

## Natural Resources and Environmental Issues

---

Volume 18 *A River Continuum Analysis of an Anthropogenically-Impacted System : The Little Bear River, Utah*

Article 6

---

8-12-2013

# Periphyton and Phytoplankton Chlorophyll a Levels in the Little Bear River and Hyrum Reservoir, Utah

Katie Fisher

Follow this and additional works at: <http://digitalcommons.usu.edu/nrei>

---

### Recommended Citation

Fisher, Katie (2013) "Periphyton and Phytoplankton Chlorophyll a Levels in the Little Bear River and Hyrum Reservoir, Utah," *Natural Resources and Environmental Issues*: Vol. 18, Article 6.  
Available at: <http://digitalcommons.usu.edu/nrei/vol18/iss1/6>

This Article is brought to you for free and open access by the Quinney Natural Resources Research Library, S.J. and Jessie E. at DigitalCommons@USU. It has been accepted for inclusion in Natural Resources and Environmental Issues by an authorized administrator of DigitalCommons@USU. For more information, please contact [becky.thoms@usu.edu](mailto:becky.thoms@usu.edu).



## Chapter 4

# Periphyton and Phytoplankton Chlorophyll *a* Levels in the Little Bear River and Hyrum Reservoir, Utah

[by] Katie Fisher

### SUMMARY

This study was conducted to assess the applicability of the River Continuum and Serial Discontinuity Concepts to the Little Bear River, using chlorophyll *a* values along the gradient of the river and within Hyrum Reservoir. Periphyton was analyzed from seven sites and phytoplankton from nine sites (including Hyrum Reservoir) in September 2012. The lower parts of the Little Bear River is heavily influenced by agricultural and anthropogenic sources of nutrients and other pollution, creating poor water quality in its lower reaches. Periphyton levels in the river increased along the gradient, peaking just below Hyrum reservoir, and then decreased with distance downstream. Phytoplankton chlorophyll *a* concentrations increased significantly with distance downstream, with concentrations near 1.5  $\mu\text{g L}^{-1}$  in the headwaters and 5  $\mu\text{g L}^{-1}$  in the slow-moving valley sections. On an aerial basis, chlorophyll in the periphyton community overwhelmingly dominated (>98 percent) the total chlorophyll levels. Within the phytoplankton continuum, there was, however, a drop below Hyrum Reservoir. Furthermore, there was a significant positive relationship between the total phosphorous concentrations and phytoplankton levels. Periphyton levels, however, were not correlated with phosphorus concentrations. The chlorophyll *a* levels found suggest that high levels of phosphorus contribute to higher levels of algal chlorophyll *a*. Although these levels were not indicative of poor water quality, mitigation of nutrient sources in the valley would likely create more uniform chlorophyll *a* levels down the gradient of the LBR.

### INTRODUCTION

The River Continuum Concept (Vannote et al. 1980) predicts that periphyton and phytoplankton communities in pristine systems should have predictable changes along the continuum from headwater streams to lowland rivers. However, most river systems in a developed landscape are not pristine, but rather, have been modified by damming, agricultural, and urban impacts (Ward and Stanford 1983; Caraco and Cole 1999). The Little Bear River located in northern Utah is an example of a system with both pristine and impacted reaches. The Serial Discontinuity Concept (SDC) of Ward and Stanford (1983) addresses this type of interruption, and consequently its precepts have helped interpret the findings of this project.

My study measured the chlorophyll *a* levels in periphyton and phytoplankton along the gradient of the Little Bear River (LBR). The South Fork of the LBR is relatively pristine with no discontinuities. These attributes make the upper LBR a good candidate for testing the RCC. However, due to the presence of Hyrum Reservoir, as well as the increasingly anthropogenic impacted landscape, the continuum of the LBR is disrupted.

Considering sources of nutrients, in a continuum, is important for developing hypotheses regarding chlorophyll abundances because nutrients within streams are shown to positively affect chlorophyll levels

(Dodds et al. 2006). Some rivers manifest community structure in “patches” as well as in continuous patterns—usually one more so than the other (Wright and Li 2002). Wright and Li (2002) found that the levels of periphyton were highly variable; however, this does not necessarily mean there was no continuity, because their study did not identify periphyton species within the community. Similarly, I did not identify specific periphyton taxa and my study was limited in the same manner as Wright and Li (2002). The presence of Hyrum Reservoir on the LBR was also a disruption to its predicted continuity. Jones (2007) noted that phytoplankton populations decreased below lakes, due to the destruction of fragile lake phytoplankton when exposed to turbulent river water. Furthermore, Acharyya, et al. (2012) found that phytoplankton blooms below a dam could be controlled through dam discharge—higher discharge led to less phytoplankton and lower discharge led to more phytoplankton. Myers et al. (2007) found that below-lake conditions favored periphyton growth due to an increase in sediment size and a decrease in scouring from small sediment.

Within the SDC, a gap in theory exists: “It is possible that limnological phenomena within reservoirs alter the food quality (as well as the amount and the chemical and size composition) of detritus, but no data are available (Ward and Stanford 1983).” Marcarelli and Wurtsbaugh (2007) found that alterations in the lake nutrients do not necessarily manifest as nutrient limitation of periphyton. This previous research leads to the prediction that periphyton levels should increase below Hyrum Reservoir. Nutrient data have also been used to predict chlorophyll *a*, since levels of nitrogen and phosphorus, as well as scour, effect presence and activity of periphyton and phytoplankton (Godwin et al., 2009).

Using the SDC and RCC framework I predicted that the chlorophyll *a* levels of the Little Bear River would gradually increase continuously downstream, shifting from periphyton to phytoplankton sources. Furthermore, just below Hyrum reservoir, I predicted that there will be a large increase in both periphyton and phytoplankton, creating a brief discontinuity of chlorophyll *a* in the Little Bear River. Overall, there should have been a shift from a periphyton dominant system to a phytoplankton dominated system (Ward and Stanford 1983).

## **STUDY AREA**

Eight study sites along the LBR were selected to measure periphyton and phytoplankton chlorophyll *a* levels (See site map in Executive Summary). Phytoplankton chlorophyll levels were measured at one additional site (Station 9). Station 2 (Photo 1) was the uppermost site, being on the South Fork of the river in a relatively pristine area. The next two Stations sampled (4 and 6) were just below the confluence of the East and South forks of the LBR. Station 6 was just above Hyrum Reservoir and Station 7 was just below Hyrum Reservoir. Sampling at Station 6 and 7 allowed me to assess the effects of Hyrum Reservoir on chlorophyll levels. A phytoplankton sample was taken below the Wellsville Lagoons to see if its discharge had any effect on chlorophyll *a* levels. Station 11 (Photo 2) was channelized and full of sediment. These sites were selected to provide chlorophyll *a* levels at the very bottom of the LBR to see the compounded effects of the continuum and anthropogenic impacts on chlorophyll *a* levels. Additionally, 13 days prior to the river sampling, phytoplankton samples were taken as part of a class activity at three stations from varying depths on Hyrum Reservoir.



**Photo 1.** Station 2, the uppermost site sampled on the Little Bear River.



**Photo 2.** Station 11, the lowermost site sampled on the Little Bear River. Note the turbidity in the river at this site.

## METHODS

### *Periphyton*

At all the study sites, except Station 9, six 5-8 cm diameter rocks were selected from a horizontal cross section of the stream (US EPA 2012). At Stations 10 and 11, there were few rocks in the streambed, so rocks were selected from the side of the stream. Each rock was placed carefully into a plastic bag, sealed, and set on ice to prevent algae from dying. Each rock was handled carefully to minimize the loss of periphyton. Rocks were subsequently frozen at 20°C to preserve the chlorophyll cells for extraction on a later date. To extract chlorophyll *a*, rocks were placed in Mason jars containing 95 percent ethanol for 16-24 hours. (Lind 1985). Then, 0.10 ml of the extracted chlorophyll was diluted into 10 ml of the ethanol (Lind 1985). The chlorophyll in the diluted fluid was then read on a fluorometer utilizing the Welschmeyer (1994) non-acidification method. At Station 10, six sticks were collected in addition to the six rocks. The same extraction procedure and subsequent planar area estimation used for the rocks was used for the sticks.

In order to account for the planar area of periphyton on substrates, the surface area (in  $\text{cm}^2$ ) of each rock or stick was measured by tracing each object's planar-surface-area outline on aluminum foil and cutting out and weighing this outline. The weight of each planar-surface-area cut-out (in grams) was then multiplied by the weight of a  $100 \text{ cm}^2$  piece of aluminum foil. The mean and s.d. of rock size was  $24 \pm 10 \text{ cm}^2$ . The product of the volume of extraction (ml), the fluorometer reading (converted to  $\mu\text{g}/\text{ml}$ ), and the dilution factor, was then divided by the planar surface area ( $\text{cm}^2$ ). This yielded the amount of chlorophyll a per unit of area ( $\mu\text{g}/\text{cm}^2$ ).

**Photo 3.** Convex spherical densitometer used for measuring overhead cover.



### **Phytoplankton**

Three water samples were taken from each site on the LBR and two samples from three sites on Hyrum Reservoir. 20 ml of each sample was filtered through a 25-mm GF/F filter with a nominal pore size of  $0.7 \mu\text{m}$ . Each filter was folded, labeled in pencil, placed in tinfoil, and then put on ice. The samples were subsequently frozen at  $20^\circ\text{C}$  to preserve the chlorophyll a trapped on each filter. These filters' chlorophyll a was then extracted and read using the same method as described in the periphyton chlorophyll a extraction. The corrected fluorometer readings ( $\mu\text{g L}^{-1}$ ) were then multiplied by the extracted volume of ethanol (ml) and divided by the volume of water filtered (ml), to yield the amount of chlorophyll in each water sample ( $\mu\text{g L}^{-1}$ ). In order to compare phytoplankton to periphyton, units of phytoplankton chlorophyll a were converted from  $\mu\text{g L}^{-1}$  to  $\mu\text{g cm}^{-2}$  using the available mean depths were measured on the same sample day.

### **Light Levels and Water Transparencies**

To obtain quantitative information on how much light was penetrating the water column, I attempted to take Secchi depth readings at each site. However, only Stations 9, 10, and 11 were deep enough to obtain a reading. To obtain information on how much light was reaching the water surface, a convex spherical densitometer (Photo 3) was used to estimate canopy cover at each site. This densitometer had 24 squares on its surface. For each reading, the number of squares obscured by canopy cover was counted while the user faced north, east, south, and west. The densitometer was held level at waist height and read across a horizontal cross section of the stream. A densitometer reading was taken at each individual

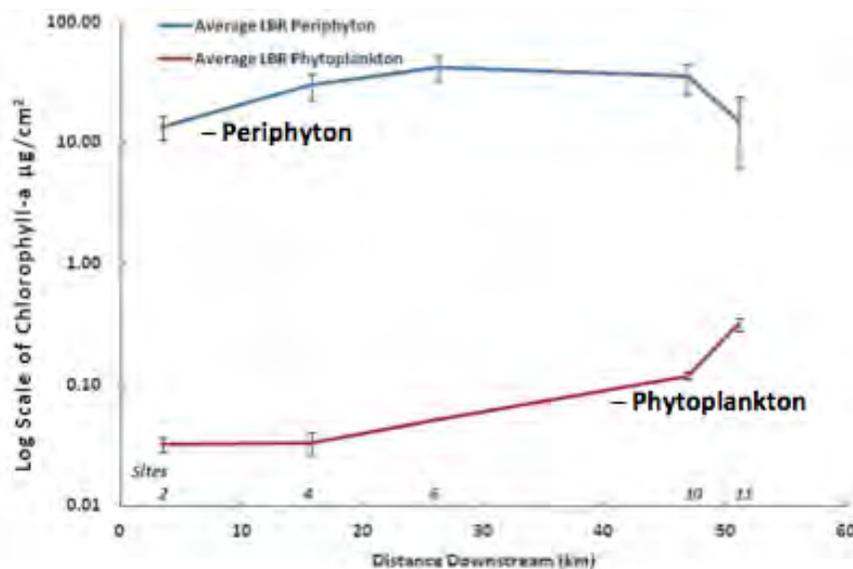
periphyton rock sample. The four readings for each compass direction were then averaged together (California Department of Pesticide Regulation Environmental Monitoring Branch, 2004). These averages were then applied to the following formula:  $100 - (\# \text{ of unfilled squares} \times 4.17) = \text{percent overstory density}$  (California Department of Pesticide Regulation Environmental Monitoring Branch 2004). Then the values were averaged for an overall average canopy density for each site.

## RESULTS

### *Chlorophyll a in Periphyton and Phytoplankton*

Periphyton chlorophyll a levels dominated over phytoplankton chlorophyll a levels throughout the entire continuity of the LBR (Figure 1). However, they both had individual trends. In particular, there was a strong linear trend in increasing levels of phytoplankton down the continuum. Phytoplankton were low in the headwaters and gradually increased, dropped slightly below Hyrum Reservoir, and then increased rapidly to the lowest site. The trend in periphyton levels was less straightforward, having started out low and increasing, peaking just above Hyrum Reservoir, and then steadily decreasing to the lowest site.

The averaged chlorophyll a levels from periphyton in the LBR were low in the headwaters ( $13.5 \mu\text{g}/\text{cm}^2$ ), and increased consistently to Station 6, peaking  $41.7 \mu\text{g}/\text{cm}^2$  just above Hyrum Reservoir, then decreased to Station 11 to  $15.03 \mu\text{g}/\text{cm}^2$  (Figure 2A). The humped nature of the longitudinal relationship resulted in a linear correlation that was insignificant ( $p > 0.05$ ). Chlorophyll levels from the rocks at each site were highly variable, as shown by the large error bars in Figure 2B. No significant relationship was found between periphyton chlorophyll-a levels and total phosphorus or total nitrogen ( $p > 0.05$ ).



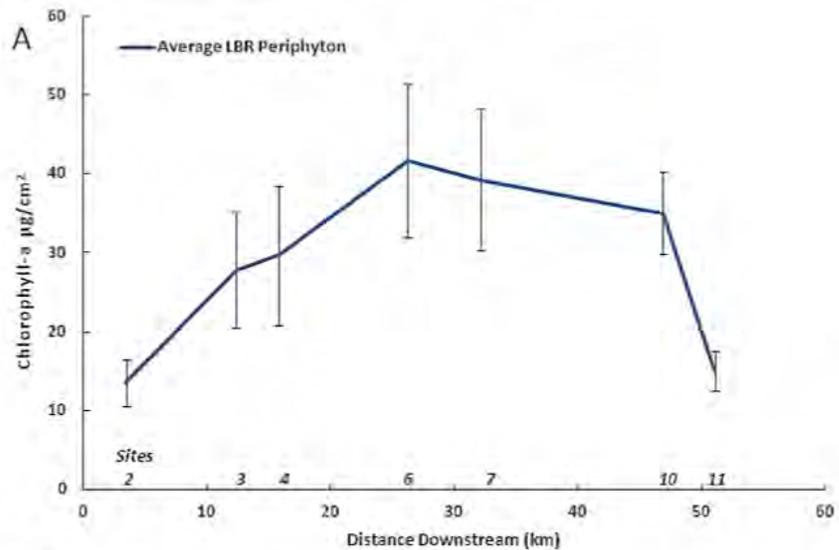
**Figure 1.** Aerial chlorophyll a levels of periphyton and phytoplankton in  $\mu\text{g}/\text{cm}^2$  in the Little Bear River, measured on 9 September 2012. Note log scale. Station numbers are shown above the X-axis.

The averaged chlorophyll a levels from phytoplankton increased linearly (Figure 2B), demonstrating a large increase from the highest site to the lowest site. The chlorophyll a levels were low in the upper reaches,  $1.6 \mu\text{g L}^{-1}$  at Station 2, reaching  $2.6 \mu\text{g L}^{-1}$  just above Hyrum Reservoir. Within the reservoir, chlorophyll a levels reached as high as  $5.81 \mu\text{g L}^{-1}$ . After Hyrum Reservoir, they dropped slightly to  $2.0 \mu\text{g L}^{-1}$ , but then increased downstream, reaching the highest chlorophyll a level of  $5.0 \mu\text{g L}^{-1}$  at the very

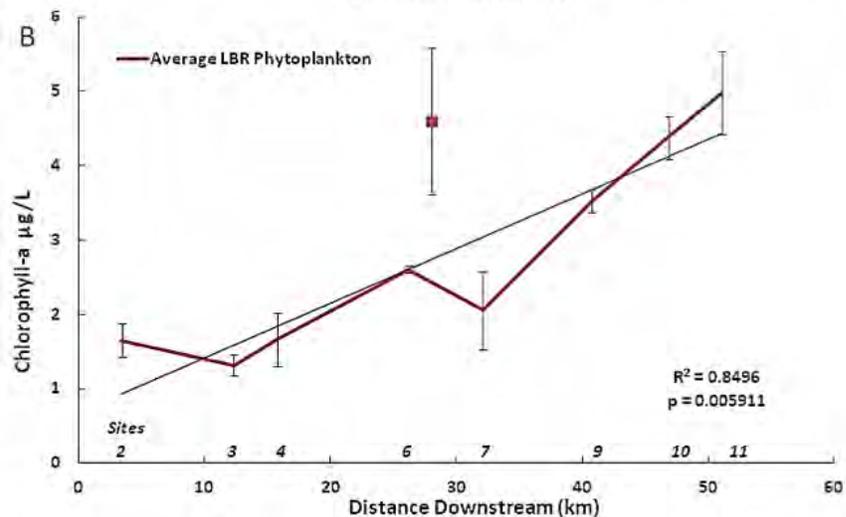
bottom site, Station 11. There was a clear correlation between the rises in chlorophyll a levels of phytoplankton as the distance downstream increases ( $p = 0.006$ ), which more than doubled from the top of the LBR to the bottom.

In comparing phytoplankton chlorophyll a levels to nutrient levels, I found that there was a significant relationship and linear trend between chlorophyll a and total nitrogen (Figure 3A;  $R^2 = 0.58$ ;  $p = 0.027$ ). As levels of total nitrogen increased from  $151 \mu\text{g L}^{-1}$  to  $1365 \mu\text{g L}^{-1}$ , chlorophyll a levels increased from  $1.3 \mu\text{g L}^{-1}$  to  $4.4 \mu\text{g L}^{-1}$ . There was an even more significant linear relationship between chlorophyll a and total phosphorus (Figure 3B;  $R^2 = 0.93$ ;  $p = 0.001$ ). As levels of total phosphorus increased from  $15 \mu\text{g L}^{-1}$  to  $75 \mu\text{g L}^{-1}$ , chlorophyll a increased from  $1.3 \mu\text{g L}^{-1}$  to  $5 \mu\text{g L}^{-1}$ .

**Figure 2. A.** The average level of chlorophyll a from periphyton, in  $\mu\text{g}/\text{cm}^2$ , along the distance downstream of the Little Bear River measured on 29-Sep-2012. The error bars indicate the standard error of the averaged values.



**Figure 2. B.** Average levels of chlorophyll a from phytoplankton in  $\mu\text{g L}^{-1}$ , plotted against the distance downstream in the Little Bear River measured on 29-Sep-2012. Average surface values of phytoplankton from three stations in Hyrum Reservoir are also shown, measured on 11-Sept-2012. The error bars indicate the standard error of the averaged values.

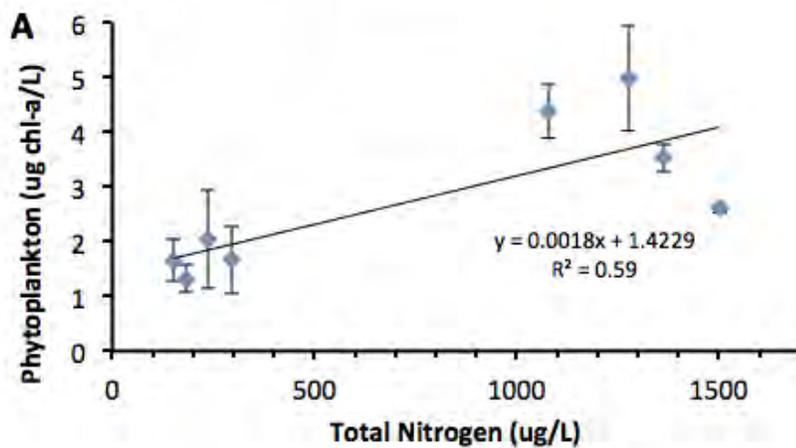


### Light Levels and Water Transparencies

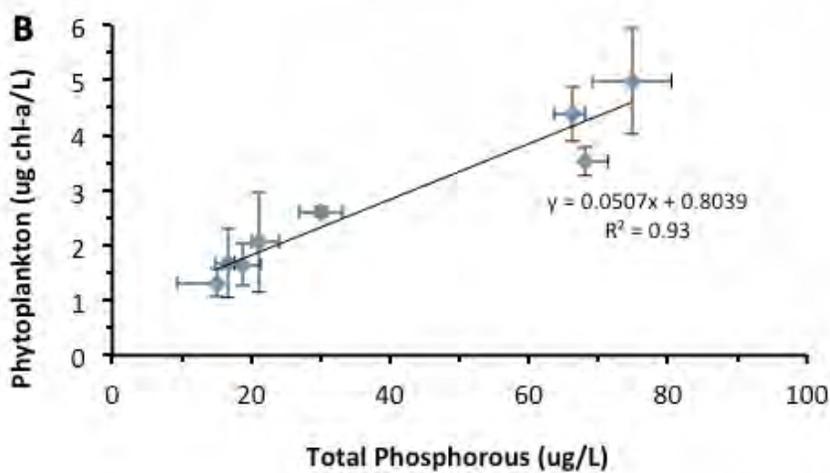
For the lower sites, the Secchi depths were low. At Station 11, where the average depth was 0.64 meters and the maximum depth was 1.2 meters, the Secchi depth was 0.40 meters. At Station 10, where the average depth was 0.27 meters and the maximum depth was 0.68 meters, the Secchi depth was 0.41

meters. At Station 9, depths were not measured, although there was a Secchi depth measurement taken of >1.2 meters deep. At all of the other sites visibility extended to the bottom of the channel.

As a general linear trend, the canopy cover increased going downstream (Figure 4). Canopy cover was not significantly correlated with periphyton chlorophyll *a* ( $p = .70$ ). However, there was a significant positive linear correlation between canopy cover and phytoplankton chlorophyll *a* (Figure 5;  $R^2 = .90$ ;  $p = .006$ ); however, this relationship does not seem to be causal. In fact, this relationship is contrary to the RCC, which indicates denser canopy cover prevents sunlight from penetrating to the water, which does not support phytoplankton—or periphyton—growth (Vannote et al. 1980).



**Figure 3. A.** Relationship between average values of phytoplankton chlorophyll *a* levels ( $\mu\text{g L}^{-1}$ ) and average values of total nitrogen in the Little Bear River, measured on 29-Sep-2011.



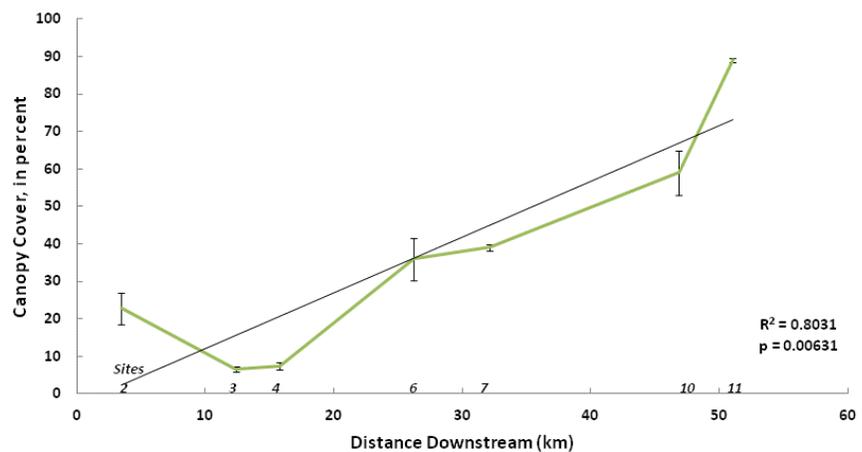
**Figure 3. B.** Phytoplankton chlorophyll concentrations relative to total phosphorus concentrations. Error bars the standard error of the average. Nutrient concentrations were derived from Fuller (this report).

## DISCUSSION

Near the top of the LBR (Station 2), the chlorophyll *a* levels for both periphyton and phytoplankton were low. Periphyton chlorophyll *a* levels rose rapidly and peaked just above Hyrum Reservoir at Station 7. The periphyton levels above and below Hyrum Reservoir were nearly identical (42 vs. 39  $\mu\text{g}/\text{cm}^2$ ). This outcome is contrary to the prediction of periphyton chlorophyll *a* levels increasing below the dam (Myers et al. 2007). Beyond the reservoir, periphyton levels continued to decrease, as expected. It should be noted that these average values for periphyton had high standard errors at most sites.

The low levels of periphyton at the bottom of the LBR, Station 11, could be attributed to many things: an increase in suspended sediment at Stations 10 and 11 from agricultural runoff, or perhaps a fining of substrate. Secchi depths (Appendix 1) at Stations 10 and 11 indicate low transparency in the water, thus high turbidity. This higher amount of suspended sediment could prevent sunlight from penetrating to the bottom substrates, thus creating scour during high-flow events and reducing the ability of periphyton to grow on substrate in the river. Furthermore, the substrate size in the stream at Stations 10 and 11 was silt/sand sized, with no apparent riffles at either site. Consequently, the rocks sampled for periphyton at Stations 10 and 11 were taken from one edge of the river in a shaded area. This restraint on the sampling was due to inadequate substrate sizes for periphyton sampling across the river. It was not determined whether or not there was algal growth in the finer substrates at Stations 10 and 11. Despite the decreases in the lower part of the river, periphyton remained dominant throughout the LBR. Furthermore, the sampling below Hyrum Reservoir, at Station 7, indicated a slight drop in periphyton levels. However, periphyton was only sampled in riffles—not pools, which had a substantial amount of periphyton growth at Station 7 (see photo in Executive Summary).

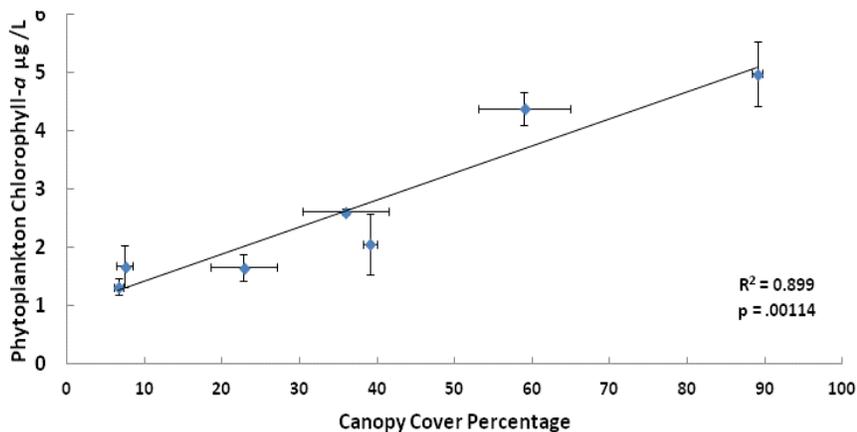
**Figure 4.** Percent canopy cover against distance downstream (km) of the Little Bear River, measured on 29-Sep-2012. Error bars show standard error at each Stations. P value calculated using a linear regression analysis.



As predicted, phytoplankton levels (Figure 2A) steadily increased from  $1.6 \mu\text{g L}^{-1}$  at the top of the LBR (Station 2) to  $5.0 \mu\text{g L}^{-1}$  at the bottom of the LBR (Station 11). The increase in phytoplankton is interrupted by a drop (from  $2.6 \mu\text{g L}^{-1}$ , at Station 6, to  $2.0 \mu\text{g L}^{-1}$ , at Station 7) below Hyrum Reservoir. This drop is contrary to the prediction that it would increase due to the outflow of the reservoir's water which was thought to have higher levels of phytoplankton. While Station 11 had increased phytoplankton chlorophyll a concentrations, this chlorophyll level was still two orders of magnitude below those of the periphyton. This indicates that there was not a shift between chlorophyll a sources in the LBR, as hypothesized.

The strong correlations between levels of phytoplankton and levels of both phosphorous and nitrogen suggest that nutrients do, indeed, influence phytoplankton chlorophyll a levels. The increase below Station 7 was probably because the water had more nutrient inputs from agricultural—among other anthropogenic sources—runoff. This trend is similar to what Dodds, et al. (2006) found in their study on temperate streams, although their study focused on benthic chlorophyll a levels. In my study, the periphyton chlorophyll a levels did not follow the trend found by Dodds, et al. (2006).

Following the RCC framework, we would expect to see a rise in phytoplankton-derived chlorophyll *a* levels from the top of the LBR to the bottom. The EPA has generalized northern Utah into a classification of “western forested mountains” (Ecoregion II). Based on the EPA’s recommendation, chlorophyll *a* levels of phytoplankton for the LBR’s location is  $1.1 \mu\text{g L}^{-1}$  for rivers and streams (US EPA, 2007). With this in mind, it is clear that the upper, forested sites of the LBR are above  $1.1 \mu\text{g L}^{-1}$ . It should be noted that the designation of “phytoplankton” also includes periphyton that had sloughed from the benthic substrate. In the upper reaches, in fact, it is likely that that algae derived from the benthos may have dominated the chlorophyll in the water column. However, the lower sites are in an agricultural valley, where the previous classification of “western forested mountains” does not apply. In the LBR’s TMDL report, total phosphorous was identified as the pollutant of concern in the impairment, causing the LBR to on Utah’s 303(d) list of water quality impaired water bodies (Utah Department of Environmental Quality). The level of total phosphorous should not exceed  $0.05 \text{ mg L}^{-1}$  (Utah Department of Environmental Quality). In the LBR, Stations 8 through 11 are above  $0.05 \text{ mg L}^{-1}$  (Appendix 2).



**Figure 5.** Levels of phytoplankton chlorophyll *a* ( $\mu\text{g L}^{-1}$ ) plotted against canopy cover (percent) on the Little Bear River, measured 29-Sept-2012.

The Utah Division of Water Quality identifies the total phosphorous pollution as being “[linked] to plant production...and more tightly associated with animal waste and fertilizer” (Utah Department of Environmental Quality). Because the levels of phytoplankton chlorophyll *a* are correlated with the levels of total phosphorous, as seen in Dodds, et al. (2006), they are likely too high at the lower reaches of the LBR— Stations 9 through 11.

In conclusion, the levels of phytoplankton chlorophyll *a* exceed the TMDL recommendations. Since there is a positive relationship of phytoplankton chlorophyll *a* to levels of both total phosphorus and total nitrogen, it is assumed that anthropogenic sources of these nutrients are the cause of the excess chlorophyll. Therefore, anthropogenic nutrient sources need to be mitigated to decrease these levels of phytoplankton chlorophyll *a*. Identifying trophic states in streams is not as common or as straightforward as it is in lakes (Dodds 2007), but the few studies available—like this one—has also identified strong correlations between nutrient levels and chlorophyll *a* levels. Therefore, identifying a threshold for nutrients designed around chlorophyll *a* in the LBR would be a step in the right direction. Even though there appears to be no relationship between nutrient levels and periphyton, changes in LBR management should proceed with caution, due to the possible limitations in the collection of periphyton.

## REFERENCES

Acharyya, T.; Sarma, V.V.S.S.; Sridevi, B.; Venkataramana, V. et al. 2012. Reduced river discharge intensifies phytoplankton bloom in Godavari estuary, India. *Marine Chemistry*. 132–133:15-22.

California Department of Pesticide Regulation Environmental Monitoring Branch. Instructions for the Calibration and Use of a Spherical Densimeter. Sacramento, 2004. <http://www.cdpr.ca.gov/docs/emon/pubs/sops/fsot00201.pdf>.

Caraco, N.; Cole, J. 1999. Regional-scale export of C, N, P, and sediment: what river data tell us about key controlling variables. Pages 239-254 In Tenhunen, J.D and Kabat, P. (eds.) *Integrating hydrology, ecosystem dynamics and biogeochemistry in complex landscapes*. New York: John Wiley and Sons Ltd.

Dodds, W.K. 2007. Trophic state, eutrophication and nutrient criteria in streams. *Trends in Ecology and Evolution*. 22:669-676.

Dodds, W.K.; Smith, V.H.; Lohman, K. 2006. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. *Canadian Journal of Fisheries and Aquatic Sciences*. 63:1190-1191.

Godwin, C.; Arthur, M.; Carrick, H. 2009. Periphyton nutrient status in a temperate stream with mixed land-uses: implications for watershed nitrogen storage. *Hydrobiologia*. 623:141-152.

Jones, N.E. 2010. Incorporating lakes within the river discontinuity: longitudinal changes in ecological characteristics in stream-lake networks. *Canadian Journal of Fisheries and Aquatic Sciences*. 67:1350-1362.

Lind, O.T. 1985. *Handbook of common methods in limnology*, 2nd ed. Dubuque, Iowa: Kendall/Hunt Pub Co. 199 pp.

Marcarelli, A.M.; Wurtsbaugh, W.A. 2007. Effects of upstream lakes and nutrient limitation on periphytic biomass and nitrogen fixation in oligotrophic, subalpine streams. *Freshwater Biology*. 52(11):2211-2225.

Myers, A.K.; Marcarelli, A.M.; Arp, C.D.; Baker, M.A.; Wurtsbaugh, W.A. 2007. Disruptions of stream sediment size and stability by lakes in mountain watersheds: potential effects on periphyton biomass. *Journal of the North American Benthological Society*. 26:390-400.

Strevenson, R.J.; Bahls, L.L. 1999. Periphyton Protocols. Chapter 6 in Barbour, M.T. et al. (eds.) *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish*, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

U.S. Environmental Protection Agency (EPA). 2007. Summary table for the nutrient criteria documents. Retrieved Sept. 20, 2012 from [http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007\\_09\\_27\\_criteria\\_nutrient\\_ecoregions\\_sumtable.pdf](http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/upload/2007_09_27_criteria_nutrient_ecoregions_sumtable.pdf).

Utah Department of Environmental Quality, Division of Water Quality TMDL Section. (n.d.). Little bear river watershed TMDL. Retrieved Dec. 6, 2012 from [http://www.waterquality.utah.gov/TMDL/Little\\_Bear\\_River\\_TMDL.pdf](http://www.waterquality.utah.gov/TMDL/Little_Bear_River_TMDL.pdf).

Vannote, R.L.; Minshall, G W.; Cummins, K W.; Sedell, J R.; Cushing, C.E. 1980. The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*. 37:130-137.

Ward, J.V.; Stanford, J.A. 1983. The serial discontinuity concept of lotic ecosystems. Pages 29-24 In T.D.I. Fontaine and S.M. Bartell (Eds.), *Dynamics of lotic ecosystems*. Ann Arbor, MI: Ann Arbor Science Publishers.

Welschmeyer, N.A. 1994. Fluorometric analysis of chlorophyll a in the presence of chlorophyll b and pheopigments. *Limnology and Oceanography*. 39:1985-1992.

Wright, K.K.; Li, J.L. 2002. From continua to patches: examining stream community structure over large environmental gradients. *Canadian Journal of Fisheries and Aquatic Sciences*. 59:1404.

## APPENDICES

**Appendix 1.** Secchi depths, average channel depths (m) and maximum channel depths (m).

Station	Distance Downstream (km)	Secchi Depth (m)	Statopm Average Depth (m)	Max Depth (m)
9	40.79	>1.2	N/A	N/A
10	46.86	0.40	0.27	0.68
11	51.07	0.41	0.64	1.20

**Appendix 2.** Average levels of phosphorus and nitrogen along the river gradient (from Fuller, this report).

Station	Average of Total Phosphorus (µg/L)	Average of Total Nitrogen (µg/L)
1	12.9	226
2	18.9	182
3	15.0	151
4	16.6	297
4.9	18.0	1008
5	26.9	997
6	30.1	1502
7	21.1	235
8	60.6	323
9	74.8	1276
10	68.2	1365
11	66.4	1079