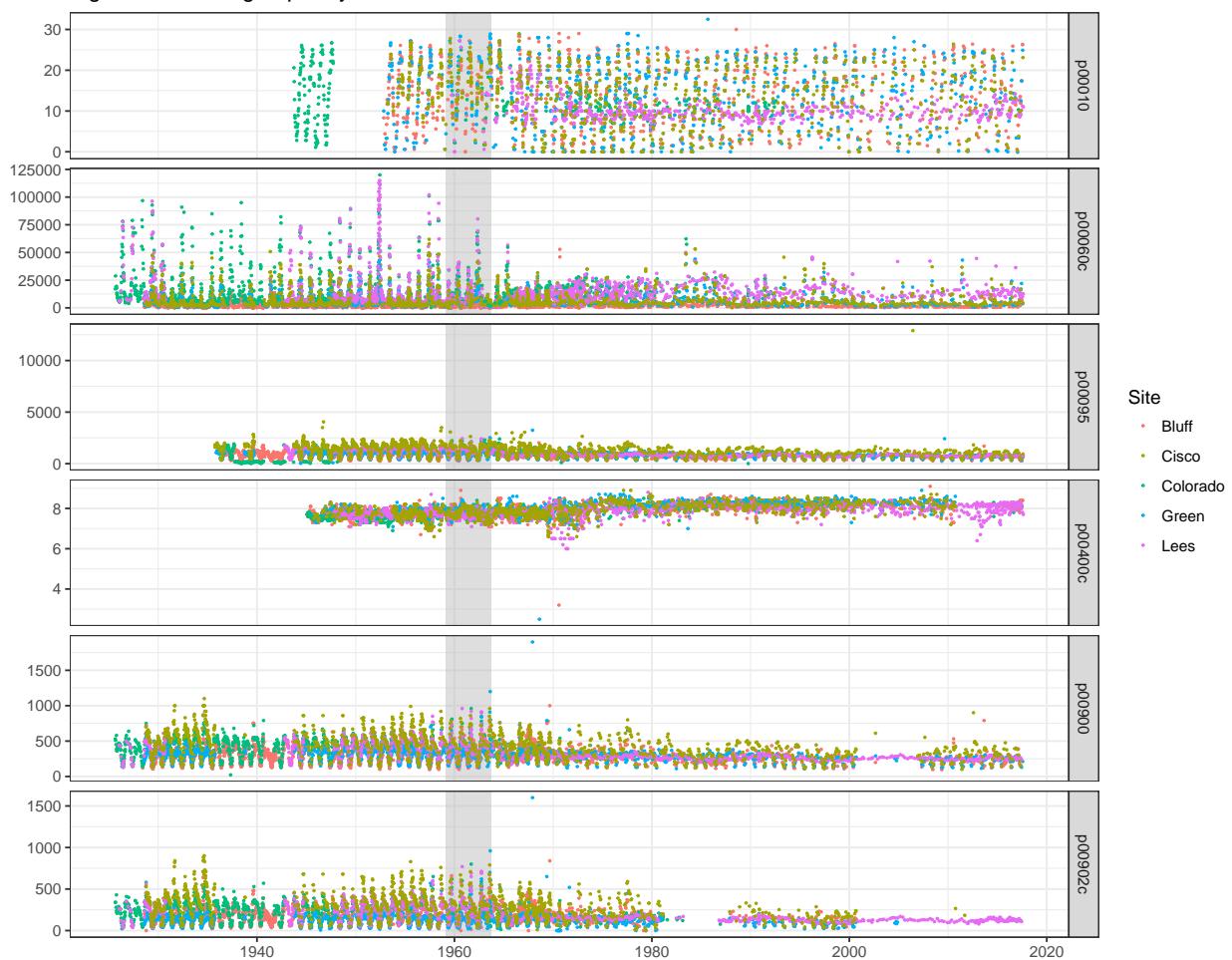
Fig 4. Parameter group: Nutrient



## Physical

Six parameters fall under the *Physical* group. Several physical parameters exhibit similar observable patterns as other parameters where prior to dam construction there is a discernable periodicity and then post dam construction there is an attenuated pattern (Fig. 5). Unlike other physical parameters, pH levels show a trend of increasing levels over time.

Fig 5. Parameter group: Physical



### Among group comparisons pre- and post-dam construction

#### Nitrate measured by nitrogen (p00613c)

Pre-dam, all sites were significantly different in nitrate concentration with the exception of Lees Ferry and Colorado. Post-dam, Lees Ferry and Colorado were significantly different, but Lees Ferry and Bluff had similar nitrate concentrations.

Pre-dam:

```
## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 1590.5962, df = 4, p-value = 0
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff      Cisco     Colorado    Green
## -----+-----
## Cisco | -30.42920
```

```

##          | 0.0000
##
## Colorado | -6.223764 19.41813
##          | 0.0000 0.0000
##
##      Green | 13.79709 36.97343 17.09723
##          | 0.0000 0.0000 0.0000
##
##     Lees | -7.116047 11.50511 -2.524858 -15.60141
##          | 0.0000 0.0000 0.0579 0.0000

```

Post-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 314.5261, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff Cisco Colorado Green
## -----
## Cisco | -9.418311
##          | 0.0000
##          |
## Colorado | -6.005590 0.696727
##          | 0.0000 1.0000
##          |
## Green | 7.439934 16.67320 11.46358
##          | 0.0000 0.0000 0.0000
##          |
## Lees | -1.974264 8.919655 5.095276 -10.30934
##          | 0.2418 0.0000 0.0000 0.0000

```

### pH (p00400c)

Pre-dam, Green was the only site to be significantly different from all other sites, and Cisco was significantly different from Colorado, and Green was significantly different from Less Ferry. All other sites were similar. Post-dam, Green and Lees Ferry were significantly different compared to all other sites, with Bluff significantly different from Colorado and Cisco. Post-dam we see more sites were significantly different in pH than pre-dam.

Pre-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 102.6063, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff Cisco Colorado Green
## -----

```

```

##    Cisco | -2.328738
##          |  0.0994
##
## Colorado |  2.305546  4.283227
##          |  0.1057   0.0001
##
## Green   | -7.922164 -5.463126 -9.313858
##          |  0.0000   0.0000   0.0000
##
## Lees    |  0.376165  2.465238 -1.759748  7.611136
##          |  1.0000   0.0685   0.3923   0.0000

```

Post-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 377.9837, df = 4, p-value = 0
##
##
##                                     Comparison of x by group
##                                     (Bonferroni)
## Col Mean-
## Row Mean |     Bluff      Cisco  Colorado      Green
## -----
## Cisco  | -2.054670
##          |  0.1996
##
## Colorado |  1.815543  3.102216
##          |  0.3472   0.0096
##
## Green   | -7.701332 -5.548586 -6.687094
##          |  0.0000   0.0000   0.0000
##
## Lees    | 11.13360  12.99779  5.053670  18.70063
##          |  0.0000   0.0000   0.0000   0.0000

```

## Calcium

Pre-dam, Lees Ferry and Bluff were the only two sites with similar calcium concentrations. Post-dam, we see more statistically similar calcium concentrations across sites with Colorado being similar to Bluff, Cisco, and Lees Ferry; and Lees Ferry and Bluff remaining the same.

Pre-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 854.6075, df = 4, p-value = 0
##
##
##                                     Comparison of x by group
##                                     (Bonferroni)
## Col Mean-
## Row Mean |     Bluff      Cisco  Colorado      Green
## -----

```

```

##    Cisco | -12.83400
##          | 0.0000
##
## Colorado | -7.400764 5.209877
##          | 0.0000 0.0000
##
##    Green | 18.82755 27.53720 23.39841
##          | 0.0000 0.0000 0.0000
##
##    Lees | -1.646013 8.839756 4.340258 -16.88316
##          | 0.4988 0.0000 0.0001 0.0000

```

Post-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 228.6106, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff      Cisco   Colorado   Green
## -----
##    Cisco | -6.641662
##          | 0.0000
##
## Colorado | -2.019840 2.357447
##          | 0.2170 0.0920
##
##    Green | 8.319678 14.83800 7.484273
##          | 0.0000 0.0000 0.0000
##
##    Lees | 0.994060 7.640860 2.671649 -7.350924
##          | 1.0000 0.0000 0.0377 0.0000

```

### Magnesium (p00925)

Pre-dam, all sites exhibited significantly different magnesium concentrations. Post-dam, Cisco showed similar concentration levels as Colorado and Green, and Green was similar to Colorado.

Pre-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 1252.3646, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff      Cisco   Colorado   Green
## -----
##    Cisco | -33.72352

```

```

##          | 0.0000
##
## Colorado | -21.87273 11.59486
##          | 0.0000 0.0000
##
##      Green | -12.26428 17.33254 6.835807
##          | 0.0000 0.0000 0.0000
##
##     Lees | -15.56975 13.11515 2.926075 -3.383352
##          | 0.0000 0.0000 0.0172 0.0036

```

Post-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 265.5488, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff Cisco Colorado Green
## -----
## Cisco | -13.83901
##          | 0.0000
##          |
## Colorado | -9.245350 -0.098739
##          | 0.0000 1.0000
##          |
## Green | -13.58489 0.272283 0.279550
##          | 0.0000 1.0000 1.0000
##          |
## Lees | -8.828083 5.123495 3.481389 4.855784
##          | 0.0000 0.0000 0.0025 0.0000

```

### Bicarbonate (p00440c)

Similar to magnesium, bicarbonate concentrations were different across all sites pre-dam. Post-dam, Bluff and Lees Ferry were similar as were Cisco and Colorado, and Green and Colorado.

Pre-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 1186.8545, df = 4, p-value = 0
##
##
## Comparison of x by group
## (Bonferroni)
## Col Mean-
## Row Mean | Bluff Cisco Colorado Green
## -----
## Cisco | -8.018303
##          | 0.0000

```

```

##          |
## Colorado | -30.46365 -19.56156
##          | 0.0000 0.0000
##
##          |
## Green   | -23.94859 -14.79653 3.386981
##          | 0.0000 0.0000 0.0035
##
##          |
## Lees    | -10.34087 -3.002199 14.49687 10.59371
##          | 0.0000 0.0134 0.0000 0.0000

```

Post-dam:

```

## Kruskal-Wallis rank sum test
##
## data: x and group
## Kruskal-Wallis chi-squared = 90.2544, df = 4, p-value = 0
##
##
##          Comparison of x by group
##          (Bonferroni)
## Col Mean-|
## Row Mean | Bluff Cisco Colorado Green
## -----
## Cisco | -4.610606
##          | 0.0000
##          |
## Colorado | -5.116702 -1.600310
##          | 0.0000 0.5476
##          |
## Green   | -8.369309 -3.897106 -1.355385
##          | 0.0000 0.0005 0.8765
##          |
## Lees    | -2.372934 2.872445 3.772298 7.237603
##          | 0.0882 0.0204 0.0008 0.0000

```