The Serial Discontinuity Effect on Water Quality downstream of the Flaming Gorge Dam in the Green River

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I. Research question(s) and testable hypothesis

Research Questions:

1. Will the water quality of the Green River restore to natural pre-dam conditions downstream from Flaming Gorge Dam?

2. How much of an influence will the Yampa River and other tributaries have on resetting the pre-dam water quality conditions?

3. Will the amplitude of cyclic diurnal water temperatures increase as we move downstream from the dam?

Hypothesis:

As we move downstream of the Flaming Gorge Dam, water quality conditions on the Green River will re-establish to pre-dam conditions due to tributary inputs and other ecological factors. Historic data shows the Green River was warmer before construction of the dam, therefore water temperature is expected to rise in the downstream direction. We expect water temperatures close to the dam to be primarily influenced by temperatures of dam releases and downstream temperatures to be more affected by tributary inputs and solar radiation. Anecdotal evidence indicates pre-dam turbidity was higher, but has subsequently been reduced due to sediment settling in the reservoir. Turbidity, which is a proxy for suspended sediment concentration, is expected to increase downstream of the dam, with a drastic increase after the confluence of the Yampa River. Specific conductivity (SC), which is a measure of dissolved solids, is expected to increase along with turbidity as tributaries and other inputs add more dissolved and solid constituents to the river. Dissolved oxygen and pH levels are expected to be a function of location, such as backwater or main channel areas, rather than river mile. Thus, our hypotheses with respect to these two parameters are not primarily linked to the Serial Discontinuity Concept.

II. Experimental design and methodology

During the trip, we used the Hydrolab multi-probe water quality instrument to measure water temperature, specific conductivity (SC), turbidity, and percent dissolved oxygen. We used a Hanna Multimeter to measure pH, and an alcohol thermometer to measure ambient air temperature. The instruments were calibrated daily using standard solutions. We took measurements in the main channel as often as possible at camp and survey sites, as well as from the back of the boat during transit, where feasible. Times and river miles were recorded for each data point. A thermistor was used to take hourly water temperature measurements by attaching it to the back of a boat and noting times and river miles when the boat was stationary. Measurements were taken in backwater habitat at survey sites to determine any difference in water quality from the main channel.

III. Results

Temperature

Figure 1 displays time and temperature data recorded from the thermistor during the study period. Approximate river mile locations of each campsite are listed next to the nightly lows. The thermistor was stationary during each night. USGS stream flow data from the Greendale gage (just downstream of Flaming Gorge Dam) indicated that releases from the dam ranged from 800 to 2000 cfs during the study period. This daily variation caused changes in river stage that beached the thermistor on a few occasions, resulting in data gaps, usually during the nighttime when the thermistor was unattended. Before the Yampa confluence, average daily temperatures ranged from approximately 11.0 to 19.0 °C, with a daily variation of approximately 4.0 °C. After the Yampa confluence, average daily temperatures ranged from approximately 19.0 °C to 21.5 °C, with daily variation of approximately 2.5 °C.

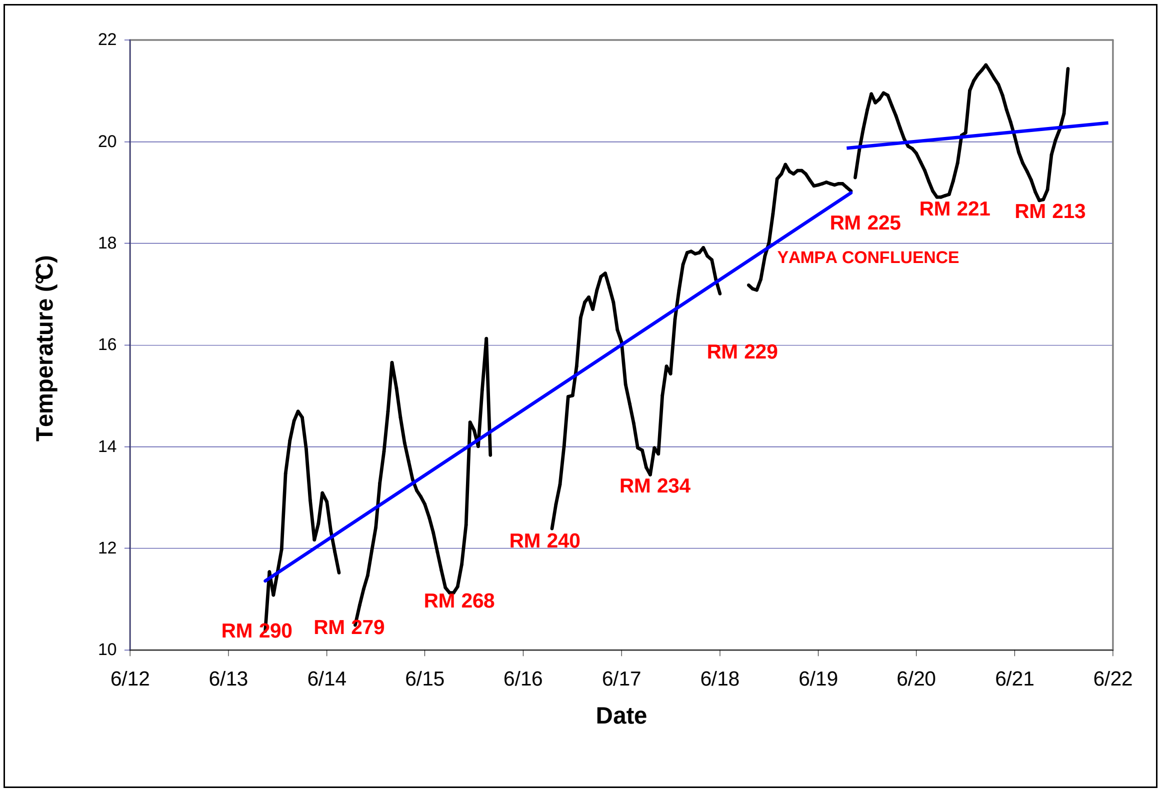

Figure 1. Temperature vs. Date with Approximate river mile locations listed at nightly lows.

Figure 2 shows water temperature as a function of ambient air temperature. Little correlation is seen between the two parameters before the Yampa confluence. After the Yampa, however, a positive correlation is observed, indicating that increasing air temperatures are associated with an increase in water temperatures.

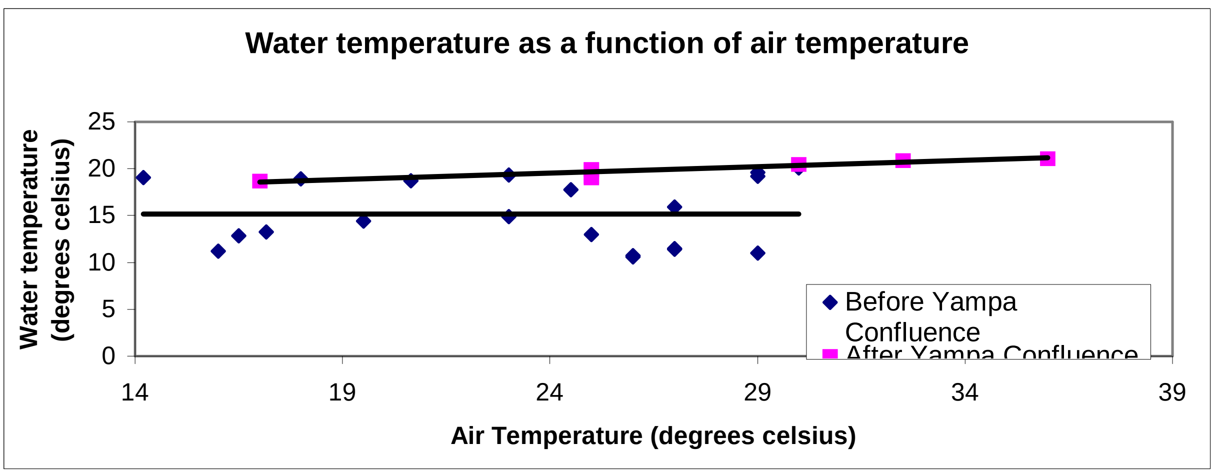

Figure 2. Water temperature as a function of ambient air temperature.

Figure 3 is a three-dimensional surface plot of data recorded by the thermistor. This plot relates temperature to distance from the dam and time of day. The black dots represent actual data points. From this plot, one can see that daily low temperatures usually occur right before sunrise from 5:30 to 6:30 AM. Daily peak temperatures usually occur in the afternoon hours from 3:00 to 6:00 PM. This plot also shows diurnal variations in temperature are greater before the Yampa confluence.

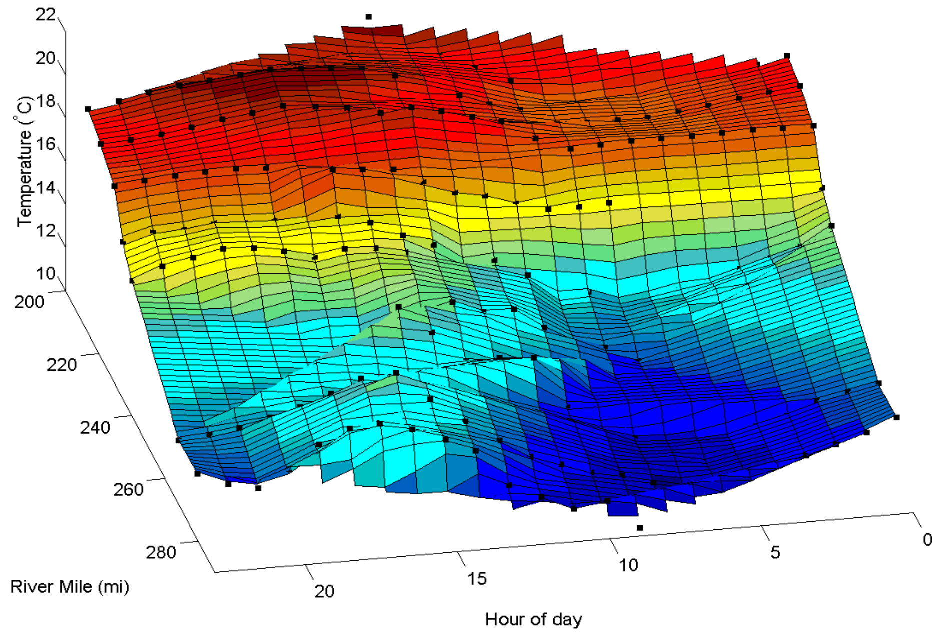

Figure 3. 3-D surface of water temperature as a function of river mile and time of day.

Turbidity

Figure 4 shows turbidity as a function of river mile. Overall, turbidity increases downstream of the dam. There is a large upward spike at Red Creek, which was found to be extremely turbid (over 1100 NTU). A slow increase in turbidity is seen through Browns Park, before decreasing sharply through Lodore Canyon. Turbidity increases suddenly at the Yampa confluence, before decreasing again through Whirlpool Canyon.

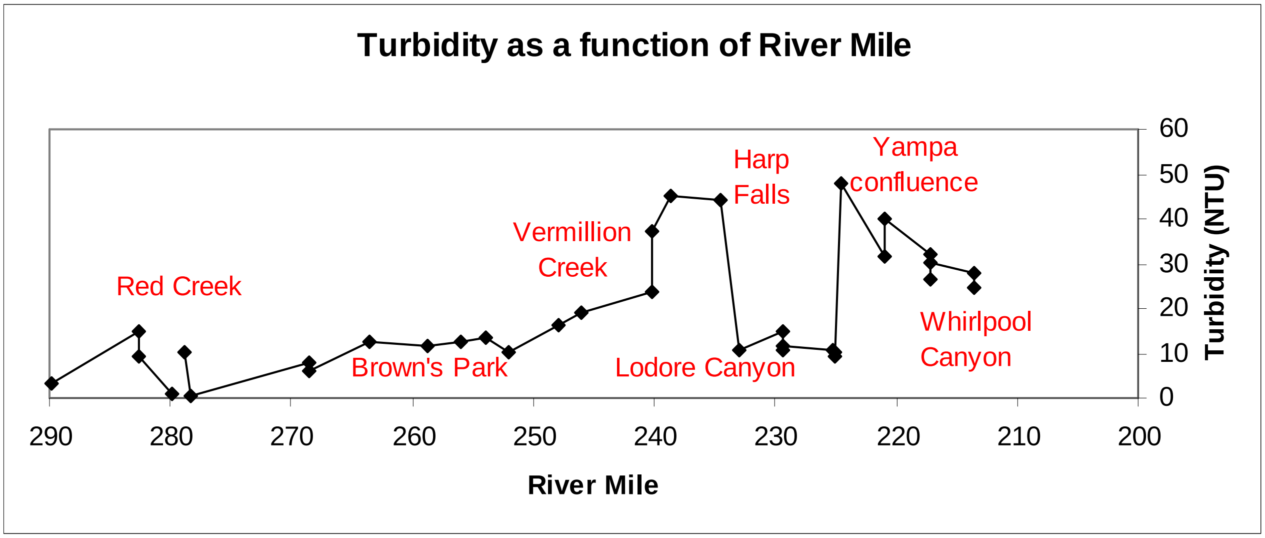

Figure 4. Turbidity as a function of river mile in the Green River.

Specific Conductivity (SC)

Figure 5 shows SC as a function of river mile. SC remains quite constant through Lodore Canyon, but with an upward spike at Red Creek and a decrease at Harp Falls. SC drops sharply at the Yampa confluence before increasing again toward previous levels. At the Green-Yampa confluence survey site, the SC of the Yampa River was 0.156 mS/cm and that of the Green River was 0.578 mS/cm. Downstream from the confluence, the SC was 0.268 mS/cm, which indicates mixing of the two rivers.

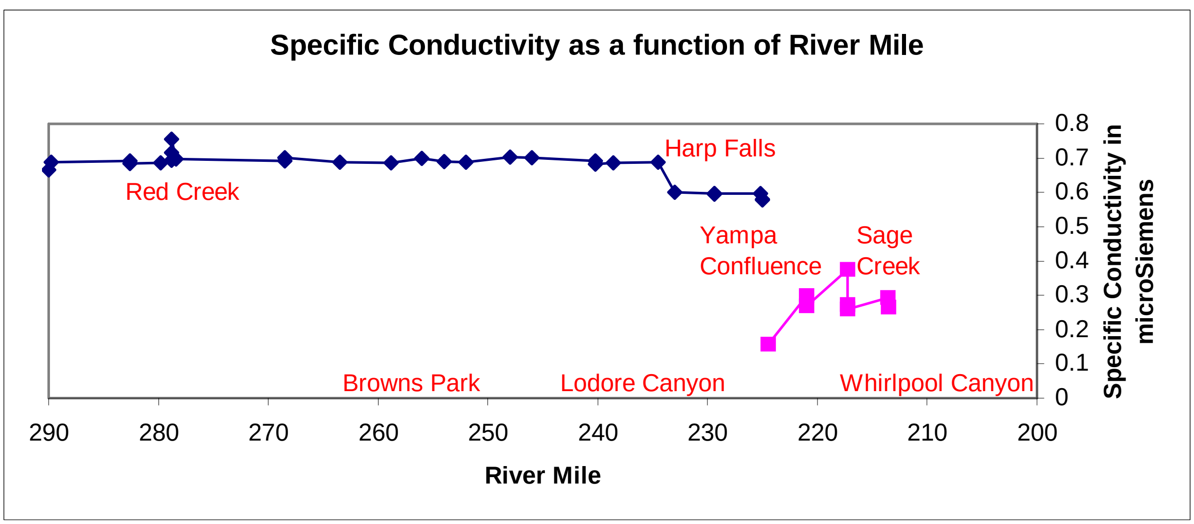

Figure 5. Specific Conductivity (SC) as a function of River Mile.

Percent Dissolved Oxygen (% DO)

No distinct pattern emerged when % DO saturation values in backwater and main channel were compared. Two sites (Red Creek and Mile 233 in Lodore Canyon) displayed equal % DO saturation values in both backwater and main channel areas, three sites had higher backwater values than those of the main channel (Red Creek, Winnie's Rapid, and Sage Creek) and five sites had higher main channel values that those of backwater areas (Trailer Draw, Green-Yampa confluence, Sage Creek, Big Island, and Crook Camp). Overall, the % DO saturation values ranged from 66.8 to 120, the lowest being in backwater at Mile 233 and the highest in the main channel at Trailer Draw.

Figure 6 shows both temperature and % DO saturation by Green river mile from the Flaming Gorge Dam (RM 290) to Big Island (RM 213.5). Although no distinct pattern is apparent in the graph, there appears to be an inverse relationship between temperature and % DO saturation at certain areas along the river such as Browns Park (RM 248) and Trailer Draw (RM 238).

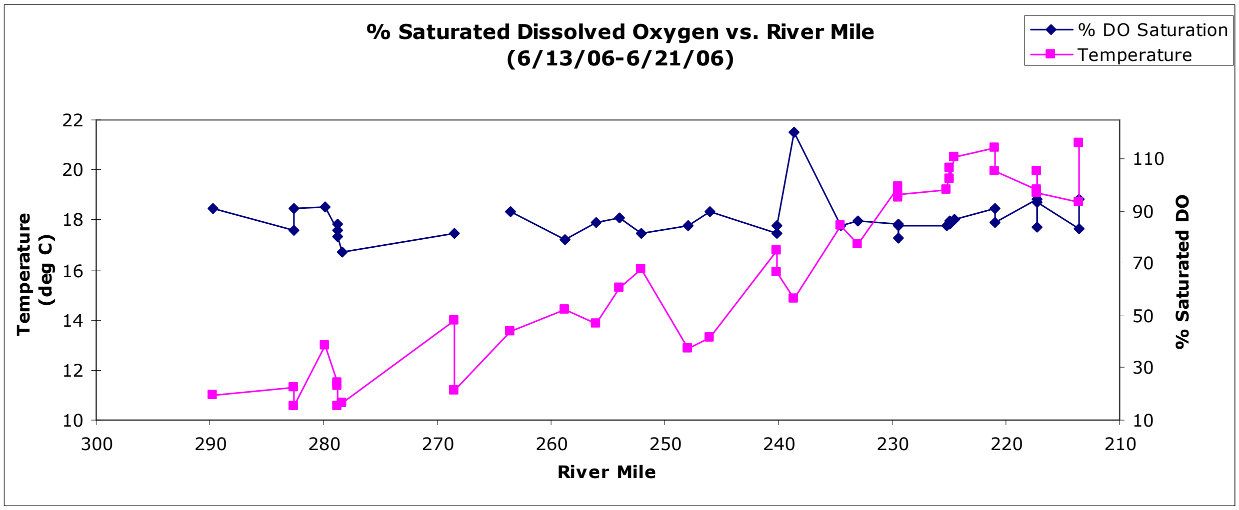

Figure 6. Temperature (°C) and % DO Saturation in the main channel vs. River mile.

Acidity (pH)

There is no notable pattern of pH per river mile. In some areas, the pH varies by 1.5 units (RM 289 to 282 and RM 240 to 238) and in other sections of the river it remains stable (RM 238 to 225). There are some days when pH did not change at all between water types, sites and time, which may indicate instrument error.

IV. Discussion

It is apparent that the fitted temperature line in Figure 1 has a steeper slope before the Yampa confluence. Furthermore, the amplitude of diurnal temperature change decreases after the Yampa confluence. The changes in slope and amplitude are due to the larger volume of water after the confluence, which is more resistant to heating and cooling. Figure 2 shows more of a relationship between ambient air temperature and water temperature after the Green-Yampa confluence due to tributary inputs and solar heating between the dam and the confluence, particularly in shallow, exposed areas, such as Browns Park. This contradicts our hypothesis that diurnal temperature changes will have higher amplitude after the Yampa confluence, but confirms that temperatures will return to pre-dam conditions in the downstream direction. Comparison of Figures 1 and 2 suggest that, before the large input of the Yampa, water temperatures can change more rapidly by tributary inputs and ambient heat than after the Yampa, where the larger volume of water is resistant to temperature change.

Another variable that complicates changes in water temperature, besides distance from dam and time of day, is flowrate. On June 17th, at river mile 238.6, water temperature was recorded as 14.87 degrees Celsius at 11:55 AM. On June 18th, at river mile 229.4, temperature was recorded as 19.04 degrees Celsius at 7:20 AM. This higher temperature at an earlier measurement time was surprising. Water levels were much lower on the morning of the 18th, indicating a lower flow release from the dam. Large flowrates are more resistant to heating and cooling because there is simply more mass to heat and cool and because they allow volumes to travel through the system in less time. Smaller volumes are easier to heat because they have less mass and take more time to travel through the system. The observed increase of roughly 4 degrees Celsius can largely be explained by this phenomenon.

Figure 4 shows that turbidity tends to increase in slow moving, wide sections, such as Browns Park, and decrease in areas of high water velocity, such as Red Creek rapids and Harp Falls. This is a surprising finding, since turbidity is generally thought to increase in higher velocity water. This may be due to the large amount of silty material lining the riverbanks in park areas, which is more easily entrained by the river current than the larger gravel material in canyon areas. It is apparent that tributary inputs cause an increase in turbidity, as can be seen at Red Creek and the Yampa confluence, and this supports the serial discontinuity hypothesis.

SC shown in Figure 5 reveals some very interesting findings. SC remains constant before the Yampa confluence. There is a small increase at Red Creek, but the river quickly absorbs the creek's low flows. At the Yampa confluence SC drops very suddenly; the Yampa River had a lower SC than the Green (0.157 and 0.578 microSiemens, respectively). This may be explained by a dilution effect because the Yampa was in a higher flow condition relative to the Green (assuming that SC values at baseflow for the two rivers are approximately equal). Differences in rock substrate surrounding the rivers may also partially explain the differences seen in SC.

Dissolved Oxygen (DO) saturation is a measure of the potential capacity of water to hold oxygen in its dissolved state. As temperature increases, warm water becomes more easily saturated with oxygen. In some cases along the Green River, % DO levels are high in backwater areas, which may be due to aquatic plant photosynthesis. In backwater areas with lower % DO than those of the main channel, there may be fewer aquatic plants present in the backwater and/or increased turbulence in the main channel providing aeration.

Photosynthesis removes dissolved carbon dioxide, which reduces the acidity of water and thereby increases pH in areas with aquatic vegetation. There is no notable relationship, however, between pH in the backwater areas and main channel in the Green River. The pH is maintained between 7 and 8.5, which indicates a well-buffered system. In areas where the pH does not change between backwater and main channel areas, this may be indicative of either an extremely well-buffered system or instrument error.

There are several random and systematic errors associated with our water quality data. Random errors include insufficient time allowed for Hydrolab parameters to stabilize during sampling. Random errors may also be attributed to inaccurate calibration methods, such as not allowing new DO membrane to soak overnight. Inconsistent sample times relative to dam flow release rates may result in less accurate data since release rates result in significant water quality changes within a 24-hour period. Measuring in areas that were previously seined may have resulted in higher turbidity values than normal. Air temperature values were taken with a thermometer and could have been inaccurate depending on whether the thermometer was placed in the sun or shade during readings. Systematic errors could be due to instrument failure, air bubbles in the Hydrolab DO membrane, and natural variations in turbidity and % DO saturation during sampling. These errors are considered in these analyses and may result in divergences from actual values during sampling.