

River Continuum Concepts

Aquatic Ecology Specialists: Rigorous Study Designs Produce Defensible Management Decisions

Hams Fork River Nutrient Assessment 2006-2008



A Follow up to the Finding of Diurnal pH Flux and Potential Roles of Nutrient Loading on the System—Progression towards 303d List Removal

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Executive Summary

The purpose of this report is to analyze the patterns of nutrient concentrations in the Hams fork or the green River, as represented by data collected by the Lincoln Conservation district (LCD) from 2006-2008. The need for this study was described by Gay (2006) in response to finding that elevated pH was related to diurnal patterns of photosynthesis in the Hams Fork (Gay 2001).

The LCD had coordinated sampling of chemical water quality data following the Sampling and Analysis Plan (SAP) of Gay (2006) to describe nutrient and pH correlations to demonstrate the nature of his diurnal flux observations (2001) as natural or as anthropogenic.

We found that there were increases in stream water nitrate, total phosphorus, and orthophosphate below the Kemmerer Waste Water Treatment Plant (WWTP), but that these values were not correlated with the pH of stream water. This was contrary to Gay's (2006) expectations, but it is not surprising since algae must actually remove nutrients from the water column to affect a change in pH.

pH levels were correlated with oxygen concentrations—corroborating Gay's (2001) suggestion that pH was related to photosynthesis. Algae consume nutrients, carbon, and light-energy to produce biomass. In the process oxygen is produced as a byproduct. It is the consumption of carbon that alters pH by altering the carbonate buffering equilibrium. Thus, changes in oxygen concentrations are proportional to changes in carbon sequestering by algae, and changes in pH. We recommend that future monitoring include dissolved oxygen for this reason.

Only two pH values in excess of 9.0 were observed over the three year period of the monitoring program. These were found on the same date (in October 2007) at the two farthest upstream locations. The finding that elevated pH can occur at upstream sites is noteworthy because it suggests that pH exceedences may occur through out the Hams Fork Basin, not just below the Kemmerer WWTP.

Sampling had to be conducted in the morning hours so that samples could arrive at the contract laboratory in time to be properly preserved. This resulted in an important short-coming in the design of the monitoring program that could not be overcome. Specifically, the timing of sample collection did not correspond with the time when diurnal flux was likely to elevate pH. Thus, we have no measure allowing comparison of the sites, when important differences among them were most likely to manifest.

We found that for the period of recent monitoring flow of the Hams Fork has been reduced dramatically by drought. In fact, when Gay described diurnal Flux the USGS gauge indicated that discharge was only 15% of the 56-year average flow. Other studies have found that western streams often experience diurnal pH flux in response to low flow (e.g., Sprague 2005, Kent et al. 2005) and the importance of flow cannot be overstated.

As with much of Wyoming's streams, geology of the Hams Fork Basin produces waters with a natural tendency toward the alkaline end of the pH spectrum. Additionally, the high phosphorus content of the local geology may help fuel diurnal photosynthesis cycles and pH flux.

We outlined an improved monitoring program using continuous data loggers, and frequent discharge measurements so that measures of pH, oxygen concentration, temperature, and discharge can be described simultaneously, and perhaps provide "good cause" for delisting.

This monitoring regime should provide useful data to evaluate the interrelations of diurnal flux, temperature, and discharge sufficiently that flow criteria could be derived and the feasibility of subtle flow augmentations from upstream reservoirs can be evaluated. The Hams Fork ecosystem should respond to augmented flows with exponential reductions of photosynthetic rates because it acts in three ways (light reduction, temperature reduction, and nutrients dilution). Thus, the monitoring proposed can be more pro-active than previous monitoring efforts. Future monitoring should be able to provide more uses, than just data archives and documentation. If the data are properly collected they can be used to document the role of discharge and recommend precisely how much flow augmentation is required during drought years—actually allowing managers to actively manage, and mitigate problems that resulted in the stream being listed.

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Preamble:

There has been a trend in science writing to favor the active voice over the passive voice—particularly among ecological journals. To some, this may seem informal, but it is generally more concise—allowing more information to be discussed in less space, while promoting greater comprehension. Usually when we prepare single-author papers, the singular first person pronoun, “I” is used extensively. However, this report is the product of much work by the Lincoln Conservation District and their stakeholders so I usually used the plural pronoun, “we” to acknowledge their contribution to the project. This does not necessarily imply that everyone involved with the project agrees with every statement or finding here in.

Suggested citation:

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Hams Fork River Nutrient Assessment 2006-2008

A Follow up to the Finding of Diurnal pH Flux and Potential Roles of Nutrient Loading on the System—Progression towards 303d List Removal

Background

The Hams Fork of the Green River was added to Wyoming's 303d list because of impairments related to elevated pH (>9.0). Earlier work on the Hams Fork (Gay 2001) documented diurnal flux in pH, with elevated values occurring in the late afternoon—in sync with peak photosynthetic activity of aquatic vegetation. The author argued that the stream should be removed from the impaired water list because pH-values >9 were clearly related to primary production. This suggestion was rejected by both the Wyoming Department of Environmental Quality (WDEQ) and the United States Environmental Protection Agency (USEPA) because it was not clear if the level of photosynthesis was natural or anthropogenic.

To determine the if high primary productivity in the Hams Fork was human-caused, the author proposed a nutrient assessment (Gay 2006) to document changes in nutrient concentrations around the town of Kemmerer, WY. The rationale was that if elevated nutrients were found near human facilities that elevated plant production could be anthropogenic, but if there were no significant differences in the area, that elevated production was "natural."

Admittedly, there are some flaws in this logic. It is analogous to measuring oxygen concentrations in a burning building to determine where the fire is. As fire consumes oxygen to burn, so the aquatic flora consume nutrients, thereby altering water chemistry. If the flora are sufficiently active to alter the stream's pH, they could be sufficiently active to deplete the concentrations of essential nutrients. Thus, the assessment of nutrient concentrations could pin-point problem areas, but failure find area's of elevated concentration cannot be used to determine the naturalness of photosynthetic levels. To rephrase, measuring nutrients does not equate to measuring nutrient uptake or primary production rates.

The Lincoln Conservation District (LCD) initiated nutrient Monitoring program in 2006 and continued monitoring through 2008. At the conclusion, they contracted this report to summarize and interpret the results. We identified several goals for the report:

- Summarize the findings of the nutrient monitoring program
- Synthesize the implications of these results given other information
- Recommend methods appropriate to assess the naturalness of diurnal flux and production.

Methods

Data Quality

Lincoln Conservation District (LCD) used trained staff to collect water chemistry samples from several sites along the Hams Fork and sent them to a certified laboratory for analysis (Energy Laboratories Inc.). They followed the protocols defined for water chemistry monitoring set forth in the WY DEQ's standard methods (WDEQ 2003), as described by the original Sample and Analysis Plan (SAP; Gay 2006). The Plan was approved by DEQ for meeting the requirements of credible data, but DEQ expressed reservations that the design may not be adequate for the intended purpose of determining the "naturalness" of primary production (Clark, WY DEQ Pers. Comm., 2008). Although we are aware of the limitations inherent in the design, the study meets the requirements for credible data.

No single water quality parameter was collected from all site-date combinations. This occurred for several reasons. Some times there was insufficient water to allow sampling. Once, a meter malfunction prevented gathering of all field measures. Inconsistencies in the measures attained from samples analyzed by the contract laboratory caused some measures to be reported some years but not in others. The net result of these events is that there were numerous missing values in the data set (Appendix 1). Still, we believe the data provide sufficient insights to Hams Fork Nutrient Dynamics to be useful.

All data were entered into a MS Excel Table and proofed for accuracy by two observers. These data were placed in a write protected spreadsheet and directly copied into other programs for statistical analysis and graphic development. A write-protected copy of the excel file was provided to LCD for posterity. To work with these data, copy them from the protected file into a new file. This helps protect the integrity of the data proofing and validation process. Hard copies of the data used for these analyses are attached as an appendix (Appendix 1).

Statistical analyses were performed using SYSTAT 11, and presented using SIGMA PLOT. Correlations were described using simple linear regression. When appropriate stepwise multiple regression was also performed using both forward and backward stepwise algorithms.

Longitudinal analysis used averages and 95% confidence intervals. The number of zero values (non-detects) caused problems with both parametric and non-parametric statistics. In the case of dissolved oxygen and pH (where there were no "zero-values"), and the assumptions of Analysis of Variance (ANOVA, e.g., Zar 1999) were met, ANOVA was used to identify significant differences among sites. Since the sites did not represent a monotonic gradient from a point source, regression analysis was inappropriate for spatial analyses. Also, temporal regression and time series analyses have a tendency to yield spurious correlations with limited data sets like the one considered herein; these methods were not used in this report.

Study Sites

Study sites were selected by LCD prior to analysis and constitute a downstream gradient. The Hams Fork is influenced by two impoundments in the Wyoming Range Mountains about 14 river-miles up stream of the upper monitoring site. Other potential anthropogenic influences include runoff from the town of Kemmerer and point-source discharge of the Kemmerer sewage treatment plant. Natural influences include extensive riparian wetlands and limestone geologic formations. The major tributary in the study area is Willow Creek.

TABLE 1. Study site location. The location of all nine study sites are presented below. The sites are numbered from 01-09 representing a downstream gradient.

Site	Description	Latitude	Longitude
HF01	Upstream Reference on the Hams Fork, upstream of the RT 233 Bridge, about 3,000 ft downstream of the public fishing access.	N41° 51.449'	W110° 33.856'
HF02	Willow Creek, an influential tributary. Near county Rt. 327.	N41° 50.254'	W110° 31.941'
HF03	Lion's Club Park	N41° 49.556'	W110° 31.869'
HF04	Culinary Water Treatment Plant. (drinking water treatment) located upstream of RT 233 bridge.	N41° 48.056'	W110° 32.060'
HF05	50' dn. stream, Kemmerer City's Children's Fish Pond	N41° 49.105'	W110° 32.250'
HF06	Below Waste Water Treatment Plant (WWTP), about 1,500 ft downstream from WWTP.	N41° 47.336'	W110° 32.066'
HF07	Near High School Football and Baseball fields, about 3,200 ft downstream from WWTP.	N41° 47.136'	W110° 32.095'
HF08	Near the community of Oakley, upstream of the HYW 30 bridge, about 50 ft. upstream from railroad bridge.	N41° 45.128'	W110° 31.952'
HF09	Downstream site, locally known as "waterfall". Pullout ~ 430ft upstream of Co. Rd. 326 bridge.	N41° 45.305'	W110° 28.430'

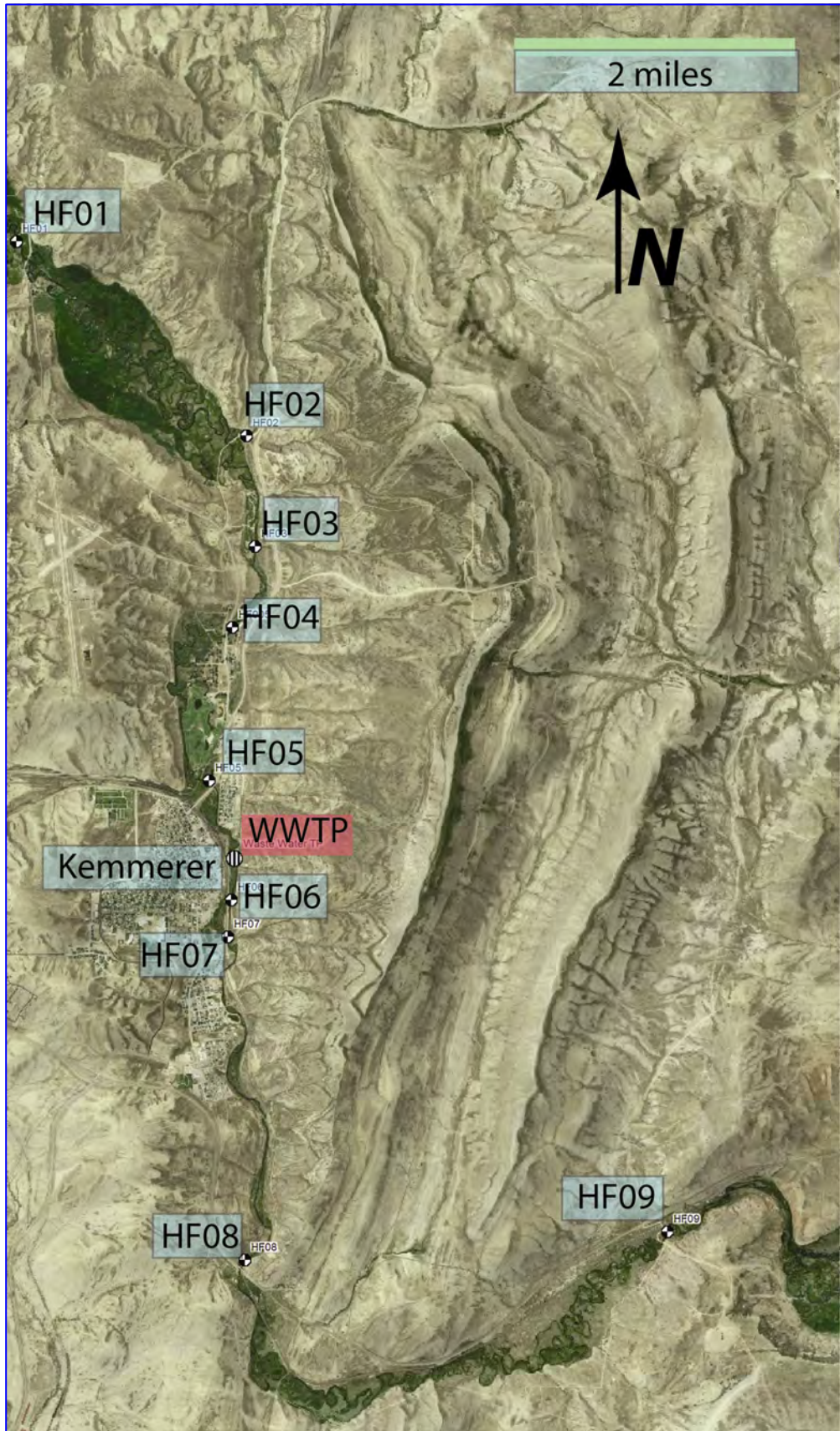


Figure 1. Hams Fork Study Area. The study area consisted of 9 sites from which chemical water quality data were collected. The direction of flow is from North to South.

Results

Overview

The pH of the Hams Fork was usually below 9.0 during the study, with only two observations above 9.0 (Fig. 2). These occurred at the sites farthest up stream on October 30, 2007 (HF01: 9.40, HF02: 9.32). This was one of the dates in which the upstream sites were sampled last—yet the observations were made much sooner (12:30, 12:50 PM) than the late afternoon, when Gay (2001) found that the pH was most likely to exceed the 9.0 threshold.

The stream's pH was most elevated during the period between 16:00-19:00 in Gay's (2001) study because the cumulative effects of day's photosynthesis peaked at this time—the period when temperature and solar energy reaching the stream's bottom were greatest.

Nutrients

We found that pH of the Hams Fork did not correlate well with either Nitrate (Fig. 3) or Total Phosphorus (Fig. 4). This makes sense because vegetation must consume nutrients to alter the pH of surrounding water and aqueous nutrient concentrations do not reflect the amount of nutrients consumed in the course of photosynthesis. However, Nitrate and TP concentrations were highly correlated with each-other (Fig. 5), suggesting that they respond similarly among samples. Thus, high nitrates tend to occur where TP is also high and vice versa. This could indicate common sources, as well as a common role in production dynamics of the Hams Fork.

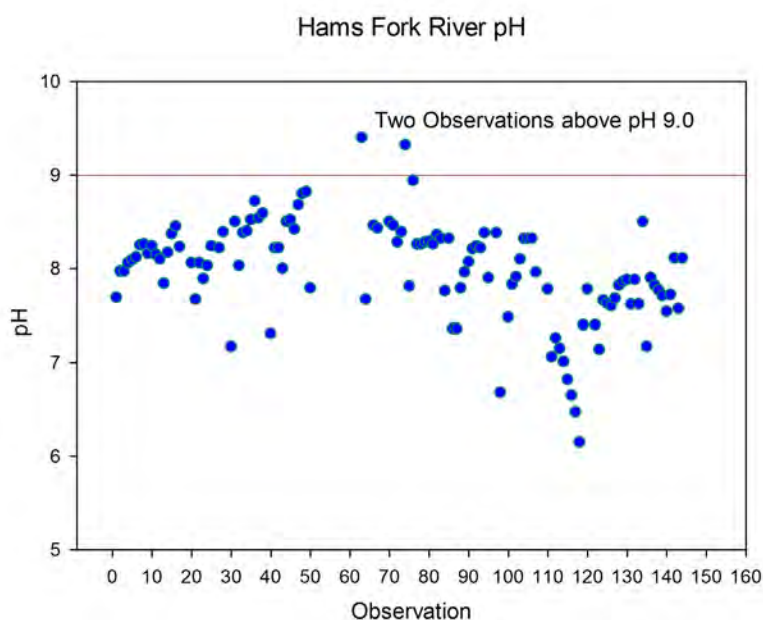


Figure 2. pH values attained from all samples. The graph shows all pH values attained for entire term of the study from all sources. Thus it includes some measurements from the Hams Fork, as well as a few grab samples directly from the effluent. The order of the samples is arbitrarily in the order reporting, so there is an element of time implied (from left to right) that is not explicitly expressed on the scale.

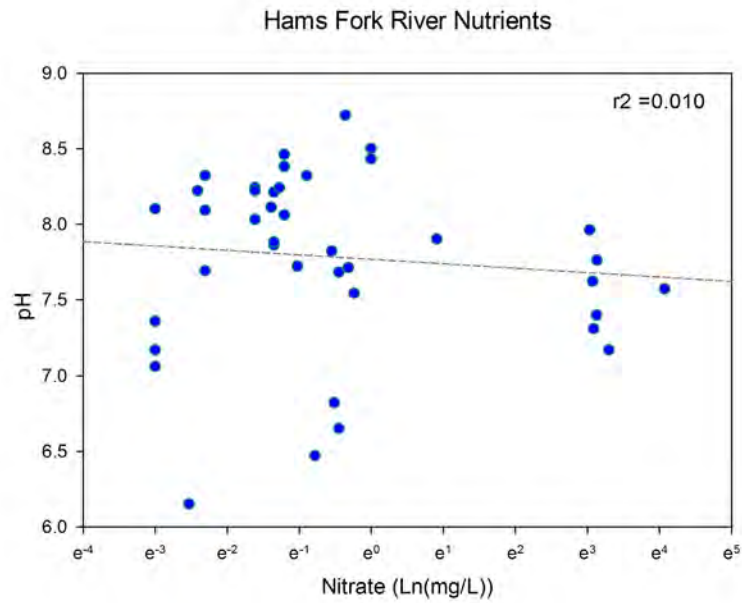


Figure 3. Nitrate and pH. Nitrate was poorly correlated with pH. Nitrate-N data were transformed using natural logarithms to homogenize the variance and to meet the assumptions of linearity. pH is expressed on a logarithmic scale, so no transformation was required.

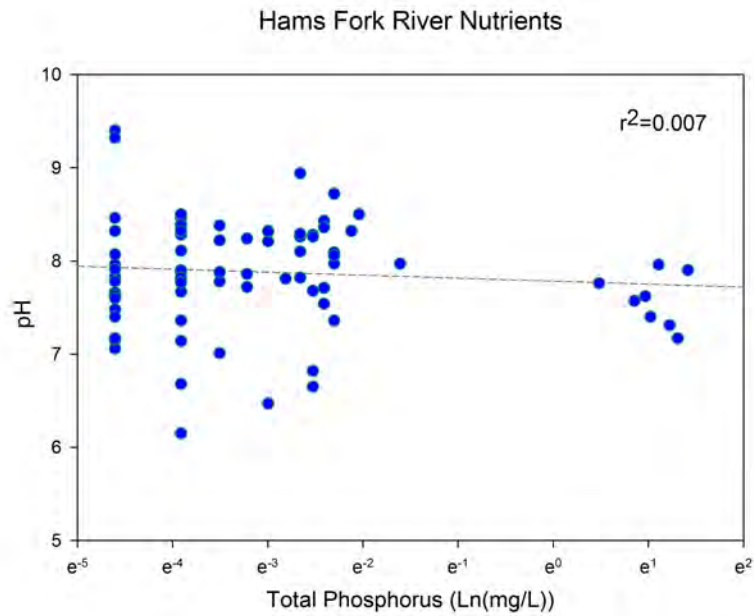


Figure 4. Total Phosphorus and pH. Total Phosphorus (TP) was poorly correlated with pH. TP data were transformed using natural logarithms to homogenize the variance and to meet the assumptions of linearity. pH is expressed on a logarithmic scale, so no transformation was required.

Hams Fork River Nutrients

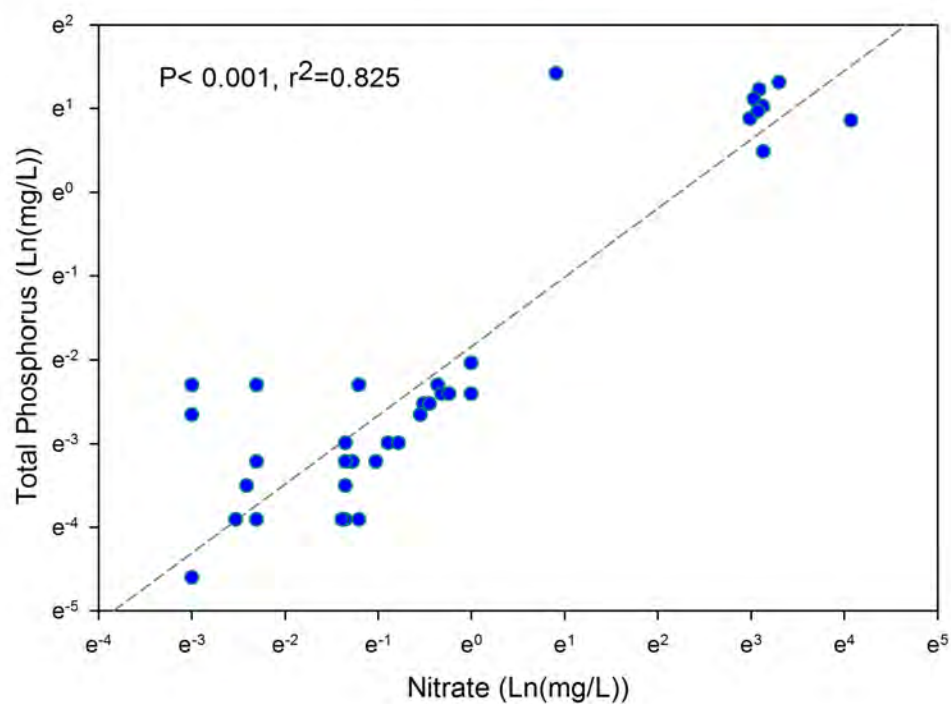


Figure 5. Total Phosphorus and Nitrate. Total Phosphorus (TP) was highly correlated with Nitrate-N. Both Nitrate and TP data were transformed using natural logarithms to homogenize the variance and to meet the assumptions of linearity. Most of the observations were very low throughout the study, with some observations (top right) being much higher than ambient levels.

Oxygen

Although the original Sample and Analysis Plan (SAP; Gay, 2006) called for comparisons of nutrient concentrations with pH to determine where primary production was greatest, we found that there was no correlation among these variables. As stated earlier, we believe this makes sense because the nutrients had to actually be consumed by vegetation in order to alter the pH of surrounding waters. However, the data collected by the LCD does include another parameter that is directly related to the Hams Fork community's net photosynthetic rate: Dissolved Oxygen. This relationship makes sense because oxygen is a by-product of photosynthesis and it must diffuse through aquatic plant tissues during the same time that plants consume nutrients and dissolved carbon (which alters the carbonate buffering capacity of water—altering the pH).

We found that dissolved oxygen was correlated with pH (Fig. 6). We also conducted a multiple regression which included both pH and Temperature as predictors, but temperature was a poorly correlated with dissolved oxygen during the study and did not improve the model sufficiently to justify its inclusion (i.e., $p > 0.05$, and only improved the r^2 from 0.409 to 0.410; an improvement that could be attained by adding any variable)¹. This underscores the fact that in-stream photosynthesis has a greater influence on oxygen concentrations in the Hams Fork than atmospheric mixing and temperature limited saturation—at least during most of the period studied. It also supports the findings of Gay 2001, which concluded that elevated pH is related to photosynthesis by aquatic flora.

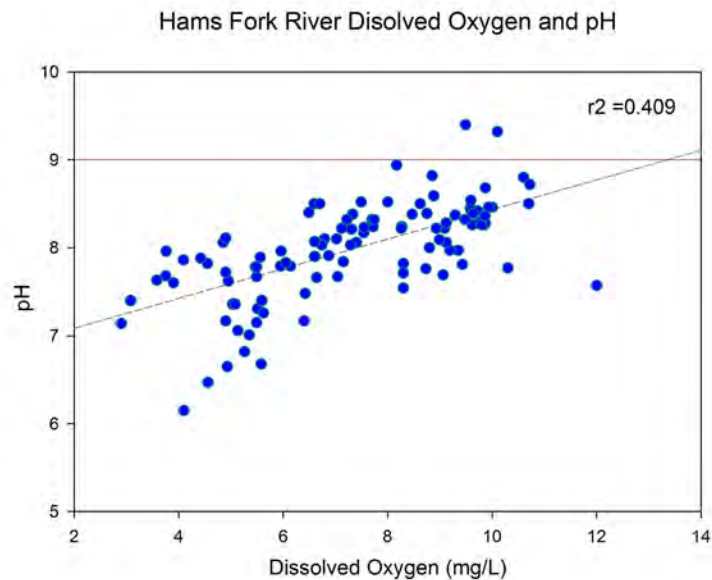


Figure 6. Oxygen and pH. Dissolved oxygen concentrations were highly correlated with pH. When plants grow, they produce oxygen, while consuming nutrients and carbon—which may cause pH to increase. The correlation among these variables was much greater than the correlation between oxygen and temperature.

¹ Both forward and backward stepwise regression excluded temperature in favor of pH as a predictor of dissolved oxygen.

Longitudinal Trends²

pH

There was no statistically significant (ANOVA $P=0.549$) or distinguishable longitudinal pattern observed in mean pH for the entire study period (Fig. 7). Even the two observations of $pH > 9.0$ were accompanied by enough low pH values that the average and the 95% confidence intervals of all sites were below pH 9.0. Thus, our data suggests that all sites usually have pH well below 9.0—sufficiently so that observations >9.0 are highly unusual—occurring less than 5% of the time. However, our data did not include samples from the time of day most likely to exhibit high pH. Recall that sampling for this program had to focus on morning hours (though early afternoon) to accommodate overnight shipping to the contract laboratory, so no samples were collected from the late afternoon or evening—when high pH has been a problem.

Oxygen

There was no statistically significant (ANOVA $P=0.672$) difference observed in dissolved oxygen during the monitoring period. We anticipate that dissolved oxygen concentration can be used as a surrogate measure of nutrient-uptake rate and net photosynthesis rates. But the lack of differences among sites could be due to homogenous levels of productivity or (more likely) due to the fact that monitoring was conducted during periods of low productivity when differences among sites were not as pronounced.

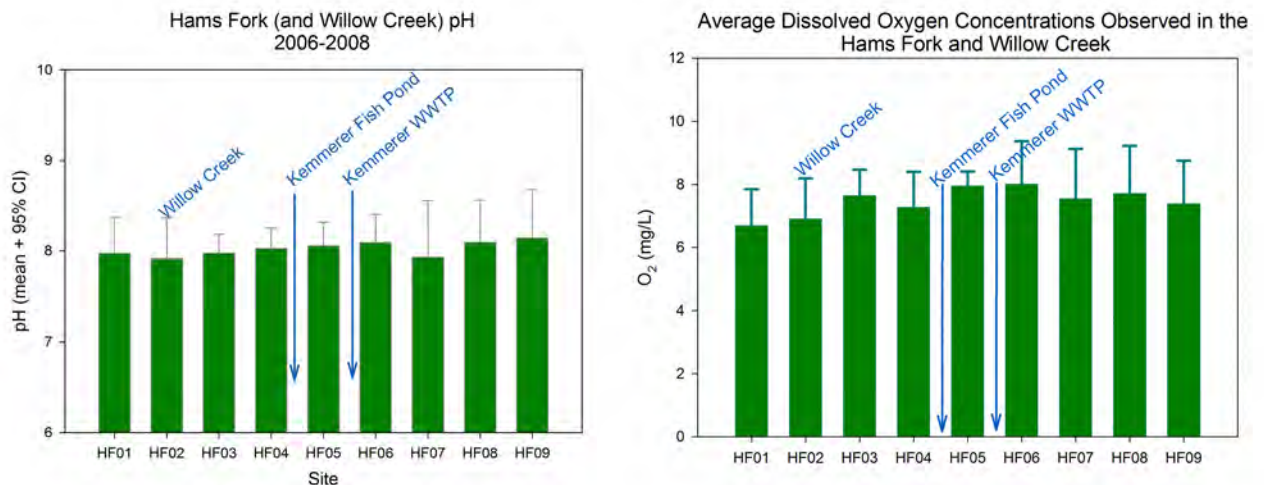


Figure 7. Longitudinal patterns in pH and oxygen. There were no significant differences among the sites neither pH nor dissolved oxygen (pH: ANOVA $P= 0.549$; DO: ANOVA $P=0.672$).

² Longitudinal refers to the River Continuum (Vannote et al. 1980), which describes how rivers change from upstream, to downstream.

Nutrients

If human activity is the cause of elevated photosynthesis in the Hams Fork, then nutrient additions are a likely source of the change. It is important to identify potential sources of anthropogenic nutrient additions if effective remedial measures are to be implemented effectively. This requires understanding the longitudinal trends in nutrient concentrations.

Ammonia

Ammonia was below the detection limit in all stream water sampled for this study. Ammonia is a natural product of anaerobic decomposition and may rapidly become oxidized to Nitrate in the presence of oxygen. It is more toxic at higher pH values.

Nitrate

Nitrate was occasionally below detection, but was detected at most sites. The average concentration of nitrate upstream of Kemmerer was low, including the tributary of Willow Creek. There was a marked increase in nitrate concentration downstream of the Waste Water Treatment Plant—suggesting that a source occurs downstream between site HF05 and HF06. The two highest nitrate observations were relatively modest (1.0 mg/L) and were measured below the WWTP. On average, the concentrations at this site were much lower (0.4mg/L) than their respective maxima.

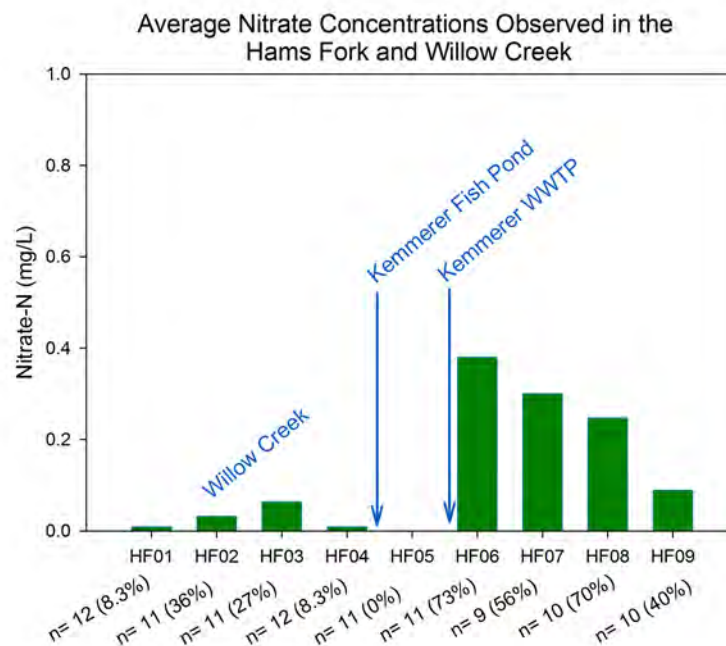


Figure 8. Longitudinal patterns in nitrate. Nitrate was very low upstream from Kemmerer, but increased below the WWTP. The number of times the measures were recorded is listed (e.g., n=12) followed by the percent of those observations having values above the detection limit. For example, 11 measures were made at HF06 and 56% of the measures were above the detection limit.

Total Phosphorus

Phosphorus is essential for the growth of all plants. Total Phosphorus includes biologically available phosphorus as well as elemental phosphorus which is not as readily used by aquatic flora. Like nitrate, it can be a limiting nutrient responsible for determining the rate of plant growth in aquatic ecosystems.

We found that there was pattern vaguely resembling the distribution of nitrate (Fig. 9). With lower concentrations of TP upstream, and slightly higher concentrations below the Kemmerer Waste water Treatment plant.

Orthophosphate

Orthophosphate is also known as biologically available phosphorus because it is easily used by aquatic flora as a nutrient. Orthophosphate concentrations showed a very similar pattern to that observed with both nitrate and total phosphorus (fig. 10). Specifically there was a marked increase in orthophosphate below the Kemmerer Waste Water Treatment plant. Furthermore, the on dates when both orthophosphate and TP were measured, the downstream sites had a greater portion of their total phosphate comprised of orthophosphate (Fig. 11).

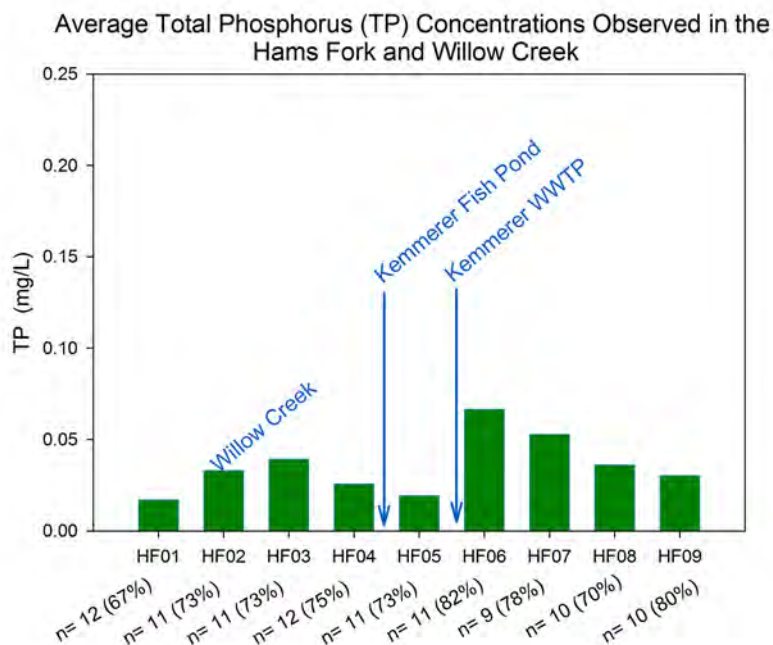


Figure 9. Longitudinal patterns in Total Phosphorus. Total Phosphorus was low upstream from Kemmerer, but increased slightly below the WWTP. The number of times the measures were recorded is listed (e.g., n=12) followed by the percent of those observations having values above the detection limit. For example, 11 measures were made at HF06 and 82% of the measures were above the detection limit.

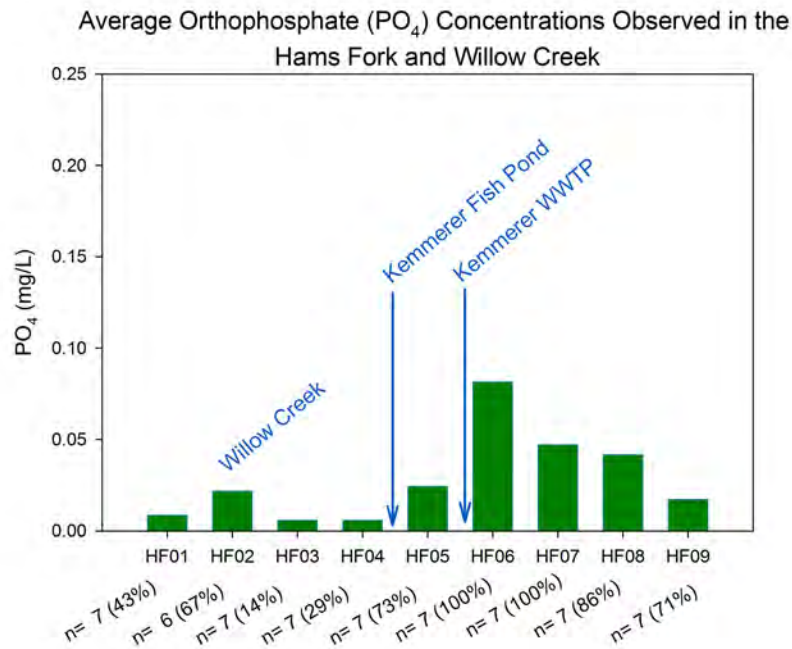


Figure 10. Longitudinal patterns in Orthophosphate. Orthophosphate was low upstream from Kemmerer, but increased slightly below the WWTP. The number of times the measures were recorded is listed (e.g., n=12) followed by the percent of those observations having values above the detection limit. For example, 7 measures were made at HF06 and 100% of the measures were above the detection limit.

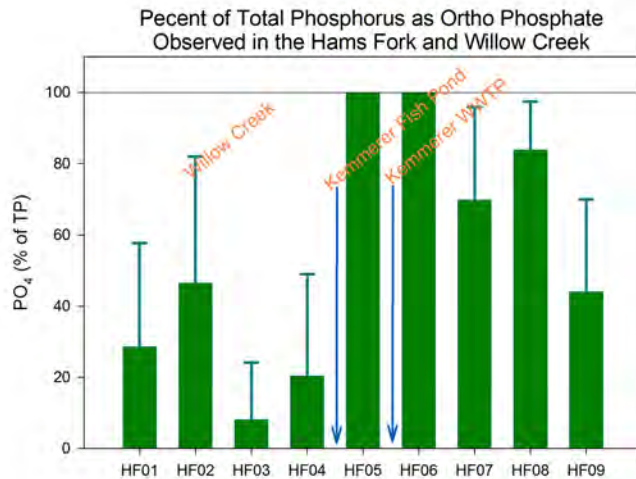


Figure 11. Mean Portion of TP as PO₄. Orthophosphate is a component of total phosphorus. We found that it comprised 100% of TP measured at HF05 and HF06 for the entire set of samples analyzed. The general pattern was that PO₄ comprised a greater portion of the TP found below Kemmerer than upstream from Kemmerer. Error bars are 95% confidence limits.

Discussion of Results

The only two observations of pH greater than 9.0 occurred upstream at HF01 and HF02 (on Willow Creek) in October 2007. Suggesting that high pH is as much of a problem upstream as it is downstream of Kemmerer. This may be because the geology of the region is naturally prone to producing higher pH waters (e.g., Limestone geology with high phosphorus content). One problem with this finding is that this study was unable to document precisely how much of a problem that really is. That is, we only found two days where the pH exceeded the 9.0 threshold, but the study did not take measures during the time of day when diurnal flux was likely to produce pH readings greater than 9.0. Chapter One of the Water Quality Standards set forth by Wyoming Department of Environmental Quality (WY DEQ 2006b) states that monitoring efforts need to focus on periods when impacts are likely to occur and that the rationale for the timing needs to be scientifically defensible and documented.

Longitudinal analysis suggested that there was an increase in nutrients downstream of the Kemmerer WWTP. This was true for nitrate, total phosphorus and orthophosphate. Thus, it is clear that nutrients increased somewhat below the town of Kemmerer, but it is unclear how much nutrients were actually consumed by aquatic flora to fuel the diurnal pH flux described by Gay (2001).

Dissolved oxygen was correlated with pH—more so than temperature. This suggests that the dissolved oxygen concentration was more strongly influenced by photosynthesis than by atmospheric diffusion and further corroborates Gays (2001) suggestion that periodic and cyclic elevated pH values are most likely related to elevated primary production.

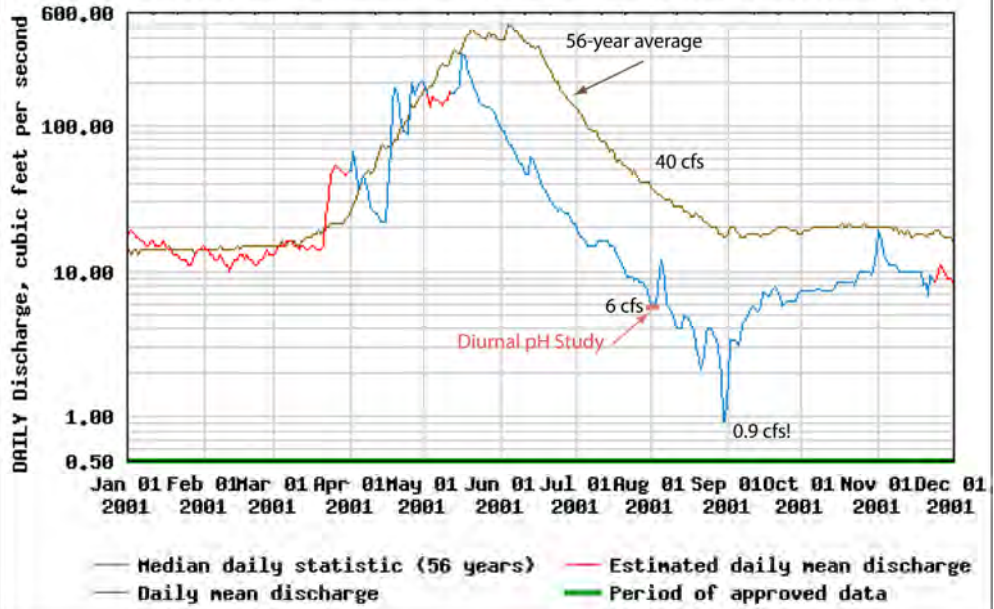
One aspect that has not been sufficiently discussed regarding the interactions among nutrients, Photosynthesis and elevated pH is the role of Hams Fork Discharge. Specifically, for much of the period that the Hams Fork pH flux has been studied, the system had experienced reduced discharge. Thus, much of the information intended to help delist the stream was gathered when the stream was subject to abnormal drought conditions³. This includes the period in which Gay (2001) originally described diurnal flux (Fig. 12) as well as most of the period monitored for this report (Fig. 13).

Streams in the west have been shown to exhibit diurnal pH changes in response to low discharge (e.g., Sprague 2005, Kent et al. 2005). Although this study was not able to “prove” that elevated pH in the Hams Fork is natural, it is possible that it may be related to (or exacerbated by) drought.

It is also important to note that during this study, the nature of the mixing zone for the Kemmerer WWTP has had its fundamental nature changed dramatically. In 2001, the Flow at the USGS gauging station got down to 0.9cfs, whereas the discharge of the Kemmerer WWTP is typically 0.9-1.0 cfs (WWTP, Pers. Comm. 2009). This illustrates the need to track the Hams Fork Discharge at a location close to Kemmerer to ensure that the role of discharge can be considered in greater detail in the future—both descriptively and as a method to provide good cause for delisting (further discussion follows).

³ WY DEQ and US EPA define several ways to determine if the flow is below average. We did not perform these calculations for this study. Rather, we used the more conservative USGS gauging station data online, which provided a >50 year baseflow we used as a reference. From 2000-2006, the Hams Fork exhibited flows that were 10-60% of normal (figs 12, 13).

USGS 09223000 HAMS FORK BELOW POLE CREEK, NEAR FRONTIER, WY



original diurnal flux study and compares it with the 56-year average discharge. The actual discharge may have been substantially different during Gay's (2001) study because this gauge is a substantial distance up river from Kemmerer. However, it serves as a demonstration the amount of moisture reaching the system was reduced during the study.

USGS 09223000 HAMS FORK BELOW POLE CREEK, NEAR FRONTIER, WY

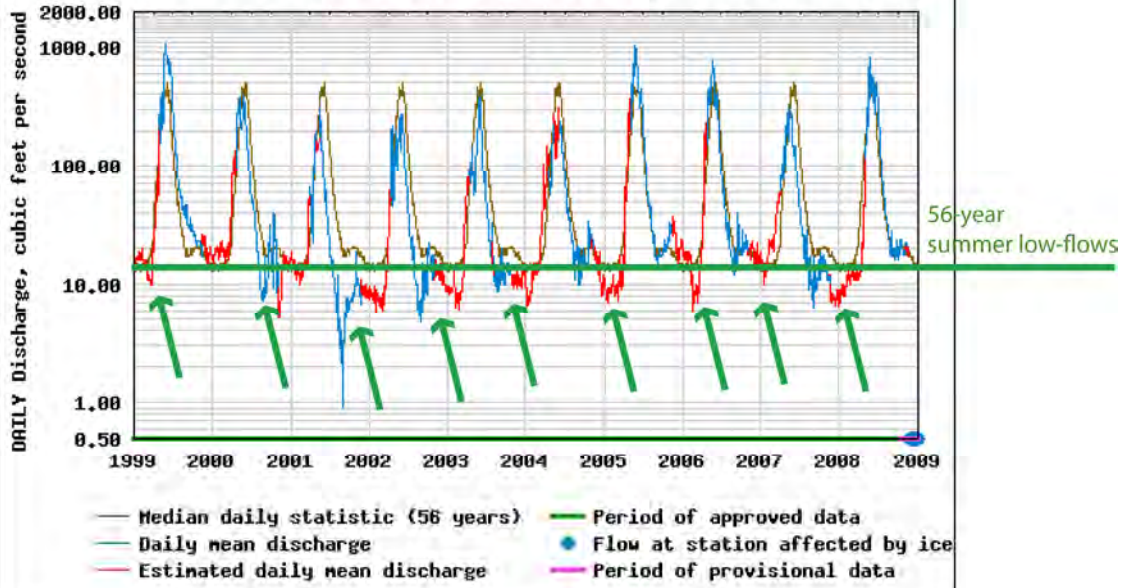


Figure 15. Hams Fork Discharge 1999-2009. The Hams Fork has had nine consecutive years of below normal discharge.

Discussion: Towards Delisting the Hams Fork

Wyoming Department of Environmental Quality (WY DEQ 2008b) sets forth a clear path towards delisting. Credible data must be collected and used to demonstrate one of the following “good causes” for delisting:

1. Provide representative data showing full support of designated uses;
2. Show flaws in the original analysis that lead to the water being listed;
3. Demonstrate that controls to remediate the original disturbance are in place and likely result in full-support attainment;
4. Removal of likely source discharges;
5. Restoration of water quality demonstrating full support attainment.

Thus, like the earlier works of Gay (2001, 2006), this study was not able to demonstrate any of these criteria demonstrating “good cause” for delisting because there were certain limitations in the design that ran deeper than data quality. Ultimately all five of these “good causes” could be required to remove the Hams Fork from the 303d list. However, given the unusual nature of this listing, there is a legitimate possibility that the first two “good cause” scenarios could yield results.

The addition of the Hams Fork to the 303d list for pH is unusual because the “problem” is caused by nutrient uptake; this is generally considered an important aspect of water quality protection (e.g., Kent et al. 2005, Craig et al. 2008). If photosynthesis rates increase, nitrate, an important pollutant, is removed from the water, and available for grazing invertebrates, which provide forage for fishes, or export nutrients to the riparian community with emergence. To phrase this in ecosystem metabolism terms, we like to see the nutrient spiral⁴ length shortened and the retention time increased. This ultimately reduces the stream’s nitrate “load.” However, in the case of Hams Fork, there is sufficient uptake of nutrients and carbon that the carbonate buffering state of the river is periodically shifted and pH becomes elevated—during the afternoon, in the summer.

Even with all the data collected on the Hams Fork River, we still do not know how long nor how frequently pH exceedences occur. This should be the first step in an earnest effort to demonstrate “good cause” for delisting. Much of the data gathered relating to the pH of the Hams Fork has occurred during below average flows⁵. Low flows may increase the temperature of stream water as well as increase the amount of solar radiation reaching benthic substrata (exponentially; e.g., Wetzel 2001, Kent et al. 2005). Elevated light and temperature increase the rate of photosynthesis during low

⁴ In most ecosystems, ecologists discuss the nutrient cycle. Since streams have a unidirectional flow, resulting in the export of nutrients, the cycle is called a spiral (e.g., Webster and Patten 1979, Newbold 1992). When the spiral length is short, nutrients spend more time in sediments and in the tissues of biota, rather than in solution where they may pose a risk to downstream beneficial uses (Craig et al. 2008).

⁵ WY DEQ and US EPA define several ways to determine if the flow is below average. We did not perform these calculations for this study. Rather, we used the more conservative USGS gauging station data online, which provided a >50 year baseflow we used as a reference. From 2000-2006, the Hams Fork exhibited flows that were 10-60% of normal (figs 12, 13).

flows. Furthermore, the diluting capacities of streams and rivers are reduced during low flows. Thus, during the period of greatest water quality monitoring, the effects of diurnal pH flux may have been exacerbated.

Gay (2001) suggested that the timing of USGS data collection may have changed over time, and that this change from morning monitoring to afternoon monitoring may be the reason that high pH readings have only recently been recorded. I have reviewed the data in greater detail and found that although the average time of day is later in recent years that all years included some readings in the morning and some from the afternoon. The data that were used to add the Hams Fork to the 303d list may have been skewed slightly by drought and by sampling time, but Gay's (2001, 2006) study designs did not provide sufficient evidence to refute these data.

We consider "good causes" numbers 1 and 2 to be related. If the occurrence of pH values >9.0 are infrequent and ephemeral, then it is likely that the stream is probably meeting its beneficial-use designation and that the data used to list the stream were incomplete or not completely representative. Thus, to take this approach, we need to acquire measurements that are very frequent and over a long time period—including hours when observations are most likely to exceed 9.0. We can attain credible data for this purpose by deploying two continuous monitors to measure pH and dissolved oxygen hourly for the entire year (q.v., Discussion: Future Monitoring).

Monitoring alone might provide sufficient data to remove the Hams Fork from the 303d list... but it might not. To get the stream removed from the list soon, we should also consider some of the other "good causes" for delisting. "Good cause" #3 could be particularly useful towards this purpose. Low discharge may be partially responsible for the dramatic effects of photosynthesis on pH of the Hams Fork. It might be possible to negotiate a slight change in release from the dam upstream of Kemmerer to hold more water back in the winter and release more in the summer. Such an arrangement would need to balance beneficial uses of the reservoir as well as safety concerns related to pool capacity. If these concerns are addressed, increasing the summer release from the dam will provide cooler and deeper water—thereby slowing photosynthesis. Additionally, nutrient additions near the town of Kemmerer will be diluted and their effects on photosynthesis (which remain unknown) will be mediated. A feasibility study should accompany any monitoring program concurrently. If data collected do not warrant "good cause" for removal from the 303d list, they can be used to demonstrate the potential effects of a beneficial flow augmentation—thereby demonstrating good cause #3.

Discussion: Future Monitoring

Wyoming DEQ is considering initiating the TMDL process for the Hams Fork (Thorp, WY DEQ pers. comm. 2009) but the process cannot begin at the current time (Newton, WY DEQ pers. Comm. 2009). Thus, continued monitoring may be useful in facilitating delisting of the Hams Fork. To ensure that the data are useful for this purpose, a Sampling and Analysis Plan (SAP) should be submitted to WY DEQ's QA/QC officer as soon as possible, the purpose of this section of the report is not to circumvent this requirement, but rather to fuel the development of a useful SAP that meets the requirement of credible data and has sufficient design to address issues pertaining to the delisting of the Hams Fork.

Community metabolism is a complex, emerging field within aquatic ecology, and the Hams Fork pH issue could be studied by assessing many aspects nutrient dynamics. Academic studies of food-web models, nutrient spiral length, nutrient uptake/limitation studies, stable isotope analyses, and assessments of both algal growth and biomass could all be justified under the auspices of understanding the problem. But, stakeholders could invest many resources into these types of studies and see very little return in terms of progress towards delisting.

We prefer a simpler approach that focuses on providing "good cause" for delisting the Hams Fork. Ideally, continuous, hourly (or semi-hourly) pH (as well as, temperature, oxygen, and discharge see below) monitoring, during the summer could show that, during normal flow (snow pack report is "good" for 2009; Grandy, LCD Pers. Comm. 2009), diurnal pH flux is usually below 9.0. This will serve to demonstrate Good Cause-1 and Good Cause-2 for delisting.

If "good cause" can not be demonstrated via Cause-1 or Cause-2, the data should be collected in such a way as to allow a test of a feasibility to attain "good cause" #3 through flow augmentation from up stream reservoirs. The simplest design should involve regular and frequent measures of the following parameters:

1. Document the actual cycles of pH and the frequency and duration of 9.0-exceedence, if any.
2. Record the relationship of pH with Dissolved oxygen. This will continue to document the cyclic nature of Hams Fork pH and its correlation with photosynthesis.
3. Measures of pH and dissolved oxygen should be accompanied with temperature data. So that %saturation can be used as a surrogate indicator of photosynthetic rates.
4. Frequent and regular discharge measurements (near the data loggers) need to be recorded so that the influence of low discharge on diurnal pH flux can be documented AND benefits of subtle flow augmentation can be quantified, modeled and documented.

The monitoring should focus on separating natural causes from anthropogenic ones—like the WWTP discharge at Kemmerer. We have evidence that upstream sites exhibited elevated pH, but the question remains: do upstream locations experience elevated pH (>9.0) as frequently and intensely as downstream reaches do? This question can be addressed by setting one data logger at the upstream site (HF01) and another below the WWTP below, the mixing zone.

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