**Rejoinder to MPCA Responses**
**Douglas Hawkins**

There are a few elements in the MPCA response to my comments that call for a specific response. My more detailed written comments submitted after the Brainerd hearing may also help answer some queries.

- *The endpoint of interest*

MPCA takes me to task for saying that the primary concern of the standard is the health of the wild rice. The technical document to which I was responding is entitled "***Final Technical Support Document: Refinements to Minnesota's Sulfate Water Quality Standard to Protect Wild Rice***." It seems a reasonable supposition from this wording that the sulfate standard should stand or fall on the basis of whether it does or does not protect wild rice. My conclusion is that there is no evidence that it does so. Rather, in the field data, the SO4, TOC and Fe levels are unrelated to either the presence of wild rice or its health, leading to the conclusion that the standard has no proven relevance to wild rice.

It is perhaps a misdirection in the MPCA response that it mentions the relevance of sulfide to wild rice health. This has no direct bearing on the relevance of sulfate to wild rice health – it is sulfate and not sulfide that is the target of the standard.

The response Hearing Exhibit 2036 Comment B also misrepresents what I said. My analyses showed that SO4, Fe and TOC have no relevance to wild rice **either individually or jointly**. This is shown by multivariate logistic regressions for presence/absence; by a multivariate $T^2$ test; and by multiple regression of stem density, an indicator of wild rice health. None of these multivariate calculations found any connection of the triad (SO4, TOC, Fe) to wild rice.

That these three quantities have a statistically significant relationship to sulfide, which in turn is statistically significantly related to wild rice presence and health, does not imply that taken together they also have a significant relationship to wild rice presence and health. In fact, the data show the opposite.

A comment on "significance" may also be apposite. Significance comes in two flavors – statistical and practical. A relationship may be statistically significant, but not strong enough to be useful in practice as the basis for decisions about the real world. While it is agreed that sulfide is a statistically significant predictor of wild rice presence and health, its practical significance is another matter. Wherever you split the data by sulfide level, many water bodies will be misclassified – high sulfide with wild rice or low sulfide without wild rice.

And when there is a further remove from sulfide back to the SO4, TOC and Fe that are believed to generate it, even statistical significance is lost.

- *Lines in the sand*

The MPCA analysis spends much time discussing various cutoffs for sulfide. No-one is suggesting that there is a sulfide level *C* for which sulfide below *C* leads to wild rice and sulfide above *C* precludes wild rice. But the purpose of a standard is to drive decisions. The meaning of a cutoff *C* is that if you believe

a water body's sulfide level to have a value above *C* you will take one action, and if you believe it to be below *C* you will take a different action.

The response says explicitly that *C* is "*rather a threshold above which the wild rice beneficial use is not sufficiently protected*". If wild rice is not sufficiently protected does that not, in and of itself, imply that some action should be taken to protect it? It seems disingenuous to fault the reader who finishes that sentence with *", and so somebody will need to do something to protect the wild rice*." I am therefore not clear on how the threshold *C* is anything other than a line in the sand.

- *The ROC curve*

The discussion around the ROC curve at the hearing was perhaps too brief to be fully clear. True positives are water bodies which do not have wild rice and whose sulfide exceeds the cutoff *C.* False positives are water bodies which do have wild rice and whose sulfide exceeds the cutoff *C*. The ROC is a parametric curve generated by calculating the rates of true and false positives for all values of the cutoff *C* and plotting the two rates against each other.

My ROC did not show the line of identity as it is not clear to me what purpose this line serves – the AUC is a direct measure of how far above the line of identity the ROC is. While the CLSI guideline I cited has the line of identity in its examples, the full-length monograph *ROC Curves for Continuous Data,* Krzanowski WJ and Hand DJ (2009) Chapman and Hall sometimes includes it and sometimes excludes it, suggesting that the line of identity is an optional extra and not a required feature of the ROC.

The unit slope line drawn on the ROC curve I presented serves a different purpose. It goes through the point maximizing the Youden index, showing where that maximum occurs, something that is not always visually obvious. The line can also be helpful in indicating whether there are other points on the ROC that also give the maximum, or close to the maximum, of the Youden index, as is indeed the case.

It is a deficiency of the ROC curve that does not show the value of the driving parameter *C* that generates the points on the curve. This lack motivates my second figure which ties the points on the ROC curve back to the cutoff values *C* that generated them. This graph shows the wide range of sulfide cutoffs leading to essentially the same Youden index.

- *Steady State*

I am aware that steady state refers to a statistical distribution being stable over time, and does not mean that there is no variation over time. However invoking the steady state assumption to infer that sampling a limited number of locations on limited number of occasions will provide a reliable picture requires that the variability within the water body be modest relative to that between water bodies.

As for the data set used, it is from the MPCA Web site:

ftp://files.pca.state.mn.us/pub/wild_rice/Wild_rice_field_survey
MPCA_Field_Survey_Data_with_calculated_protective_sulfate_concentration.xlsx

downloaded on October 6, 2017. In the 267 data records, R code identified 165 distinct DNR IDs, 53 of which had more than one data record. These are the water bodies studied. The X axis on the comparative box and whisker plots refers to the serial number of that water body in the data set. As the

specific identity of the water body does not seem relevant for the plots, this terse labeling seems adequate for purposes of displaying the variation within and between water bodies.

- *Predicting sulfide from SO4, Fe and TOC*

My multiple regression was of sulfide on SO4, Fe and TOC, and showed that the regression explained a little under half the variance in sulfide, leaving the other half unexplained.

I did not comment on the multivariate logistic regression of the indicator "Sulfide > 120" on these same predictors. The analysis of deviance of this fit gives:

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    Null deviance: 141.276  on 107  degrees of freedom
Residual deviance:  96.499  on 104  degrees of freedom
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In other words, the logistic regression explains 44.777, or 32%, of the total deviance, leaving 68% unexplained, a figure actually somewhat worse than the regression of sulfide itself. This multiple logistic regression therefore paints the same picture of SO4, Fe and TOC as statistically significant but imperfect indicators of the level of sulfide.

In summary, the conceptual framework

- Sulfide in high enough concentrations is harmful to wild rice; and
- Sulfide comes from somewhere, plausibly the reduction of sulfate in surface water,

seems both reasonable and supported by the field data. However the leap from there to setting a sulfate level that will protect wild rice is not supported by the field data. I therefore remain skeptical that the sulfate standard has any demonstrated benefit for wild rice.