Consensus report for the International Joint Commission on RESPEC 2016 report "The development of a stressor-response model for the Red River of the North".

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This report represents a peer review of the RESPEC report (2016 report: The development of a Stressor Response Model for the Red River of the North, referred to in this document as the "report" for brevity), with specific attention to concerns raised by the Minnesota municipalities (Letter of July 11, 2018 and two attachments).

Summary of the goals of the study and concerns highlighted by Minnesota Municipalities
A key goal of the RESPEC report was "to develop a stressor-response model for the Red River and to use the model to identify biological thresholds/criteria which identify the thresholds at which biologic response variables in the Red River respond to nutrients".

The letter from the four mayors noted "this report proposes new restrictive numeric nutrient targets under the assumption that the Red River is impaired for TN [total nitrogen] and TP [total phosphorus]. We are concerned with this finding, given that our knowledge the river is not presently impaired based on Minnesota's recently adopted River Eutrophication Standards and is not listed as impaired for nutrients on the Clean Water Act Section 303(d) impaired waters list of Minnesota or North Dakota". "The recommended nutrient targets for TP and TN contained within the RESPEC report could lead to multimillion dollar expenditures for our communities if adopted or used by our states or the federal government as the basis for regulating our treatment facilities. As a result, we want to ensure that methodologies used to assess the river, develop the recommended targets and develop nutrient reduction strategies are scientifically defensible and will lead to meaningful water quality improvements."

To this end, we review the original report as well as address the specific concerns outlined in the Hall and Associates assessment of the report. We were contracted to assess the following points:

1. Do you agree with 1 through 5 under "Primary Issues of Concern" pages 2 through 6 in the Hall and Associates report (***Attachment C***)? Explain your answer.
2. Was the stressor-response model developed for the Red River appropriate to address the charge from the Statement of Work (SoW)?
3. Was the stressor-response model appropriately applied to address the charge from the SoW?
4. Was the field study design and data collected appropriate to fill data gaps and address the charge from the SoW?
5. Were the statistical methods used applied correctly to address the charge from the SoW?

These points are taken directly from the statement of work for the US contractor. The Canadian statement of work was very similar, so we chose just one of the two for simplicity.
PART 1. Do you agree with 1 through 5 under "Primary Issues of Concern" pages 2 through 6 in the Hall and Associates report (***Attachment C***)?

CONCERN 1 (Hall and Associates Review). "The recommended nutrient target limits presented in the report (at 64) were based on a skewed evaluation of non-representative data and are not related to any accepted metric of aquatic life use impairment. Consequently the recommended nutrient target limits are not scientifically defensible."

Upon consideration of the original report and some re-analysis of the data we suggest that the nutrient targets suggested were within a range of reasonable numbers that could be derived from the data. We re-analyzed the the data to check the results with a simple independent approach and came up with similar numbers. We recognize some lack of clarity with the original approach in the report and attempt to address these issues. However, after considering these potential problems, we still find that the targets suggested are reasonable and potentially even not stringent enough to protect the river and downstream Lake Winnipeg.

The targets within the RESPEC report were established based on the sites with the strongest nutrient-related responses as indicated by where they fall on a principal components analysis axis space that was used to account for the confounding factors of high turbidity as represented by total suspended solids (TSS). It was necessary to exclude the effects of high TSS which may alter the response of primary producers to elevated nutrients. Tables 7-8 and 7-9 (RESPEC) provide details on these sites, and associated conditions. The specific sites for assessment were analysed within RESPEC figure 7-12 (partial redundancy analysis of site-specific phytoplankton data against water chemistry; Note: Figure 7-12 appears to have one point mislabelled as 54, and should be 547), with similar sites and results reflected in Figure 7-14 (periphyton data).

Concern was noted by Hall & Associates regarding the use of measures such as saprobity metrics, nutrient tolerance, and nitrogen uptake metabolism group. These metrics are provided in the report, but the establishment of the criteria on page does not appear to rely on these metrics, instead, it relies on the partial redundancy analysis of taxonomic data averaging the three sites where the strongest and weakest relationships were found -- and using nutrient concentrations at these sites to estimate the nutrient concentrations associated with more desirable communities. Functionally this allowed identification of minimally impacted sites in a highly impacted ecosystem, and those minimally impacted sites were used to identify target nutrient concentrations, an approach consistent with EPA recommended methodology. We recognize that there is a certain degree of subjectivity to determine minimally impacted sites on the river based on this approach. However, the points that were chosen as low nutrient stand out relatively clearly against the rest of the sites. A core problem here is identifying reference sites in a river that impacted throughout its entire watershed as evidenced by the considerable degree of agricultural land cover in all watersheds.

Large portions of the river also have high turbidity, which interferes with using periphyton or phytoplankton chlorophyll as response variables. The river does have some areas of lower turbidity (headwaters and near river mouth) -- which are expected to have the greatest sensitivity to nutrients in their chlorophyll response. As a result, focussing on areas which show the strongest nutrient response is justified, particularly given the well characterized masking effects or turbidity and TSS on algal response to nutrients related to light limitation of primary production. The additional approach taken to overcome limitations associated with high TSS was to use floating slides (periphytometers) to assess potential for algal growth.

Hall and Associates noted concerns regarding use of periphytometers, suggesting that communities and biomass do not represent the natural or existing condition of the river and cannot be used to infer information regarding aquatic ecosystem health, or impairment. While periphyton growing on slides near the water surface are not completely natural, they do represent species that occur in the system and would grow on other surfaces. The use of glass slides as a way to indicate attached algal communities in aquatic habitats has a long record in aquatic ecology and biological assessment and can be beneficial in reducing variability among sites and substrata. The use of phytoplankton communities and biomass is completely natural and defensible. Hall and Associates state (p2): "In order to evaluate Periphyton growth, which occurs on the *bottom* of the river...". This is not entirely correct as periphyton can live on any substrata, for example, using woody materials or aquatic plants as a substrata, and as such, they may be near the surface of the water in natural habitats.

Given the potential statistical problems (or subjectivity) in the original report with determination of reference sites, we took an alternative approach to visually assess the validity of the results of the report. Using data presented on page E1 we explored simple relationships within the TP, TN, and periphyton chlorophyll data. First, we restrict data to samples where TSS was <100mg/L. This was done to exclude samples where light availability might impair chlorophyll response to phosphorus availability. Within the remaining data, we see a strong relationship between TP and periphyton chlorophyll (Figure 1 below). We note that interpretation of this plot is sensitive to the TSS threshold applied, with a lower threshold leading to greater linearity. Nonetheless, we conclude the proposed TP criteria (from page 64 of RESPEC) of 0.15 mg TP/L is representative of more desirable conditions based on the lower periphyton chlorophyll a. We see similar results with a plot of chlorophyll and TN (Figure 2 below). Another important point here is that the suggested criteria in the report lead to a N:P molar ratio of 18. This is very close to the Redfield ratio and indicates that the suggested criteria match the expected ratio of algal demand for nutrients.

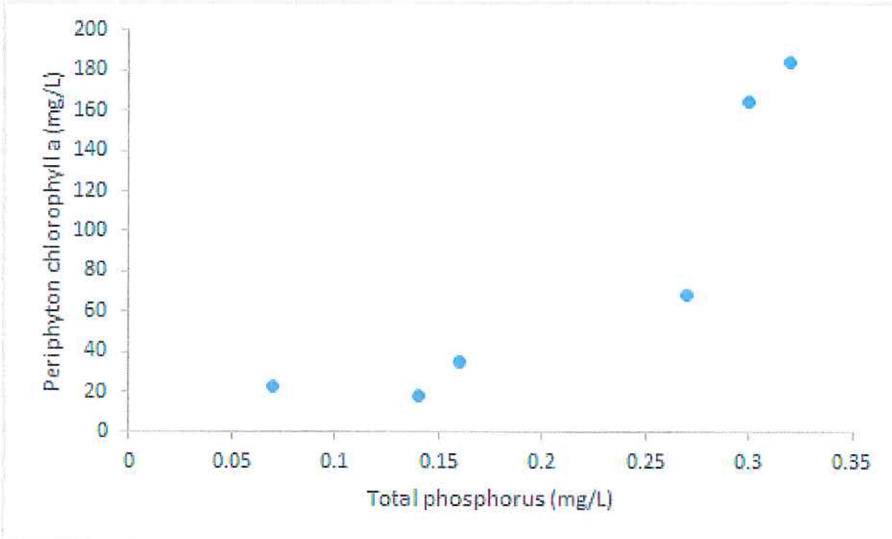

Figure 1: Relationship between periphyton chlorophyll a and total phosphorus concentrations at TSS <100mg/L. Data are derived from page E1 of RESPEC 2016. Note: These analyses could be revisited and formalized with the original files as these are digitized files, limited by the small amount of information in the table caption and table of contents, hence we are not assured of the completeness or accuracy of these data. The relationship is sensitive to the TSS cutoff used.

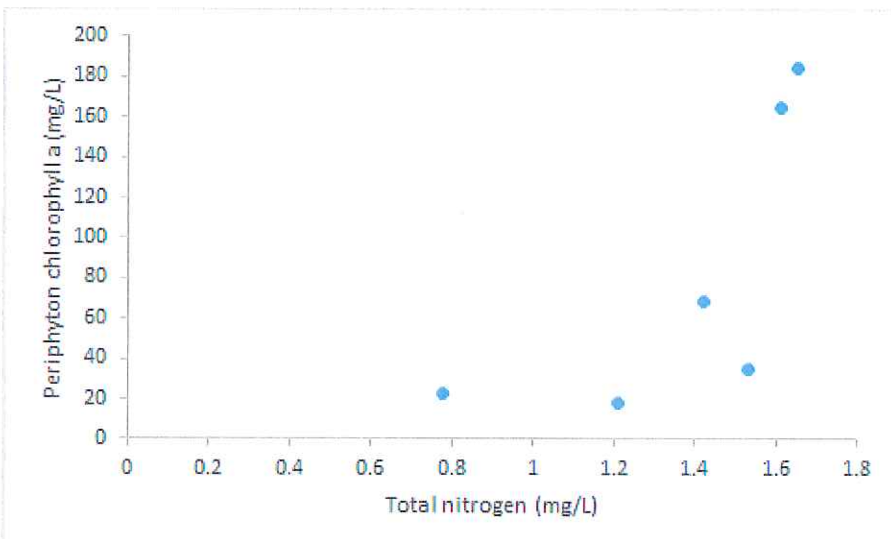

Figure 2: Relationship between periphyton chlorophyll a and total nitrogen concentrations at TSS <100mg/L. Data are derived from page E1 of RESPEC 2016. Note: These analyses could be revisited and formalized with the original files as these are digitized files, limited by the small amount of information in the table caption and table of contents, hence we are not assured of the completeness or accuracy of these data. The relationship is sensitive to the TSS cutoff used.

We conclude that the data from these sites is adequate to derive the TN & TP targets, but suggest that presentation of the simple relationships (approaches similar to Figure 1 & 2 here) is required to help support these conclusions in light of relatively low explanatory power of the multivariate analyses. We also note that more stringent targets may be merited (see conclusions and Table 1). Finally, we note that additional data identified in RESPEC 2016, but not available at the time of the report may now be available to further assess proposed targets. Analyses of invertebrate data, for example, could strengthen the results here, but they will also be influenced by high TSS so will have similar problems of analyses. Parallel efforts underway to identify conditions protective of Lake Winnipeg will also be informative, and are likewise expected to be lower than the targets proposed in RESPEC Table 7-11.

CONCERN 2: "The recommended nutrient target limits establish TN concentrations...to protect aquatic ecosystem health. The establishment of a TN target is inconsistent with MPCAs adopted RES criteria and are not scientifically defensible because they are based on metrics that are not accepted impairment metrics."

The Hall and Associates document states that "TN is generally not considered a nutrient of concern with regard to eutrophication in rivers because TP is generally considered the limiting nutrient for fresh water systems". However, this view is not well supported in the literature. Dodds and Smith (2016) provide a review of the evidence that contradicts this statement. Perhaps the most relevant data for this point with respect to rivers and streams of the upper Midwest have been published by Wang et al. (2007). They found invertebrate and fish responses across Wisconsin yielding far lower TN and TP thresholds than the values the original RESPEC report came up with.

Algal species composition and associated metrics can be early warning indicators of broader community and biomass change associated with impairment, and as such are suitable for this work. In several cases, potential for use impairment was noted (e.g., page iii of RESPEC 2016 notes blue green algae near urban areas, nuisance periphyton levels near the mouth of the river). As well, factors such as taxa with a preference for lower BOD and higher DO (e.g., page 40) can potentially be used as indicators of use impairment, and are suggestive of major changes from headwater to river mouth (page 41). Finally, Figure 7-11 of the report shows cyanobacteria are a large proportion of total biovolume near the border, which could be indicative of growing risks, particularly for potential cyanotoxin producers (page 46), although toxin risk remains low in most rivers.

With respect to concern noted by Hall and Associates that taxonomic metrics (e.g., saprobity, nutrient tolerance) are not associated with clear impairment thresholds we note these data are largely contextual. Our response to comment 1 outlines the methodology -- which relied on multivariate analysis of community composition to group sites, and identify minimally impacted sites. Within the report, taxonomic change was used as the major indicator of stressor response. EPA 2000 (p41) states "species composition is highly informative, especially when linked to the ecology of a species in relation to the environment, i.e., the autecological information about the species (Stevenson and Bahls 1999)", hence the approach used here, of assessing changes in species composition, and describing associated ecological differences is consistent with EPA methodology. We also note that preliminary analyses via Figures 1 & 2 presented here suggest proposed targets are also supported by simple relationships between TN & TP and associated changes in periphyton biomass at low TSS.

It is correct that of the variables noted in the RESPEC report, only phytoplankton chl a is noted as a numeric use impairment indicator by MPCA (2016). Additional productivity-related variables are considered by MPCA -- but data were not available within this report. The TP threshold proposed by MPCA is routinely exceeded in the river; however, phytoplankton chlorophyll a is not, presumably related to high turbidity. As a transboundary river, indicators beyond those derived by MPCA should be considered, particularly as supporting data beyond phytoplankton chlorophyll are not available. We note that the use of broader metrics is also supported by EPA methods.

CONCERN 3: "The primary assessment metric, Periphyton growth, was based on surface mounted samplers that have nothing to do with actual plant growth conditions in the river."

This statement is somewhat true, as the original study did not assess plant responses, and plants are taxonomically distinct from algae. Plants in the river (e.g. macrophytes) may use nutrients from the sediment so may not be related to periphytometer results. However, we assume that the Hall and Associates report is using the term colloquially to include algae. It is not correct to say that the assessment has "nothing" to do with growth conditions in the river. It is undoubtable that numerous shallow solid surfaces in the river occur upon which algae can grow. The conditions may be somewhat different than average conditions in the river, but the statement that they have nothing to do with growth conditions is not correct. Algae that are in the river colonize the periphytometers, and they are subject to the same forms and concentrations of nutrients that occur throughout the river.

Figure 7.2 is compelling. At the lowermost reaches of the river the nutrients are high, sediments low, and chlorophyll concentrations are high. Figure 7.4 controls for the fact that TSS and TP are often cross-correlated. Given that the phytometers were deployed for 4 weeks, they are an excellent measure of the potential for algal growth in the river. The high phytoplankton at the mouth of the river is also concerning, and phytoplankton concentrations are relatively high for rivers in spite of the turbidity. Values are in the upper third of the survey by Van Nieuwenhuyse and Jones (2006) and verging on values found in eutrophic lakes where probability of cyanobacterial blooms increases (Downing et al. 2001).

Extrapolation to specific conditions in the river (e.g. a mean chlorophyll of 100 mg/m^2) may be difficult as we do not know if the substrata used have more or less chlorophyll per unit area given nutrients in the river, than would other substrata found in the river. In general, smooth substrata can attain lower amounts of chlorophyll than rougher substrata as sloughing is greater and a complex surface gives more area to colonize (Murdock and

Dodds 2007). However, many may be more shaded than the periphytometers except in shallow portions.

CONCERN 4: "The Report claims to have followed USEPAs stressor response guidance (2010) in developing the proposed nutrient targets, but it is clear that this was not done. The analyses presented in the report are scientifically deficient and do not support the proposed nutrient targets"

The stressor-response approach is not extremely prescriptive by the EPA, and the approach was followed in general. The report identified the responses (periphyton and phytoplankton biomass and community structure). The statistical analyses identified the sites that were most and least influenced by nutrients, then used these to identify nutrient conditions. The original report generally follows the stressor response framework.

The work did use several response variables that would be reasonable. These include phytoplankton and periphyton biomass and community structure. This comment could be construed to allude to a deeper issue, will trophic state in general be altered to influence biotic responses when nutrients are increased? There are several aspects to this point. Brett et al. (2017) review the considerable data that even in rivers with small amounts of algal growth, they are disproportionately important to the system. Thus, even in a turbid river, nutrients could alter an important part of the food web. Additionally, heterotrophic responses are common in response to nutrients, and a very turbid river is likely dominated by heterotrophic activities. Dodds (2007) discusses some of the deeper issues concerning trophic state in streams that are not directly addressed when just focusing on autotrophs.

Consistent with the US EPA stressor-response approach, potentially confounding effects of TSS were identified in the conceptual model, and addressed using statistical approaches in a reasonable fashion. The low r^2 associated with model fits (0.15 and 0.16) is a concern. However, a simple plotting of the data in appendix E -- (Figure 1 & 2 here) shows the proposed TP and TN criteria from the RESPEC report is a reasonable one (see response to point 1 above).

CONCERN 5: "Reported effects on taxonomic metrics and algal growth may not be related to instream nutrient concentrations but may be caused by adjacent land use characteristics."

We do not see strong evidence for adjacent land use characteristics driving algal biomass at specific sites. Figure 7-13 does indicate that phytoplankton community characteristics are related to local conditions. However, figure 7-12 shows a clear trend of communities shifting along the nutrient gradient toward the river mouth, and there are not different cumulative land use patterns as we move to larger and larger watershed areas above each point moving downstream. The fact that nutrients continue to increase downstream, but the cumulative land use metrics seem about the same, indicates that upstream conditions are contributing nutrients and they continue to accumulate as one moves down to the mouth of the river.

The Hall and Associates argument is made partially based on flow in from oxbow wetlands potentially causing low DO. However, these oxbow wetlands are fed by the river during floods, and the nutrients then cause large algal blooms in the wetlands that can be washed back into the river. Thus, the nutrient load in the river still could be the ultimate cause of this DO condition. The effect is well documented for riparian wetlands elsewhere (e.g. Tockner et al. 1999).

Part *2:* Was the stressor-response model developed for the Red River appropriate to address the charge from the SoW?

The original SoW was:
1. Develop a conceptual model for the Red River.
2. Identify data available from multiple jurisdictions and agencies and identify data gaps.
3. Perform exploratory data analysis to understand relationships among the ecological components of the system, evaluate how human disturbance might impact these relationships, and suggest statistical approaches for stressor-response modeling.
4. Collect additional data needed to fill gaps in stressor-response model development.
5. Complete stressor-response modeling using the available dataset and statistical modeling approaches.
6. Identify biological thresholds along a stressor (nutrient) gradient using approaches such as nonparametric change point analysis.

The report satisfied points 1 to 5. The expert panel selected and modified a conceptual model from Heiskary et al. 2013 (Figure 5-2 in RESPEC). Data were identified (RESPEC Table 4-1) and data gaps noted. The report notes that exploratory analyses were performed, including some simple plots such as 7-2 that help understand spatial changes in nutrients and periphyton as they relate to TSS, although the exploratory analyses noted appear to have followed the collection of additional data, rather than informing it. Detailed additional data collection was performed, and statistical modelling was completed. They did not identify specific biological "thresholds" (point 6), rather they found conditions in least impacted areas and used those to recommend criteria.

Part 3: Was the stressor-response model appropriately applied to address the charge from the SoW?

We find that overall the stressor-response model was appropriately applied. We discuss some of the more nuanced points in the responses to the Hall and Associates report.

PART 4: Was the field study design and data collected appropriate to fill data gaps and address the charge from the SoW?

The field design was reasonable, with some problems on sampling/analysis. The initial statement of work appeared to suggest a greater reliance on existing data, which could have added value complementing existing work (e.g., chemical monitoring and chlorophyll data). It is unfortunate that the existing data macroinvertebrate and fish data were not used/made available -- which would be useful in understanding impacts, particularly as the SoW asked that the contractor use all available data. Historic data were not included in setting criteria in the report (although the potential to do so is not clear).

PART 5. Were the statistical methods used applied correctly to address the charge from the SoW?

The SoW noted the use of 'accepted statistical modelling approaches (e.g., simple linear regression, quantile regression, locally weighted scatterplot smoothing, non-parametric change point analyses and regression tree analyses).' While the list provided is certainly not exhaustive, within the report none of these approaches were used, and instead multivariate approaches were employed. The multivariate approaches seem reasonable; however had relatively low explanatory power and did not include thorough reporting of uncertainty in the derived targets. Numerous statistical options are outlined in EPA 2010, and the reporting of uncertainty is described in detail. While direct methods to constrain uncertainty associated with the analyses performed by RESPEC are not indicated, further assessment of uncertainty in the targets developed is merited, and possible options from EPA 2010 and other sources should be explored. In addition to options to explore uncertainty in targets derived from multivariate analyses of community composition, the more direct approach to addressing uncertainty in criteria may be the addition of linear regression (e.g., from relationships in Figures 1 & 2 here or incorporating advice from section 5.1 of EPA 2010), change point analyses or similar. This could help further validate the conclusions, and allow estimation of error in identification of targets. At a minimum, the report could confidence intervals around the mean values obtained from the least impacted sites.

Conclusions

We think the original report made substantial progress towards identifying nutrient targets in a system where there are substantial challenges to setting targets owing to widespread human impacts (affecting the entirety of the river), and high turbidity in many reaches which can alter biological responses to nutrients. There are some aspects of the current report used to recommend nutrient targets that can be criticized, and we discuss these above. One important missing ingredient in this process is comparison to other studies in the region of attainable baselines and consideration of potential for eutrophication in Lake Winnipeg. We already mentioned the work by Wang et al (2007) that finds thresholds for biological integrity substantially lower than targets recommended in the original RESPEC report (1.15 mg/L TN, 0.15 mg/L TP) based on thresholds for aquatic life in the Upper Midwest. Most of the US portion of the watershed lies in the Glaciated Upper Midwest Nutrient Ecoregion with a bit in the Corn Belt Nutrient Ecoregion. Table 1 indicates how much lower the estimates are for baseline nutrient conditions than the recommended values. More concerning is the fact that the values are also outside of the expected range of values under natural conditions as reported by Dodds et al. (2009). The RESPEC recommended values are also in excess of nutrient criteria proposed for the Canadian Prairies (Chambers et al. 2012; TP: ~0.1 mg/L, TN: 0.39-0.98 mg/L). Finally, the values of TP exceed those expected for hypereutrophic conditions in lakes and TN are close to or exceed those values (Nurnberg 1996), so would not be expected to protect downstream Lake Winnipeg. These considerations suggest that the target numbers in the initial RESPEC report could be significantly above those that would be expected to protect biotic integrity and water quality.

The EPA (2010) notes specifically that "Candidate criteria derived using other methods (e.g., reference site distributions, literature values) can be compared qualitatively with criteria derived using stressor-response relationships". We suggest consideration of Table 1 and broader methodology as data permit; however, these data suggest the targets in the report are not below the expected range for protection of rivers in the region.

Table 1: Baseline nutrient concentrations from various sources on the two US nutrient ecoregions in which the watershed of the Red River of the North is located. These numbers represent the estimate of nutrient concentrations in the absence of anthropogenic influences.

Location	TP (mg/L)	TN (mg/L)
RESPEC suggested targets	0.15	1.15
Smith et al. (2003)		
Glaciated Upper Midwest	0.013	0.165
Corn Belt	0.054	0.355
Dodds and Oakes (2004)		
Glaciated Upper Midwest	0.028	0.589
Corn Belt	0.023	0.215

References

Brett, M. T., Bunn, S. E., Chandra, S., Galloway, A. W., Guo, F., Kainz, M. J., . . . Power, M. E. (2017). How important are terrestrial organic carbon inputs for secondary production in freshwater ecosystems? *Freshwater Biology, 62*(5), 833-853.

Chambers, P. A., McGoldrick, D. J., Brua, R. B., Vis, C., Culp, J. M., & Benoy, G. A. (2012). Development of environmental thresholds for nitrogen and phosphorus in streams. *Journal of Environmental Quality, 41*(1), 7-20.

Dodds, W. K. (2007). Trophic state, eutrophication and nutrient criteria in streams. *Trends in ecology & evolution, 22*(12), 669-676. doi:DOI 10.1016/j.tree.2007.07.010

Dodds, W. K., & Oakes, R. M. (2004). A technique for establishing reference nutrient concentrations across watersheds affected by humans. *Limnology and Oceanography Methods, 2*, 333-341.

Dodds, W. K., Bouska, W. W., Eitzmann, J. L., Pilger, T. J., Pitts, K. L., Riley, A. J., . . . Thornbrugh, D. J. (2009). Eutrophication of US Freshwaters: Analysis of Potential Economic Damages. *Environmental Science & Technology, 43*(1), 12-19. doi:Doi 10.1021/Es801217q

Dodds, W., & Smith, V. H. (2016). Nitrogen, phosphorus, and eutrophication in streams. *Inland Waters, 6*(2), 155-164.

Downing, J. A., Watson, S. B., & McCauley, E. (2001). Predicting cyanobacteria dominance in lakes. *Canadian Journal of Fisheries and Aquatic Sciences, 58*, 1905-1908.

EPA (2000). Nutrient criteria technical guidance manual. Rivers and streams. Office of Water. Washington DC. EPA-822-B-00-002

EPA (2010). Using stressor-response relationships to derive numeric nutrient criteria. Office of Water. Washington DC. EPA-820-S-10-001.

Hall & Associates (2018). Review of: The development of a stressor-response model for the Red River of the north. Original report by RESPEC June 2016. Prepared for cities of Breckenridge, Moorhead, Roseau, Warroad and Thief River Falls. Washington DC.

MPCA. (2016). Guidance manual for assessing the quality of Minnesota surface waters for determination of impairment: 305(b) report and 303(d) list. Minnesota Pollution Control Agency. St. Paul Minnesota.

Murdock, J. N., & Dodds, W. K. (2007). Linking benthic algal biomass to stream substratum topography. Journal of Phycology, 43(3), 449-460.

Nürnberg, G. K. (1996). Trophic state of clear and colored, soft-and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. *Lake and Reservoir Management, 12*(4), 432-447.

RESPEC. (2016). The development of a stressor-response model for the Red River of the north. Roseville, Minnesota. Topical Report RSI-2611.

Smith, R. A., Alexander, R. B., & Schwarz, G. E. (2003). Natural background concentrations of nutrients in streams and rivers of the conterminous United States. *Environmental Science and Technology, 37*(14), 2039-3047.

Tockner, K., Pennetzdorfer, D., Reiner, N., Schiemer, F., & Ward, J. V. (1999). Hydrological connectivity, and the exchange of organic matter and nutrients in a dynamic river–floodplain system (Danube, Austria). *Freshwater Biology, 41*(3), 521-535. doi:doi:10.1046/j.1365-2427.1999.00399.x

Van Nieuwenhuyse, E. E., & Jones., J. R. (1996). Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. *Can. J. Fish. Aquat. Sci. 53:99-105.*

Wang, L., Robertson, D. M., & Garrison, P. J. (2007). Linkages between nutrients and assemblages of macroinvertebrates and fish in wadeable streams: Implication to nutrient criteria development. *Environmental Management, 39*, 194-212.