Peer Review of Draft Feasibility Study for the Lower Fox River Natural Resources Damage Assessment Site

In February 1999, ThermoRetec Consulting Corporation of St. Paul submitted a Draft Feasibility Study (FS) for the Lower Fox River Natural Resources Damage Assessment Site to the Wisconsin Department of Natural Resources (WDNR). This Draft FS was conducted under the direction of WDNR, with funding and technical assistance from the United States Environmental Protection Agency (U.S. EPA) Region V. U.S. EPA subsequently contracted a panel comprising Clayton Patmont (Anchor Environmental, Seattle, WA), Michael Barden (Geoscience Resources, Albuquerque, NM) and Danny Reible (Louisiana State University, Baton Rouge, LA) and charged them with reviewing was charged with reviewing the Draft FS. Robert Gilbertsen of Roy F. Weston, Inc., moderated the panel. Specifically, the team was charged with responding to two questions:

1. Is natural recovery appropriately characterized? If not, identify major deficiencies and provide specific recommendations.
2. Are the literature review and subsequent analyses complete regarding the environmental transformation (e.g., dechlorination, changes in toxicity) of PCBs in sediments? If not, identify major deficiencies and provide specific recommendations.

These questions are interrelated in that in situ transformation is one of the processes associated with natural recovery of the sediment. In addition, although these questions are relatively limited in scope, the panel cannot adequately respond to them without consideration of the broader goals and conclusions of the Draft FS. In particular, all remedial options leave a residual contamination for which the associated recovery and risks are the result of the natural attenuation processes. Thus adequately responding to the two defined questions entails a broader evaluation of the assumptions and analyses of the Draft FS.

The Draft FS had the following objectives

- Establishment of remedial action objectives.
- Identification and screening of general response actions and technologies.
- Development and detailed analysis of remedial alternatives.

The comparative evaluation of remedial alternatives, including natural recovery, is largely dependent upon the understanding of the physical, chemical and biological processes that are responsible for the exposure and risks of the sediment contaminants to human and ecological health. In particular the characterization of natural recovery, as identified in the charge to the peer review panel, is dependent upon these processes and the ability of models to apply these processes to predict the fate and transport of contaminants into the future. The panel finds, however, that the documentation and use of these processes and models are inadequate in the Draft FS. It is critical that the assumptions and analyses included in the FS be transparent and technically justified. Instead the panel feels that the Draft FS relies significantly on assumptions and analyses that are not adequately referenced and supported. In fact, this inadequacy raised serious concerns with the quality of the document. To respond to the charges properly, it was necessary for the panel reviewed many of the technical reports and articles that form the basis for the FS. While this highlights deficiencies in the documentation provided by the Draft FS, from this review the panel gained additional confidence in the statements and conclusions of the FS. The panel feels strongly that the FS should be a standalone document that, at a minimum, provides a summary of relevant information and appropriate references to key documents. In some instances, however, the information provided in the FS seems unsupported or even contradicts the conclusions of the technical support documents. These concerns are identified below in the detailed responses to the charges to the panel.

Charge #1

Is natural recovery appropriately characterized? If not, identify major deficiencies and provide specific recommendations.

Natural recovery is not appropriately characterized in the Draft FS. Also, it should be recognized that natural recovery is lumped under "no action," and is, in the context of U.S. EPA's policy on monitored natural attenuation (U.S. EPA, 1999), misrepresented. The discussion in the Draft FS implies that natural recovery is a "walk away" alternative.

Natural recovery is generally defined for this peer review as naturally-occurring physical, chemical, or biological processes that reduce the risks associated with contaminants in sediments over time. The term natural recovery implies both attenuation (those processes that reduce overall environmental exposures) and recovery (reestablishment of viable ecological communities through time, and restoration of other beneficial uses). It is important to note that a reduction in concentration at the point of exposure is not necessarily contingent on a reduction in mass. Within the context of the Draft FS, natural recovery should be characterized to the extent necessary to support the following objectives:

- To evaluate the protectiveness and practicability of a watershed source control and monitored natural recovery alternative, consistent with relevant sediment cleanup guidelines and the need for an evaluation of a broad range of potential response actions.

- To evaluate long-term risk reductions that may be achieved by implementation of a wide range of alternatives, including active removal. This is particularly important since the effectiveness of every remedial alternative evaluated in the Draft FS is based on underlying assumptions of natural recovery (e.g., of dredging residuals) over the long term. For example, the Draft FS (Section 8.0) states that: "Time and the level of risk reduction become the metrics for assessing the efficacy of a specific remedial alternative."

The Draft FS should evaluate natural recovery of sediments as one possible cleanup alternative among many, and is normally evaluated along with a range of active cleanup alternatives. Site-specific field studies and/or models are typically required to determine whether natural recovery is an alternative that will meet the project objectives, and long-term monitoring is necessary to verify its success. In addition, a contingency plan may be required if natural recovery does not proceed as predicted.

EPA has incorporated the concept of natural recovery into its agency-wide Contaminated Sediment Management Strategy (EPA, 19989). The Strategy states, "In certain circumstances, the best strategy may be to implement pollution prevention measures as well as point and nonpoint source controls to allow natural attenuation. Natural attenuation may include natural processes that can reduce or degrade the concentration of contaminants in the environment including biodegradation, dispersion, dilution, sorption, volatilization, and chemical or biologic stabilization, transformation or destruction of contaminants, and the deposition of clean sediments to diminish risks associated with the site. In other cases active remediation may be necessary." EPA lists factors to consider in determining whether natural recovery is appropriate: "the specific contaminants present and their associated risks, the designated uses impaired during recovery, the size of the affected area, the feasibility and cost of remediation, site hydrodynamics, including the potential for downstream transport, the time required for natural recovery, and … the liability associated with active remediation."

The Strategy (EPA, 1998) discusses some of the trade-offs in determining the net environmental benefit of natural recovery at a specific site. It states that natural recovery is the best option when cleaning up contaminated sediments would do more harm then good. For example, dredging or capping may harm sensitive habitats that would require take a very long time to recover from physical disturbance. On the other hand, EPA concludes that "natural recovery is normally not acceptable where contamination poses severe and substantial risks to aquatic life, wildlife, and human health".

Consistent within this framework contaminants in sediments are generally only of concern if they are present in the surface layer in which biological receptor organisms live, termed the "biologically active zone". The depth of the biologically active zone defines a depth over which the sediment quality standard should be met to be protective of human health and the environment. It is important to recognize that the biologically active layer may change over time as a result of erosion or dredging. Natural recovery may be considered to be a viable alternative if it will result in sediments in the biologically active zone meeting the site-specific sediment cleanup standards within a reasonable timeframe. If viable, natural recovery must then be weighed against active cleanup alternatives as part of the Draft FS.

Evaluation of natural recovery for sediments requires resolution of a range of technical issues, as well as integration into a comprehensive sediment management program. EPA and various states have published a number of guidance documents and reports on natural recovery assessments and natural recovery predictive modeling. These reports include reviews of natural recovery assessment methods, guidance on application of the recommended natural recovery models, and guidance on integrating natural recovery considerations into investigations and evaluations of alternatives for cleanup.

The technical basis of the natural recovery analysis is not sufficiently described in the Draft FS to permit an acceptable review of the methodology used, or to assess the confidence that can be placed on natural recovery predictions. However, review of several documents referenced in the Draft FS suggests that there may be a strong technical basis from which to conclude that natural recovery processes will substantially reduce environmental exposures to PCBs in the Lower Fox River over time. Nevertheless, the Draft FS, while referencing these same documents, refers to little or no improvement in mass discharges to Green Bay through the next 100 years (e.g. Section 8.3), while in other cases the document refers to more significant reductions.

Natural Recovery Characterization within the Lower Fox River Fate and Transport Evaluation

Contaminant concentrations in sediments can be reduced in a variety of ways. These include source control and various fate and transport processes such as sediment transport, burial, mixing, transformation and degradation, dissolution into water and/or air, transfer of contaminants into the food web, and groundwater advection. Depending on site conditions, some or all of these may be considered natural recovery processes, in that overall risks to the environment can be reduced, considering all media and all exposure pathways.

Source Control. One of the key processes that needs to be characterized in natural recovery assessments is source control. If sources of contamination are not sufficiently reduced, natural recovery may be slowed. Based largely on the results of the Lower Fox River Mass Balance Study referenced in the Draft FS, there appears to be a sufficient basis from which to conclude that control of both point and non-point sources has occurred to a level that would support natural recovery. The current sources of PCBs into the Lower Fox River has been estimated at approximately 3 to 5 kg/yr, which represents more than a 99.9 percent reduction relative to historical inputs (1954 to 1971).

Hydrodynamics. Sediments and associated contaminants may be transported off-site through erosion and suspension or bedload transport during the natural recovery period. A considerable amount of information describes pertinent hydrodynamic processes occurring within the Lower Fox River. This information is compiled and summarized in WDNR's Lower Fox River transport model report, as well as in peer-reviewed journal articles. Overall, the degree of characterization of the hydrodynamic system meets the standard of care as generally defined by relevant guidance documents and other similar projects. In systems like the Lower Fox River, it is particularly critical to evaluate the potential for large-scale sediment transport events such as infrequent floods that have the potential to mobilize underlying contaminated sediments, and these evaluations have been performed as part of the WDNR transport model development.

The influence of these flood events have not been adequately described in the Draft FS. Instead, the Draft FS implies that the PCB flux to Green Bay will be essentially constant over the next 100 years. The work of Velleux and Endicott (1994) and Velleux et al. (1995), and the summary of Fitzgerald and Steuer (1996), however, suggest that the transport of PCBs over the DePere Dam accounts for a majority of the PCBs transported into Green Bay and that the mass of PCBs transported over the DePere Dam should decrease by 50% every 5 years as a result of natural recovery processes. Maintenance of high PCB fluxes to Green Bay over the natural recovery period is therefore dependent upon resuspension events in the lower reaches of the Fox River. Velleux et al. (1995) indicate that a considerable proportion (25%) of the estimated 30,000 kg of PCBs in the Fox River sediments may be transported into Green Bay under expected high flow conditions but that 50% of the in-place PCBs would be unlikely to ever be transported out of the Fox River. Dredging activities, however, would expose this sediment, and contaminant losses would give rise to a residual whose natural recovery must be assessed.

The Draft FS should more clearly present the uncertainties associated with the various elements of the hydrodynamic characterization consistent with the individual studies that form the basis for the characterization. Although there is a considerable hydrodynamic database, the Draft FS contains an inadequate discussion of the sensitivity and resulting uncertainty associated with the hydrodynamic modeling.

Mixing/Bioturbation. The FS should include further discussion of the assumed thickness and bioturbation rate within the surface mixed layer (or biologically active zone) in determining overall risk reductions. This information is important both from the standpoint of addressing/supporting a fundamental concept of natural recovery (i.e., biological exposure is limited to surface sediments), and also to clarify for decision-makers the affects of parameter uncertainties on overall conclusions reached in the Draft FS. For example, though not well documented in the Draft FS, the natural recovery model developed by WDNR (1995) and apparently used in the Draft FS, assumes that the upper 5 cm of surface sediments is fully mixed. Sediments below this depth interval are assumed to be beyond the limits of biological exposure. Although this assumption appears generally consistent with the available data, other equally valid interpretations of these data are also possible (e.g., depth-varying bioturbation rates or variable mixed depths). These differing assumptions result in significant changes to model output. In addition, there appears to be a discrepancy between the maximum depth of bioturbation as reported in the Draft Risk Assessment (10 to 15 cm), and the 5 cm mixed depth assumption used in the Draft FS. At a minimum, these issues should be addressed within the context of an uncertainty analysis.

Biodegradation/Transformation Biodegradation and transformation of contaminants occur in sediments, and these processes can be important contributors to natural recovery. An important consideration in assessing the environmental effect of biodegradation is the intermediate and end products of biodegradation, and their relative toxicity and bioavailability compared to the parent compounds. PCBs may undergo dechlorination to less-chlorinated congeners, but may not be completely mineralized. Lower-chlorinated PCB congeners are generally less toxic. Other trade-offs may occur; for example, anaerobic dechlorination of PCBs generates lower-chlorinated congeners that are less toxic, but more soluble and volatile, and hence, bioavailable than the parent compounds. The natural recovery modeling performed for the Lower Fox River conservatively assumed no degradation. While this is conservative and appropriate from a risk assessment standpoint by likely overestimating concentrations and mass transport, it ignores a potentially significant environmental fate process for PCBs relevant to natural recovery. The natural transformation and degradation processes are discussed in more detail in the response to Charge # 2.

Phase Partitioning The partitioning and mass transfer of contaminants between media (e.g., pore water diffusion; volatilization) was evaluated in the Lower Fox River as part of screening-level analyses. One point of concern is the fact that volatilization (as well as degradation) occurs at congener-specific rates and that the calculated loss rates may not adequately characterize changes in toxicity and risk. Although the degree of characterization of these processes in this case is limited, the relatively small mass transfer rates suggested by the screening-level evaluations suggest that these processes have been adequately characterized for the purpose of natural recovery analyses.

Natural Recovery Predictive Modeling of the Lower Fox River

Modeling predictions are used almost exclusively for drawing comparisons between remedial alternatives in the Draft FS. Natural recovery models for sediments generally try to take into account all or substantially all of the relevant processes, and depending on site conditions can range from simple spreadsheet models to complex hydrodynamic models capable of detailed assessment of multiple sources and a complex receiving environments. For complex systems such as the Lower Fox River, the Water Quality Analysis Simulation Program (WASP) model, a three3-dimensional model developed and recommended by EPA and used by other regulatory agencies, is the preferred approach (PTI, 1993; EPA, 1993). However, use of such a model requires a great deal of site-specific information, as described above.

The panel finds that the development, calibration, and verification of the Lower Fox River WASP model, as reported in various WDNR publications referenced in the Draft FS or in the open literature, can provide a suitable tool for appropriate natural recovery predictions. These references include those of Velleux and Endicott (1994), Velleux et al. (1995), WDNR (1995), and the summary of Fitzgerald and Steuer (1996). Although the Draft FS references the WDNR model as the basis for the natural recovery predictions, the Draft FS does not provide sufficient information presented on input assumptions or model outputs to permit an adequate assessment of the accuracy or reliability of the predictive modeling. In fact, as indicated above, in some cases the Draft FS seems to contradict previously published reports on the WDNR model.

The WDNR model can also be used to assess the recovery of residual contamination remaining after application of any remedial activity. The assessment of this residual and the natural recovery associated with that residual is a key component of any comparative evaluation of remedial options. The panel is concerned that assumptions about the magnitude, fate and transport of this residual largely control the subsequent natural recovery that would occur after other remediation efforts. The Draft FS does not provide an adequate evaluation of the sensitivity and the resulting uncertainty related to such assumptions.

The calibration of the WDNR model was based, in large part, on correlations with observed mass transport data, both within the lower river and in Green Bay (Velleux et al., 1995; Manchester-Neesvig et al., 1996). While such data are useful within the context of mass balance calculations, these data are not directly applicable to surficial sediment concentrations, a critical input into the assessment of human and ecological risks within the river. WDNR (1995) provides detailed coring data that should be used as a basis to assess the accuracy of the model predictions of sediment concentrations (PTI, 1993; EPA, 1993).

Reliable long-term predictions of contamination with depth are critically important when it is recognized that the Draft FS indicates that only 4.8% of the contaminants in the DePere to Green Bay Reach of the Fox River are presently located within 10 cm of the surface. The presence of more than 95% of the contaminants at depths below the biologically active zone also raises concerns for active removal options that will expose and redistribute a portion of this material. This redistribution is recognized in the Draft FS in that partial remediation options assume a residual surficial sediment concentration of 2 mg/kg PCBs. Complete remediation options, however, assumed 250 μg/kg residual surficial sediment concentrations. These differing assumptions may significantly influence the relative effectiveness of partial and complete remedial options.

Evaluation of Long-Term Risks

As discussed above, natural recovery was defined for the purpose of this peer review as reduction of risks associated with contaminated sediments over time. Thus, the results of the contaminant fate and transport modeling, which take the form of concentrations within various model segments over space and time, need to be expressed in terms of overall human health and ecological risk reductions. Although the Draft FS and accompanying risk assessment documents present broad assessments of various risk measures, the document should provide additional discussion and uncertainty analysis of the following:

- Surface sediment points of exposure.;
- Residual sediment concentrations assumed for various remedial alternatives.;
- Summation of risks across multiple exposure pathways;. and,
- Comparisons with preliminary risk targets and remedial action objectives (RAOs)..

The FS should include further discussion of the assumed thickness and bioturbation rate within the surface mixed layer (or biologically active zone) in determining overall risk reductions. In addition to the importance of this parameter for fate and transport as discussed previously, it provides an indication of risks to benthic organisms and a basis for assessing transfer up the food chain. Again, the discrepancy between the depth of the biologically active zone as reported in the Draft Risk Assessment (10 to 15 cm), and the 5-cm mixed depth assumption used in the Draft FS should be addressed. At a minimum, these issues should be addressed within the context of an uncertainty analysis.

The FS Report should also include a better explanation and discussion of the residual sediment concentrations assumed for various remedial alternatives. Assessments of the magnitude of the initial residual, and the natural recovery associated with these residuals, are key components of the comparative evaluation of those remedial options involving dredging. Again, these issues should be addressed within the context of an uncertainty analysis. In addition, this panel was surprised that the Draft FS did not include an explicit source control/monitored natural recovery alternative, consistent with the EPA Strategy referenced above. Such a "new" natural recovery alternative should include (and more fully document) source control, remediation, and/or restoration projects that are already underway or in the final planning stages, and which would occur regardless of the outcome of this RI/FS. An example is the remediation of Deposit "A", which appears to be proceeding under a separate action.

Consistent with the definition of natural recovery as reduction of risks over time, this panel believes that further work is necessary in the FS to describe cumulative risks across multiple site pathways, so that overall risks to the larger Lower Fox River exposed populations can be assessed. For example, while the panel we recognizes that a detailed risk characterization methodology has not yet been developed for Green Bay, it is nevertheless important to address whether there is a net reduction in overall risks as a result of continued transport of PCBs from the Lower Fox River to Green Bay. This issue should be more fully developed as part of forthcoming risk assessment peer reviews of the Lower Fox River RI/FS.

Finally, it is critically important that the FS appropriately describe the context of remedial alternative comparisons (e.g., using various natural recovery model outputs) with preliminary risk targets. Although the preliminary RAOs may be reasonable and consistent with information presented in the various RI/FS documents, they are just that preliminary. Among other elements, the FS should discuss how the alternatives may or may not achieve different risk outcome measures (e.g., different eco-risk endpoints), and the effects of various institutional controls (e.g., short-term fish consumption advisories) on overall effectiveness of the alternatives. Within this context, the FS should also more fully describe WDNR's risk-based targets (10^{-6} for individual carcinogenic constituents and 10^{-5} cumulative risk target cited in NR 720.19). The success or failure of natural recovery as a stand-alone option or in concert with other remedial options may be influenced by the risk-based criteria selected.

Charge #2

Are the literature review and analyses complete regarding the environmental transformation (e.g., dechlorination, changes in toxicity) of PCBs in sediments? If not, identify major deficiencies and provide specific recommendations.

There is no literature review and analysis regarding environmental transformation of PCBs presented in the Draft FS for the Lower Fox River. Any discussion regarding fate processes is cursory at best, and at worst, some statements are so general as to be substantively incorrect. The discussion in Section 2.5 of the Draft FS consists of five paragraphs, cites no references, and provides no substantive "analysis". This can hardly be construed as a "complete" presentation.

The lack of even a summary discussion of environmental fate processes specific to the primary constituents of concern (PCBs) in the Draft FS is a major deficiency. In addition, there exists no thorough examination of environmental transformation mechanisms in any of the background documents on the Lower Fox River project available to the panel. This lack of information would tend to preclude any meaningful evaluation of natural recovery as a remedial alternative. In order to evaluate natural recovery, one must understand all the relevant mechanisms and their interrelations.

While the Draft FS does not include any substantive discussion of the environmental transformation of PCBs in sediments, some information is provided in other background documents. Some minimal discussion of environmental transformation of PCBs is provided in Section 5.6.2 of the Draft Risk Assessment (RA). This discussion provides a cursory overview of the transformation behavior of PCBs. However, it provides no substantive "analysis," either in general terms or specifically relevant to the Lower Fox River.

The discussion in the Draft RA cites two studies by Sokol et al. (1998a, 1998b) involving laboratory incubation of PCB-contaminated sediments from the St. Lawrence River in New York, which found apparent concentration-related limits on PCB dechlorination. The Draft RA concludes that little microbially mediated dechlorination will occur in the Lower Fox River and Green Bay since the sediment concentrations are for the most part lower than the "threshold" concentrations found in these studies. However, why the two recent papers by Sokol et al. (1998a, 1998b) are considered directly relevant to the exclusion of other studies showing different results is not explained. Various studies have indicated different "threshold" concentrations (e.g., Quensen et al., 1988; Abramowicz et al., 1993; Fish, 1996; Beurskens et al., 1993). The fact that the papers of Sokol et al. are more recent does not make them necessarily more relevant. Additionally, the threshold level may be congener-specific (Sokol et al, 1995; 1998b).

PCB compounds are generally resistant to biological transformation, but it does occur. The highly chlorinated PCBs can undergo a slow process of microbially mediated reductive dechlorination (Bedard and Quensen, 1995; Quensen et al., 1988). The lesser chlorinated PCBs (those with 1 to 4 chlorines) are amenable to oxidative degradation by microbes under aerobic conditions (Harkness et al., 1993). In general, the rate of such degradation decreases with increasing number of chlorines, and the reactions are strongly influenced by the bioavailability of the PCB compounds.

The microbially mediated reductive dechlorination of PCBs in anaerobic environments is a potentially important environmental transformation process for PCBs that can lead to substantial detoxification. The first indication of microbially mediated dechlorination of PCBs was based on observed differences in PCB congener distribution patterns in sediments of the upper Hudson River and the source Aroclor mixtures (Brown et al., 1984). Subsequent work demonstrated similar patterns for a variety of other aquatic sediments (Brown et al., 1987a; 1987b). This field evidence is confirmed by numerous laboratory studies for a variety of Aroclor mixtures (Quensen et al., 1988, 1990; Bedard and Quensen, 1995).

Reductive dechlorination is generally recognized as a microbial respiratory process and may involve single populations of dehalogenating microbes or the interaction of different populations (Bedard and Quensen, 1995). The specific PCB congeners affected involved tend to vary among samples, and at least six distinct dehalogenation patterns are recognized and exhibit distinct patterns of congener specificity (Bedard and Quensen, 1995). These generally involve dechlorination at the *meta* (3,3',5,5') or *para* (4,4') positions, or some combination, and *ortho*-substituted (2,2',6,6') chlorines are unaffected. This leads to enrichment of residual PCBs in *ortho*-substituted congeners that are typically less toxic (or effectively non-toxic).

Bedard and Quensen (1995) put it quite cogently,:

> "PCB declorination may be extensive . . . or it may be highly selective. Clearly, limited dechlorination is more difficult to identify than extensive dechlorination, and the ability to detect and correctly interpret dechlorination will be directly related to the sensitivity, accuracy, and thoroughness of the congener-specific analysis. Until very recently analysts have routinely reported PCBs in environmental samples in terms of whichever commercial Aroclor had about the same average chlorine number. This explains why environmental dechlorination was often not recognized in the past and may still be overlooked. Such misreporting also underscores the importance of a complete and quantitative congener-specific analysis." (p. 135)

The panel would expect to see some form of PCB congener pattern analysis as part of a natural recovery evaluation. Accurate analysis and interpretation of PCB transformations in the environment requires quantitative congener-specific analysis (Bedard and Quensen, 1995). At a minimum, a baseline is necessary to allow future monitoring of natural recovery.

The Draft FS also does not address the question of biotransformation leading to changes in toxicity. The characterization is substantially biased toward Aroclor mixtures with the tacit presumption that a general reduction in toxicity is related to a reduction in the percentage of chlorine. This approach ignores the fact that the toxic effects associated with PCBs are often linked to those coplanar PCB congeners that are dioxin-like in structure and are Ah-receptor agonists.

In summary, it appears that no adequate assessment of in-situ biodegradation has been conducted at the site. This assessment is critical to the legitimate evaluation of natural recovery of the sediment and river and, ultimately, to the comparative evaluation of remedial options. A recent National Research Council committee report (NRC, 1993) has defined three criteria for demonstrating (or conversely disproving) in situ bioremediation:

- Documented loss of contaminants from the site.
- Laboratory assays showing that microrganisms from the site have the potential to transfer the contaminants under the expected site conditions.
- Evidence showing that the biodegradation potential is realized in the field.

The panel did not find any is no documentation that any site-specific evaluation of these criteria was attempted. The Draft FS cannot attempt to describe such studies if they have not been conducted, but any work that has been completed should be documented to improve confidence in the conclusions reached by the Draft FS with respect to naturally occurring transformation processes.

Bioturbation of sediments is briefly discussed in Section 5.2.2.2 of the 1996 Remedial Investigation (RI) (GAS/SAIC, 1996) and provides the observation that benthic infauna are present to depths up to 60 cm in the Lower Fox River deposits. This discussion also alludes to benthic infauna being common in the upper 15 to 30 cm of sediments, but the wording of the text is unclear as to whether this is a general statement or a specific observation for the Lower Fox River sediments. The presence of benthic infauna does not directly relate to the extent of sediment mixing. The degree and extent of bioturbation is important since both factors affect the degree of oxygenation of surface sediments. This is directly related to potential microbially mediated transformation by controlling the biogeochemistry.

Reductive dechlorination of PCBs occurs under strongly anaerobic conditions. There is no information or discussion of the environmental setting in terms of biogeochemical characterization and conditions. Without such information, potential PCB transformation can only be addressed in a hypothetical manner.

References

Abramowicz, D.A., 1990, Aerobic and anaerobic biodegradation of PCBs: A review. Biotechnology, v. 10, no. 3, p. 241-251.

Abramowicz, D.A., M.J. Brennan, H.M. VanHort, and E.L. Gallagher, 1993, Factors influencing the rate of polychlorinated biphenyl dechlorination in Hudson River sediments. Environmental Science and Technology, v. 27, p. 1125-1131.

Bedard, D.L. and J.F. Quensen III, 1995, Microbial reductive dechlorination of polychlorinated biphenyls, *in* L.Y. Young and C.E. Cerniglia (eds.), Microbial Transformation and Degradation of Toxic Organic Chemicals. Wiley-Liss, Inc., New York, p. 127-216.

Beurskens, J.E.M, G.A.J. Mol, H.L. Barreveld, B. Munster, and H.J. Winkels, 1993, Geochronology of priority pollutants in a sedimentation area of the Rhine River. Environmental Toxicology and Chemistry, v. 12, p. 1549-1566.

Brown et al, 1984, PCB transformations in upper Hudson sediments. Northeast Environmental Science, v. 3, p. 167-179.

Brown et al, 1987a, Polychlorinated biphenyl dechlorination in aquatic sediments. Science, v. 236, p. 709-712.

Brown et al, 1987b, Environmental dechlorination of PCBs. Environmental Toxicology and Chemistry, v. 6, p. 579-593.

EPA, 1993, Assessment and remediation of contaminated sediments (ARCS) program: Risk assessment and modeling overview document, Chicago, IL, Great Lakes National Program Office. EPA 905-R93-007.

EPA, 1998, U.S. EPA contaminated sediment management strategy. Office of Water, U.S. Environmental Protection Agency, Washington, D.C. EPA-823-R-98-001. April 1998.

Fitzgerald, S.A. and J.J. Steuer, 1996, The Fox River PCB Transport Study - Stepping Stone to a Healthy Great Lakes Ecosystem, USGS Fact Sheet 116-96.

Fish, K.M., 1996, Influence of Aroclor 1242 concentration on polychlorinated biphenyl transformation in Hudson River test tube microcosms. Applied and Environmental Microbiology, v. 62, p. 3014-3016.

GAS/SAIC, 1996, Remedial Investigation Report for Contaminated Sediment Deposits on the Fox River (Little Lake Butte des Morts to the De Pere Dam). Graef,Anhalt, Schloemer & Associates, Inc., and Science Applications International Corporation, 24 September, 1996.

Harkness, et al, 1993, In situ stimulation of aerobic PCB biodegradation in Hudson River sediments. Science, v. 259, p. 503-507

Manchester-Neesvig, J.B., A.W. Andren and D. N. Edgington, 1996, Patterns of mass sedimentation and of deposition of sediment contaminated by PCBs in Green Bay, J. Great Lakes Res. 22 (2) p. 444-462.

NRC, 1993, In Situ Bioremediation B When Does it Work? National Academy Press, Washington, DC. p. 63.

PTI Environmental Services, 1993, WASP application guidance manual, Olympia, WA, Washington Department of Ecology.

Quensen, J.F., III, S.A. Boyd, and J.M. Tiedje,, 1990, Dechlorination of four commercial polychlorinated biphenyl mixtures (Aroclors) by anaerobic microorganisms from sediments. Applied and Environmental Microbiology, v. 56, p. 2360-2369.

Quensen, J.F., III, J.M. Tiedje, and S.A. Boyd, 1988; Reductive dechlorination of PCBs by anaerobic microorganisms from sediments. Science, v. 242, p. 752-754.

Rochkind, M.L., J.W. Blackburn, and G.S. Sayler, 1986, Microbial decomposition of chlorinated aromatic compounds. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH, EPA/600/2-86/090, 269 p.

Sokol, R.C., C.M. Bethoney, and G-.Y. Rhee, 1995, Effect of PCB concentration on reductive dechlorination and dechlorination potential in natural sediments. Water Research, v. 29, p. 45-48.

Sokol, R.C., C.M. Bethoney, and G-.Y. Rhee, 1998a, Effect of Aroclor 1248 concentration on the rate and extent of polychlorinated biphenyl dechlorination. Environmental Toxicology and Chemistry, v. 17, no. 10, p. 1922-1926.

Sokol, R.C., C.M. Bethoney, and G-.Y. Rhee, 1998b, Reductive dechlorination of preexisting sediment polychlorinated biphenyls with long-term laboratory incubation. Environmental Toxicology and Chemistry, v. 17, no. 6, p. 982-987.

Velleux, M. and D. Endicott, 1994, Development of a mass balance model for estimating PCB export from the lower Fox River to Green Bay, J. Great Lakes Res., 20 (2) p. 416-434.

Velleux, M., D. Endicott, J. Steuer, S. Jaeger, and D. Patterson, 1995, Long-term simulation of PCB export from the Fox River to Green Bay, J. Great Lakes Res. 21 (3), p. 359-372.

Wisconsin Department of Natural Resources (WDNR), 1995, A deterministic PCB transport model for the lower Fox River between Lake Winnebago and Depere, Wisconsin. WR 389-95.