THE BRAKE PAD PARTNERSHIP

Compilation of Technical Reviewers' and Stakeholders Comments' on Estimating Copper Loading to the Watershed from Vehicle Brake Sources Draft Report

April 27, 2005

Background

Copper in the San Francisco Bay has been a pollutant of concern since the State of California listed the Bay as a high-priority impaired water body in 1996. In 1998, the State of California listed copper and several other metals as pollutants of concern for the San Francisco Bay. These listings triggered a regulatory requirement that Total Maximum Daily Loads (TMDLs) be developed for copper and the other pollutants of concern. Since then, site specific objectives for copper have been established for the bay South of the Dumbarton Bridge, and a copper TMDL process is currently underway for the bay North of Dumbarton Bridge.

The Brake Pad Partnership's efforts are aimed at evaluating the potential impact of copper from brake pads on water quality in the South San Francisco Bay. Three environmental modeling studies are at the core of the Partnership's effort, including an air deposition model, watershed model and Bay model. The air deposition model has two time scales. For the regional background, the model uses a 5-year average set of meteorology and the temporal resolution is going to be a month. For the local (Castro Valley watershed) scale model, the model is based on one-year daily meteorology that will be used to drive the model, with the goal to compare against air deposition monitoring data. The watershed and Bay model uses daily mean output values for multiple years, which may include roughly 1989-2003. One of the most critical inputs to the modeling efforts is the estimate of the quantity of copper released to the watershed from vehicle brake pads (brake sources) and other copper sources (non-brake sources). The Brake Pad Partnership has contracted with Kirsten Sinclair Rosselot of Process Profiles who is working with the BPP Steering Committee to develop a plan for estimating copper releases from vehicle brake pad sources. The release estimates will be used as inputs to the air deposition and watershed models.

Estimation of the amount of copper released in brake pad wear debris in the study watershed requires taking into account a variety of factors, including different brake material compositions for different types of vehicles, brake pad wear and replacement rates, age of the vehicle fleet, and traffic volumes. A complicating factor in conducting this work involves reconciling the different categorization approaches used in developing traffic-related versus data on brake types and composition.

The Brake Pad Partnership Steering Committee is seeking an independent expert review of the Draft Report for Estimated Copper Loading to the Watershed from Vehicle Brake

Sources to ensure that the approach and results of this element of the Partnership's work are technically sound, to determine if there are feasible opportunities to strengthen this work, and to help build in-depth understanding of and confidence in the technical studies on the part of the Steering Committee and the stakeholder communities.

Charge

With the aim of meeting these objectives, the Steering Committee has developed the following questions on which it is seeking specific comments from the reviewers:

1. What is your assessment of the analysis performed and its reliability for estimating copper releases from brake sources?

2. Does the report clearly describe the uncertainties and sensitivities in the analysis?

3. Based on your experience with similar release estimate efforts, what feasible improvements can you recommend to the Brake Pad Partnership in estimating and sources loadings from brake pads?

4. Are the specific copper release estimates appropriate inputs for the atmospheric deposition, watershed, and bay models?

5. Is the method for allocating sources spatially in the watershed appropriate? Do you have any suggestions for how it could be improved using available data?

Comments Received

Comments of Robert Frosch, Belfer Center for Science and International Affairs, Harvard University, (April 20, 2005)

I have read Kirsten's Draft Final Report on Brake sources. I did not try to go through the math etc. in detail, and couldn't really figure out how to use the Excel spreadsheet material (not my kind of thing, anyway).

I think it is a very good job, with due attention to variability, and results that are as convincing as one is likely to get, given all the difficulties. The results are at least fairly precise; there is no way to know how accurate they are, but that's in the nature of the case.

Tremendous progress!

Answers to questions in the Draft Charge:

1. It is a very good analysis, and the results probably about as reliable as possible given

the nature of the available data.

2. Yes, very well, and tests for them nicely, given the problems with the data.

3. Short of going out and getting more data, I doubt much more can be squeezed out of the existing data.

4. I think they'll have to be; that's about all that can be done, given the data. Given the variances, the analysis will, at least, provide an adequate bracketing of the likely possibilities.

5. I really don't see how to do better with these data.

Other comment: when the whole thing comes together (brake pad and non-brake pad sources, and into the models) we'll have to look to see whether, given the variances, we can be reasonably sure about the reliability of the indicated result. In my experience, it is at the end, when it all comes together, that it is possible to review the whole chain of reasoning and numbers, and decide whether the result is ok, or what it really does say to the analyst. That sometimes means one has to go back into the analytical reasoning chain and ask some more questions. So far, it's not clear (to me, at least), what that result will look like. It is perfectly possible that it will be very clear whether brake pads are an important source, and how important, or it could be that the variances are large enough so the result is very 'iffy'.

Thanx. Bob Frosch
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Comments of Kelly Moran, representing the Bay Area Storm water Management Agencies, (04-25-05)

Thanks for the opportunity to review this draft report. I think it is a good report. The care in its preparation shows. I think the level of detail, the clear delineation of assumptions, and the tables detailing the data sources give us just what we need in terms of content and quality for this critical input into our modeling efforts.

I'm impressed at how well the estimates by very different methods match. The tunnel study data that were selected do seem like the best source to use as the basis for the BPP's load estimates. While I could question various elements in the calculation methods, I don't find anything substantive to question about the selection of the tunnel study data as the preferred data source--and my questions on the data inputs into the other methods diminish when I compare them to the tunnel study results and see such similar results.

I also believe that the partitioning approach is reasonable, and makes sense in light of the available data.

I have just a few comments, which are listed below in the order of the report:

(1) If I'm correctly understanding the variable naming, I think that there's a typo on page 2.1-5, line 16--shouldn't this be CCu, pass, old-disc? (rather than new-disc)

(2) I found the description of the value for the fraction of brake pad wear debris that is not trapped in drum brakes (page 2.3-6 first paragraph and page 2.3-1, second paragraph) confusing. The selected value (0.3) is outside of the range provided (0.5-1). Is this because the range of 0.5-1 is for fraction trapped, and the value of 0.3 is the value for fraction NOT trapped?

(3) It would be helpful if the author could give the report a "once over" for references. There are some implied references that are not yet cited in the text. For example, I expect that the intent was to cite the Garg paper as the source of the information in the last sentence on Page 1-2. There are also at least two cited references (von Uexkull and Ntziachristos) that are fully cited in the tables, but not yet listed in Section 7.

Finally, it would be helpful to add the tunnel study (Gillies et al.) to our technical reference library. I would also like to discuss it a bit on the teleconference. Specifically, I am interested in discussing whether we would want to account for the difference between the copper content of PM10 (which is the basis of the Gillies et al. emissions factor) and the total copper emissions using the Haselden et al. results (91% of Cu was in the PM10 fraction). I'm not sure this is worthwhile given that this understatement is well within the uncertainty of the load estimate, but would like to hear the views of our scientific advisors on this question. I was also intrigued by how well the Gillies data reality checks with other brake pad emissions data--for example, the Cu/Sb ratio in Gillies (2.4) is consistent with other published Cu/Sb ratios for brakes (Adachi 2.5; Sternbeck 4.6 + or - 2.3) and how the Cu emissions factor ratio between PM10 and PM2.5 in Gillies appears to be consistent with the Haselden et al. particle size fractions (which unfortunately don't cut exactly at PM 2.5).

Additional comments:

In the draft report on emissions from brake pads, you mention values for "black box" replacement brake pads cited from the Armstrong report. It turns out that those values reported by Armstrong in the main text of his report are incorrect, which can be seen by looking at the laboratory data reports in the appendix. The actual reported copper concentrations for the two pads were Napa--23,200 mg/Kg and Masterstop--24,500 mg/Kg.

In other words, these pads were 2.3% and 2.45% copper, respectively (not <0.2% as described in the text). If you want to verify this (which you might) and you don't have the appendices, Connie has them at Suscon. The data are fairly early in the appendix volume (about 20 pages in) on a page numbered "INORGANICS - Page 3"

FYI, I've been aware of this error for more than 10 years and have previously raised it in BPP discussions, so folks may have forgotten it, but it isn't new. My apologies for forgetting to include this information in my original comments.

Kelly Moran
TDC Environmental

Comments of Betty Pun, AER, Air Modeler, (April 21, 2005)

I have a couple of terminology clarifications for you and a "conceptual model" issue for discussion.

Please confirm if my understanding is correct. The uncertainty estimates are based on the use of the standard deviation as a measure of uncertainty (the terminology is "standard uncertainty" in the report). The formula used, range / (2 x root3), is the standard deviation, by definition, and not just "a means of estimating the standard deviation of a uniform distribution" (i.e., it is THE means to estimate the standard deviation of a uniform distribution).

Could you include a reference for the Kline-McClintock equation?

Now to the "conceptual model" question. I think when we first started this work, there is some a priori assumption that light, medium, and heavy duty vehicles give different emissions of brake pad copper. The conclusion of the report seems to be that the same emission factors should be applied based on the least uncertain estimates from the tunnel study. In our air quality work, we wrestle with the idea of structural (or model) uncertainties vs. data uncertainties. The perfect model means nothing when there is no good data to support it. On the other hand, the best data, when applied in the wrong model, also give rise to inaccurate results. In this case, I wonder what the reasoning was in the first place to try to obtain different estimates of light, medium, and heavy duty vehicles. How does the a priori reasoning jive with the use of one emission factor for all classes?

Thanks.
Betty

Comments of Steven Wall, California Department of Health Services, (April 21, 2005)

The technical nature of the draft report required more time investment than anticipated, so I can offer some general comments at this point. As my schedule allows, I would be willing to examine in more detail the bases for the assumptions and approximations necessary, due to the not unexpected holes in the available data for the analysis.

In general, error analysis and the extensive reference tables provide a good basic structure to the draft report. Particularly interesting is the apparent similarity in the emission

factors calculated with the three different approaches, within a vehicle class and across vehicle classes. However, I wonder if defaulting to the tunnel study data in each case is the best approach. More discussion is required concerning how the tunnel study was conducted, and how the measurements were effected by deposition within the tunnel. Additionally, it is not clear that the emission of PM10 from drum brakes can be discounted so easily based on our work, which found that the brake shoe dust, unlike brake pad dust, is initially trapped in a small region and continuously available for re-suspension. The issue about the amount of copper in brake shoes in OEM and aftermarket brakes needs clarification. Finally, the connection between the air emissions, and deposition (road and brake system wash off) to surfaces expected to impact the aquatic ecosystem is not completely clear.

Specific comments include the following:

- Some important references to underscore assumptions seem to be missing (for example page 1-2 line 20)
- The K-M equation page 1-4 line 8) seems to be given in an awkward form without a summation expression. What is K?
- Equation numbering would be useful and equation variables need to be more clearly defined
- Language needs editing for clarity, for example page 1-4 lines 13-16. remove “in that they can be” and “that means that it is desired that the”, use “probable” rather than “likely”
- Consider the assumptions in section 2.1 about drum brakes. Consider that rear drum (and disc brakes) last three times longer than fronts and are likely to be OEM.
- Include more discussion of values used in calculations rather that just refer the summary tables.
- The particle distribution discussion is somewhat vague and contains apparent mismatches (for example Fig 3-1 shows many size cuts and table 3-1 only shows three for Haseldon’s work)
- More details on the Haseldon measurement need to be included to support the text discussion and qualify the measurements usefulness.
- The discussion in section 4 requires information on the braking cycles for the measurements and how these differences could bias the data.

I was unable to find the time to review the other documents sent.
I hope this helps and I would be interested in looking at another draft, but my time will not free-up for at least another month.

Comments of Eric Stein, Watershed Department, Southern California Coastal Water Research Project, (April 26, 2005)

The report is interesting and thorough in its analysis. The authors have done a nice job considering the various factors that influence brake-wear sources of copper and this information will be very useful to regional planners and managers. I found the particle

size distribution data of particular interest. The predominance of copper on 7-10 um particles in the air is generally consistent with the storm water literature, which states that copper is concentrated on storm water particles less than 20 um.

My main criticism is that the presentation is not as clear as it could be. The introduction does a poor job of stating the overall purpose of the study and how it is important to regional management of copper in storm water runoff. The sections on low, medium, and heavy duty vehicles are redundant. The general methodological discussion should be consolidated in one location, following by comparative analysis of emissions from the various types of vehicles. Finally, the report simply ends with no discussion of how this information should be used support regional air or water quality models. The interest and accessibility of this report could be improved by a thorough text edit and some reorganization.

1. What is your assessment of the analysis performed and its reliability for estimating copper releases from brake sources?

The authors have done a nice job in accounting for many of the key variables that may affect copper emissions from brake pads. It appears that the results of light and medium duty vehicles are more reliable than the estimates for heavy duty vehicles. I am not convinced that applying the results of the tunnel study to heavy duty vehicles is as appropriate as for the other classes of vehicles. There was no data on the distribution of vehicles that used the tunnel during the study; however, it is reasonable to assume that proportionately less heavy duty vehicles use the Sepulveda tunnel (I am familiar with that tunnel and have driven through it often – few heavy duty vehicles use it due to the narrowness of the road). Furthermore, unlike the other classes, estimations based on the composition/wear and composition/emission methods were less than half the estimates derived from the tunnel study. Therefore, for this class of vehicle the tunnel study may overestimate true emissions.

2. Does the report clearly describe the uncertainties and sensitivities in the analysis?

The authors have done a nice job summarizing uncertainties. However, they could add some sensitivity analysis by using ranges of values in several of the key formulas and reporting on which variables have the greatest effect on overall estimates of copper emissions. Such and exercise would allow future researchers to focus and prioritize variables where uncertainty has the greatest influence on the reliability of emission estimates.

3. Based on your experience with similar release estimate efforts, what feasible improvements can you recommend to the Brake Pad Partnership in estimating and sources loadings from brake pads?

It would be interesting to use the dynamometer test to investigate how different types of driving affect emissions. (e.g. frequent acceleration & braking as occurs in stop-and-go driving vs. steady freeway speeds)

4. Are the specific copper release estimates appropriate inputs for the atmospheric deposition, watershed, and bay models?

I am most familiar with watershed models – so I will restrict my comments to this area. The estimates are a good first step for inputs to watershed models. However, there are several intermediate steps that would need to occur. 1) Atmospheric transport/distribution, transformation and flocculation processes need to be accounted for; and 2) Wet and dry deposition studies (or models) need to be coupled to this information. This would allow the emissions estimates to be translated into deposition estimates for use in the washoff parameters of watershed models.

5. Is the method for allocating sources spatially in the watershed appropriate? Do you have any suggestions for how it could be improved using available data?

It appears that emissions were assumed to uniformly occur over the entire 9-county area. It does not appear that differences for traffic density or prevailing winds were included in the analysis.

Comments of Terry Cooke, URS, Bay Modeler, (April 26, 2005)

Thanks for the opportunity to comment on this draft of the report.

Our overall comment is Kristen did a great job in pulling together a wide variety of data sources of various certainty and uncertainty and doing the EF estimates and uncertainty analysis. These comments mainly are to improve readability and clarity of the report.

0) The report needs a summary up front

1) Emission Factor should be defined early in the report. "mass of copper released from vehicle brake debris per km traveled"

2) The report might benefit from a simplified schematic/equations early on that presents the overall purpose and approach for the study and shows the different results that are calculated such as EFair, EFroad-direct, EFroad-indirect, EFpotw, before getting into the details of how the data are used to do the calculation for each vehicle class, considering replacement frequencies, number axles, new and old pads etc.

3) The Tunnel study needs some more back-up explanation to show it is an appropriate representation of Bay Area Traffic. Maybe include a description of the type of vehicles that were observed (was the sampling period representative of vehicle miles driven by each class of vehicle?).

4) In the summary of values and uncertainty tables units for copper should state ug-Cu/mg or ug-Cu/km rather than ug/mg or ug/km.

5) Use of mass fraction for copper concentration data is unusual in env studies and maybe should be supplemented on the table with another more common unit (such as mg/Kg or ppm)

6) Uncertainty and variability are different. It appears we are calling both "uncertainty". Uncertainty may be reduced with additional samples; variability is inherent and cannot be reduced after a representative sample is collected. It's important to distinguish the two (if possible). This maybe an exercise for the overall project report on next steps.